E+A galaxies in the near-IR: Broad band photometry

Gaspar Galaz\textsuperscript{1}

Carnegie Observatories. Las Campanas Observatory, Casilla 601, La Serena, Chile

gaspar@azul.lco.cl

Received \_________________________; accepted \__________________________

Accepted for publication in the \textit{Astronomical Journal}

\textsuperscript{1}Andes-Carnegie Fellow
We present near-IR photometry of a selected sample of southern hemisphere E+A galaxies. The sample includes 50 galaxies from nearby ($z \sim 0.05$) and distant ($z \sim 0.3$) clusters as well as E+A galaxies from the field ($z \sim 0.1$). We also observed 13 normal early-type galaxies from the field and from clusters to be compared with the E+A sample. The photometry includes $J$, $H$ and $K_s$ apparent magnitudes and colors. Observed colors are obtained from the apparent total magnitudes and compared to spectrophotometric models of galaxy evolution GISSEL96. There is an overall agreement between integrated colors of models and observed ones, for both the E+A located in clusters and in the field, at $z \lesssim 0.1$. However, large differences are found between colors predicted from models and those observed in E+A galaxies located in clusters at $z \sim 0.3$.

We also compute rest-frame colors for all the galaxies using two different sets of K-corrections, and obtain average colors for all the samples.

We investigate systematic properties of the E+A sample as a function of their environment. Results seem to indicate that cluster E+As (at low redshift) are bluer than field E+As at $z \sim 0.1$. Even this conclusion does not depend whether we use comoving or rest-frame colors, nor on the models used to obtain rest-frame colors; the difference is not significant enough, considering color dispersions between the samples. If differences are real, they could imply different stellar content for the E+A galaxies located in the field, compared to the cluster E+A.

Subject headings: galaxies: fundamental parameters — galaxies: photometry galaxies: stellar content
1. Introduction

The attention drawn to E+A galaxies (or post-starbursts) has increased since it was claimed that their fraction observed in clusters is correlated with the Butcher-Oemler effect (Butcher & Oemler 1978; Dressler & Gunn 1983; Rakes & Schombert 1995). The E+A galaxies present a peculiar spectrum in the optical: strong Balmer absorption lines, representative of a large population of A and B stars, but a lack of emission lines typical of blue, star forming galaxies, like \([\text{OII}]\lambda 3727\), \([\text{OIII}]\lambda 5007\), and \(\text{H}\alpha\). Because of the further detection of metallic absorption lines such as \(\text{Mg b}\ \lambda 5175\), \(\text{Ca H \\& K}\ \lambda 3934, 3968\) and \(\text{Fe}\ \lambda 5270\), indicative of an old population dominated by G, K and M spectral types they were called E+A (Dressler & Gunn 1983). In addition, their spectra in the optical cannot be reproduced simply by a young stellar component without nebular emission lines: it is necessary to add an old population of stars, like the one present in quiescent elliptical galaxies (Liu & Green 1996).

During the last 3 years, research on the E+A galaxies has seen a revival after the discovery of more such galaxies not only in nearby clusters, like Coma and others (e.g. see Caldwell & Rose (1997) and references therein), but also in the field; in particular those discovered during the Las Campanas Redshift Survey (LCRS, Shectman et al. 1996) by Zabludoff et al. (1996). An interesting feature is the apparent existence of two classes of E+A galaxies (Couch & Sharples 1987). One is formed by “blue” post-starburst galaxies and the other by redder, \(\text{H}\delta\)-strong (HDS) galaxies (Fabricant, McClintock & Bautz 1991). These subclasses of E+As have colors and absorption line features related to the morphology: HDS E+As have in general a noticeable bulge and/or spheroidal component when compared with the blue class. In addition, the HDS class can be divided into 2 subclasses: bulge and disk HDSs (as observed in A665 and in Coma (Franx 1993)).

An almost unexplored domain of these E+A galaxies is their near-IR properties. In fact,
no catalogue or systematic observations exist on this subject. Is the bright, red population, dominated mainly by giants and stars of the asymptotic giant branch (AGB) of the E+As, different from the red population of other elliptical galaxies, in particular the perturbed ellipticals? Is there any conspicuous signature in the near-IR colors of the E+A galaxies, as in the optical wavelengths? Do the cluster E+A galaxies have bluer colors than those in the field at these wavelengths? Are the near-IR colors of the E+A galaxies similar to the colors of normal galaxies, as predicted by spectrophotometric models?

In this paper, we investigate these questions with new data taken at Las Campanas Observatory, in Chile. The sample includes E+A galaxies from the field (most of them from the LCRS) and from nearby clusters as well as clusters at $z \sim 0.3$.

The paper is organized as follows. In §2 we present the galaxies selected for this work. In §3 we explain the observations, and in §4 the data reduction procedures. In §5 we present the results of the photometry, the apparent magnitudes, colors, and K-corrections. Both, observed and rest-frame colors are compared with colors obtained from spectrophotometric models of galaxy evolution in §6. In §7 we discuss the limitations of our results and the implications for some properties of the E+A galaxies from our near-IR colors. Conclusions are presented in §8.

2. The Sample

All of the galaxies selected for this study have been spectroscopically classified as E+A galaxies from the analysis of their Balmer absorption lines (particularly the equivalent widths of Hδ and Hβ) and the lack of nebular emission lines, representative of an ongoing stellar formation process. We have selected most of the southern E+A galaxies existent in the literature at present. The sample of galaxies is divided into 4 subsamples. The first subsample
corresponds to 21 field E+A galaxies from the LCRS selected from a catalogue of $\sim 19000$ galaxies with redshift between $z \sim 0.07$ and $z \sim 0.18$ (Zabludoff et al. 1996). The second subsample contains 22 E+As from the nearby clusters DC2048-52, DC1842-63, DC0329-52, and DC0107-46 (Caldwell & Rose 1997) at $z \sim 0.05$. Seven E+A galaxies from rich clusters at $z \sim 0.31$ (AC103 and AC114) constitute the 3rd subsample (Couch & Sharples 1987). Some “control” galaxies were observed also (the 4th subsample, 13 galaxies). These galaxies have well-known properties and provide a reference sample to compare the observables of the E+A sample. The control sample includes mostly elliptical and lenticular galaxies (from clusters and the field), as well as a few galaxies between $z \sim 0.01$ to $z \sim 0.04$. Table 1 summarizes the sample of 63 galaxies which have been observed.

3. Observations

All of the observations presented here were carried out at Las Campanas Observatory, Chile, during photometric conditions. Most of the images were obtained with the 40-inch Swope telescope, using a NICMOS3 HgCdTe array ($256 \times 256$ pixels, 0.599 arcsec/pix, $2.5 \times 2.5$ arcmin FOV), in March, July, August and November 1998. We employed also the 100-inch du Pont telescope in September 1998, with a NICMOS3 detector, yielding a scale of 0.42 arcsec/pix (1.8 $\times$ 1.8 arcmin FOV). We use the following filters: $J$, $H$, and $K$ short ($K_s$), centered at 1.24$\mu$m, 1.65$\mu$m, and 2.16$\mu$m, respectively, and bandwidths of 0.22$\mu$m, 0.30$\mu$m, and 0.33$\mu$m. For a detailed discussion of the photometric system see Persson et al. (1998).

Between 5 and 8 standard stars from Persson et al. (1998) were observed each night. The observation procedure for all the objects (standards included) was as follows. Each object was observed at several positions on the array, some amount of time in each position (I call this an observing sequence for a given object in a given filter). The amount of time
depended on the magnitude of the object, on the sky brightness, and on the linearity regime of the array. The NICMOS3 becomes noticeably non-linear when the total counts (sky + object) exceed 17000 ADU. We exposed in each position between 60 and 120 seconds in $J$, between 30 and 60 seconds in $H$, and between 30 and 50 seconds in $K_s$. Total exposure times for a given observing sequence and filter varied between 10 and 45 minutes. For the standard stars (with magnitudes between $K_s \approx 10 - 12$), the exposure time ranged between 5 and 20 seconds in each position, for both telescopes. Typically, the number of non-redundant positions at which each object was observed varied between 4 and 10, depending on the size and/or magnitude of the object. A pre-reduction was made at the beginning of each observing sequence in order to estimate the total exposure time required to reach a minimum central S/N $\approx 12 - 15$. This pre-reduction consisted in the construction of a sky image averaging all of the stacked images for a given object (with a sigma-clipping rejection threshold), the subtraction of the sky image from each individual image, and the combination after registration of the individual sky-subtracted images.

4. Data Reduction

The images have to be corrected for all of the instrumental effects, namely, non-linear deviations, dark-current contribution (dark subtraction), and pixel-to-pixel response differences (flat-field division).

For the determination of the linearity corrections, we take several dome-flats with different exposure time. Then, we plot the ratio of the average counts and the integration time of each frame, as a function of the average counts. After normalizing, we transform the count value $I_{in}$ of each pixel into $I_{out} = I_{in} \left[1 + C \times I_{in}\right]$, and we solve for the constant $C$ which proved to vary between $1.0 \times 10^{-6}$ and $5.0 \times 10^{-6}$. At 14000 counts, for example, which corresponds to $\sim 75\%$ of the whole range of the signal, the departure from linearity is only
At the beginning of the night we took series of 20 dark frames, the number of series depending on the number of different exposure times we used through the night. The flat-field images were constructed from (a) dome-flats and twilight sky-flats and (b) the raw science images of the night, which allowed us to construct super-flats from the combination of the individual frames. The useful images for these super-flats were those where the objects were faint and/or a small number of objects were observed. Because galaxy fields were in general uncrowded, it was always possible to construct super-flats. Typically, each super-flat was constructed from no less than 30 science images, for each filter. The results show that the super-flats allow to correct for fringes appearing in the stacked and combined images. The fringes are present in the 3 filters ($J$, $H$ and $K_s$), but are particularly prominent in the H images. Except for the presence of fringes, the dome- and sky-flats are quite similar to the super-flats (at the 0.6% level). However, given the better photon statistics of the super-flats and the fact that the fringes are better represented by the super-flats we chose the super-flats to remove the pixel-to-pixel variations. From the object frames, the dark and flat-fielding corrections were made on the images using the SQIID\(^2\) reduction package, implemented under IRAF\(^3\). At this stage, a mask with the bad pixels was created (using the dark images) to correct those pixels by interpolation with their neighbor pixels in all the images.

Once the linearity corrections were done, as well as the dark correction and flat-fielding

\(^2\)Simultaneous Quad-color Infrared Imaging Device software package, developed by Michael Merrill and John Mac Kenty.

\(^3\)IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
procedures in all the raw images, the procedure to obtain stacked and combined sky-subtracted images began. This part was done using DIMSUM\textsuperscript{4}, also implemented under IRAF. The general procedure for a given \textit{observing sequence} follows.

(a) A scaling factor for each image was computed using a \(5\sigma\) iterated rejection method about the mean. The scaling factor is the median of the unrejected pixels, and is stored as a descriptor in the image header. This provides a first estimate for the sky level.

(b) For each image in the observing sequence, a specified number of neighboring images of the sequence were selected. To construct a sky image, we selected only the neighboring images taken within \(\pm 5\) min from the given image. This provides a sample of sky images within a short-period of time during which the variations of the sky level are not larger than 1\% to 3\% of the mean, in order to reduce the r.m.s. variation in the thermal emission background as well as the OH sky lines, characteristic of the NIR (see Figure 1). Furthermore, the higher background in \(K_s\) produces higher shot noise even if this background did not vary with time. This is a key step.

At each pixel a specified number of low and high values in the scaled images were rejected and the average of the remainder values was taken as the sky for that pixel. The resulting sky image was subtracted from the object image to create a sky subtracted object image.

(c) Cosmic rays were found using a threshold algorithm applied to the ratio of the image and a median filtered image. The detected cosmic rays were replaced by the local median. A cosmic ray mask was created to record the location of the cosmic rays.

\textsuperscript{4}DIMSUM is the Deep Infrared Mosaicing Software package developed by Peter Eisenhardt, Mark Dickinson, Adam Stanford, and John Ward, and is available via ftp from ftp://iraf.noao.edu/iraf/contrib/dimsumV2/dimsum.tar.Z
(d) For a given observing sequence, a shift list is created to define the offsets between the images. To create this list it is first necessary to have at least one object in common among all of the images of the observing sequence (usually a star). Next we selected a set of additional objects to improve the determination of the relative shifts. These objects were used in constructing the shift list using a centroid-based algorithm.

(e) A registration stage was done by shifting and combining the images of the sequence. A matching exposure map was also created, which allows to obtain a final mosaic properly weighted by the effective exposure time of each section of the mosaic.

(f) To provide combined images free of “holes” arising from the sky subtraction, two different masks are created for each registered image of the observing sequence. The detailed procedure is explained in the DIMSUM package.

(g) The sky subtraction is repeated as in the first pass, before the masking procedure, except that the pixels in the individual masks derived from (f) are ignored.

(h) Finally, all the sky-subtracted images of an observing sequence are shifted and combined, and the different parts of the mosaic are scaled to an exposure time of 1 s.

5. Photometry

5.1. Photometric calibrations

The photometric calibrations were done using the faint standard stars from the list of Persson et al. (1998). This list includes standard magnitudes in J, H, K and K_s for equatorial and southern photometric standard stars. Five to eight standards were observed every night at airmasses similar to those of the galaxies (no larger than 1.2). This minimizes the dimming and reddening due to the airmass contribution, especially in colors involving
the $J$ filter.

Instrumental magnitudes were computed using the code SExtractor (Bertin & Arnouts 1996), which computes isophotal, isophotal corrected, and total magnitudes for all the objects detected above a given threshold. We have also computed instrumental aperture magnitudes using DAOPHOT, and verified that DAOPHOT aperture magnitudes for the standards do not differ by more than 0.5% from the total magnitudes yielded by SExtractor. The aperture used for the standards in DAOPHOT is the maximum aperture after analyzing the shape of the grow curve for the instrumental magnitudes, and typically take radii values $\sim 6.0$ arcsec. We conclude that the instrumental magnitudes given by SExtractor are reliable, which we adopt hereafter.

The adopted photometric transformations between the instrumental and the calibrated magnitudes are:

$$J = A_1 + j - 0.10X$$

$$H = A_2 + h - 0.04X$$

$$K_s = A_3 + k_s - 0.08X$$

where the $A_N$ coefficients ($N = 1, 2, 3$) are the zero points, $X$ is the airmass, and the extinction coefficients are from Persson et al. (1998). Note that we do not try to solve for airmass corrections night by night, as this can lead to spurious values for coefficients if the extinction is variable and non-gray. The latter is relevant at the filter passband edges where water vapor influences the effective width of the passband (Persson et al. 1998).

The zero points $A_1$, $A_2$ and $A_3$ were determined on a nightly basis, and proved to vary between 1% and 7%. We do not include color terms in these transformations (equations 1, 2, and 3) since they are smaller than 0.04 mag, a value close to the observational magnitude errors. We emphasize that all of the standards and the galaxies reported in this paper
were observed during completely photometric nights. The photometric transformations have
typical r.m.s. residuals of $\sim 0.02 - 0.05$ mag on both telescopes (see Figure 2). This gives
an internal error in the photometric calibrations around 2\% to 5\%.

The main source of error are, in fact, the short-term sky fluctuations (in particular in $K_s$), which are of the order of 3\% to 6\% in time intervals spanning the longest exposure time of individual frames during each of the observing sequences (120 s in $J$, 60 s in $H$, and 50 s in $K_s$). Some galaxies were observed twice, even using the two telescopes, and therefore there is a good estimate of the global photometric errors, which proves to be around 7\% for photometric nights. The observation of the same object during two photometric nights but with different telescope/instrument is the best way to estimate the photometric quality of the data (see §5.2), and the real dispersion of magnitudes.

5.2. Galaxy photometry

Instrumental apparent magnitudes for all the galaxies were obtained on the registered and combined images using the code SExtractor (Bertin & Arnouts 1996). Given the differences in size, shape and luminosity of the galaxies, the total magnitude is a better estimator than the aperture or isophotal magnitudes. SExtractor computes aperture magnitudes, isophotal magnitudes and “total” magnitudes for all of the objects detected above a given threshold. The total apparent instrumental magnitude for a given object is given by one of the two following approaches. (1) It is computed using an adaptive aperture magnitude or (2), using a corrected isophotal magnitude. In order to give the best estimate of the total magnitude, the adaptive aperture method is performed, except if a neighbor is suspected to bias the magnitude by more than 0.1 mag. If this happens, the corrected isophotal magnitude is taken as the total magnitude. This leads to the so-called MAG\_BEST magnitude, in the SExtractor output catalogue.
In order to check the calibrated magnitudes for our galaxies, and to have an idea of the accuracy of our total magnitudes, we observed some of the galaxies on two different nights, with the 40-inch and the 100-inch telescopes. For the 8 galaxies which were observed twice (2 for each subsample), we found r.m.s differences $\Delta J = 0.037$, $\Delta H = 0.042$ and $\Delta K_s = 0.061$. These differences, although large when taken at face value, represent the most realistic errors in the total magnitudes, since they were obtained with different instrumental set-ups during different observing runs.

5.3. Apparent magnitudes and K-corrections

Once the instrumental magnitudes are calculated using SExtractor, they are transformed to the standard system using the package PHOTCAL in IRAF. Table 2 shows the apparent calibrated total magnitudes for all of the galaxies of the 4 subsamples. The $K_s$ magnitude for galaxy # 25, AC114.89, was not computed since it was observed under possibly non-photometric conditions, and was marked with a NC (not calibrated). No internal reddening correction was applied to these magnitudes, nor a Galactic foreground extinction correction: both corrections are smaller than the photometric error and, in particular, are smaller than the uncertainty given by the K-correction, as we show in §5.6. The reddening by dust is $\Delta(J - H) \lesssim 0.03$ and $\Delta(H - K_s) \lesssim 0.02$, if we consider a simple screen model based on the reddening law of Cardelli, Clayton & Mathis (1989). If we consider a more complicated extinction model, following the star-dust mixture recipe by Wise & Silva (1996), the amount of reddening is similar. The correction due to Galactic extinction is also small for the 3 passbands ($\lesssim 0.03$), which proves to be well within the photometric uncertainties (for the Galactic reddening corrections in the near-IR photometric bands see Schlegel, Finkbeiner & Davis (1998)). We emphasize, however, that Galactic and internal reddening corrections are systematic effects, while the photometric uncertainty is random. Given their small values,
no attempt is made to correct for the extinctions. If we include foreground and internal extinction, the $J - H$ color redden probably no more than 0.03 – 0.05 (but see discussion at the end of §6).

Since the K-terms can significantly modify the intrinsic colors of the galaxies, they are critical in correcting the observed colors and magnitudes to the galaxy rest-frame. If $m_1$ and $m_2$ are the apparent magnitudes in the passbands 1 and 2, respectively, for a galaxy at a redshift $z$ and with a known spectral type $T$, then the rest-frame color for this galaxy is

$$M_1 - M_2 = m_1 - m_2 - \{K_1(z, T) - K_2(z, T)\},$$

where $M_1$ and $M_2$ are the corresponding absolute magnitudes, $K_1(z, T)$ and $K_2(z, T)$ are the K-corrections for the passband 1 and 2, respectively, for the galaxy with spectral type $T$ at redshift $z$. K-corrections are not included in the magnitudes and colors presented in Table 2 since they can have a wide range of values depending on the spectral energy distribution (SED) employed in their computation. When the SED is not available for a given object, it is common practice (although risky) to adopt K-terms from the correlation between spectral type and morphological classification, provided the latter is available.

In our case, we only have approximate morphological types for the E+As from the literature, nor do we have spectral information for the galaxies in the near-infrared part of the spectra. Even though most of our E+A galaxies are early types, we can ask the following. How will the near-IR K-corrections depend on the spectrophotometric model of galaxy evolution used to compute them? In order to study the model dependence in $J$, $H$ and $K$, take for example 2 SED models which provide (or allow us to compute) K-terms in the near-IR. The first K-terms were taken directly from Poggianti (1997), who computed K-corrections from the near-UV to the infrared. Poggianti (1997) provides K-corrections in several bands in the Johnson-Bessel & Brett photometric system, up to $z = 3$ as a function of morphological type. The values are computed according to an evolutionary
synthesis model that reproduces the integrated galaxy spectrum in the range 1000-25000 Å, and uses the code of GISSEL93 (Bruzual & Charlot 1993). The models are instantaneous bursts with solar metallicity and Scalo IMF (Scalo 1986). The age after the burst gives the SED which is compared with galaxies of known morphological type through colors. Note that the comparison is done in the optical part of the spectrum, mostly between 3000 and 8000 Å. The second set of K-corrections were derived using the model PEGASE\(^5\) (Fioc & Rocca-Volmerange 1997) to generate synthetic spectra between 7000 Å and 30000 Å, and convolving these SEDs with the filter response functions (see Persson et al. 1998), using the definition of the K-correction (Oke & Sandage 1968).

Figure 3 shows the K-corrections in \(J\), \(H\) and \(K\), calculated by Poggianti (1997) for 3 different morphological types, namely, E (solid line), Sa (dotted line) and Sc (dashed line). Note that the K-corrections in the near-IR are not necessarily small. Nevertheless, in most of the photometric bands they do not depend strongly on the spectral type or the morphological type. K-corrections are large (and negative) for the \(K\) band, for \(z \lesssim 0.5\), for all galaxy types (this makes galaxies to appear brighter than they really are). The average redshift in our sample is \(\approx 0.08\), and K-corrections in all the bands are less than 0.1 mag for most of the cases. The exceptions are the E+A galaxies in AC103 and AC104 (at \(z \sim 0.3\)). For these objects K-corrections can be larger and around \(-0.3\) mag in \(K\) for the late type galaxies. Figure 4 shows the K-term calculated from PEGASE. These K-corrections are calculated from SEDs with solar metallicity and also instantaneous bursts. The IMF is from Scalo (1986). In PEGASE, the authors define their morphological types by directly comparing spectra generated from their models with Kennicutt (1992) optical spectra of nearby galaxies. Poggianti (1997), on the other hand, matches colors obtained from her model with observed colors of galaxies, taken from Persson, Frogel & Aaronson (1979) and

\(^5\)Projet d’Etude des GAlaxies par Synthèse Evolutive.
Comparing Figure 3 and 4, we conclude that although the K-corrections are quite different from one model to another, they are similar for $z \lesssim 0.1$. For $z \gtrsim 0.2$, differences are larger. K-corrections for different Hubble types are more similar if they are derived from PEGASE than from the models of Poggianti. Figure 5 shows the differences between these K-corrections for the two models, in the 3 passbands, and for the 3 Hubble types. Up to $z \sim 0.5$ the difference for the E type in $J$ and $H$ is less than 0.05 mag. However, the difference is $\sim 0.1$ mag for the later types. Equation (4) implies that the differences in $J - H$ will be less than 0.05 mag. However, this is not the case for colors involving the $K$ band ($J - K$ and $H - K$), due to the large difference in the K-corrections, for all the Hubble types, as shown also in Figure 5. The difference in $K$ for the K-corrections reaches values $\sim 0.4$ mag at $z \sim 0.3$. This shows that K-correction uncertainty will have the largest impact on rest-frame colors. Other studies also show large differences between their K-corrections, although some of them are comparable to the values of this work, showing also large negative K-corrections in $K$ (Frogel et al. 1978; Persson, Frogel & Aaronson 1979; Bershady 1995). For example, Bershady (1995) obtains type-averaged K-corrections in $K$, reaching $-0.33$ and $-0.60$ at $z = 0.14$ and $z = 0.30$, respectively. These values are larger than values from Poggianti (1997), but similar to those obtained from PEGASE (see Figure 3 and 4).

6. Comparison with models

As shown in the preceding section, K-corrections in the near-IR can be very different depending on the spectrophotometric models used. Therefore, we do not use rest-frame colors, i.e. we do not de-redshift the data. Instead, we redshift current epoch SEDs. Although this approach is similar to work with rest-frame colors, it is more robust, since the SEDs of the current epoch models can be determined absolutely. In order to give an idea whether
synthetic SEDs compare well with spectra of galaxies at the current epoch, we consider GISSEL96 models (Charlot, Worthey & Bressan 1996) and compare them with real, local galaxy spectra of known morphological types, given by Kennicutt (1992). As it is well-known, the age-metallicity degeneracy prevents us for deriving age and metallicity directly from colors, as was shown by Worthey (1994); Ferreras, Charlot & Silk (1998). Therefore, we consider instantaneous bursts of fixed (solar) metallicity. Subsequent evolution is determined by adopting passive stellar evolution, measured in Gyrs and indicated by the label “age” for each model spectrum in Figure 6. A simple $\chi^2$ test is used to determine the model spectra closest to the observed (Kennicutt) sample. We use a starting sample of 20 GISSEL96 spectra and 27 spectra representative of normal galaxies of known Hubble types (Galaz & de Lapparent 1998). Figure 6 shows the better spectral match between some Kennicutt spectra and the 20 selected GISSEL96 models.

The Hubble sequence fits well with an evolutionary sequence in the optical, but care has to be taken in the interpretation since more than one solution can be obtained from a synthetic set where both age and metallicity vary (Ronen, Aragon-Salamanca & Lahav 1999). Even though metallicity can vary from one galaxy to another, it is realistic to set metallicity close to solar. Extremely metal-poor ($Z \lesssim 0.5 \, Z_\odot$) or metal-rich ($Z \gtrsim 1.5 \, Z_\odot$) cases are unlikely in this set of galaxies (Liu & Green 1996). Moreover, the fact that colors are obtained from integrated total apparent magnitudes, imply that colors are an average over the whole galaxy light and therefore likely to be representative of solar metallicity or lower in the luminosity weighted mean (see for example Edmunds (1992)).

In order to compare the observed colors with models, we take the 20 spectra from GISSEL96 and we “redshift” them to several redshift values (from the rest-frame to $z = 0.5$). Afterwards, we compute synthetic colors using $J$, $H$ and $K_s$ passbands (Persson et al. 1998) for the 20 synthetic spectra. Figure 7 shows the color-color diagram for the E+A sample and
the control sample (indicated as filled circles), as well as for the model spectra (indicated as open symbols) situated at different redshifts (as indicated by labels). We include 3 different evolving tracks in figure 7, for instantaneous bursts after 1 Gyr, 3 Gyr and 16 Gyr indicated by circles, squares, and triangles, respectively. After 10 Gyr, the near-IR colors are almost independent of age, for a given redshift.

Figure 7 shows that there is an overall agreement between near-IR colors of all subsamples and models, except for subsample 3. The average color \(< H - K_s > = 0.41 (\sigma = 0.05)\) of subsample 1 (average redshift \(< z > = 0.09, \sigma = 0.02\) agrees well with any model older than 3 Gyr at \(z = 0.10\). However, the average \(< J - H > = 0.66 (\sigma = 0.06)\) appears bluer than the same models by \(\sim 0.1\) mag. Otherwise, \(< J - H >\) is well fitted by a model with age \(\lesssim 3\) Gyr at \(z = 0.10\), but then \(< H - K_s >\) of subsample 1 is redder by \(\sim 0.1\) mag. These differences are twice the color dispersion for this subsample. Therefore we can conclude that colors of the models and the data do not differ by more than 2\(\sigma\). In subsample 2, the average colors \(< H - K_s > = 0.29 (\sigma = 0.07)\) and \(< J - H > = 0.69 (\sigma = 0.05)\), with average redshift \(< z > = 0.046 (\sigma = 0.014)\), are well fitted by a model at \(z = 0.05\) and 2.8 Gyr. Subsample 3, having \(< H - K_s > = 0.61 (\sigma = 0.23)\), \(< J - H > = 0.75 (\sigma = 0.25)\), and average redshift \(< z > = 0.31 (\sigma = 0.01)\) is not fitted by the GISSEL96 models, even though the average color \(< H - K_s >\) is closer to the \(z = 0.3\) redshifted color of models. Subsample 4 (the control sample) matches the models colors well, despite the rather large scatter. This subsample has average colors \(< H - K_s > = 0.29 (\sigma = 0.08)\), \(< J - H > = 0.74 (\sigma = 0.06)\), and average redshift \(< z > = 0.030 (\sigma = 0.012)\). These average colors correspond to a model located at \(z = 0.05\) and age 3 Gyr. This subsample shows a larger scatter in the color-color diagram. Most of these galaxies are nearby galaxies (from the PGC and NGC catalogues) and some galaxies from DC clusters (Caldwell & Rose 1997). All have secure Hubble types, and most of them have known photometric properties in the optical (for \(B\) and \(R\) total magnitudes see Table 2). The majority of these galaxies are well matched by the colors
provided by the spectrophotometric models, for ages representative of early type galaxies. These galaxies have large apparent radii, and therefore, their photometry is more sensitive to color gradients. This is not a problem for more distant galaxies because of the poorer spatial resolution.

Now we compare color properties of subsample 1 (field E+As from the LCRS) and 2 (cluster E+As). From Figure 7 it is apparent that subsample 1 has the same average \(< J - H >\) (with a difference of 0.03), but a redder \(< H - K_s >\) than subsample 2 (see above). The difference of 0.12 mag is 2.4σ and \(\sim 1.7\sigma\) away from the intrinsic dispersion of subsample 1 and subsample 2, respectively. The expected color difference due to K-corrections between \(< z > = 0.09\) (subsample 1) and \(< z > = 0.046\) (subsample 2) is \(\sim 0.06\) mag, for a 2 Gyr model (half of the 0.12 color difference between the two subsamples), which fits the average colors of both subsamples 1 and 2 better. Therefore, we can only conclude with a \(\sim 1.5\sigma\) confidence level that E+A galaxies from the field are redder than cluster E+As. The fact that dust extinction is much more notorious in \(J - H\) than in \(H - K_s\) suggest that the color difference observed in \(H - K_s\) between subsample 1 and subsample 2 is not due to differential internal dust extinction. However, because of the observed color dispersion, we cannot give a robust answer supporting stellar population differences instead of internal reddening differences due to extinction. We stress that our differences are only at 1.5σ significance level. It is worth noting that \(J - H\) color would redden systematically \(\sim 0.03 - 0.05\) if we account for foreground or internal extinction (see §5.3). This would make ages inferred from colors (see Figure 7) slightly older (0.5 to 1 Gyr), but in any case alter the results of the analysis, since changes are the same for all the galaxy samples.
7. Further analysis and discussion

7.1. Photometry uncertainties

In order to interpret correctly the color properties of the observed galaxy sample, it is important to keep in mind the sources of uncertainty which affect the colors. The first source of uncertainty is of course the data acquisition itself. Given the nature of the near-IR imaging, the thermal variation of the sky affects the photometry for the faint objects, which require longer integration time than the brighter ones, sometimes much longer than the typical time of the sky fluctuations (see Figure 1). However, the nature of these variations is well understood and the fact that the sky fluctuations are sampled in real-time and subtracted for each image can reduce this error to 5% (see §3). The second important source of errors is the procedure employed to compute the magnitude. It is well known that total magnitudes depend on the cut level where the light contribution is null or not significant. In our case, SExtractor computes total magnitudes integrating all the light up to a given threshold above the sky (typically 1.5σ), and fitting elliptical isophotes to the profiles. An elliptical aperture for a given galaxy, defined by the elongation $\epsilon$ and position angle $\theta$, is computed from the 2nd order moment in the light distribution, above the isophotal threshold. The “first moment” $r_1$ is then computed within an aperture twice as large as the isophotal aperture, in order to reach the light distribution in the wings. This approach is very similar to the approach of Kron (1980). The parameter $r_1$ is then used to define the adaptive aperture where the total magnitude will be computed. The main axes of the ellipse are defined as $\epsilon kr_1$ and $kr_1/\epsilon$, where $k$ is a value to be fixed by the user. We carried out some tests with both faint and bright galaxies and found that the value $k = 2.5$ allows us to include between 90% and 95% of the total flux without introducing additional noise within the aperture. Further details

\[ r_1 = \frac{\sum r I(r)}{\sum r I(r)} \]
Another source of uncertainty is the photometric errors due to the transformation of the instrumental magnitudes to calibrated magnitudes. This process is well understood and in general the scatter is small. The errors of the zero points are $\sim 2\%$ to $\sim 7\%$.

The largest uncertainties (now for rest-frame colors) are due to the K-corrections. These uncertainties, as shown in the previous section, can be very large for galaxies with $z \gtrsim 0.25$, where the change in magnitude produced by the computation of K-corrections assuming one or another SED can reach differences as large as 30%, propagating these differences to the rest-frame colors (see Figure 5). For galaxies with $z \lesssim 0.2$, differences are smaller: $\sim 10\%$ for $0.15 \lesssim z \lesssim 0.2$ and $\sim 5\%$ for $0 \leq z \lesssim 0.15$. In order to compute reliable K-corrections, it is fundamental to obtain calibrated spectra at $9000 \lesssim \lambda \lesssim 25000$ Å for different spectral types, including E+A galaxies. Of course, the nature of the uncertainties lies in the fact that K-corrections are expressed in term of the morphological type instead of the spectral type. The morphological type relies on a subjective classification procedure, often dependent on the passband through which the images are obtained (more or less sensitive to the star population which delineates the galaxy morphology) and is always strongly dependent on the image quality. On the other hand, there is no unique and reliable relationship between the spectral type and the morphological type of the galaxies. Even though this is approximately true for normal Hubble types (Folkes, Lahav & Maddox 1996; Galaz & de Lapparent 1998), the dispersion can be large for some spectral types or active galaxies (Sodre & Stasinska 1999), leading to large uncertainties in the K-correction $= f(z, T\text{-type})$. However, we note that independently of what spectrophotometric models are used in obtaining rest-frame colors, the K-corrections in $K$ (or $K_s$ band), are only weakly dependent on the spectral type for $z \lesssim 0.2$ (see Figures 3, 4, and 5).
7.2. Implications from near-IR colors

We now examine some color properties of the E+A galaxies observed in the near-IR, keeping in mind the limitations of the accuracy of our photometry, as discussed above.

Studying the position of the E+A galaxies in the $H - K_s/J - H$ plane shown in Figure 7, we see that field galaxies located at $<z> \sim 0.09$ (subsample 1), have an average $J - H$ color similar to that of E+A galaxies located in nearby clusters ($<z> \sim 0.05$, subsample 2), but are slightly redder in the average $H - K_s$ color (see preceding section). The fact that the color difference of 0.12 mag in only significant at $\sim 1.5 \sigma$ level prevents us from proposing a robust conclusion. However, we can now ask how the K-corrections can change this result. Here we examine the answer to this question using the two sets of K-corrections show in §5.3 the PEGASE and the Poggianti K-corrections.

Figure 8 shows average rest-frame colors for our sample of galaxies computed using both sets of K-corrections. Also shown are the colors of the sample of elliptical galaxies from Silva & Bothun (1998). We show the average colors for the cluster and the field galaxies separately. This Figure demonstrates that, although the color differences are small, the same trend is observed, independently of which set of K-corrections is used. The color difference in $<H - K_s>$ between field and cluster E+As is about 0.04 mag using PEGASE K-corrections and 0.15 mag using Poggianti K-corrections. Note that in Figure 8 we compare cluster-field colors also for the LCRS sample (3 LCRS E+As belong to clusters). The field E+As from LCRS are also redder in $<H - K_s>$ than the LCRS cluster E+As.

As demonstrated by Persson et al. (1983), stellar populations containing a large fraction of AGB stars (1 to 3 Gyr old), have redder $H - K$ color (but similar $J - H$ index), compared with populations that lack such stars. This might suggest that the E+A galaxies in the field have a larger fractions of AGB stars than those in clusters. We emphasize that, although the difference given by the K-correction between $z \sim 0.1$ and $z \sim 0.05$ for subsamples 1
and 2, respectively, does change the corresponding average colors, the observed color trend field/cluster does not change.

Note that three out 21 LCRS E+As are embedded in clusters (LCRS # 4, 11 and 20, These galaxies have an average color $<H - K_s> = 0.160 \pm 0.041$, using the PEGASE K-corrections, and $<H - K_s> = 0.260 \pm 0.005$, using the Poggianti K-corrections. These values are 35% and 22% bluer, respectively, than the average $H - K_s$ color for the LCRS E+A galaxies located in the field, and are consistent with the comparison field/cluster between subsamples 1 and 2.

Galaxies in more distant clusters (subsample 3), appear redder in $J - H$ (at 2σ significance level) than those at lower redshift (compared with both subsamples 1 and 2). As discussed above, although for this subsample K-corrections are critical, the $J - H$ color does not change if one uses a different set of K-corrections. This could be interpreted as a temperature change of the first-ascent giant branch (FAGB) in the stellar populations of these $z \sim 0.3$ E+A galaxies (see Charlot, Worthey & Bressan (1996)). A further spectroscopic analysis in the near-IR would settle this question, and also will help to disentangle possible significant extinction in the $J$ band.

One can also compare the integrated rest-frame colors between the E+A galaxies from subsample 2 with the control galaxies which also belong to these nearby clusters (e.g. galaxies # 52, 53, 59, 60 and 61 in Table 2. We note that the average $H - K_s$ color for both sets of galaxies is similar, and therefore any difference (in the mean) is observed between E+A galaxies and elliptical galaxies belonging to the same cluster. This is not the case if one compares the colors between subsamples 1 and 2, as shown before. We emphasize that the average $J - H$ color of the E+A galaxies of subsamples 1 and 2 is similar to the average $J - H$ of the control sample (at 1σ significance level, see Figure 7).

It is worth noting that all the K-corrections used to obtain average rest-frame colors,
as shown in Figure 8, have been computed using solar metallicity models, assuming that K-corrections, for a given IMF, age and SFR scenario do not depend strongly on metallicity. We tested this assumption using GISSEL96 SEDs with different metallicity. Several tests were carried out for different ages, IMFs, and SFRs, and metallicity between the extreme values of \([\text{Fe/H}] = -1.65\) and \([\text{Fe/H}] = +1.00\). Differences in K-corrections between these two extreme metal-poor and metal-rich models can reach up to 0.3 mag in \(J\) at \(z = 0.3\), for a large range of fundamental parameters (age, IMF, and SFR). For more modest metallicity differences between models (probably more realistic), variations in K-corrections, for the different near-IR photometric bands, are between 0.15 mag for \(J\) and 0.05 mag for \(H\) and \(K_s\), at \(z = 0.3\). For smaller redshifts, these differences are even smaller. Figure 9 shows K-correction differences in near-IR bands, as a function of redshift, for two SEDs (shown in the inset) with different metallicity (\([\text{Fe/H}] = -0.30\) and \([\text{Fe/H}] = +0.1\)), derived from instantaneous bursts with the same age and IMF (in both cases Scalo IMF). These K-corrections differences imply \(J - H\) and \(H - K_s\) colors shifts no larger than 0.08 mag up to \(z \sim 0.3\), given that differences in K-corrections, due to different metallicity have the same sign. We conclude that for a typical interval of metallicity found in the field and in clusters, the effect of varying metallicity should not be significant on the K-correction uncertainties, and hence on rest-frame colors. However, for more accurate estimates of near-IR colors from broad band photometry, especially at higher redshift (\(z \gtrsim 0.5\)), metallicity does play a significant role on the K-corrections.

8. Summary and conclusions

The E+A galaxies reported here include 32 galaxies from clusters and 18 galaxies from the field. In addition, 13 nearby galaxies which do not present post-starburst activity, were observed (5 located in clusters at \(z \sim 0.05\) and 8 located in the field at very low redshift).
All the galaxies have been observed in the near-IR bands $J$, $H$ and $K_s$ during photometric nights at Las Campanas Observatory. Total apparent magnitudes and colors were derived. The color-color diagram $H - K_s/J - H$ of the observed galaxies is compared to the expected corresponding colors of spectrophotometric models of galaxy evolution, at different redshifts. The models are those generated by GISSEL96 (Charlot, Worthey & Bressan 1996). There is an overall agreement between these expected colors and the observed ones, for the E+A located in nearby clusters ($< z > \sim 0.05$) and for E+As located in the field ($< z > \sim 0.1$). The comparison of the colors of these two samples shows that even though cluster E+As appear bluer than field E+As, the color difference is only significant at $\sim 1.5\sigma$ level, and therefore we cannot strongly affirm that stellar population differences are observed between these two populations.

The colors of the E+A galaxies located in more distant clusters $z = 0.3$, on the other hand, do not agree with the color expected from models. In the mean, they appear bluer than expected in $H - K_s$ (by $\sim 0.3$ mag) and redder in $J - H$ (by $\sim 0.15$ mag). The possible interpretation of the failure is strong internal reddening (mostly in the $J$ band), not considered in models.

In order to derive a more complete comparison with models, rest-frame colors were also obtained using two different sources of K-corrections: one based on the work of Poggianti (1997), and the other computed using the spectrophotometric model PEGASE (Fioc & Rocca-Volmerange 1997). We have shown that such K-corrections can be significant for $z \sim 0.2$ in the $K$ bands (or any band centered at 2$\mu$m), although they are not a strong function of spectral type. In addition, large differences exist in the K-corrections between these two models, having a large impact on the derived quantities, like rest-frame colors for high redshift galaxies. We have compared average rest-frame colors of E+A galaxies located in the field and in clusters. Results show that average rest-frame near-IR colors of E+A
galaxies located in clusters at $z \sim 0.05$ (Caldwell & Rose 1997) and field E+As located at $z \sim 0.1$ (from the LCRS, Zabludoff et al. 1996), follow the same color trend in $J - H$ and $H - K_s$ observed in the comoving color-color diagram: E+A galaxies located in nearby clusters appear bluer than field E+As ($z \sim 0.1$).

As well as comparing the observed colors with the GISSEL96 colors at different redshifts, the models do not fit the rest-frame colors of the E+A galaxies observed in clusters at $z \sim 0.3$. Their $H - K_s$ colors appear bluer (using the K-corrections of PEGASE), or redder (using the K-corrections of Poggianti) compared to the models. Their $J - H$ color index, although not particularly sensitive to one or the other K-correction, is also redder than the colors predicted by the models. The color of control galaxies, most of them ellipticals at $z \lesssim 0.01$, and the others from clusters at $z \sim 0.05$, agree with the near-IR colors predicted by models.

Integrated colors between the field E+As and the cluster E+As of the LCRS (LCRS # 4, 11 and 20; see Table 2) are similar, although those in clusters seem to be slightly ($\sim 25\%$) bluer in $H - K_s$ than the average color. This result is the same for both sets of rest-frame colors, the set corrected by the PEGASE K-corrections and the set corrected by the Poggianti K-corrections (see Figure 8). On the other hand, the corresponding $J - H$ color is similar for the cluster and field E+As in subsample 1.

In order to build more robust results, more field and cluster E+A galaxies have to be observed between $z = 0.1 - 1.0$. Spectroscopic observations of normal and E+A galaxies at different redshifts in the near-IR are necessary to (1) obtain calibrated SEDs and realistic K-corrections, and (2) to compare the spectra of the E+A galaxies with those of normal galaxies in the whole spectral range $3500 \, \AA \lesssim \lambda \lesssim 25000 \, \AA$. We expect to continue this research by imaging new E+A galaxies in the near-IR at higher redshift, as well as obtaining near-IR spectra in order to construct a useful and larger database of normal and post-starburst galaxies in a large spectral range. In order to increase the number of E+A galaxies, some
field galaxies already classified as E+As, are being observed in the near-IR at Las Campanas. Some of these galaxies belong to the ESO-Sculptor Survey (de Lapparent et al. 1997), and results will be published soon. Other wide-field surveys will provide a wealth of data for E+A galaxies at $0.01 \lesssim z \lesssim 0.2$, like SLOAN (Loveday & Pier 1998; Fan et al. 1998), and the 2DF survey (Colless 1998), whose data are expected to become available to the public. In a forthcoming paper, we shall investigate systematic properties on the surface photometry and colors of the E+A galaxies.

I would like to thank the anonymous referee for useful comments and suggestions on how to improve this paper. I thank Ron Marzke, Eric Persson, and Ann Zabludoff for fruitful discussions on the nature of the E+A galaxies. I acknowledge Mauro Giavalisco for his help with the DIMSUM software. I also acknowledge Mario Hamuy, René Méndez, Mark Phillips, Miguel Roth, and Bill Kunkel in helping to improve the preliminary version of this paper. It is a pleasure to thank all the staff at Las Campanas Observatory. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This work is made possible through the fellowship # C-12927, under agreement between Fundación Andes and Carnegie Institution of Washington.
REFERENCES

Arnouts, S. 1996, PhD thesis, Université Paris VII.

Bershady, M. 1995, AJ, 109, 87

Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393

Bower, R., Lucey, J., & Ellis, R. 1992a, MNRAS, 254, 589

Bower, R., Lucey, J., & Ellis, R. 1992b, MNRAS, 254, 601

Bruzual, G., & Charlot, S. 1993, ApJ, 405, 538 (GISSEL93).

Butcher, H., & Oemler, A. 1978, ApJ, 219, 18

Caldwell, N., & Rose, J. 1997, AJ, 113, 492

Cardelli, J., Clayton, G., & Mathis, J. 1989, ApJ, 345, 245

Charlot, S., Worthey, G., & Bressan, A. 1996, ApJ, 457, 625 (GISSEL96)

Colless, M. 1998, in Wide Field Surveys in Cosmology, 14th IAP meeting, Paris. Publisher: Editions Frontières.

Couch, W., & Sharples, R. 1987, MNRAS, 229, 423

de Lapparent, V., Galaz, G., Arnouts, S., Bardelli, S., & Ramella, M. 1997, The Messenger, 89, 21

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H., Buta, R., Paturel, G., & Fouqué, P. 1991, Third Reference Catalogue of Bright Galaxies, Springer-Verlag, Berlin, Heidelberg, New York (RC3)
de Vaucouleurs, G., de Vaucouleurs, A., & Corwin, H. 1976, *Second Reference Catalogue of Bright Galaxies (Austin: University of Texas Press)*

Dressler, A., & Gunn, J. 1983, ApJ, 270, 7

Edmunds, M. G. 1992, in The Stellar Populations of Galaxies, ed. B. Barbuy & A. Renzini (Dordrecht: Kluwer Academic), 277

Fabricant, D., McClintock, J., & Bautz, M. 1991, ApJ, 381, 33

Fairall, A., Willmer, C., Calderón, J., Latham, D., da Costa, L., Pellegrini, P., Nunes, M., Focardi, P., & Vettolani, G. 1992, AJ, 103, 11

Fan, X., Strauss, M., Gunn, J., Hennessy, G., Ivezić, Z., Knapp, G., Lupton, R., Newberg, H., & Schneider, D. 1998, American Astronomical Society Meeting no. 193, 02.05

Ferreras, I., Charlot, S., & Silk, J. 1998, ApJ, in press

Fioc, M., & Rocca-Volmerange, B. 1997, A&A, 326, 950 (PEGASE)

Folkes, S., Lahav, O., & Maddox, S. 1996, MNRAS, 283, 651

Franx, M. 1993, ApJ, 407, L5

Galaz, G., & de Lapparent, V. 1998, A&A, 332, 459

Frogel, J., Persson, E., Matthews, K., & Aaronson, M. 1978, ApJ, 220, 75

Kennicutt R. 1992, ApJS, 79, 255

Kron, R. 1980, ApJS, 43, 305

Liu, C., & Green, R. 1996, ApJ, 468, L63
Loveday, J., & Pier, J. 1998, in Wide Field Surveys in Cosmology, 14th IAP meeting, Paris.
Publisher: Editions Frontières.

Loveday, J. 1996, MNRAS, 278, 1025

Oke, J., & Sandage, A. 1968, ApJ, 154, 21

Persson, E., Murphy, D., Krzeminski, W., Roth, M., & Rieke, M. 1998, ApJ, 116, 2475

Persson, E., Cohen, J., Matthews, K., Frogel, J., & Aaronson, M. 1983, ApJ, 266, 105

Persson, E., Frogel, J., & Aaronson, M. 1979, ApJS, 39, 61

Poggianti, B. 1997, A&AS, 122, 399

Prugniel, P., & Hérédéau, P. 1998, A&AS, 128, 299

Rakos, K., & Schombert, J. 1995, ApJ, 439, 47

Ronen, S., Aragon-Salamanca, A., & Lahav, O. 1999, MNRAS, 303, 284

Scalo, J. 1986, Fund. Cosmic Phys., 11, 1

Schelegel, D., Finkbeiner, P. & Davis, M. 1998, ApJ, 500, 525

Shectman, S., Landy, S., Oemler, A., Tucker, D., Lin, H., Kirshner, R., & Schechter, P. 1996, ApJ, 470, 172

Silva, D., & Bothun, G. 1998, AJ, 116, 85

Sodre, L., & Stasinska, G. 1999, astro-ph/9903130

Spellman, K., Madore, B., & Helou, G. 1989, PASP, 101, 360

Wise, M., & Silva, D. 1996, ApJ, 461, 155
Worthey, G. 1994, ApJS, 95, 107

Zabludoff, A., Zaritsky, D., Lin, H., Tucker, D., Hashimoto, Y., Shectman, S., Oemler, A., & Kirshner, R. 1996, ApJ, 466, 104
Table 1. The sample.

| ID(1) | S-ID(2) | Name(3) | RA(4)   | DEC(5)   | z(6)  | Cluster/Field(7) | T-type(8) | Reference(9) |
|-------|---------|---------|---------|----------|-------|------------------|-----------|--------------|
| 1     | 1       | g515    | 15:24:26| +08:09:06| 0.0870| Abell 665        | 0         | (1)          |
| 2     | 1       | dc204852_26 | 20:49:52| −53:02:58 | 0.0397| ACO 3716        | −2        | (2)          |
| 3     | 1       | dc184263_39m | 18:42:49| −63:12:28 | 0.0144| DC1842-63       | −3        | (2)          |
| 4     | 1       | dc204852_100 | 20:51:49| −52:44:45 | 0.0493| ACO 3716        | −2        | (2)          |
| 5     | 1       | dc204852_148 | 20:49:13| −52:33:51 | 0.0429| ACO 3716        | −2        | (2)          |
| 6     | 1       | dc204852_39  | 20:50:01| −52:59:56 | 0.0489| ACO 3716        | −2        | (2)          |
| 7     | 1       | dc204852_45  | 20:52:10| −52:56:09 | 0.0484| ACO 3716        | −2        | (2)          |
| 8     | 1       | dc204852_104 | 20:51:07| −52:43:34 | 0.0493| ACO 3716        | 0         | (2)          |
| 9     | 1       | dc204852_149 | 20:48:30| −52:33:07 | 0.0569| ACO 3716        | 0         | (2)          |
| 10    | 1       | dc204852_192 | 20:51:56| −52:03:45 | 0.0473| ACO 3716        | −5        | (2)          |
| 11    | 1       | dc204852_77  | 20:52:54| −52:47:28 | 0.0452| ACO 3716        | −2        | (2)          |
| 12    | 1       | dc204852_174 | 20:51:46| −52:16:09 | 0.0448| ACO 3716        | −5        | (2)          |
| 13    | 1       | dc204852_184 | 20:54:00| −52:08:15 | 0.0469| ACO 3716        | −2        | (2)          |
| 14    | 1       | dc204852_216 | 20:49:24| −51:56:56 | 0.0490| ACO 3716        | −2        | (2)          |
| 15    | 1       | dc204852_231 | 20:51:40| −51:45:22 | 0.0459| ACO 3716        | −2        | (2)          |
| 16    | 1       | dc032952_135a | 03:29:31| −52:27:18 | 0.0519| ACO 3128        | −2        | (2)          |
| 17    | 1       | dc032952_156a | 03:31:15| −52:22:28 | 0.0604| ACO 3128        | −2        | (2)          |
Table 1—Continued

| ID(1) | S-ID(2) | Name(3)       | RA(4)   | DEC(5)     | z(6)  | Cluster/Field(7) | T-type(8) | Reference(9) |
|-------|---------|---------------|---------|------------|-------|------------------|-----------|--------------|
| 18    | 1       | dc010746_30b  | 01:10:51| −45:51:52  | 0.0267| ACO 2877         | −5        | (2)          |
| 19    | 1       | dc032952_82a  | 03:31:09| −52:36:49  | 0.0576| ACO 3128         | −5        | (2)          |
| 20    | 1       | dc032952_158b | 03:29:35| −52:39:58  | 0.0500| ACO 3128         | 0         | (2)          |
| 21    | 1       | dc010746_22m  | 01:08:23| −46:09:09  | 0.0200| ACO 2877         | 0         | (2)          |
| 22    | 1       | dc010746_45m  | 01:09:07| −45:44:29  | 0.0300| ACO 2877         | 0         | (2)          |
| 23    | 2       | ac103_132     | 20:57:18| −64:38:48  | 0.3047| AC 103           | 0         | (3)          |
| 24    | 2       | ac114_22      | 22:58:50| −34:48:13  | 0.3354| AC 114           | 0         | (3)          |
| 25    | 2       | ac114_89      | 22:58:49| −34:46:57  | 0.3169| AC 114           | 0         | (3)          |
| 26    | 2       | ac103_03      | 20:56:55| −64:40:11  | 0.3118| AC 103           | 0         | (3)          |
| 27    | 2       | ac103_106     | 20:56:47| −64:40:56  | 0.3091| AC 103           | 0         | (3)          |
| 28    | 2       | ac103_280     | 20:57:26| −64:42:11  | 0.3111| AC 103           | 0         | (3)          |
| 29    | 2       | ac103_145     | 20:57:07| −64:38:29  | 0.3105| AC 103           | −2        | (3)          |
| 30    | 3       | lcrs01        | 11:01:19| −12:10:18  | 0.0746| Field            | 1         | (4)          |
| 31    | 3       | lcrs17        | 10:13:52| −02:55:47  | 0.0609| Field            | 0         | (4)          |
| 32    | 3       | lcrs21        | 11:15:24| −06:45:13  | 0.0994| Field            | 0         | (4)          |
| 33    | 3       | lcrs13        | 11:19:52| −12:52:39  | 0.0957| Field            | 1         | (4)          |
| 34    | 3       | lcrs14        | 13:57:01| −12:26:47  | 0.0704| Field            | 0         | (4)          |
| 35    | 3       | lcrs12        | 12:05:59| −02:54:32  | 0.0971| Field            | 1         | (4)          |
| 36    | 3       | lcrs03        | 12:09:05| −12:22:37  | 0.0810| Field            | 1         | (4)          |
| 37    | 3       | lcrs16        | 12:19:55| −06:14:01  | 0.0764| Field            | 1         | (4)          |
| ID  | S-ID | Name  | RA   | DEC   | z     | Cluster/Field | T-type | Reference |
|-----|------|-------|------|-------|-------|---------------|--------|-----------|
| 38  | 3    | lcrs15| 14:40:44 | −06:39:54 | 0.1137 | Field        | 0      | (4)       |
| 39  | 3    | lcrs06| 11:53:55 | −03:10:36 | 0.0884 | Field        | 0      | (4)       |
| 40  | 3    | lcrs08| 14:32:03 | −12:57:31 | 0.1121 | Field        | −2     | (4)       |
| 41  | 3    | lcrs07| 22:41:09 | −38:34:35 | 0.1141 | Field        | 0      | (4)       |
| 42  | 3    | lcrs20| 00:38:44 | −38:57:12 | 0.0632 | Cluster      | −2     | (4)       |
| 43  | 3    | lcrs18| 00:22:46 | −41:33:37 | 0.0598 | Field        | 0      | (4)       |
| 44  | 3    | lcrs05| 01:58:01 | −44:37:14 | 0.1172 | Field        | −2     | (4)       |
| 45  | 3    | lcrs19| 02:07:49 | −45:20:50 | 0.0640 | Field        | 0      | (4)       |
| 46  | 3    | lcrs11| 01:14:49 | −41:22:30 | 0.1216 | Cluster      | 0      | (4)       |
| 47  | 3    | lcrs02| 02:17:39 | −44:32:47 | 0.0987 | Field        | 2      | (4)       |
| 48  | 3    | lcrs09| 01:17:38 | −41:24:23 | 0.0651 | Field        | 0      | (4)       |
| 49  | 3    | lcrs10| 02:11:43 | −44:07:39 | 0.1049 | Field        | 0      | (4)       |
| 50  | 3    | lcrs04| 04:00:00 | −44:35:16 | 0.1012 | Cluster      | 1      | (4)       |

Control galaxies

| ID  | S-ID | Name         | RA   | DEC   | z     | Cluster/Field | T-type | Reference |
|-----|------|--------------|------|-------|-------|---------------|--------|-----------|
| 51  | 4    | pgc35435     | 11:30:05 | −11:32:47 | 0.0178 | Field        | −3     | (5)       |
| 52  | 4    | dc204852_116 | 20:51:19 | −52:40:41 | 0.0441 | ACO 3716     | −5     | (2)       |
| 53  | 4    | dc204852_66  | 20:51:45 | −52:51:19 | 0.0410 | ACO 3716     | −5     | (2)       |
| 54  | 4    | pgc60102     | 17:20:28 | −00:58:46 | 0.0304 | Field        | −2     | (6)       |
Table 1—Continued

| ID(1) | S-ID(2) | Name(3)     | RA(4)   | DEC(5)   | z(6)  | Cluster/Field(7) | T-type(8) | Reference(9) |
|-------|---------|-------------|---------|----------|-------|------------------|-----------|--------------|
| 55    | 4       | eso290-IG_050 | 23:06:46 | −44:15:06 | 0.0290 | Field            | −2        | (7)          |
| 56    | 4       | pgc62615     | 18:57:41 | −52:31:46 | 0.0280 | Field            | 2         | (8)          |
| 57    | 4       | pgc57612     | 16:15:04 | −60:54:26 | 0.0183 | Field            | −5        | (9)          |
| 58    | 4       | ngc6653      | 18:44:39 | −73:15:47 | 0.0172 | Field            | −5        | (9)          |
| 59    | 4       | dc204852-115 | 20:51:21 | −52:39:17 | 0.0440 | ACO 3716        | −5        | (2)          |
| 60    | 4       | dc204852-126 | 20:51:44 | −52:37:57 | 0.0489 | ACO 3716        | −2        | (2)          |
| 61    | 4       | dc204852-38  | 20:50:05 | −53:00:28 | 0.0454 | ACO 3716        | −2        | (2)          |
| 62    | 4       | ngc6328      | 17:23:41 | −65:00:37 | 0.0142 | Field            | 2         | (6)          |
| 63    | 4       | pgc62765     | 19:05:59 | −42:21:59 | 0.0193 | Field            | −2        | (6)          |

(1) Correlative number of the galaxy.
(2) Sample ID. Sample 1, Nearby cluster E+As; sample 2, distant cluster E+As; sample 3, LCRS E+As; sample 4, control galaxies.
(3) Galaxy Identification used in this paper.
(4) Right ascension in hh:mm:ss (J2000).
(5) Declination in °′″(J2000).
(6) Redshift.
(7) Column indicating whether the galaxy belongs to a cluster or to the field.
(8) Morphological type in T-type units, from the de Vaucouleurs classification system (de Vaucoulers, de Vaucouleurs & Corwin 1976).
(9) Reference where quantities other than magnitudes have been extracted.

References. — (1) Franx (1993); (2) Caldwell & Rose (1997); (3) Couch & Sharples (1987); (4) Zabludoff et al. (1996); (5) Fairall et al. (1992); (6) de Vaucouleurs et al. (1991); (7) Loveday (1996); (8) Spellman, Madore & Helou (1989); (9) Prugniel & Hérédeau (1998)
Table 2. Apparent magnitudes and colors.

| ID(1) | Name(2) |  \(J(3)\) |  \(H(4)\) |  \(K_s(5)\) |  \((J - H)(6)\) |  \((H - K_s)(7)\) |  \((J - K_s)(8)\) |  \(z(9)\) |  \(B(10)\) |  \(R(11)\) | S-ID(12) | T-Type(13) |
|-------|---------|----------|----------|----------|--------------|--------------|--------------|--------|--------|--------|--------|----------|
| 1     | g515    | 13.86    | 13.11    | 12.75    | 0.75         | 0.36         | 1.11         | 0.0870 | ...    | ...    | 1      | 0       |
| 2     | dc204852_26 | 13.82    | 13.16    | 12.99    | 0.66         | 0.17         | 0.83         | 0.0397 | 16.99  | 15.38  | 1      | -2      |
| 3     | dc184263_39m | 11.01    | 10.27    | 10.05    | 0.74         | 0.22         | 0.96         | 0.0144 | ...    | ...    | 1      | -3      |
| 4     | dc204852_100 | 14.62    | 13.95    | 13.64    | 0.67         | 0.31         | 0.98         | 0.0493 | 17.61  | 16.19  | 1      | -2      |
| 5     | dc204852_148 | 14.44    | 13.74    | 13.44    | 0.70         | 0.30         | 1.00         | 0.0429 | 17.57  | 16.01  | 1      | -2      |
| 6     | dc204852_39 | 14.50    | 13.81    | 13.48    | 0.69         | 0.33         | 1.02         | 0.0489 | 17.77  | 16.16  | 1      | -2      |
| 7     | dc204852_45 | 15.04    | 14.39    | 14.03    | 0.65         | 0.36         | 1.01         | 0.0484 | ...    | ...    | 1      | -2      |
| 8     | dc204852_104 | 14.99    | 14.25    | 13.95    | 0.74         | 0.30         | 1.04         | 0.0493 | ...    | ...    | 1      | 0       |
| 9     | dc204852_149 | 13.91    | 13.24    | 12.91    | 0.67         | 0.33         | 1.00         | 0.0569 | ...    | ...    | 1      | 0       |
| 10    | dc204852_192 | 13.83    | 13.13    | 12.80    | 0.70         | 0.33         | 1.03         | 0.0473 | 16.98  | 15.40  | 1      | -5      |
| 11    | dc204852_77  | 14.88    | 14.16    | 13.90    | 0.72         | 0.26         | 0.98         | 0.0452 | ...    | ...    | 1      | -2      |
| 12    | dc204852_174 | 14.84    | 14.15    | 13.88    | 0.69         | 0.27         | 0.96         | 0.0448 | 18.09  | 16.43  | 1      | -5      |
| 13    | dc204852_184 | 14.29    | 13.60    | 13.25    | 0.69         | 0.35         | 1.04         | 0.0469 | 17.36  | 15.78  | 1      | -2      |
| 14    | dc204852_216 | 13.87    | 13.18    | 12.88    | 0.69         | 0.30         | 0.99         | 0.0490 | ...    | ...    | 1      | -2      |
| 15    | dc204852_231 | 13.58    | 12.88    | 12.58    | 0.70         | 0.30         | 1.00         | 0.0459 | 16.72  | 15.18  | 1      | -2      |
| 16    | dc032952_135a | 14.34    | 13.52    | 13.09    | 0.82         | 0.43         | 1.25         | 0.0519 | 18.09  | 16.21  | 1      | -2      |
| 17    | dc032952_156a | 13.22    | 12.48    | 12.15    | 0.74         | 0.33         | 1.07         | 0.0604 | 16.61  | 14.93  | 1      | -2      |
| 18    | dc010746_30b | 14.99    | 14.42    | 14.21    | 0.57         | 0.21         | 0.78         | 0.0267 | 17.90  | 16.41  | 1      | -5      |
| 19    | dc032952_82a | 14.96    | 13.45    | 13.18    | 0.61         | 0.17         | 0.78         | 0.0576 | 17.81  | 16.42  | 1      | -5      |
| 20    | dc032952_158b | 14.13    | 13.41    | 13.02    | 0.72         | 0.39         | 1.11         | 0.0500 | 17.26  | 15.76  | 1      | 0       |
| 21    | dc010746_22m | 14.49    | 13.87    | 13.60    | 0.62         | 0.27         | 0.89         | 0.0200 | ...    | ...    | 1      | 0       |
| 22    | dc010746_45m | 14.98    | 13.42    | 14.16    | 0.66         | 0.16         | 0.82         | 0.0300 | 17.37  | 16.24  | 1      | 0       |
| 23    | ac103_132 | 18.45    | 18.24    | 17.23    | 0.21         | 1.01         | 1.22         | 0.3047 | 19.34  | 18.45  | 2      | 6       |
| 24    | ac114_22  | 18.26    | 17.57    | 16.76    | 0.69         | 0.81         | 1.50         | 0.3354 | ...    | ...    | 19.85  | 2      |
| 25    | ac114_89  | 17.79    | 17.24    | 16.08    | NC NC        | 0.55         | 0.11         | ...    | ...    | ...    | 19.78  | 2      |
| 26    | ac103_03  | 16.33    | 15.44    | 15.09    | 0.89         | 0.35         | 1.24         | 0.3118 | 19.95  | 18.12  | 2      | 0       |
| 27    | ac103_106 | 17.15    | 16.34    | 15.76    | 0.81         | 0.58         | 1.39         | 0.3091 | ...    | ...    | 2      | 0       |
| 28    | ac103_280 | 17.21    | 16.23    | 15.76    | 0.98         | 0.47         | 1.45         | 0.3111 | 21.00  | 18.93  | 2      | 0       |
| 29    | ac103_145 | 17.20    | 16.31    | 15.90    | 0.89         | 0.41         | 1.30         | 0.3105 | 19.66  | 2      | 3       |
| 30    | lcrs01   | 16.18    | 15.57    | 15.10    | 0.61         | 0.47         | 1.08         | 0.0746 | ...    | ...    | 17.05  | 3      |
| 31    | lcrs17   | 15.83    | 15.19    | 14.75    | 0.64         | 0.44         | 1.08         | 0.0609 | 16.99  | 3      | 0       |
| ID  | Name             | $J$  | $H$  | $K_s$ | $(J - H)$ | $(H - K_s)$ | $(J - K_s)$ | $z$  | $B$    | $R$  | S-ID | T-Type |
|-----|------------------|------|------|-------|-----------|-------------|-------------|-----|--------|------|------|--------|
| 32  | lcrs21           | 15.55| 14.94| 14.53 | 0.61      | 0.41        | 1.02        | 0.05| 0.994  | 16.93| 3    | 0      |
| 33  | lcrs13           | 14.49| 14.20| 13.77 | 0.70      | 0.43        | 1.13        | 0.04| 0.957  | 12.97| 3    | 1      |
| 34  | lcrs14           | 14.90| 13.82| 13.04 | 0.64      | 0.43        | 1.05        | 0.07| 0.810  | 16.05| 3    | 0      |
| 35  | lcrs12           | 15.02| 14.10| 13.47 | 0.60      | 0.34        | 0.94        | 0.05| 0.764  | 16.69| 3    | 1      |
| 36  | lcrs16           | 15.35| 14.41| 13.53 | 0.59      | 0.36        | 0.95        | 0.06| 0.632  | 15.96| 3    | 2      |
| 37  | lcrs18           | 14.70| 14.62| 13.62 | 0.68      | 0.40        | 1.08        | 0.05| 0.598  | 16.59| 3    | 0      |
| 38  | lcrs05           | 15.36| 14.32| 13.42 | 0.56      | 0.48        | 1.04        | 0.11| 0.717  | 16.73| 3    | 0      |
| 39  | lcrs19           | 14.95| 14.24| 13.90 | 0.71      | 0.34        | 1.05        | 0.04| 0.640  | 16.42| 3    | 0      |
| 40  | lcrs11           | 15.48| 14.78| 14.38 | 0.70      | 0.40        | 1.10        | 0.05| 0.121  | 16.96| 3    | 0      |
| 41  | lcrs07           | 13.62| 12.45| 12.96 | 0.73      | 0.44        | 1.17        | 0.06| 0.111  | 15.00| 3    | 0      |
| 42  | lcrs20           | 14.48| 13.89| 13.53 | 0.59      | 0.36        | 0.95        | 0.06| 0.632  | 15.96| 3    | 2      |
| 43  | lcrs18           | 14.70| 14.40| 13.62| 0.68      | 0.40        | 1.08        | 0.05| 0.598  | 16.59| 3    | 0      |
| 44  | lcrs05           | 15.36| 14.32| 13.42| 0.56      | 0.48        | 1.04        | 0.11| 0.717  | 16.73| 3    | 0      |
| 45  | lcrs19           | 14.95| 14.24| 13.90| 0.71      | 0.34        | 1.05        | 0.04| 0.640  | 16.42| 3    | 0      |
| 46  | lcrs11           | 15.48| 14.78| 14.38| 0.70      | 0.40        | 1.10        | 0.05| 0.121  | 16.96| 3    | 0      |
| 47  | lcrs02           | 14.95| 14.28| 13.95| 0.67      | 0.33        | 1.00        | 0.04| 0.987  | 16.36| 3    | 2      |
| 48  | lcrs09           | 15.98| 15.30| 14.96| 0.68      | 0.34        | 1.02        | 0.06| 0.651  | 17.47| 3    | 0      |
| 49  | lcrs10           | 15.29| 14.65| 14.27| 0.64      | 0.38        | 1.02        | 0.05| 0.104  | 16.68| 3    | 0      |
| 50  | lcrs04           | 14.49| 13.80| 13.41| 0.69      | 0.39        | 1.08        | 0.05| 0.101  | 15.68| 3    | 1      |
| 51  | pgc35435         | 11.75| 10.98| 10.66| 0.77      | 0.32        | 1.09        | 0.04| 0.178  | 13.75| ...  | 4      |
| 52  | dc204852_116     | 12.62| 11.92| 11.65| 0.70      | 0.27        | 0.97        | 0.06| 0.441  | 15.84| 14.06| 4      |
| 53  | dc204852_66      | 14.45| 13.62| 13.36| 0.83      | 0.26        | 1.09        | 0.06| 0.410  | 17.48| 15.88| 4      |
| 54  | pgc60102         | 12.96| 12.13| 11.65| 0.84      | 0.47        | 1.31        | 0.07| 0.0304 | 15.36| 4    | 4      |
| 55  | eso290-IG_050    | 13.46| 12.74| 12.39| 0.72      | 0.35        | 1.07        | 0.04| 0.0290 | 15.18| 14.21| 4      |
| 56  | pgc62615         | 12.65| 11.92| 11.63| 0.73      | 0.29        | 1.02        | 0.06| 0.0280 | 16.82| 4    | 2      |
| 57  | pgc57612         | 10.99| 10.23| 10.10| 0.77      | 0.11        | 0.88        | 0.04| 0.0183 | 13.30| 11.33| 4      |
| 58  | ngc6653          | 11.53| 10.79| 10.59| 0.74      | 0.20        | 0.94        | 0.06| 0.0172 | 13.75| ...  | 4      |
| 59  | dc204852_115     | 14.98| 14.33| 14.04| 0.65      | 0.29        | 0.94        | 0.04| 0.0440 | 18.13| 16.53| 4      |
| 60  | dc204852_126     | 15.01| 14.29| 14.01| 0.72      | 0.28        | 1.00        | 0.06| 0.0489 | 18.21| 16.60| 4      |
| 61  | dc204852_38      | 13.49| 12.90| 12.56| 0.59      | 0.34        | 0.93        | 0.06| 0.0454 | 16.73| 15.12| 4      |
| 62  | ngc6328          | 11.33| 10.57| 10.24| 0.77      | 0.32        | 1.06        | 0.05| 0.0142 | 13.17| 11.45| 4      |
| 63  | pgc62765         | 11.42| 10.68| 10.36| 0.74      | 0.32        | 1.06        | 0.05| 0.0193 | 13.75| ...  | 4      |
Table 2—Continued

| ID | Name | $J_s$ | $H$ | $K_s$ | $(J - H)$ | $(H - K_s)$ | $(J - K_s)$ | $z$ | $B$ | $R$ | Sample ID | T-Type |
|----|------|------|-----|------|----------|------------|------------|-----|-----|-----|-----------|--------|

(1) Correlative number.
(2) Name of the galaxy.
(3) $J_s$ apparent magnitude and photometric error.
(4) $H$ apparent magnitude and photometric error.
(5) $K_s$ apparent magnitude and photometric error.
(6) $J - H$ color index and its error.
(7) $H - K_s$ color index and its error.
(8) $J - K_s$ color index and its error.
(9) Redshift.
(10) $B$ apparent total magnitude in the Johnson system. This magnitude is provided by NED.
(11) $R$ apparent total magnitude in the Cousins system. This magnitude is provided by NED.
(12) Sample ID (see Table 1).
(13) Morphological T-type provided by NED.
Fig. 1.— Typical sky variations in the near-IR passbands $J$, $H$, and $K_s$ during 1 hour. Each point represents the mean sky level for an individual image during an observing sequence. The error bars are given by the standard deviation in the image counts. Note the larger error bars for the $K_s$ band, where the thermal variations are in fact larger (where also the shot noise is higher, compared to that of other filters). This behavior limits the accuracy of the sky subtraction procedure applied to the near-IR images (see text).

Fig. 2.— Average errors in the photometric calibrations for the standards observed with the 100-inch du Pont telescope (triangles), and for the standards observed with the 40-inch Swope telescope (circles). Every point corresponds to an average error of several (typically no less than 3) measurements for the same standard, observed in different nights.

Fig. 3.— K-corrections from the models of Poggianti (1997) for passbands $J$, $H$ and $K$, as a function of redshift and for Hubble types E, Sa and Sc. Note the large and negative K-corrections for the $K$ band for $z \gtrsim 0.5$.

Fig. 4.— K-corrections derived from the PEGASE models (Fioc & Rocca-Volmerange 1997) for the $J$, $H$, $K$ and $K_s$ bands as a function of redshift and Hubble type (lines as in Figure 3). Compare with Figure 3.

Fig. 5.— K-correction differences obtained from 2 spectrophotometric models of galaxy evolution, indicated in Figures 3 and 4. Differences are computed for $J$, $H$, and $K$ and for Hubble types E, Sa and Sc. Note the large difference for the K-corrections in the $K$ band.

Fig. 6.— Some Kennicutt (1992) spectra of observed normal galaxies (as indicated in each panel) with known Hubble types (thick lines), and fitted synthetic spectra from GISSEL96 (Charlot, Worthey & Bressan 1996) (thin lines). The fitted models correspond to instantaneous bursts of solar metallicity and different ages of the passively evolving stellar populations. The closest model spectrum is obtained using a simple $\chi^2$ fitting algorithm.
between the Kennicutt spectra and 20 model spectra. The good match shows that at the optical wavelengths models agree with observations. The same kind of models are compared to the near-IR colors. See text for details.

Fig. 7.— Observed colors of the E+A galaxies reported in this paper (filled circles) compared with spectrophotometric models of galaxy evolution (open symbols joint by lines). Each panel corresponds to a different E+A sample (as indicated in each panel). Each line represent a redshift track of an instantaneous burst of solar metallicity, at a given age of 1, 3 and 16 Gyr, indicated by circles, squares, and triangles, respectively, for the redshifts indicated in the lower right panel. The crosses are the error bars in the colors. See text for explanations.

Fig. 8.— Averaged rest-frame colors of E+As lying in different environments. The LCRS symbols corresponds to the 21 E+As from the sample of Las Campanas Redshift Survey (Zabludoff et al. 1996). Most of these galaxies are located in the field (at $<z> \sim 0.1$), but 3 of them lie in clusters. The DC cluster E+As correspond to the E+As from the sample of Caldwell & Rose (1997), and all of them are located in clusters with $<z> \sim 0.05$. Filled symbols indicate that rest-frame colors have been obtained using the Poggianti (1997) K-corrections. Open symbols are averaged rest-frame colors obtained using the PEGASE (Fioc & Rocca-Volmerange 1997) K-corrections. Asterisks correspond to elliptical galaxies observed by Silva & Bothun (1998). The solid line correspond to colors of a GISSEL96 (Charlot, Worthey & Bressan 1996) instantaneous burst of solar metallicity at $z = 0$ and at different ages (indicated by solid dots and labeled). See text for details.

Fig. 9.— K-correction differences in $J$, $H$, $K$ and $K_s$, as a function of redshift, for two SEDs having different metallicity. The two SEDs, shown in the inset, are simple instantaneous bursts with a Scalo initial mass function (Scalo 1986) and with an age of 10 Gyr. Differences in K-corrections are expressed as the difference between K-correction for SED 1 ([Fe/H] = −0.30) and K-correction for SED 2 ([Fe/H] = +0.10).
Sample 1: LCRS E+As

Sample 2: Nearby cluster E+As

Sample 3: Cluster E+As at z = 0.3

Sample 4: Control galaxies at z = 0.0
