HST Optical-NIR Colors of Nearby $R^{1/4}$ and Exponential Bulges

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ABSTRACT

We have analysed $V$, $H$ and $J$ HST images for a sample of early- to late-type spiral galaxies, and reported elsewhere the statistical frequency of $R^{1/4}$-law and exponential bulges in our sample as a function of Hubble type, and the frequency of occurrence and structural properties of the resolved central nuclei hosted by intermediate- to late-type bulges and disks (see references in the text). Here we use these data to show that:

(i) The $V - H$ color distribution of the $R^{1/4}$ bulges peaks around $< V - H > \sim 1.3$, with a sigma $\Delta(V - H) \sim 0.1$ magnitudes. Assuming a solar metallicity, these values correspond to stellar ages of $\approx 6 \pm 3$ Gyrs. In contrast, the $V - H$ color distribution of the exponential bulges peaks at $< V - H > \sim 0.9$ and has a sigma $\Delta(V - H) \sim 0.4$ mags. This likely implies significantly smaller ages and/or lower metallicities for (a significant fraction of the stars in) the exponential bulges compared to the $R^{1/4}$-law spheroids.

(ii) Most of the central nuclei hosted by the exponential bulges have $V - H$ and $J - H$ colors which are compatible with relatively unobscured stellar populations. Assuming no or little dust effects, ages $\gtrsim 1$ Gyrs are suggested for these nuclei, which in turn imply masses of about a few $10^6$ to a few $10^7$ M$\odot$, i.e., sufficient to dissolve progenitor bars with masses consistent with those inferred for the exponential bulges by their luminosities.

(iii) While different bulge-nucleus pairs cover a large range of $V - H$ colors, each bulge-nucleus pair has quite similar $V - H$ colors, and thus possibly similar stellar populations. The HST photometric analysis suggests that exponential-type bulge formation is taking place in the local universe, and that this process is consistent with being the outcome of secular evolution processes within the disks. The structures which are currently formed inside the disks are quite dissimilar from the old elliptical-like spheroids which are hosted by the early-type disks.

subject headings: galaxies: formation - galaxies: evolution - galaxies: structure - galaxies: nuclei - galaxies: bulges
1. Introduction

The size of the central bulge compared to the size of the disk is one of the classification criteria of the entire Hubble sequence (Sandage & Bedke 1994). Furthermore, bulges host a large fraction of the baryons which have been converted into stars during the Hubble time (e.g., Fukugita, Hogan & Peebles 1998). It is also likely that the formation of bulges plays a role in polluting the intergalactic medium with processed matter and radiation, and thus affects the formation of luminous structure on larger scales. Yet, to date, it is not understood not only ‘how’ bulges form, but even whether they form before, contemporaneously with, or after the disks (e.g., see the detailed review by Wyse, Gilmore & Franx 1997, and also Bouwens, Cayon & Silk 1999). In the one extreme, bulges may arise from the collapse of a primordial gas cloud into clumps which then merge together, and the disk be a later accretion by gas infall (e.g., Eggen et al. 1962; Larson 1975; Carlberg 1984). In the opposite extreme, bulges may form by vertical dynamical instabilities of the disks (e.g., Combes et al. 1990; Pfenniger 1993).

Historically, ‘bulges’ have been recognized as such because they appear as high surface brightness, concentrated objects in the considerably larger and fainter disks. These ‘bulges by definition’ often also have quite a distinct color, and, as the name suggests, are considerably fatter than the disks. Superficially, they appear to share many properties with small elliptical galaxies: The relatively few and typically rather massive disk-embedded spheroids which have been studied in detail show an $R^{1/4}$ radial light profile, relatively old and metal-enriched stellar populations, and are rotationally-supported systems (Wyse et al. 1997 and references therein). Despite the temptation of historical inertia, clearly wanting us to restrict the use of the name ‘bulge’ to this sort-of-well-defined class of stellar systems only, it is however unwise, in the quest for clarifying the origin of these fundamental components of one-Hubble-time-old galaxies, to ignore that different kinds of stellar structures are also often found in the centers of the local-universe disks (Wyse et al. 1997).

Significant differences between the ‘bulges’ of intermediate- to late-type disks and the more
massive spheroids have in fact been found. First, preliminary studies suggest that the stellar populations of small bulges in general may be younger and more metal-poor than those of the large bulges (Trager et al. 1999). Furthermore, several studies have revealed ‘pseudo-bulges’ with e.g., cold kinematics (Kormendy 1993), a peanut-shape morphology associated with bar-like kinematics (e.g., Kuijken & Merrifield 1995; Bureau & Freeman 1999) or an exponential – rather than $R^{1/4}$ – fall-off of the light distribution (hereafter exponential bulges; e.g., Kormendy & Bruzual 1978; Shaw & Gilmore 1989; Courteau et al. 1996 and references therein).

The pseudo-bulges also appear as clearly distinct structures from the disks, and replace the ‘classical’ bulges in disks that, at least superficially, look rather similar to others that host instead the canonical $R^{1/4}$ structures. It is unclear how these strange central structures relate to their $R^{1/4}$ relatives. However, the fact that they ‘substitute for’ the $R^{1/4}$ bulges in otherwise normal intermediate-type disks provides an argument for including them in any thorough exploration which is aimed at clarifying the origin and evolution of the spheroidal components of the local disk galaxies. These pseudo-bulges may lead us to understand by comparison which are the required circumstances for forming a dense elliptical-like spheroid (failing which, only a pseudo-bulge is formed), or may indicate the occurrence of fundamental changes with cosmic time in the evolutionary paths of galaxies, or may turn out to be consistent with being evolutionary related to the ‘classical’ bulges for which we seek the origin and progenitors.

In order to help clarify the origin of the structural diversity between the largest and the smallest disk-embedded spheroids, we performed a Hubble Space Telescope (HST) snapshot survey of $\approx 80$ spiral galaxies randomly-selected out of a complete sample of 134 targets. The central regions of the selected objects were imaged in the visual (with WFPC2 and the F606W filter) and in the near-infrared (NIR; with NICMOS and mostly the F160W and occasionally the F110W filter). The observations and the data reduction are fully described in a series of papers, separately for the WFPC2 survey (Carollo et al. 1997; Carollo et al. 1998; Carollo & Stiavelli 1998; Carollo 1999) and the NICMOS survey (Carollo et al. 2000, paper I; Seigar et al. 2000, paper II).

The high angular resolution of the HST data allowed us to mask out from several of the images
patches of dust and knots of star formation, and thus derive for those targets ‘clean’ isophotal models for the underlying galaxian light. Two-component ‘bulge plus disk’ analytical fits were applied to the so-derived radial light profiles. Echoing previous voices, we considered as a ‘bulge’ that distinct central structure which ‘contains all the light in excess of the inward extrapolation of a constant scalelength exponential disk’ (Wyse et al. 1997; Gilmore 1999). Within this more general definition of bulge, we found that the bulge light profile was typically best modeled with an $R^{1/4}$-law in the early-type disks and with an exponential law in the later types, in agreement with previous studies (e.g., Courteau et al. 1996).

In this paper we combine the NIR measurements presented in papers I and II with the WFPC2 measurements so as to investigate the optical-NIR colors of the exponential versus $R^{1/4}$-law bulges found in our HST survey, as well as the colors of the photometrically-distinct nuclei which we found embedded in the dynamical centers of all the exponential bulges. The objects included in this study are listed in Table 1, together with the information on whether they have an $R^{1/4}$-law or an exponential bulge, on the $V - H$ color for the host bulges, and on the $V - H$ color for the embedded nuclei. The intrinsic dust-age-metallicity degeneracy of broad-band colors for intermediate-to-old age stellar populations is a well-known problem. Nonetheless, although the calibrations of absolute ages and metallicities do remain elusive, photometric indicators can still be a powerful bench-mark for ‘ranking’ the stellar populations among diverse kinds of bulges, and among bulges and other galactic sub-components such as the photometrically-distinct nuclei. We briefly discuss plausible implications of our results for the formation of bulges during the course of cosmic history.

2. Results

2.1. The Colors of Exponential and $R^{1/4}$-law Bulges
The majority of the $R^{1/4}$-law bulges found in our sample are bright (massive) systems embedded in early-type disks, in contrast with the fainter exponential bulges which are found mostly in Sb to Sc hosts, in agreement with previous studies (see Figure 1, where the absolute $V$ magnitude of exponential and $R^{1/4}$-law bulges is plotted versus their $V - H$ colors). Figure 2 shows the $V - H$ color distribution for the $R^{1/4}$-law (solid line) and exponential (dashed line) bulges detected in our HST survey. The measurements are expressed in $AB$ magnitudes. The colors are obtained by integrating the smooth analytical fits to the bulge light profiles inside $1/2R_e$ (or within $6''$ if that radius exceeds the radial extension of the NICMOS data); therefore they exclude (or at least minimize) any contribution from e.g., the nuclei, strong dust lanes/patches and knots of recent star formation.

The $V - H$ color distribution of the $R^{1/4}$ bulges peaks around $< V - H > \sim 1.3$, with a sigma $\Delta(V - H) \sim 0.1$ magnitudes. Bruzual & Charlot models, calibrated into the F606W and F160W filters with Synphot/IRAF, indicate that the average metallicity of these systems must be at least half-solar for their age to be smaller than that of the universe. Assuming a solar metallicity, the average $< V - H >$ color corresponds to an average age for the population of $\approx 6$ Gyrs, with a spread of about 3 Gyrs around this average. The presence of a small fraction of younger stars cannot be clearly excluded on the basis of the available data alone. In the absence of dust, the bluest colors that we observe in the $R^{1/4}$ bulges could be obtained by contaminating, e.g., a 9 Gyrs old underlying population with a 10%, 1% or 0.1% in mass of stars 1 Gyr, 100 Myrs or less-than-5 Myrs old, respectively. Possible ‘solutions’ clearly exist also in the presence of dust: Using the ‘screen-approximation’ and a Cardelli extinction law (Cardelli, Clayton & Mathis 1989) as a benchmark, with e.g., an extinction in the $V$ band of $A_V = 3$, about 10% (in mass) of the population should be less than 5 Myrs old in order to reproduce the bluest end of the $R^{1/4}$ bulges ($V - H$) distribution. A more modest $A_V = 1.5$ could accomodate a fraction as high as $\sim 70\%$ of young stars, if these were about 100-Myrs-old. On the other hand, the smooth morphology of this class of objects and their color maps, virtually featureless at all radii, make it rather implausible that these systems contain large amounts of dust. In fact, the only features detected in the color maps for the $R^{1/4}$ bulges are some mostly-nuclear patches of dust. The effects of these dust
patches are removed by measuring the colors by integrating over the light profiles (since the latter are obtained by means of isophotal fits in which the patches of dust are masked out). The most plausible solution for the $R^{1/4}$ bulges is therefore that at least more than 90% of their stars are older than several Gyrs. This finding echos previous results for the $R^{1/4}$-law bulges (e.g., Peletier et al. 1999 and references therein) by supporting the idea that many of these dense spheroids are, at least population-wise, similar to small ellipticals.

The $V - H$ color distribution of the exponential bulges, in contrast, presents some surprises. The average $\langle V - H \rangle$ of these systems is in fact $\sim 0.4$ magnitudes bluer than the corresponding average for, and the sigma $\Delta(V - H) \sim 0.4$ magnitudes is significantly larger than that of, the $R^{1/4}$ bulges. Furthermore, although a few of the exponential bulges are actually as red as the reddest of the $R^{1/4}$-law bulges, the former extend to significantly bluer colors than the latter, down to a $(V - H) \sim 0$. In principle, adding a small fraction of young stars to an underlying old stellar population could again explain the observed colors. For example, in the absence of dust, a 10% of 100 Myr old stars mixed to the remaining 9-Gyr-old population would be sufficient to obtain a $(V - H) \sim 0.5$ magnitudes; the required percentage of young stars would clearly decrease for even younger stellar populations. In the presence of substantial amounts of dust, say $A_V$ up to 2 magnitudes, the age of the population should decrease down to $\lesssim 5$ Myr in order to obtain a $(V - H) \sim 0.5$ with a 10% or smaller contamination of young stars. Still, thanks to the high angular resolution of the HST images which allow to perform an accurate masking of any localized feature in the images, the effects of dust patches and possible knots of star formation are also in this case negligible in the colors derived from the light profiles (from isophotal fits). Therefore, while a diffuse younger component well-mixed with the underlying old population cannot clearly be ruled out by the $(V - H)$ color alone, the most appealing solution for the exponential bulges is that they are on average significantly younger than their $R^{1/4}$ relatives.

2.2. Colors of the Nuclei
About a third of our sample was imaged in all three filters $J$, $H$ and $V$. In Figure 3 we plot the $J - H$ color versus the $V - H$ color for the compact nuclei found embedded in intermediate- to late-type galaxies, including the nuclei which are found in the centers of the exponential bulges. Actually, each exponential bulge in our sample hosts one such a nucleus (Carollo 1999). In the Figure, squares are the nuclei embedded in the exponential bulges. The triangles represent instead the nuclei embedded in systems with no isophotal fit, i.e., systems whose central regions are heavily obscured by dust or complicated by recent star formation, so that for them no reliable isophotal fit could be performed (see previous papers for the corresponding list of measurements). Dust extinction affects points on this diagram by shifting them along the arrow shown in the upper-left corner of the Figure. The arrow is drawn for a 1 mag extinction in the $V$ band. Theoretical tracks derived from Bruzual & Charlot models for metallicities $Z = 0.02Z_\odot$ (dotted line) and $Z = Z_\odot$ (solid line) are also shown in Figure 3. Stellar ages increase upward along the tracks from $\approx 100$ Myr to 18 Gyr.

Many central compact nuclei (typically in hosts without an analytical fit to the bulge) have $V - H$ and $J - H$ colors which are incompatible with arising from unobscured stellar populations. These nuclei are embedded in very complex circum-nuclear structures, e.g., in strong dust lanes/arms or rings/arms of recent star formation. For a few of these systems information on the central spectral properties is available at ground-based resolution, i.e., at a resolution covering an area $\approx 100$ times larger than that covered by the nuclei, an area which includes this complex circum-nuclear structure as well (making the spectra not suitable for studying the physical properties of the central compact nuclei, for which we have to rely on the HST photometry only). On ground-based scales of $\approx 1$ kpc, these galaxies show an active-type central spectrum, either of AGN- or of HII-type. It is therefore not surprising that the optical/NIR light from their central resolved nuclei can also be polluted by several magnitudes of extinction, and/or can contain non-thermal emission from a central AGN.

In contrast, most of the central nuclei which are embedded in the exponential bulges have $V - H$ and $J - H$ colors which are compatible with arising from nearly unobscured stellar
populations. Spectral information is not available for most of their host galaxies, not even from
the ground. In principle, large amounts of dust extinction cannot be ruled out even for these
nuclei. However, in contrast with the complexity of structure generally underlying the central
nuclei with very red $V - H$ and $J - H$ colors, the exponential bulges are generally rather smooth,
amorphous systems, showing not much evidence for the presence of large amounts of dust. This
supports the idea that the optical/NIR light of the nuclei of exponential bulges is mostly stellar,
i.e., it is not heavily polluted by a non-thermal component or by large amounts of dust. Under
this assumption, relatively old ages – of the order of $\approx 1\text{Gy}$ and above – are suggested by the
combined $V - H$ and $J - H$ colors for several of these nuclei embedded in the exponential bulges.

If spectroscopically confirmed for at least some of these nuclei, these relatively old ages would
have interesting consequences for the masses of these systems. In Figure 4 we plot the absolute
magnitude $V$ against the $V - H$ color for all the nuclei for which both a $V$ and an $H$ image
are available (for several of these a $J$ image is not available; this is the reason why there are
more points here compared to Figure 3). Age increases from top to bottom along the plotted
Bruzual & Charlot tracks; these refer to a $2.5 \times 10^6 M_\odot$ star cluster of metallicities $Z = 0.02Z_\odot$
(dotted line) and $Z = Z_\odot$ (solid line). Dust extinction shifts points along the direction indicated
by the upper-left arrow. The mass of a stellar cluster and the age of its stellar population have
nearly fully degenerate effects on a color-magnitude diagram: The tracks can be shifted upward
(downward) by increasing (decreasing) the mass of the star cluster (a 2.5 magnitudes shift implies
a factor 10 variation in mass); correspondingly, a larger (lower) stellar age will be associated with
any fixed point encompassed by the tracks on the $V$ vs $V - H$ diagram. In this enlarged sample,
again most of the central compact nuclei which are embedded in the complex circum-nuclear
structure of those hosts without an analytical fit have $V - H$ colors which are incompatible with
arising from unobscured/unpolluted stellar populations. And again most of the nuclei embedded
in the exponential bulges are instead consistent with being relatively unobscured stellar structures.
They are also, at face value, more enriched than e.g., the Milky Way globular clusters, since
they typically lie rightward of the metal-poor stellar track. If the large ages estimated from the
$(J - H) - (V - H)$ diagram are assumed for (some of) these nuclei, their location on the $V - (V - H)$
plane implies masses in the thereabouts of a few $10^6$ to a few $10^7$ M$_\odot$, depending on the exact dating of the stellar structure between $\approx 1$ and many Gyrs.

2.3. Comparison between Nuclei and Host Exponential Bulges

In Figure 5 we show the comparison between the $V - H$ color of the exponential bulges and the $V - H$ color of their hosted nuclei. Within the error bars there is a positive trend between the colors of the nuclei and those of their host bulges (Spearman’s and Kendall’s rank order tests give a probability of correlation greater than 94% and 95%, respectively). The slope of the correlation is compatible with being unity, but the error bars are too large to determine it reliably. Different bulges-nuclei pairs cover a large range of $V - H$ colors (consistently with what discussed in Figure 2), but most bulge-nucleus pairs seem to have possibly rather similar $V - H$ colors. Conspiracies may be at play; on the other hand, this result suggests that the nuclei embedded in the exponential bulges may have stellar populations similar to those of their host bulges.

3. Discussion

It is by now a decade ago that e.g., Hasan & Norman (1990), Norman & Hasan (1990) and Pfenniger & Norman (1990), proposed some basic dynamical mechanisms that produce an amplification of the accretion rate of gas clouds into the central regions of barred galaxies, and discussed their effects on the evolution of disk galaxies and their implications for bulge formation. Only a few years later John Kormendy presented the first evidence for cold kinematics in intermediate-type bulges at the IAU Symposium 153, thereby providing extremely compelling observational “evidence that some bulges are really disks” (Kormendy 1993). Since then, several other studies have been performed that further support a close connection between bulges and disks in Sb-Sc galaxies (e.g., Kuijken & Merrifield 1995; Bureau & Freeman 1999; Courteau et al.
1996 and references therein), and thus possibly the growth of bulges inside the disks due to the secular evolution of the latter.

The theoretical suggestions for how the ‘disk-driven’ bulge formation may take place invoke the presence of non-axisymmetric perturbations, i.e. ‘bars’, generated by some kind of disk instabilities. First, the stars initially in a bar can be kicked off the plane of the disk by ‘buckling’ instabilities, and form a three-dimensional bulge (e.g., Combes et al. 1990). Furthermore, numerical experiments indicate that a very efficient way to induce significant evolution along the Hubble sequence is to accrete mass in the centers of galaxies hosting a tumbling triaxial structure such as a bar. The addition of a central mass concentration of \(\approx 1\%\) of the total mass in fact disrupts orbits essential to its existence (e.g., Pfenniger & Norman 1990; Hasan, Pfenniger & Norman 1993; Norman, Sellwood & Hasan 1996). Bars do greatly enhance the efficiency of dissipative mass transfer to the centers of the disks (Shlosman 1994; Shlosman & Robinson 1995; Shlosman, Begelman & Frank 1990). Thus, provided there is an efficient mechanism for funneling the dissipative disk material down to the very center, the bar itself is dissolved, and its stars are deflected out of the plane of the disk, giving birth to a three-dimensional bulge-like structure.

The broad-band photometric analysis presented here is clearly afflicted by the well-known full-degeneracy of mass, age, metallicity, dust, emission lines. The arguments of plausibility which lead to the age and mass estimates for the exponential bulges and their central nuclei discussed above are indeed to be taken with care: Spectroscopic confirmation is needed. Still, within the caveats, those assumptions are a plausible solution with several implications for the formation of bulges as a function of cosmic time.

First, if dust effects are not at play, the fact that some exponential bulges appear to be as red as the elliptical-like bulges suggests that this ‘mode’ of bulge formation may have been active even at the early stages in our universe. However, the fact that the exponential bulges appear to be bluer on average than the elliptical-like bulges does suggest that, as a class, they are younger (and likely less metal-enriched) than the latter. Therefore, on the one hand these new observations support the idea that the growth of central structure within the disks is still going on
in our universe. On the other hand, this growth seems to occur in the form of ‘exponential-type’
structure only, i.e., a structure quite dissimilar from the dense $R^{1/4}$-law relics of the early times.

The mechanisms that grow the central exponential bulgelike structures remain clearly
indetermined. However, at face value, the ‘photometrically-estimated’ central masses of the central
nuclei embedded in the exponential bulges are well-matched to those which would have been
required, in the bar formation/dissolution scenario, to disrupt progenitors bars with masses of
about a few $10^7$-$10^9 M_\odot$. These masses are consistent with the masses inferred for the exponential
bulges from their total $V$ luminosities (assuming similar $M/L_V$ ratios for the exponential bulges
and their nuclei; see also Carollo 1999).

The above arguments clearly do not prove that the bar formation/dissolution mechanism
operates: For example, the central nuclei may have grown inside the exponential bulges due to
dynamical friction of globular clusters, as suggested by Tremaine, Ostriker & Spitzer (1975) for the
nucleus of M31. At a time $t$, any globular cluster within a radius $r \propto (Gmt/\sigma)^{1/2}$ will fall into the
center dragged by dynamical friction. For plausible values of $m$, the mass of the infalling globular
cluster, and $\sigma$, the velocity dispersion of the exponential bulge, all the globular clusters within a
few to several half-light radii of the exponential bulges should have converged to their centers in
about 1 to a few Gyrs. The range of masses inferred from the broad-band colors imply that about
10–100 globular clusters should have formed within such a radial range, a value which is not ruled
out given that many more globular clusters will have formed than those which would be currently
observed (and given that the low central stellar densities inferred for the exponential bulges, would
allow the newly-borned clusters to sink in the galaxy centers without being tidally-destroyed
during their infall, see Carollo & Stiavelli 1998).

On the other hand, the fact that the nuclei appear to be typically more enriched than the

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4No kinematic data are yet available for the exponential bulges, so that ‘plausible’ in this context
means ‘as derived from the Faber-Jackson (1976) relation and allowing for generous ($\approx 50\%$)
variations around the Faber-Jackson value.
Milky Way globular clusters, and the similar $V - H$ colors of the nuclei and their host exponential bulges, does argue in favour of similar stellar populations and thus of a synchronous formation of these two galactic sub-components. A natural way to synchronously form the exponential bulge and its central nucleus would indeed be a scenario where the stars in the bulge and the central nucleus are grown together by dissipative material infalling into the galaxy center.

In summary, the high-resolution photometric analysis of intermediate-type bulges, while far from being ‘conclusive’, does indicate that ‘non-classical’ bulge formation is taking place in the universe around us, and that this bulge formation is consistent with arising from secular evolution processes within the disks. In contrast, there is growing evidence that the early-type, massive bulges not only are ‘old’, but may even be as old as the Coma cluster ellipticals, with an internal age-spread of only $\approx 2$ Gyr (Peletier et al. 1999). Together, these results suggest that the processes that have formed the dense elliptical-like spheroids in the centers of the early-type disks are quite dissimilar from the processes which are growing the disk-like central structures within the later-type disks today.

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Fig. 1.— Absolute magnitude versus $V - H$ color for exponential (filled squares) and $R^{1/4}$ (empty circles) bulges (AB magnitudes). The typical error bar is given for reference.

Fig. 2.— The $V - H$ distribution for exponential (dashed line) and $R^{1/4}$ (solid line) bulges (AB magnitudes).

Fig. 3.— $J - H$ vs $V - H$ color-color diagram for the compact nuclei (AB magnitudes). Squares are the nuclei embedded in the exponential bulges (see Table 1). The triangles are the nuclei embedded in systems with no isophotal fit (measurements reported in Carollo et al. 2000). Tracks refer to Bruzual & Charlot models of metallicities equal to $0.02Z_{\odot}$ (dotted line) and $Z_{\odot}$ (solid line). The upper-left arrow shows the effects of one magnitude of dust extinction in $V$. The typical error bar is plotted in the upper-left corner.

Fig. 4.— $V$ vs $V - H$ color-color diagram for the compact nuclei (AB magnitudes). Symbols are as in Figure 3. The Tracks refer to Bruzual & Charlot models for a $2.5 \times 10^6 M_{\odot}$ star cluster of metallicities $0.02Z_{\odot}$ and $Z_{\odot}$. The typical error bar is plotted in the bottom-right corner.

Fig. 5.— $V - H$ color of the exponential bulges versus $V - H$ color of their own compact nuclei (AB magnitudes). The typical error bar is also plotted.
Table 1: The sample of exponential (left side) and $R^{1/4}$-law (right side) bulges included in this study. The measurements, in $AB$ magnitudes, are from Carollo et al. 1997, Carollo et al. 1998 and Carollo et al. 2000.
