The resolved stellar populations of M32
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Conclusions and future prospects

In this thesis we have obtained the most complete inventory yet possible of the resolved stellar populations of the nearest elliptical galaxy M32. We have used very high resolution Hubble Space Telescope (HST) observations to construct and analyze deep color-magnitude diagrams (CMDs) and to search for RR Lyrae variables in the fields observed to extract information about the stellar ages and metallicities distributions in this galaxy. The present work significantly improves our knowledge on the stellar populations of M32 and sheds light on M32’s origins and evolution. Furthermore, the results obtained in this thesis provide an unprecedented rich data base to compare with unresolved stellar population models and test their applicability to more distant galaxies. This is of crucial importance to augment our understanding on how galaxies, in particular ellipticals, form and evolve throughout cosmic time. In Section 5.1 we summarize the main results presented in this thesis. Follow up studies based on this work are discussed in Section 5.2.

5.1 Results of this thesis

- **The intermediate-age and older stellar populations of M32**

  In Chapter 2 we have obtained the deepest optical CMD of M32 ever constructed, which we qualitatively analyzed with the aid of theoretical isochrones. We find that, from the morphology and CMD position of the RC, the bulk of M32’s population is composed of 8–10 Gyr old stars. We detected the RGB and AGB bumps for the first time in M32. These, together with the RC, indicate that the mean age of M32 is between 5–10 Gyr. In Chapter 3, by comparing the distribution of stars in the observed CMD with that of a model CMD, we were able to quantify these intermediate-age and old population. They contribute $\approx 56\%$ of the mass of M32 at $\sim 2'$ from its center.
• **The youngest and intermediate-age stellar populations of M32**

The CMD of M32 presented in Chapter 2 displays a blue plume (BP) and bright AGB stars. These demonstrate the presence of young and intermediate-age populations in M32, with the youngest population being \( \sim 0.5 \) Gyr old. We furthermore find in Chapter 3 that the 2–5 Gyr old stars of this population contribute \( \approx 40\% \) of the mass of M32 at \( \sim 2' \) from its center. Stars younger than 2 Gyr that constitute the BP contribute \( \approx 4\% \) of the mass. Roughly half of that mass is composed by genuine young metal-rich stars while the remaining half is composed by young, metal-poor stars, which we associate with blue stragglers belonging to an older metal-poor population.

• **The ancient metal-poor stellar populations of M32**

Despite the high spatial resolution of the ACS/HRC images, the detection of the oldest MSTOs of M32 were out of reach due to the severe crowding in the observed fields. We also found no clear blue horizontal branch (BHB) in its CMD, typically associated with ancient metal-poor populations. Moreover, we detected virtually no stars on the RGB with \([\text{Fe/H}] < -1.5 \text{ dex}\) that could be associated with such a population (Chapter 2). Nevertheless, in Chapter 4, we detected \( 7^{+4}_{-3} \) variable RR Lyrae stars in M32. They represent an ancient (older than 10 Gyr) metal-poor (\([\text{Fe/H}] \sim -1.6 \text{ dex}\)) population in this galaxy, which contributes, at most, 4\% of the mass of M32 at \( \sim 2' \) from its center (Chapter 4).

• **The metallicity of M32**

We have derived the photometric metallicity distribution function (MDF) of M32 in Chapter 2, which shows that the majority of the stars have a slightly sub-solar metallicity of \( [\text{M/H}] \sim -0.2 \text{ dex} \). Metal-poor stars with \( [\text{M/H}] < -1.2 \) contribute at most 6\% of the total V-band luminosity (\( \sim 4.5\% \) of the mass, assuming a metal-poor 10 Gyr old population) of M32 in our field’s position. This implies that the enrichment process largely avoided the metal poor stage. In Chapter 3, we derived the age–metallicity relation of M32 and find that it is basically constant. We note that an almost constant age–metallicity relation appears to suggest that M32 has not experienced any metal enrichment. However, the lack of resolution in age means that we cannot extract detailed information on stars older than 5 Gyr. Most of the chemical evolution of the system has likely occurred during that 5–14 Gyr period. The mass-weighted metallicity of M32 is \( [\text{M/H}] \sim 0.2 \text{ dex} \). Stars with metallicities lower than \( [\text{M/H}] \lesssim -1 \text{ dex} \) only contribute \( \sim 5\% \) of the mass of M32 at \( \sim 2' \) from its center, which is consistent with the values discussed above.

• **Origins of M32**

We find that our results, in particular the substantial population of 2–5 Gyr old stars, do not agree with models of M32’s formation that suggest a spiral galaxy as its progenitor. Instead, we favor the idea that M32 is a low-luminosity elliptical galaxy that has had a dissipative merger event.
5.1. RESULTS OF THIS THESIS

Figure 5.1: Specific SFR \( SSFR = SSFR/M_* \) as a function of redshift. The lower and upper limits represent the SSFR assuming an uniformly distributed star formation over the age bin considered and a starburst at 1 Gyr of the bin, respectively. The values of SSFR agree reasonably well with those observed for galaxies with masses \( \sim 10^9 M_\odot \) at the different redshifts considered (e.g., Noeske et al. 2007; Santini et al. 2009).

- **Downsizing of star formation in galaxies**

  The results presented in this thesis refer to a small fraction of the galaxy M32 at \( \sim 2' \) from its center. If we make the (admittedly bold) assumption that the field studied is representative of the whole galaxy, we can use the SFH derived in Chapter 3 to place M32 into a cosmological context. We calculate the specific SFR of M32, \( SSFR = SSFR/M_* \), as a function of redshift, where \( M_* = 10^{8.66} M_\odot \) is the total stellar mass of M32 (Cappellari et al. 2006). The results are shown in Figure 5.1. The limiting values of the SSFR are obtained assuming that the stellar mass was formed uniformly in the given age interval (lower limit) or only in 1 Gyr of such interval (upper limit). The SSFR values obtained are typical of or even lower than the observed SSFR in galaxies with masses \( \sim 10^9 M_\odot \) at redshifts \( 0.3 \lesssim z \lesssim 2 \) (e.g., Noeske et al. 2007; Santini et al. 2009). Thus, assuming that the field studied is representative of the whole galaxy, the stellar populations found in M32 at \( \sim 2' \) support the scenario of downsizing of star formation in galaxies, where low-mass early-type galaxies form the majority of their stars at lower redshifts than the peak of the star formation rate density of the universe (e.g., Hopkins & Beacom 2006) (Chapters 2 & 3).

- **The stellar populations in the inner regions of M31**

  From qualitative and quantitative analysis of the CMD of our background field, we find that the stellar populations of the inner regions of the disk and spheroidal components of M31 are older and more metal-poor than M32.
The mean mass-weighted age and metallicity of the inner regions of M31 are \( \langle \text{Age} \rangle = 8.7 \pm 1.2 \text{ Gyr} \) and \( \langle [\text{M/H}] \rangle = -0.15 \pm 0.10 \text{ dex} \), respectively. M31’s population at \( \sim 5 \) kpc from its center has two main components: \( \sim 55\% \) of the mass composed by a 8–14 Gyr old metal-poor population and \( \sim 40\% \) of the mass in more-metal rich stars of 5–8 Gyr old. The remaining \( \sim 5\% \) is in a 0.5–5 Gyr old population. The inner disk and spheroidal stellar populations seem to be indistinguishable from those of the outer disk and spheroid. Assuming that M31’s disk at our field location (\( \sim 1 \) disk scale length) has a mean age between \( \sim 5 \) and 8 Gyr, our results are in agreement with inside-out disk formation models.

We conclude that M32 has had an extended SFH and is composed of two main dominant populations at F1: \( \sim 40\% \) of the mass in a 2–5 Gyr old, metal-rich population and \( \sim 56\% \) of the mass in stars older than 5 Gyr, with slightly subsolar metallicities. We do not expect a significant contribution from stars older than 10 Gyr in M32 at \( \sim 2' \) from its center, although there are a few ancient metal-poor stars present in M32, as revealed by the presence of RR Lyrae. The \( \sim 4\% \) of the rest of the mass is roughly equally divided between a young metal-rich population and a young metal-poor population. We associate the latter with blue straggler stars belonging to an old (likely metal-poor) population. The mean mass-weighted age and metallicity of M32 at \( \sim 2' \) from its center are \( \langle \text{Age} \rangle = 6.8 \pm 1.5 \text{ Gyr} \) and \( \langle [\text{M/H}] \rangle = -0.1 \pm 0.08 \text{ dex} \), respectively, where the uncertainties are due to uncertainties in the measured SFH.

## 5.2 Future prospects

### 5.2.1 Calibration of stellar population synthesis models with M32

The spectral energy distribution (SED) of elliptical galaxies is typically the only means available to study their stellar populations. The large distances of these galaxies in combination with their high surface brightnesses prevent detection of their intrinsically fainter individual stars. Thus, we rely strongly on unresolved stellar population models to learn about their star formation histories (SFHs). To this end, unresolved stellar populations synthesis models have been developed (e.g. Worthey 1994) to study moderate-resolution spectra (e.g. González 1993; Coelho et al. 2009) and have become very sophisticated in disentangling the non-trivial age–metallicity. Nevertheless, they still suffer from uncertainties: e.g., it is difficult to distinguish between a young or hot old population since the latter is not necessarily accounted for in the models (Maraston & Thomas 2000). Calibration of these models, which requires observations of individual stars in giant elliptical galaxies, is a key ingredient that needs to be further developed. The lack of giant elliptical galaxies in the Local Group leaves M32 as the best template available for these galaxies. M32, although a low-luminosity compact elliptical, is the nearest system
with properties similar to the giant elliptical galaxies. Moreover, in general, models applied to giant ellipticals reach the same conclusions as those applied to M32 (e.g., Worthey 1998). M32 is therefore a vital laboratory to test the applicability of the stellar population models to more distant galaxies. A comparison of the stellar parameters obtained using resolved stars and integrated luminosity is fundamental to provide a calibration to the unresolved stellar models with an actual elliptical.

Extensive spectroscopic studies of M32 have been performed, mostly in the central regions and out to \( r_e \) (e.g., O’Connell 1980; González 1993; Worthey 2004; Rose et al. 2005). All studies agree that the central stellar population has an SSP-equivalent age of 2.5–5 Gyr and roughly solar metallicity, with an age gradient that increases the age at \( r_e \) by \( \sim 3 \) Gyr and a mild negative metallicity gradient. Various synthetic population models have claimed that M32 underwent a period of significant star formation in the recent past, i.e., about 5–8 Gyr ago, (e.g., O’Connell 1980; Pickles 1985; Bica et al. 1990) based on the presence of enhanced H\( \beta \) absorption in the integrated spectrum of M32, a signature of an intermediate-age population (e.g., Rose 1994; Trager et al. 2000b; Worthey 2004; Schiavon et al. 2004; Rose et al. 2005; Coelho et al. 2009). To date, only Coelho et al. (2009) have attempted to probe the unresolved stellar populations as far from the center of M32 as the ACS/HRC field presented in this thesis lies, using longslit observations with GMOS on Gemini. They propose that an ancient and intermediate-age population are both present in M32 and that the contribution from the intermediate-age population is larger at the nuclear region. They claim that a young population is present at all radii, in particular they suggest that there is a strong component of either very young (< 0.3 Gyr) and/or very old (> 10 Gyr), metal-poor stars even in their outermost field.

We presented throughout this thesis the most complete analysis to date of the resolved individual stars of M32, and thus we provide an unprecedented rich data base to compare with unresolved stellar population model. We used the inferred SFH of M32 derived in Chapter 3 at F1 to compute line strength indices and to predict the spectrum of M32 from its derived SFH, using the models of Bruzual & Charlot (2003, hereafter BC03). Figure 5.2 shows the predicted SED for M32 at F1 after blue-shifting the spectrum to \( v = -204 \) km s\(^{-1}\) and smoothing to \( \sigma = 72 \) km s\(^{-1}\), as expected for (the center of) M32.

Using the BC03 models, we obtain a \( B \)-band luminosity-weighted mean age and metallicity of 5.1 Gyr and \([M/H] = -0.19\) dex, respectively, for M32 at F1 from its resolved SFH. Coelho et al. (2009) find an average luminosity-weighted age of 5.7 ± 1.5 Gyr using BC03, which agrees with our result within the uncertainties, but their inferred mean metallicity is much lower, \([M/H] = -0.6 ± 0.1\) (see their Table 3). Moreover, as mentioned above, they suggest that there is a strong component of either very young (< 0.3 Gyr) or very old (> 10 Gyr), metal-poor stars in their field at a radius similar to our F1 field, which is inconsistent with our data.

We note that Howley et al. (2010, priv. comm.) have suggested that the appropriate value of M32’s velocity dispersion at the position of F1 is \( \sigma \approx 45 ± 7 \) km s\(^{-1}\), with nearly the same radial velocity as at M32’s center. At the resolution of our spectrum, the difference between Howley et al.’s value and the central value is nearly negligible.
Figure 5.2: Predicted SED of M32 at F1’s location, using BC03 models and the inferred SFH of M32 calculated in Chapter 3, after smoothing to M32’s velocity dispersion and shifting to its radial velocity. The flux distribution $F_{\lambda} \propto L/L_\odot^{-1}$, where $L_\odot = 3.8 \times 10^{33}$ ergs/s. The H\(\delta\), H\(\gamma\), H\(\beta\), Mgb, Fe5270, and Fe5335 indices are indicated. The blue, black and red solid lines show the blue, central and red values in the definition of the corresponding Lick indices, respectively (see e.g. Burstein et al. 1984; Worthey et al. 1994; Trager et al. 1998).

We have also calculated SSP-equivalent parameters that can be compared with the values obtained from the integrated luminosity of this galaxy. Using the BC03 models, the SSP-equivalent values of M32 obtained from its inferred SFH at F1 are 3.3 Gyr and $[M/H] = -0.06$ dex, respectively. Given the radial age and metallicity gradients known to be present in M32 (e.g., Rose et al. 2005), we cannot directly compare these SSP-equivalent values with those obtained from the central luminosity integrated of M32 (by, e.g., Trager et al. 2000b). We therefore do the following. We use the values of the line strength indices from Worthey (2004) and compute the SSP-equivalent parameters from polynomial fits to the absorption-line strengths as a function of radius (his Table 1) using the modified BC03 models described in Trager et al. (2008). We then fit straight-line gradients to the SSP-equivalent parameters as a function of radius and extrapolate these fits to 110'', F1’s position. The SSP-equivalent age and metallicity of M32 at F1 from this extrapolation are $8.9 \pm 0.5$ Gyr and $[M/H] = -0.23 \pm 0.03$ dex, respectively. We note that Worthey’s values for Mgb are low compared with González (1993) and Trager et al. (1998), and thus the SSP-equivalent age we have obtained may be slightly overestimated.
Figure 5.3: SSP-equivalent age (left panel) and metallicity (right panel) values from Worthey (2004) data as a function of radius from the M32’s center. The lines are linear fits to the data. We can see the steep positive age gradient from M32’s center to $r_e \sim 40''$. An extrapolation of these fits to $\log(110'' \sim 2.04$ gives the SSP-age and metallicity values at F1: 8.9 Gyr and $[M/H] = -0.23 \pm 0.03$ dex, respectively. The SSP-equivalent parameters calculated from the inferred SFH of M32 (big dots) are in stark contrast with predictions of spectral studies.

whereas the SSP-equivalent metallicity may be underestimated. Taken this into account, we obtained an SSP-equivalent age of $\sim 8.4$ Gyr and a SSP-equivalent metallicity of $[M/H] \sim -0.13$ dex. Figure 5.3 shows the SSP-equivalent parameters from Worthey (2004). The linear fits to the $\log(age/\text{Gyr})$ and $[M/H]$ as a function of $\log(r/''$) are also shown. The big dots indicate the SSP-parameters obtained from the inferred SFH of M32 from BC03 models.

The predicted age and metallicity at F1 from the extrapolation of the absorption line gradients are older and lower, respectively, than those obtained from the inferred SFH of M32. This suggests that either the extrapolation of line strength indices or the stellar population models, or both, may be in error, but we are currently unable to discern which. Color profiles in many colors of M32 are rather flat (Peletier 1993). Since M32 does not contain dust, integrated colours can be good population indicators and the fact that there are no gradients in colors agree with the results from the inferred SFH. Davidge & Jensen (2007) have also challenged the radial gradients in mean stellar parameters obtained from spectral studies. They find no evidence for a radial age gradient in M32, based on the properties of observed brightest AGB stars, in contrast to the results by Worthey (2004) and Rose et al. (2005), who found (as described above) a significant radial gradient in the mean luminosity-weighted age of M32.

The only way to address this apparent contradiction is with a spectrum of M32 at the position of F1, with which we can compare the SSP-equivalent parameters obtained from the resolved population. With this goal in mind, we have obtained new VIRUS-P observations of spectra of M32 taken at the position of field F1, where the SFH has been resolved. These data will be fully analyzed in the near future.
et al. 2008) on the 2.7 m Harlan J. Smith telescope at McDonald Observatory is the largest field of view (FoV) integral field unit spectrograph to date, composed of 246 optical fibers each with a $4'' \times 1''$ diameter on the sky for a FoV’s size of $1.7 \times 1.7$. The fibers are laid out in hexagonal close-packing, roughly square array with a 1/3 fill factor of $\sim 8$ pixel spacing between the fibers.

The data were taken over two nights and two partial nights in October 2010. We observed both the ACS/HRC fields presented in Chapter 2 (F1 and F2) and the center of M32. Given the 1/3 fill factor, three dithered exposures per field position were taken to sample the complete FoV. In addition, sky nods were necessary. These constituted about 1/3 of our observing time. We observed three sky fields that were obtained $\sim 2^\circ$ off the field positions and outside of the major M31 substructure regions (see e.g., McConnachie et al. 2009). The data for F1 and F2 were acquired through a cadence of 20 minute science exposures bracketed by 5 minute sky exposures. In total, 6 exposures per dither position were obtained for F1 for an effective exposure time of 120 minutes and 5 exposures per dither position for an effective exposure time of 100 minutes were obtained for F2. The center of M32 was observed with 3 exposures per dither position of 30 minutes each, for an effective exposure time of 90 minutes. The observing conditions for the entire run were good. The typical seeing during the observations was $\sim 2''$.

Determining the unresolved stellar population parameters of the fields requires high signal-to-noise (S/N) spectroscopy. We therefore used VIRUS-P’s $R \sim 900$ grating over 3500–5800 Å, which covers the critical $\text{H}_\beta$, $\text{Mg}_b$, $\text{Fe}5270$, and $\text{Fe}5335$ indices (Burstein et al. 1984, Worthey et al. 1994, Trager et al. 1998), the higher-order Balmer lines $\text{H}\delta$ and $\text{H}\gamma$, and the as-yet barely exploited blue region from 3500–4000 Å. As shown by Cardiel et al. (1998), an age-dating accuracy of 1 Gyr for an ancient population ($> 10$ Gyr) requires $S/N > 95$ at the Lick/IDS resolution of $\sim 200$ km/s. Given the surface brightness of fields F1, $\mu_V = 21.5$ mag/arcsec$^2$, and F2, $\mu_V = 22.7$ mag/arcsec$^2$, and the exposure time observed per field, we expect to reach $S/N = 100$ per spectral resolution element of 5 Å in F1 by averaging 20 fibers and $S/N = 85$ per spectral resolution element of 5 Å in F2 by averaging 45 fibers.

At the moment, only data obtained at F1’s position have been partially reduced. The data reduction steps were performed using VACCINE (Adams et al., in prep.), a pipeline specifically developed for VIRUS-P data at University of Texas. Details about the reduction steps can be found in Murphy et al. (2011). Figure 5.4 shows a total intensity map of the VIRUS-P field centered at F1 after the data were reduced, overlaid on a ground-based image of M32. The units are arbitrary. Each small circle represents a fiber of VIRUS-P instrument. We can clearly see how the intensity increases as we get closer to the galaxy’s center.

Figure 5.5 shows the spectrum of one of the brightest of the 738 available fibers in this VIRUS-P pointing. The data quality is clearly excellent. This spectrum has not yet been fully flux-calibrated, so the continuum shape in Figure 5.5 cannot be compared directly to Figure 5.2.

The final, complete reduction and analysis of these observations will be performed in the near future. With these observations, it will finally be possible to
Figure 5.4: Intensity map of the 738 regions sampled by VIRUS-P in the three dither positions for F1, overlaid on a ground-based image of M32. Each region of the intensity map has a diameter of 4″.1. The FoV of VIRUS-P is a 1′.7 × 1′.7 box consisting of an array of 246 optical fibers. The ACS/HRC F1 field is indicated with a black square and corresponds to the central ∼ 50 regions of this map. North is up and East is to the left.
**Figure 5.5:** SED of one of the brightest fibers observed at F1. The spectrum has not yet been fully flux-calibrated. Some of the critical indices required for determining the age and metallicity of the galaxy, H\(\delta\), H\(\gamma\), H\(\beta\), Mg\(b\), Fe5270, and Fe5335, are indicated. The blue, black and red solid lines show, respectively, the blue, central and red limits in the definition of the corresponding Lick indices. The figure shows the excellent quality of the data.

compare the SSP-equivalent parameters from the inferred SFH of M32 in Chapter 3 when the ones obtained from to the real spectrum of M32 and calibrate the stellar population models with an actual elliptical galaxy for the first time. This will of course help to better understand how to interpret the integrated luminosity of galaxies, and therefore their SFHs. In addition, given the large areal coverage never before obtained for M32, these observations will allow us to spatially resolve the stellar populations of this galaxy from the center out to \(\sim 3r_e\) and study radial age and metallicity gradients.

### 5.2.2 M32 as a possible progenitor of substructures in the halo of M31

According to the current models of galaxy formation, galaxies form hierarchically through the accretion of smaller objects that, due to gravity, merge together and form larger systems as we see them today (e.g. White & Rees 1978). Predictions of this theory, such as the existence of streams and satellite galaxies, have been supported by observations not only in our own Galaxy (e.g. Helmi & White 1999).
Belokurov et al. 2006) but also in external galaxies (e.g. Martínez-Delgado et al. 2009). The system of M31 and its satellites represents an ideal laboratory for mapping the progressive stages of hierarchical galaxy formation. Our external and global view of this system removes complications due to crowding and highly variable extinction that affect the observation of stellar substructures in the Milky Way. As a result, the structures observed in M31 are easier to interpret.

Over the last decade, ground-based wide-field observations of M31’s halo have detected the presence of several substructures (e.g. the giant stream, Ibata et al. 2001), which are remnants of dwarf galaxies disrupted by the tidal field of M31 (e.g. Ferguson et al. 2002). Recently, deep HST ACS/WFC observations of 14 fields located in the inner halo of M31 were analyzed and the stellar populations of identified streams were characterized (Richardson et al. 2008). Richardson et al. (in prep.) extracted their SFHs and determined that most of these streams have a common progenitor. The progenitor of these streams is expected to be only one system with a complex SFH, with the bulk of star formation at intermediate and old ages. However, its nature has not been established yet.

We have shown in Chapter 3 that M32 has also had a complex SFH, composed of two main intermediate-age and old populations. Whereas kinematical results have indicated that M32 is not a good candidate (Fardal et al. 2008), Block et al. (2006) showed that a possible head-on collision of M32 to M31 could deposit all the substructures seen in the halo of M31. We can further investigate whether the origin of the substructures in the inner halo of M31 can be associated to M32 by using stellar populations. The observations that we presented in Chapter 2 are located at the outer regions of M32, where its isophotes are known to be distorted (Choi et al. 2002) possibly due to interactions with M31 that would have tidally stripped off some of M32’s material. A direct comparison of the SFH of M32 extracted from its resolved stellar populations in Chapter 3 with that of the stream-like fields obtained in the halo of M31 can confirm or rule out M32 as the progenitor of these substructures.

5.2.3 The rare oldest and youngest stars of M32

We have shown in this thesis that M32 has \( \sim 2\% \) of its mass composed of stars younger than 2 Gyr and \( \sim 40\% \) of stars with ages between 2 and 5 Gyr. We confirm the presence of the younger population through the presence of bright AGB stars in our CMD. However, our field of view was very small and it was positioned well away from M32’s center. Thus, some contamination from M31 stars may remain, even though we accounted for it with an appropriate background field.

On the other hand, we have a hint of the presence of an ancient-metal-poor population from our marginal detection of RR Lyrae stars (Chapter 4). Our results indicate that old metal-poor stars contribute to \( \sim 5\% \) of the mass of M32 at F1. However, due to the small field of view of the ACS/HRC camera we only detected a marginal amount of these stars, which moreover had no clear difference in pulsational properties with the ones found in our background field of M31.
Thus, we still lack a complete census of both the oldest and youngest populations of M32, which are crucial to understand how M32 started to form and when its last epoch of star formation took place. Shallower observations over a wider area closer to M32’s nucleus can be used to identify and quantify these populations. Firstly, contamination from M31 stars will be minimal as we approach the nucleus of M32. Secondly, a wider coverage will not only allow the detection of gradients (if any) in the M32 populations and test spectroscopic results (e.g. Worthey 2004; Rose et al. 2005) but will also provide statistically-significant detection of RR Lyrae and AGB stars, which was difficult in this thesis due to the very small HRC FoV. For example, UVIS WFC3 images can be used to search for RR Lyrae and quantify the presence of ancient, metal-poor stellar populations, and NIR WFC3 observations can be used to determine the youngest ages of AGB stars, since bright AGB stars in NIR filters show a distinct sharp edge corresponding to their maximum luminosity.

Combining the results of this thesis with the forthcoming answers to these questions will allow us, in the near future, to place stronger constraints to the process of formation and evolution of elliptical galaxies.