CONSTRAINING STELLAR POPULATION MODELS –
I. AGE, METALLICITY AND ABUNDANCE PATTERN COMPILATION FOR GALACTIC GLOBULAR CLUSTERS

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ABSTRACT

We present an extensive literature compilation of age, metallicity, and chemical abundance pattern information for the 41 Galactic globular clusters (GGCs) studied by Schiavon et al. (2005). Our compilation constitutes a notable improvement over previous similar work, particularly in terms of chemical abundances. Its primary purpose is to enable detailed evaluations of and refinements to stellar population synthesis models designed to recover the above information for unresolved stellar systems based on their integrated spectra. However, since the Schiavon sample spans a wide range of the known GGC parameter space, our compilation may also benefit investigations related to a variety of astrophysical endeavours, such as the early formation of the Milky Way, the chemical evolution of GGCs, and stellar evolution and nucleosynthesis. For instance, we confirm with our compiled data that the GGC system has a bimodal metallicity distribution and is uniformly enhanced in the α-elements. When paired with the

ages of our clusters, we find evidence that supports a scenario whereby the Milky Way obtained its globular clusters through two channels, in situ formation and accretion of satellite galaxies. The distributions of C, N, O, and Na abundances and the dispersions thereof per cluster corroborate the known fact that all GGCs studied so far with respect to multiple stellar populations have been found to harbour them. Finally, using data on individual stars, we also confirm that the atmospheres of stars become progressively polluted by CN(O)-processed material after they leave the main sequence and uncover evidence which suggests the α-elements Mg and Ca may originate from more than one nucleosynthetic production site.

We estimate that our compilation incorporates all relevant analyses from the literature up to the mid-2012. As an aid to investigators in the fields named above, we provide detailed electronic tables online of the data upon which our work is based[1].

Subject headings: Astronomical data bases: miscellaneous, Galaxy: abundances, Galaxy: globular clusters: general, Galaxy: stellar content

1. Introduction

The stellar content of galaxies represents the time integral, up to the epoch of observation, of both their star formation and chemical enrichment histories. This implies that an understanding of stellar populations is essential in the study of the galaxy formation problem. The nature of galaxies' stellar populations may be pursued through multi-band photometric and/or spectroscopic datasets. The latter tend to be more highly valued for their greater number of population tracers (i.e. absorption line/band strengths or full spectra versus broad-filter fluxes), reduced sensitivity to dust (MacArthur 2005) and multiplexed ability to simultaneously constrain stellar ages, metallicities, chemical abundance patterns, dynamics and mass distributions (e.g. see Conroy & van Dokkum 2012). The present work concerns spectroscopic-based stellar population studies.

Stellar population synthesis (SPS) models are the tools which connect observations of stellar systems to their physical parameters. In order to apply them with confidence, the accuracies of their predictions must be subjected to in-depth evaluations first. The standard approach to SPS model evaluations is to verify that the predictions uniquely reproduce, to within some desired tolerance, the benchmark values of various parameters for well-characterized stellar systems obtained by way of independent and trustworthy techniques (Schiavon & Barbuy 1999; Schiavon et al. 2002a,b, 2004; Thomas et al. 2003; Proctor et al. 2004; Lee & Worthey 2005; Mendel et al. 2007; Schiavon

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[1]www.astro.queensu.ca/people/Stephane_Courteau/roediger2013/index.html

2007; Graves & Schiavon 2008; Koleva et al. 2008; Percival et al. 2009; Vazdekis et al. 2010; Thomas et al. 2011b)).

The stellar systems best suited for evaluations of SPS models are the many star clusters found in the Milky Way and its nearby satellite galaxies. The reasons for this are two-fold. First, those clusters are defined by comparitively simple star formation and chemical enrichment histories, making them the closest tangible approximation to the most basic stellar system treated by SPS models. In other words, they best embody the concept of the so-called simple stellar population: a collection of stars born from an instantaneous burst of star formation and having a uniform chemical composition. Second, the relative proximity of these clusters allows their stellar content to be resolved well below their respective main sequence turn-offs. This makes it possible to accurately constrain their ages via isochrone fitting to colour-magnitude diagrams (CMDs) and abundance patterns from the synthesis of high-resolution spectra of individual members.

Of all the star cluster systems found in the nearby Universe, the Galactic globular clusters (GGCs) are most valuable for SPS model evaluations, albeit in the regime of old ages and low to solar metallicities, akin to quiescent galaxies, spiral bulges, and extragalactic globular cluster systems. The value of GGCs in this respect is tied to the fact that their stellar contents have been the most extensively studied to date through CMDs and spectral syntheses. Somewhat ironically, it is because of the special attention paid to GGCs that we now know of many instances where they systematically deviate from the textbook definition of a simple stellar population, largely through inhomogeneities in the abundances of several light elements (see Gratton et al. 2012a for a recent and detailed review). Given the necessity of model evaluations though, the emergent complexity of GGCs is insufficient grounds to void their status as the premier sample for such purposes. Instead, modellers should adjust the aim of their evaluations to reproducing the *mean* abundance patterns of those GGCs known to harbour multiple populations, but progress along these lines is only in its infancy (Coelho et al. 2011).

Amongst the many public SPS models, that of Schiavon (2007, hereafter S07) is one of three designed to recover the abundances of light elements for an observed stellar population, in addition to the usual diagnostics of age and metallicity; the other two models are from Thomas et al. (2011a) and Conroy & van Dokkum (2012). Of these three models, that of S07 stands out as the one whose abundance predictions have been the most rigorously tested thus far over a considerable metallicity range[2] (Δ[Fe/H] $\sim$ 1.2 dex). Graves & Schiavon (2008) found that the S07 model reproduces, to within ± 0.1 dex, the known ages, metallicities, and abundance ratios of the GGCs 47 Tuc, NGC 6441 and NGC 6528, as well as the Galactic open cluster M67. Despite their success, the

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[2]The Conroy & van Dokkum (2012) models, however, are only intended for use on stellar populations of approximately solar metallicity.

sample analysed was rather small, totalling five clusters, implying that a more extensive evaluation covering a wider range in GGC properties, e.g. horizontal branch morphology, is still needed to establish the ultimate robustness of this model. For instance, these authors noted that the calcium abundance recovered for the metal-poor GGC NGC 6121 was ~0.3 dex lower than that measured by Ivans et al. (1999). This discrepancy led them to caution about the use of the S07 model in the regime [Fe/H] $\lesssim$ -1.0, precisely where the reliability of this model has been poorly validated to this point.

In their analysis, Graves & Schiavon (2008) used the library of high-quality integrated blue spectra measured by Schiavon et al. (2005, hereafter S05) to recover the ages, metallicities and abundance patterns for the four GGCs in their sample. Indeed, the work of S05 was inspired by the need for in-depth evaluations of the accuracies of spectroscopic-based SPS model predictions. As such, the authors selected their targets (41 in all) to be representative of the entire GGC system, spanning a wide range of metallicities, horizontal branch morphologies, concentrations, Galactocentric coordinates, and Galactocentric distances. To this day, the S05 library remains the only one of its kind. In addition to it, SPS model evaluations require a matching database of independent age, metallicity, and abundance pattern estimates for the 41 S05 GGCs against which the model predictions may be compared. Existing compilations of GGC parameters do not satisfy these needs, however, because they either provide metallicity information alone (Harris 1996, 2010 edition[3]; hereafter Ha10) or overlook the abundances of certain light elements (e.g. C, N) and cover only a fraction of the full S05 sample (Pritzl et al. 2005, hereafter Pr05). These shortcomings have arguably been at the heart of the statistically weak tests of the S07 and Thomas et al. (2011a) models to date[4]. Stringent validations of such SPS models are thus stymied until a more complete database of independent stellar population information for this sample is assembled.

In this paper, we wish to rectify this situation by presenting the most extensive combined compilation yet of available GGC ages, metallicities, and abundance patterns. To do so, we draw on existing compilations of GGC parameters (Marín-Franch et al. 2009, hereafter MF09; Ha10), as well as the vast literature on the chemical compositions of the S05 clusters. The application of our data set to a statistically robust evaluation of the S07 and other SPS models will be presented elsewhere (Roediger et al., in prep.; hereafter Paper II).

The layout of the present paper is as follows. In Section 2.1-2.2, we discuss the GGC sample, methodology and some of the principal data sources which underlie our compilation. Granted that our sample is representative of the GGC system as a whole, we use our compilation in Section 2.3

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[3]http://www.physics.mcmaster.ca/$\sim$Harris/mwgc.dat

[4]Recall that the Conroy & van Dokkum (2012) model has a limited metallicity range, meaning that it can only be tested on metal-rich Galactic star clusters at this time (e.g. M67, NGC 6528; Conroy et al. 2013b).

to draw insights into a variety of topics related to the stellar populations of these objects. Comparisons of our work with other prior compilations of GGC stellar population data are presented in Section 2.4. Finally, we conclude and contemplate other possible uses of this compilation in Section 3.

2. Data & results

Spectroscopic-based SPS models are designed to predict the full spectra and/or strengths of absorption line/band indices over a wide range of ages and metallicities for simple stellar populations of any specified abundance pattern. The ability of the S07 model to fit for chemical abundances is realized by inverting its functionality, that is, by perturbing the specified abundance pattern until the same age and metallicity are obtained amongst all possible index-index pairs under consideration for an observed stellar system. Practically speaking, the model steps through the n-dimensional parameter space spanned by the available data in a hierarchical fashion, beginning with indices most sensitive to age and metallicity effects (e.g. Hβ, Fe5250, Fe5335) and ending with those that trace chemical abundances (e.g. Mgb, Ca4227). In this way, the model simultaneously predicts the best-fit age, metallicity and light-element abundance pattern ([Mg/Fe], [C/Fe], [N/Fe], [Ca/Fe]) for a given system. While the S07 model can, in principle, fit for the ratios [O/Fe], [Na/Fe], [Si/Fe], [Cr/Fe], and [Ti/Fe] as well, their values are fixed at this time[5] since they are not reliably traced by existing Lick indices. Graves & Schiavon (2008) presented an efficient algorithm, "EZ_Ages", to carry out the required inversion of the S07 model so that it can be applied to the measured indices of any stellar system. Further details on either the S07 model or EZ_Ages are provided in those introductory papers, as well as in Paper II.

For a robust evaluation of the S07 and other SPS models (Paper II), we will draw upon the S05 library of intermediate-dispersion, high-S/N integrated blue spectra for 41 GGCs, as do most other investigators for such purposes. An important aspect of this library is the sample's wide coverage of the known GGC parameter space (see Figure 1 and Table 1), which makes it fairly representative of the entire GGC system as well as the stellar populations of whole galaxies (e.g. early-types) or their sub-components (e.g. bulges). Either a suite of absorption-line/band strengths measured from these data or the full spectra themselves may be fitted using one of several different SPS models to recover the ages, metallicities, and abundance patterns of these GGCs. The performance of any given model is then judged by comparing these fitted parameters against the most complete compilation yet of similar but independently-derived information for the S05 GGCs, the latter of

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[5][O/Fe] is fixed at 0.0 or +0.5, depending on the adopted isochrone (solar-scaled versus α-enhanced), and [Cr/Fe] at 0.0, while [Na/Fe], [Si/Fe], and [Ti/Fe] track [Mg/Fe].

which is the primary focus of this work.

Although the preceding discussion has largely focussed on the S07 model, it must be appreciated that our compilation is perfectly general and can be applied to the evaluation of *any* spectroscopic-based SPS model (e.g. Thomas et al. 2011a; Conroy & van Dokkum 2012). In fact, such an undertaking would undoubtedly help highlight the merits of the particular ingredients and/or fitting techniques adopted by different models. Our compilation may also be useful to any other field concerned with GGCs, such as the formation of the Milky Way, or stellar evolution and nucleosynthesis. In the following sub-section, we describe the methodology by which our compilation was assembled given the wealth of literature data pertaining to our needs. For reasons that will be made clear, this discussion will largely revolve around the abundance patterns of our clusters.

2.1. Compilation methodology

The over-arching principle for our compilation of the available literature on the stellar populations of the S05 GGCs is that it be as comprehensive and complete of a record as possible. For each one of our clusters then, we have strived to obtain as many estimates as we could for its age, metallicity, and abundances of light elements, with the extent of the latter group being dictated by those elements currently treated within SPS models (i.e. Mg, C, N, Ca, O, Na, Si, Cr, Ti)[6]. While extensive and homogeneous compilations already exist with respect to GGC ages and metallicities, and cover large fractions of the S05 sample (e.g. MF09, Ha10; see Section 2.2), resources of similar quality on the individual chemistries of these clusters is more limited and heterogeneous.

The premium compilation of GGC chemical compositions until now was presented by Pr05, who gathered α-element abundances (Mg, Ca, Si, Ti) from high-resolution spectroscopic analyses in the literature for a sample of 45 GGCs. Their results prove less than ideal for the purposes of SPS model evaluations since the elements C, N, O, Na, and Cr, which SPS models now cover, were omitted and their sample has a rather small overlap with that of S05 (15 clusters only). To improve upon the shortcomings of Pr05, we extracted from the literature measurements of the relevant chemical abundance ratios for each S05 cluster from as many references as possible. In so doing, we have found that specifying a complete abundance pattern for any one S05 GGC often required data from at least two references; for example, the abundances of carbon and nitrogen are

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[6]We explicitly include the latter five elements to enable the most complete evaluations possible of *all* SPS models that predict abundance patterns. In future revisions to the present work, we envisage adding information on heavier elements which yield other unique insights from the perspective of galaxian stellar population analyses (e.g. Sr, Ba; Conroy et al. 2013a).

usually studied together but separately from those of the other elements listed earlier. Our desire for completeness therefore naturally encouraged us to draw on multiple sources when assembling the abundance patterns we are advocating for use here. In doing so, we have combined the results from *all* chemical composition studies on each cluster[7].

The abundance pattern we adopt as the benchmark for each cluster was built by calculating the mean value and root-mean-square (rms) dispersion of the available independent measurements for each of the elements listed above. This aspect of our compilation embodies some noteworthy advantages. First, merging results as we do should reduce the *statistical* error in the value that we recommend for any given abundance ratio, albeit at the price of increasing its *systematic* error. We do not consider this a drawback but rather another advantage of our approach since systematic errors (e.g. sample selection, solar abundances, atomic parameters) might be a significant source of discrepancy between abundance patterns predicted by SPS models and star-by-star spectral syntheses. Having a metric for the degree of systematic error involved in the latter, via the dispersions, will undoubtedly be very helpful for judging the reality of model predictions. The last advantage of our approach is that it should also naturally reflect the existence of putative multiple stellar populations when present within a given cluster (again, via the dispersions). A hallmark of the multiple population phenomenon is that, amongst the members of an affected cluster, the abundances of several elements either correlate (Al-Si) or anti-correlate (C-N, Na-O, Mg-Al) with one another (Gratton et al. 2012a). Modulo the particulars on sample selection, we then expect to find large spreads in the abundance ratios of these elements between the stars from either a single study or multiple ones[8]. Moreover, by combining such scattered measurements into a single estimate for a cluster's abundance pattern, we can be assured that the corresponding dispersions reflect the presence of multiple populations by being comparitively large to those of species which are excluded from the above trends (e.g. Ca). Note that any and all claims we make herein as to the causes of inflated rms dispersions (re: systematics versus multiple populations) are ultimately suggestive and not based on thorough quantitative analyses.

Another major principle for our compilation involves concentrating, where possible, on studies whose results pertain solely to evolutionary stages from the main sequence (MS) through the asymptotic giant branch (AGB). We impose such a restriction because the onset of thermal flashes, third dredge-ups, dust-gas separation (winnowing) and mass loss during the final (post-AGB) stage in the evolution of low-mass stars can give rise to surface abundances which poorly

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[7]We have created an electronic data table which lists these results for each cluster in our sample. These data tables may be retrieved online at www.astro.queensu.ca/people/Stephane_Courteau/roediger2013/index.html

[8]As discussed below and in Section 2.3, the C, N, and O abundances of individual GGC stars also depend on their evolutionary status, which results in an additional source of dispersion amongst these parameters

reflect the chemical composition of the gas from which they formed (e.g. Şahin & Lambert 2009). Third dredge-up episodes, in particular, would pollute the surfaces of such highly-evolved stars with CNO-processed material from the hydrogen-burning shell (if present), effectively lowering the abundance of carbon and raising that of nitrogen there, relative to those of MS stars (e.g. Mooney et al. 2004). Stars ascending the sub-giant and red giant branches (SGB and RGB, respectively) can also have their surface chemistries of C, N, and O affected by mixing episodes (e.g. Iben 1964, Sweigart & Mengel 1979; Section 2.3), but given that most spectroscopic analyses of individual GGC members do not penetrate to fainter magnitudes than this phase precludes our rejection of such data. In other words, limiting our mean carbon and nitrogen abundances only to measurements obtained from MS stars would significantly thin out our compilation. Instead, we embrace such data and simply caution SPS modellers to consider the evolutionary stage down to which their predicted [C/Fe] and [N/Fe] values correspond. In Section 2.3 we highlight the possibility that carbon depletion and nitrogen enhancement as a function of position along the SGB/RGB may be crudely quantified.

In addition to highly-evolved stars, we also exclude from our compilation (again, where possible) data corresponding to "exotic" stages of stellar evolution, such as very hot ($T_{eff} > 11\ 500$ K) horizontal branch (HB) stars. In this case, the surface abundances of elements are often perturbed by effects like radiative levitation and gravitational sedimentation (e.g. Pace et al. 2006). Unlike the case of mixing along the SGB/RGB though, it is unclear that empirical corrections for these processes are forthcoming simply because it is rare to find individual GGCs with mixtures of exotic plus "normal" ($T_{eff} < 11\ 500$ K) HB stars, let alone homogeneous abundance analyses thereof. Thus, unless data from the MS, SGB, RGB, (cooler) HB, and AGB for a cluster are all not available, we deem abundance ratios based on the most advanced and exotic stages of stellar evolution unsuitable for our purposes and omit them from our compilation.

In light of the above caveats, we wish to provide the exact rationale behind our compiled abundance pattern for each S05 cluster. We do just this, in brief and on a per cluster basis, in the Appendix, with attention being paid to the following related themes: adopted references, omitted data, systematic errors, and evidence of multiple populations from both our data and other methods (where applicable). Tables 2-3 also provide the relevant references from which our recommended ages, metallicities, and abundance patterns for the S05 GGCs were drawn. In the following section, we specifically address our sources and methodology used to arrive at the ages and metallicities of the S05 clusters. Much of that information will therefore not be repeated in the Appendix.

2.2. Age and metallicity sources

Our selection of sources for age and metallicity information on the S05 GGCs embraces similar principles as described above regarding their abundance patterns. In terms of their ages, a cursory review of the relevant literature reminds us of genuine discrepancies on a per cluster basis. While isochrone fitting of one form or another to CMDs has long been the standard by which GGC ages are obtained, the results therefrom appear to be plagued by rather large uncertainties. The origins of these discrepancies are most likely tied to the values of various parameters assumed by the scientist (i.e. distance, reddening, metallicity, etc.) and/or each isochrone set (i.e. mixing length, helium abundance, etc.). Since little is to be practically learned by merging together the available absolute age determinations for any given cluster (unlike the case with their chemical abundances), we prefer our compiled values of this parameter to come from a single source.

The majority of the ages adopted in our compilation come from MF09. These authors have performed the most extensive and homogeneous age analysis of GGCs to date, totalling 64 clusters in all and using HST/ACS photometry plus many flavours of isochrones (Bertelli et al. 1994; Girardi et al. 2000; Pietrinferni et al. 2004; Dotter et al. 2007). The ages in this work from the Dotter et al. isochrones were cast in terms of both the Zinn & West (1984) and Carretta & Gratton (1997) metallicity scales. By normalizing their results from each isochrone set to the corresponding mean absolute age of their 13 lowest-metallicity GGCs, MF09 found that the *relative* ages were robust to the particular choice of isochrone (see their Table 4) and carried a formal precision between 2-7%. For the 25 S05 GGCs which overlap with the MF09 sample, we adopt their relative ages based on the Dotter et al. isochrones and Carretta & Gratton scale. From their §6.1, we assume a normalization factor of 12.80 ± 0.17 Gyr to put these ages on an absolute footing. Note that the uncertainty in the normalizing factor does not account for systematics, e.g. bolometric corrections, but we anticipate this issue will be thoroughly addressed in forthcoming work on absolute GGC ages by the same group, as alluded to in MF09.

To bolster the reliability of their *relative* ages, MF09 also compared them against those of De Angeli et al. (2005), the formerly largest homogeneous GGC age compilation, totalling 55 clusters in all. In doing so, they found mutual consistency between the two datasets to within their own published error bars, where De Angeli et al.'s HST and ground-based sub-samples yielded mean residuals of -0.04 ± 0.07 and -0.02 ± 0.08, respectively. Furthermore, MF09 failed to detect any trends in the residuals as a function of metallicity. We conduct a similar comparison in Figure 2, but in terms of *absolute* ages and with respect to multiple prior age compilations (Rosenberg et al. 1999; Salaris & Weiss 2002; Dotter et al. 2010), where the relative ages from Rosenberg et al. were transformed assuming a zeropoint of 13.2 Gyr (see their §4). To ensure the comparison is fair, we limited it to the twelve S05 GGCs common to all four compilations examined therein. The mutual overlap between the samples of MF09 and other age compilations in the

literature (Chaboyer & Kim 1995; Chaboyer et al. 1996; Richer et al. 1996; Buonanno et al. 1998; Salaris & Weiss 1998; VandenBerg 2000; Meissner & Weiss 2006) is actually poorer than this and so we have omitted those results from Figure 2. Instead, we compare in the Appendix (wherever possible) our adopted ages against *all* other estimates in the literature known to us, on a per cluster basis. Such an exercise provides us with a first-order impression of the systematic discrepancies involved between any two individual age determinations. There, we also provide the normalization factors or constants we have used to transform those ages originally expressed on relative scales into absolute terms.

The most striking feature from Figure 2 is the presence of several clusters in each panel whose ages from prior compilations disagree egregiously with those of MF09. These disagreements are found in different age and metallicity regimes[9], depending on the source under consideration: young ages and low metallicities for Rosenberg et al. (1999), old ages and high metallicities for Salaris & Weiss (2002), and at both age and metallicity extrema for Dotter et al. (2010). Of course, the identification of these inconsistencies hinges on how representative the published uncertainties are of the total error budget. The error bars shown in Figure 2 are largely statistical in nature and do not consider the systematic effects of uncertainties in, amongst many others, distance modulus, reddening and stellar evolution model. With exception to the results of Dotter et al., this criticism may be unwarranted or overstated since the investigators employed distance- and reddening-independent methods (Rosenberg et al.; Salaris & Weiss) and/or provided *relative* ages only (Rosenberg et al.; MF09). Overall then, Figure 2 leaves us with the impression that systematic uncertainties in absolute age dating of GGCs resides (at worst) at the 2-3 Gyr level. Neglecting ages which exceed that of the Universe (13.76 ± 0.11 Gyr; Komatsu et al. 2011), this estimate is corroborated by our cluster-by-cluster comparisons of individual age determinations in the Appendix. A more detailed examination than that of this issue lies beyond the scope of this paper.

While the existence of significant systematics in absolute age determinations might suggest that, for now, it be best to evaluate age predictions from SPS models in a relative sense, it is not clear that this can be done in practice. One complication is that the S05 sample does not contain the same clusters upon which MF09 base their normalization. Another is that, for the sake of completeness of our compilation, we appeal to five other sources of age information for 13 of the 16 S05 GGCs which do not overlap with the MF09 sample. Based on Figure 2, it is clear that transformations of these results onto the MF09 scale would at best be crudely defined. Therefore, until a more complete source of relative ages for the S05 GGCs becomes available, SPS modellers will have to bear in mind the systematics underpinning the absolute ages against which they test

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[9]The age regimes quoted here refer, in a qualitative manner, to the values from MF09.

their predictions. To assist in this awareness, we explicitly caution the reader in the Appendix about those clusters in our sample for which their adopted age *does not* come from MF09. Our extensive list of references which provide independent age measurements for the S05 GGCs is summarized globally in Table 2 and for individual clusters in Table 3. Note that the specific reference of our adopted age for each cluster is shown in boldface in the latter.

Our knowledge of the metallicities of the S05 GGCs has greatly improved with the work of Carretta et al. (2009c). Based on high-resolution optical spectra for about 2000 RGB stars belonging to 19 GGCs (13 of which are in the S05 sample), these authors have created the premier database of homogeneous and spectroscopic metallicities for GGCs. Through it, they have defined a new GGC metallicity scale spanning almost the full range of values exhibited by these systems in this parameter space, from [Fe/H] $\sim$ -2.4 to -0.3 dex. Since Carretta et al.'s sample overlaps with those from previous metallicity scales (Zinn & West 1984; Carretta & Gratton 1997; Rutledge et al. 1997; Kraft & Ivans 2003) by ten clusters or more, they were also able to derive transformations between those and their own. This enabled them to express the metallicities of all 133 GGCs from the 2003 version of the Harris (1996) catalogue, which encompasses our whole sample, in terms of their own scale.

Ha10 improves upon the work of Carretta et al. (2009c) by merging the latter's results with those of Armandroff & Zinn (1988), after first transforming them to the Carretta et al. scale, as well as metallicities for individual clusters from other studies. Given its complete coverage of the S05 sample and the sheer popularity of this database, we would ideally adopt the metallicities from Ha10 for our compilation. However, since Ha10 do not provide uncertainties on their values, we instead calculate the mean metallicities of our clusters using the same references and weighting scheme as Ha10. The bottom panel of Figure 3 shows the differences between the Ha10 metallicities and our replicas thereof. Considering the complete S05 sample, the agreement between the two datasets is superb, with 68% of the data points exhibiting differences of ±0.01 dex or less. We also find that our adopted metallicities compare favorably with those from Carretta et al. (Figure 3, *top*), albeit with 68% of the data points showing differences up to ±0.05 dex. This agreement is not all that surprising as the Ha10 metallicities, and thus our replicas as well, are weighted to the data of Carretta et al. by a factor of three more than those from any other source.

2.3. The stellar populations of Galactic globular clusters

The results of our literature compilation on the stellar population properties of the S05 GGCs are presented in Tables 4-5 and Figures 4-7. In Table 4, we list the recommended age (column 2), mean metallicity (column 3), and mean Mg, C, N, and Ca abundances (columns 4-7) for each cluster, while Table 5 gives their mean O, Na, Si, Cr, and Ti abundances (columns 2-6). Entries

therein which we consider suspect with respect to our compilation principles (elucidated above) appear in boldface; the reader is referred to the Appendix for the rationale behind each of these flags. Recall that, because of practical limitations which bar the computation of relative ages from both literature data and SPS models for *all* of the S05 GGCs, we have cast all of our compiled ages into absolute terms. In light of the apparent systematics which afflict absolute age estimates, we look forward to future work from expert groups which properly address this issue. Until then, SPS modellers will simply have to be mindful of these uncertainties in our compiled data, which we optimistically gauge to be ∼2-3 Gyr, when evaluating age predictions.

While the original intent of the present compilation was for evaluations of SPS models, we foresee its broad applicability to a variety of astrophysical endeavours since the S05 sample is representative of the whole GGC system (Figure 1; Table 1). To demonstrate this point, we use our compilation in the following sub-sections to garner some brief insight into the early formation and chemical evolution of the Milky Way, atmospheric mixing during stellar evolution and the sites of explosive stellar nucleosynthesis.

2.3.1. Ages & metallicities

In Figures 4-7 we show the distributions of all the stellar population diagnostics presented in Tables 4-5 for the whole S05 sample. Referring to Figure 4 and the MF09 results shown therewithin (black histogram), it is seen that the S05 sample has an age distribution which is both strongly-peaked (between 12.5 and 13 Gyr) and skewed to very old ages. Those clusters whose ages come from other sources in the literature are represented by the gray histogram. These additional estimates tend to broaden the overall distribution to both younger and older ages, as well as the strong peak described by the MF09 results. The fact that over half of these other age determinations are found to have extreme values in relation to those from MF09 bolsters our position on treating them with caution. Note that the shaded region in Figure 4 demarcates ages which exceed that of the Universe (Komatsu et al. 2011) and while some of our clusters are found there, the statistical errors on their values alone overlap with the allowed (unshaded) region.

From the MF09 ages in Figure 4, it is tempting to conclude that the S05 GGCs originated from a two-component star formation history. This history could be described as consisting of either a sharp burst superimposed upon a comparitively steady background (lasting ≳4 Gyr) or a vigourous early episode which quickly peaked and was then regulated down to a more sustainable level. By broadening the overall distribution to more extreme ages, the additional literature data shown in Figure 4 seems to agree better with the first of these two scenarios. Modulo systematics, these data would temper this scenario though by spreading the burst component over a longer timescale (∼1.0-1.5 Gyr).

The metallicity distribution for the S05 GGCs (Figure 5) also appears to support the idea that these clusters arose from at least two distinct channels given its clear bimodal shape (in agreement with Zinn 1985), with a peak-to-peak separation of about ~1.0 dex. When we examine the available MF09 ages of the clusters comprising each metallicity sub-group however (Figure 6), there does not appear to be a strong correlation between the two parameters. The metal-poor and metal-rich GGCs of our sample, separated at [Fe/H] = -1.0 dex, which overlap with MF09 have a mean age and rms dispersion of 12.0 ± 1.1 Gyr and 12.8 ± 0.7 Gyr, respectively; the distinction of these two groups by age only worsens when we consider all of our adopted values.

The situation seen in Figure 6 can be attributed to the presence of several old GGCs (>12 Gyr) in our metal-poor sub-sample, whereas only one of our metal-rich GGCs has an age of <12 Gyr. Moreover, our metal-rich sub-sample harbours a high incidence of very old clusters in that three (four, if the metal-rich/-poor boundary lay slightly lower; e.g. [Fe/H] = -1.05) of our six oldest objects are contained therewithin. Since our sample is representative of the entire GGC system, these findings bear some implications with regards to the formation of the Milky Way, in particular its halo. For instance, the parameter spread in Figure 6 would be hard to explain within a scenario in which *all* of the S05 GGCs formed in situ since one would expect the metal-poor GGCs to be *older* than the metal-rich ones, not younger. Instead, this spread is consistent with a picture in which the GGC system arose from its members either forming in situ or being accreted from satellite galaxies. Although the possible correlation of these two channels with metallicity remains unclear, we interpret the older, metal-rich and younger, metal-poor clusters as the descendants of the former and latter, respectively. Similar conclusions have been reached by other analyses of the GGC age-metallicity relation using much larger samples (e.g. MF09, Forbes & Bridges 2010; Dotter et al. 2011). Further insight into this topic might be achieved by searching for correlations between the above parameters and those from the Ha10 catalogue, particularly velocity information, but such a task is beyond the scope of this work. Salaris & Weiss (2002) and MF09 already investigated the relationship between age and galactocentric radius for GGCs, and found none.

2.3.2. *Chemical abundance distributions & atmospheric mixing*

Further critical insight into the stellar populations that comprise GGCs can be gleaned from the distributions of their mean chemical abundance ratios, as shown in Figure 7. These, in turn, afford us with further information on the formation of the Milky Way, as well as certain aspects related to stellar evolution. From Figure 7, we first note that the distributions of the mean abundances of the α-elements (Mg, Ca, Si, Ti) amongst these systems all show sharp peaks towards super-solar values. The respective median values for the [Mg/Fe], [Ca/Fe], [Si/Fe] and [Ti/Fe] distributions are +0.38, +0.30, +0.36 and +0.24 dex, which implies that the GGC system, on the

whole, formed over rapid timescales. On the other hand, slightly broader distributions are found for mean abundances of carbon, nitrogen, and oxygen amongst our GGCs, in that we obtain rms dispersions of $\gtrsim 0.15$ dex for them compared to $\lesssim 0.1$ dex for the α-elements. Apart from possible undersampling effects[10], we interpret the broader distributions of these elements as reflecting the combined and well-known phenomena of atmospheric mixing and multiple stellar populations within these clusters. We concentrate on the former for the remainder of this sub-section and take up the latter in the next.

To bolster the above argument, we show with coloured points in Figure 8 the mean abundances and luminosities of stars from each individual study of the carbon and nitrogen abundances in the S05 GGCs. Unfortunately, not all studies we cite in this regard could be represented in these plots since luminosity information is not available to us in many cases. This may be responsible for the apparent gap in the data in the range $-0.5 < M_V < +0.5$ mag. The point types in Figure 8 reflect whether the assorted samples consist of CN-weak (triangles) or CN-strong (diamonds) stars; circles are used when CN strengths are unknown to us. Moreover, looking from bright to faint luminosities, the evolutionary status of the sample changes from predominantly RGB stars (leftmost-to-middle) to SGB/MS stars (rightmost).

Concentrating only on the mean values for CN-weak and CN-strong stars, an evolutionary trend is apparent from Figure 8 whereby [C/Fe] tends to monotonically decrease as a given star leaves the MS and ascends the RGB. Over the same evolutionary path, [N/Fe] for the star will decrease to a minimum at about $M_V \sim +1$ mag and rise thereafter. These same trends are also conveyed by the coloured points in Figure 9, where we circumvent the need for luminosity information and thus benefit from better statistics. The significant scatter amongst the data points representing both individual stars and mean values for unclassified samples may be due to mundane issues like systematics or more nuanced ones like mixtures of CN-weak and CN-strong stars within any one study. An example of each case might be the solar-like [C/Fe] value of upper-RGB stars in NGC 6121 at $M_V \sim -2$ mag (Smith et al. 2005) for the former and the [N/Fe] value of lower-RGB stars in NGC 7078 at $M_V \sim +2$ mag (Cohen et al. 2005) for the latter. The mixture interpretation is supported by analyses of *single* clusters that have found large spreads in [C/Fe] and [N/Fe] of stars at any common evolutionary phase from the MS through the tip of the RGB (e.g. NGC 0104, 6205, 6254, 6397, 6752, 7006; Carretta et al. 2005, Smith et al. 2005, and references therein).

The evolutionary trends seen in Figures 8-9 are commonly associated with a combination of the first dredge-up (e.g. Iben 1964) followed by deep atmospheric mixing (e.g. Sweigart & Mengel 1979) that occur in the atmospheres of low-mass stars after they complete core-hydrogen burning.

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[10]We possess α-element abundances for 25 of our GGCs, while C, N, and O abundances are known for half of our sample, at best.

The first dredge-up is defined by the mixing of partially-processed material from the stellar interior into the outer atmosphere as the convective envelope grows in size during the star's SGB phase. It is responsible for the gentle decline observed in both [C/Fe] and [N/Fe] from the MS to about the midpoint of the RGB ($M_V \sim +1$ mag). Once the star reaches the RGB bump, deep mixing is thought to set in and create the rapid rate of depletion and (now) enhancement of atmospheric carbon and nitrogen, respectively. Deep mixing accomplishes this by bringing CN(O)-processed material from the hydrogen-burning shell into the outer atmosphere once the shell overcomes the molecular weight barrier left by the first dredge-up and expands into the outer convective envelope. Both the luminosity of the bump (i.e. onset of mixing) and the depletion rate of carbon are known to decrease as a function of metallicity (Fusi Pecci et al. 1990; Martell et al. 2008). These two dependencies may help explain some of the scatter seen in Figure 8 at high luminosities ($M_V \gtrsim 0$ mag).

In light of the fact that evolved stars undergo episodes of atmospheric mixing, it seems conceivable that the distributions of [C/Fe] and [N/Fe] in our compilation would be somewhat broader than those of unaffected species, as seen in Figure 7. The reason for this is that spectroscopic studies of resolved GGC members have historically measured [C/Fe] and [N/Fe] from a variety of evolutionary stages. Were measurements of these ratios for MS stars to become available for our entire sample, we would anticipate a tightening of the corresponding distributions. Until that time comes, the reality of these mixing episodes should compel SPS modellers to carefully consider the luminosity biases of published spectroscopic studies of individual GGC members when evaluating the accuracies of their [C/Fe] and [N/Fe] predictions[11].

2.3.3. Multiple populations

In addition to mixing phenomena, Figure 8 also shows that some intrinsic degree of broadening in the [C/Fe] and (especially) [N/Fe] distributions for the S05 GGCs is to be expected on account of the multiple populations found within many of them. From those plots, it is seen that the dichotomy in CN band strength (weak/strong) extends down to the MS, the CN band is much more sensitive to [N/Fe] than [C/Fe], and CN-weak stars are characterized by lower [C/Fe] and higher [N/Fe] values than CN-strong stars. The union of these facts then creates the potential for the mean values of [C/Fe] and [N/Fe] from any given study to be biased either low or high depending on how accurately the sample embodies the true CN distribution of the associated cluster. In fact, we might be able to infer the as yet unknown CN strengths of certain samples based on the

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[11]The depth of the data being modelled must also be considered. For instance, the luminosities of individual GGC members down to which the S05 spectra are sensitive has yet to be firmly established (but see Barber et al., in prep.).

relative proximity of circlular points to the triangular or diamond points in Figure 8.

Another hallmark of the multiple population phenomenon is the anti-correlation of [O/Fe] and [Na/Fe] ratios exhibited by stars from all major evolutionary stages within affected clusters (Gratton et al. 2012a). The existence of this anti-correlation would thus tend to bias estimates of a given cluster's mean abundances of these species if not accounted for during sample selection. We suspect that this effect may be at least a contributing factor to the relatively broader distribution for [O/Fe] seen in Figure 7, compared to those of abundance ratios that are not known to vary from star-to-star. This suspicion could be tested by investigating whether the breadth of our [O/Fe] and [Na/Fe] distributions is *simultaneously* consistent with the observed ranges in these abundance ratios for individual stars from the large, homogeneous Na-O anti-correlation study of Carretta et al. (2009a,b). This is beyond the scope of the present work however.

It is worth mentioning at this juncture that the exact origins of the multiple populations observed in GGCs remains unknown. The perpetuation of chemical abundance variations down to unevolved, MS stars makes strongly certain that the existence of a second (and sometimes third; Carretta et al. 2009a) generation of stars is tied to an external agent. However, at least three candidates could be responsible for the pattern of enhanced nitrogen, sodium, aluminum, and (possibly) helium abundances plus depleted carbon, oxygen, and magnesium abundances that typifies the younger generations: (i) massive AGB stars (Ventura et al. 2001), (ii) massive rotating MS stars (Decressin et al. 2007) and (iii) as in (i) but for intermediate masses (Ventura & D'Antona 2008). One way to help distinguish between these candidates is to study whether the sum of the CNO elements varies between the populations in each affected cluster. Simply put, massive stars are expected to alter the individual abundances of these elements but leave their sum unchanged, while intermediate-mass AGB stars, by way of the third dredge-up, will not. Evidence thus far of variations in the CNO sum within individual clusters has been contentious (Ivans et al. 1999; Carretta et al. 2005; Cohen & Meléndez 2005; Cassisi et al. 2008; Milone et al. 2008; Ventura et al. 2009; Yong et al. 2009; Villanova et al. 2010). With some work, our extensive compilation of carbon, nitrogen, and oxygen abundances for individual GGC stars may be helpful in shedding further light on this issue, but will not be investigated further here.

2.3.4. *Source(s) of α-elements*

While Figures 8-9 point to the existence of atmospheric mixing episodes within the evolved stars of the S05 GGCs, Figure 7 shows that the mean abundances of α-elements amongst these clusters remain more or less homogeneous. This homogeneity is accounted for within the context of mixing by the fact that α-elements are exempt from the CN(O) cycle, such that their abundances likely reflect the chemistry of the gas from which these GGCs were born. Moreover, that the α-

element abundance ratios for the S05 GGCs are all greater than the solar value by factors of 1.7-2.4 implies that these systems must have formed quite rapidly, on timescales less than that of Type Ia supernovae ($\sim$1 Gyr).

An interesting corollary on the chemical enrichment of GGCs, based on their α-element abundances, is presented in Figure 10. The left-hand panel shows [Ca/Fe] versus [Mg/Fe] for individual stars from our compilation and belonging to the 13 S05 clusters having the most measurements in this regard. These data are clearly uncorrelated and scatter about their centroid at ([Mg/Fe],[Ca/Fe]) $\sim$ (+0.4,+0.3) with rms dispersions (0.13-0.14 dex) comparable to the median errors in the individual stellar abundances (0.12-0.14 dex). These evidences are enough to suggest that the production sites of these two chemical species are not one and the same.

In the right-hand panel of Figure 10, we show with open squares the mean magnesium and calcium abundances from Pr05 for the nine clusters in the left-hand panel that fall within their sample. Excluding the single outlier at ([Mg/Fe],[Ca/Fe]) $\sim$ (+0.10,+0.24), we find the rather surprising result that these abundances are *anti*-correlated for this sub-sample and data. Not surprisingly, the corresponding values from our compilation (filled circles) exhibit no such correlation. This discrepant behaviour between our results and those of Pr05 could arise from the different approaches taken with respect to the following issues: (i) scope of input data, (ii) averaging method, and (iii) systematics. The latter refers to Pr05's attempt to homogenize all of their input data to the same loggf and solar abundance scale, something we neglect to do. To appreciate the potential role of systematics, we also show in this panel, with open circles, the mean abundances we derive based on the same references and averaging method used by Pr05, but without loggf and solar abundance corrections. For each cluster, we connect with a line the abundances from the three distinct methods. Comparing the positions of open squares and circles, it is clear that the choice of atomic constants and solar abundance pattern often plays a significant role in setting the values of [X/Fe] for any element X, by as much as $\pm$0.2 dex. On the other hand, the offsets between open and filled circles may be regarded as the effect of our using more references per cluster and straight averages, as well as neglecting systematic corrections. Our methodology clearly affects our adopted abundance patterns as well, but this should not reflect any fundamental flaws in our results.

The prospect of anti-correlated magnesium and calcium abundances amongst the GGC population supports the inference that the production sites of these two species are not one and the same or, even more intriguing, that the yields of Type II supernovae fluctuate on an element-by-element level. Note that such a trend is also found amongst the points in the right-hand panel of Figure 10 which represent the results of our attempt to mimic the approach of Pr05 (open circles), again modulo a single outlier. When the full sample of either compilation is considered, however, this anti-correlation changes to a weak positive correlation. The fact that neither sample is complete though implies that further investigation of the ratios [Mg/Fe] and [Ca/Fe] amongst individual

GGC stars on a larger, more homogeneous basis may be warranted.

The suggestion that the abundances of magnesium and carbon do not track one another within any given stellar population is not new. For instance, several studies of the central stellar populations of early-type galaxies have concluded that [Mg/Fe] increases modestly with velocity dispersion amongst these systems, but that [Ca/Fe] is uniform, at about the solar value (Vazdekis et al. 1997; Worthey 1998; Trager et al. 1998; Henry & Worthey 1999; Saglia et al. 2002; Thomas et al. 2003; Cenarro et al. 2003, 2004; Smith et al. 2009; Worthey et al. 2011). Prochaska et al. (2005) casted doubt on the authenticity of these results by pointing out that the Ca4227 index, a popular tracer of calcium abundance, has its blue pseudocontinuum contaminated by a CN band. Graves et al. (2007) and Conroy et al. (2013b) have shown, however, that the [Ca/Fe] ratio remains uniform amongst red sequence galaxies even when the abundances of carbon and nitrogen are properly accounted for *a priori*.

In the Milky Way, Fulbright et al. (2007) found that while [Ca/Fe] decreases with increasing [Fe/H] for RGB stars in the bulge, their [Mg/Fe] ratios remain more or less uniform at $\sim$ +0.3 dex. Earlier claims to this same effect were made by McWilliam & Rich (1994), Zoccali et al. (2004), and Alves-Brito et al. (2006). These discrepant trends may only apply to the Galactic bulge though, since the calcium abundances of both metal-poor field and thick disk stars behave in a fashion consistent with that exhibited by the other α elements (Wheeler et al. 1989; Edvardsson et al. 1993; Reddy et al. 2003).

The sum of the above discrepancies results in a confusing picture, to say the least, of how stellar systems enrich themselves in the α-elements. One possible solution is that the abundance pattern of a system, and thus the source(s) of its chemical evolution, depends sensitively on the intensity of the star formation from which it was created. For instance, the spheroidal systems which seem to exhibit genuine differences in the behaviours of their Mg and Ca abundances (i.e. early-type galaxies, Milky Way bulge, and GGCs) likely formed most of their stellar mass over rapid timescales. In other systems, the star formation history could very well have been more protracted, leading to potentially different sources of chemical enrichment. A most useful test of this proposed solution would be to see if and how chemodynamical simulations could reproduce the precise pattern of α-element abundances we find in our GGCs.

2.4. Comparison with previous work

Having presented our compilation and advertised some of the immediate science that can be gleaned from it, it would also be prudent to assess the robustness of our results by comparing them to those from previous similar work. The comparison of our adopted ages and metallicities against

other sources of such information has already been performed elsewhere (Section 2.2; Appendix) so that we need only focus here on the chemical abundance patterns of our clusters.

As stated before, the most extensive survey of the literature on GGC chemical abundance patterns prior to our compilation was made by Pr05. We already compared their results against ours in terms of the ratios [Mg/Fe] and [Ca/Fe] in the right-hand panel of Figure 10. In Figure 11 we expand on this comparison by plotting our estimates versus theirs of the metallicities and α-element abundances (Mg, Ca, Si, Ti) for the 15 GGCs common to both samples. Despite several outliers, a good correspondence clearly exists between the Pr05 metallicities and our own. Conversely, the large scatter and low Pearson coefficients (shown at top-left) exhibited by the other sets of points in Figure 11 means we cannot reach the same conclusion regarding the abundances of α-elements. Specifically, our results compare least favourably to those of Pr05 in terms of [Ca/Fe]. By inspection of Pr05's methodology, we find that the most egregious discrepancies between the two sets of abundance ratios can be explained by two effects. These are: (i) our inclusion of references that post-dated their work, and (ii) corrections that Pr05 implemented to standardize literature data to a common log gf system and solar abundance pattern. The latter corrections can often be significant in size ($\sim$0.2 dex), a point which was already hinted at in Figure 10. As Pr05 point out though, abundance analyses are often published without specifying the assumed log gf values and solar abundances, making it difficult (if not impossible) to gauge what those corrections should be. We therefore abstain from attempting such corrections ourselves and instead embrace the fact that our adopted abundance patterns likely suffer from the full effect of the systematics which underpin spectral syntheses.

3. Conclusions

Drawing on a wealth of literature data up to mid-2012, we have assembled a new compilation of the known ages, metallicities, and chemical abundance patterns for the 41 GGCs studied by S05. This extensive compilation represents a singular expansion upon similar but more limited previous work on the stellar populations of these systems (Harris 1996; Pritzl et al. 2005; Marín-Franch et al. 2009). We anticipate that it will prove to be a key ingredient for stringent evaluations of the absolute reality and robustness of predictions from the latest suite of SPS models designed to recover the above information for unresolved systems (Roediger et al., in prep.).

Given the wide range of parameter space spanned by the S05 sample, our compilation should also benefit a wide range of other astrophysical interests. The age distribution for these clusters suggests that they arose from a star formation history that consisted of a strong peak (12.5-13.0 Gyr ago) superimposed upon a relatively smooth background. Combining this information with their metallicities and α-element abundances, it appears that each GGC was formed rapidly either

in situ or in a satellite galaxy and subsequently accreted onto the Milky Way. Furthermore, with our compiled abundance patterns we confirm previous claims that (i) the surface abundances of C and N in evolved stars are altered by mixing episodes as they ascend the SGB/RGB, (ii) many GGCs host at least two distinct stellar populations, and (iii) the enrichment of α-elements in these systems, specifically Mg and Ca, likely occurred through multiple channels. The fact that the mean chemical abundance patterns of GGCs are sensitive to the first two phenomena are important caveats that must be considered during SPS model evaluations. Similarly, we estimate that absolute age determinations for GGCs are subject to systematic uncertainties on the order of $\sim$2-3 Gyr.

While the above results are certainly of some value, it is our opinion that many other applications of our compilation have yet to be explored. To enable the community to further pursue such ancillary science or modify the results of our compilation as they see fit, we provide electronic tables of the input data online[12] for each one of our clusters.

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[12]http://www.astro.queensu.ca/people/Stephane_Courteau/roediger2013/index.html

Table 1.   Sample clusters[1]

NGC ID (1)	Other ID (2)	l (deg) (3)	b (deg) (4)	R_{GC} (kpc) (5)	$E(B-V)$ (6)	c (7)	$(B-R)/(B+V+R)$ (8)
0104	47 Tuc	305.89	-44.89	7.4	0.04	2.07	-0.99
1851		244.51	-35.03	16.6	0.02	1.86	-0.36
1904	M79	227.23	-29.35	18.8	0.01	1.70	0.89
2298		245.63	-16.00	15.8	0.14	1.38	0.93
2808		282.19	-11.25	11.1	0.22	1.56	-0.49
3201		277.23	8.64	8.8	0.24	1.29	0.08
5286		311.61	10.57	8.9	0.24	1.41	0.80
5904	M5	3.86	46.80	6.2	0.03	1.73	0.31
5927		326.60	4.86	4.6	0.45	1.60	-1.00
5946		327.58	4.19	5.8	0.54	2.50	-
5986		337.02	13.27	4.8	0.28	1.23	0.97
6121	M4	350.97	15.97	5.9	0.35	1.65	-0.06
6171	M107	3.37	23.01	3.3	0.33	1.53	-0.73
6218	M12	15.72	26.31	4.5	0.19	1.34	0.97
6235		358.92	13.52	4.2	0.31	1.53	0.89
6254	M10	15.14	23.08	4.6	0.28	1.38	0.98
6266	M62	353.57	7.32	1.7	0.47	1.71	0.32
6284		358.35	9.94	7.5	0.28	2.50	-
6304		355.83	5.38	2.3	0.54	1.80	-1.00
6316		357.18	5.76	2.6	0.54	1.65	-1.00
6333	M9	5.54	10.71	1.7	0.38	1.25	0.87
6342		4.90	9.72	1.7	0.46	2.50	-1.00
6352		341.42	-7.17	3.3	0.22	1.10	-1.00
6356		6.72	10.22	7.5	0.28	1.59	-1.00
6362		325.55	-17.57	5.1	0.09	1.09	-0.58
6388		345.56	-6.74	3.1	0.37	1.75	-
6441		353.53	-5.01	3.9	0.47	1.74	-
6522		1.02	-3.93	0.6	0.48	2.50	0.71
6528		1.14	-4.17	0.6	0.54	1.50	-1.00
6544		5.84	-2.20	5.1	0.76	1.63	1.00
6553		5.26	-3.03	2.2	0.63	1.16	-1.00
6569		0.48	-6.68	3.1	0.53	1.31	-
6624		2.79	-7.91	1.2	0.28	2.50	-1.00
6626	M28	7.80	-5.58	2.7	0.40	1.67	0.90
6637	M69	1.72	-10.27	1.7	0.18	1.38	-1.00
6638		7.90	-7.15	2.2	0.41	1.33	-0.30
6652		1.53	-11.38	2.7	0.09	1.80	-1.00
6723		0.07	-17.30	2.6	0.05	1.11	-0.08
6752		336.49	-25.63	5.2	0.04	2.50	1.00
7078	M15	65.01	-27.31	10.4	0.10	2.29	0.67
7089	M2	53.37	-35.77	10.4	0.06	1.59	0.96

[1]All data adopted from the 2010 edition of Harris (1996).

Table 2.   Reference key

	Ages				Metallicities & abundance ratios				
Number	Reference	Number	Reference	Number	Reference	Number	Reference	Number	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	Marín-Franch et al. (2009)	47	Fullton (1996)	1	Carretta et al. (2009c)	47	Barbuy et al. (1999)	92	Carretta et al. (2007c)
2	De Angeli et al. (2005)	48	Jimenez et al. (1996)	2	Armandroff & Zinn (1988)	48	Cohen et al. (1999)	93	Gratton et al. (2007)
3	Meissner & Weiss (2006)	49	Renzini et al. (1996)	3	Carretta et al. (2009a)	49	Ivans et al. (1999)	94	Lee (2007)
4	Dotter et al. (2010)	50	Richer et al. (1996)	4	Carretta et al. (2009b)	50	Sneden et al. (2000a)	95	Valenti et al. (2007)
5	Salaris & Weiss (2002)	51	Samus et al. (1996a)	5	Searle & Zinn (1978)	51	Sneden et al. (2000b)	96	Wallerstein et al. (2007)
6	Rosenberg et al. (1999)	52	Samus et al. (1996b)	6	Cohen (1979)	52	Carretta et al. (2001)	97	Haynes et al. (2008)
7	Alcaino & Liller (1981)	53	Sandquist et al. (1996)	7	Bell & Dickens (1980)	53	Coelho et al. (2001)	98	Kirby et al. (2008)
8	Harris et al. (1983)	54	Bruzual et al. (1997)	8	Da Costa & Cottrell (1980)	54	Gratton et al. (2001)	99	Koch & McWilliam (2008)
9	Buonanno et al. (1984)	55	Kravtsov et al. (1997)	9	Pilachowski et al. (1980)	55	Ivans et al. (2001)	100	Marino et al. (2008)
10	Cacciari (1984)	56	Buonanno et al. (1998)	10	Gratton (1982)	56	Klochkova & Samus (2001)	101	Martell et al. (2008)
11	Da Costa et al. (1984)	57	Guarnieri et al. (1998)	11	Pilachowski et al. (1983)	57	Cohen et al. (2002)	102	McWilliam & Bernstein (2008)
12	Sandage & Roques (1984)	58	Jimenez & Padoan (1998)	12	Smith & Manduca (1983)	58	Behr (2003)	103	Origlia et al. (2008)
13	Caputo et al. (1985)	59	Richtler et al. (1998)	13	Geisler (1984)	59	Carretta et al. (2003)	104	Pasquini et al. (2008)
14	Alcaino & Liller (1986)	60	Salaris & Weiss (1998)	14	Langer et al. (1985)	60	Howland et al. (2003)	105	Yong & Grundahl (2008)
15	Burstein et al. (1986)	61	Alcaíno et al. (1999)	15	Gratton et al. (1986)	61	Meléndez et al. (2003)	106	Yong et al. (2008a)
16	Gratton & Ortolani (1986)	62	Brocato et al. (1999)	16	Smith & Stryker (1986)	62	Mishenina et al. (2003)	107	Yong et al. (2008b)
17	Heasley et al. (1986)	63	Gibson et al. (1999)	17	Gratton (1987b)	63	Ramírez & Cohen (2003)	108	Yong et al. (2008c)
18	Hesser et al. (1987)	64	Heitsch & Richtler (1999)	18	Costar & Smith (1988)	64	Yong et al. (2003)	109	Barbuy et al. (2009)
19	Richer & Fahlman (1987)	65	Piotto et al. (1999)	19	Gratton & Ortolani (1989)	65	Briley et al. (2004)	110	Feltzing et al. (2009)
20	Janes & Heasley (1988)	66	Chaboyer et al. (2000)	20	Beers et al. (1990)	66	Carretta et al. (2004a)	111	Takeda et al. (2009)
21	Sagar et al. (1988)	67	Davidge (2000)	21	Brown et al. (1990)	67	Carretta et al. (2004b)	112	Villanova et al. (2009)
22	Alcaino et al. (1989)	68	Feltzing & Gilmore (2000)	22	François (1991)	68	Cavallo et al. (2004)	113	Worley et al. (2009)
23	Buonanno et al. (1989)	69	Heasley et al. (2000)	23	Sneden et al. (1991)	69	Jasniewicz et al. (2004)	114	Yong et al. (2009)
24	Dorman et al. (1989)	70	VandenBerg (2000)	24	Suntzeff & Smith (1991)	70	Zoccali et al. (2004)	115	Bragaglia et al. (2010b)
25	Hurley et al. (1989)	71	Beaulieu et al. (2001)	25	Brown & Wallerstein (1992)	71	Alves-Brito et al. (2005)	116	D'Orazi & Marino (2010)
26	Sato et al. (1989)	72	Ortolani et al. (2001)	26	Barbuy et al. (1992)	72	Carretta et al. (2005)	117	D'Orazi et al. (2010)
27	Alcaino et al. (1990a)	73	Testa et al. (2001)	27	Briley et al. (1992)	73	Clementini et al. (2005)	118	Koch & McWilliam (2010)
28	Alcaino et al. (1990b)	74	von Braun & Mateo (2001)	28	Drake et al. (1992)	74	Cohen et al. (2005)	119	Valenti et al. (2010)
29	Alcaino et al. (1990c)	75	Zoccali et al. (2001)	29	McWilliam et al. (1992)	75	Gratton et al. (2005)	120	Villanova et al. (2010)
30	Ferraro et al. (1991)	76	Grundahl et al. (2002)	30	Sneden et al. (1992)	76	Origlia et al. (2005)	121	Worley & Cottrell (2010)
31	Straniero & Chieffi (1991)	77	Feltzing & Johnson (2002)	31	Minniti et al. (1993)	77	Smith et al. (2005)	122	Carretta et al. (2011a)
32	Chaboyer et al. (1992)	78	von Braun et al. (2002)	32	Armosky et al. (1994)	78	Smith et al. (2005)	123	Gratton et al. (2011)
33	Demarque & Lee (1992)	79	Gratton et al. (2003)	33	Drake et al. (1994)	79	Valenti et al. (2005)	124	Lai et al. (2011)
34	Ferraro & Piotto (1992)	80	Layden & Sarajedini (2003)	34	Da Costa & Armandroff (1995)	80	Yong et al. (2005)	125	Marino et al. (2011)
35	McWilliam et al. (1992)	81	Momany et al. (2003)	35	Kraft et al. (1995)	81	Alves-Brito et al. (2006)	126	O'Connell et al. (2011)
36	Ortolani et al. (1992)	82	Pulone et al. (2003)	36	Minniti (1995a)	82	Carretta (2006)	127	Sobeck et al. (2011)
37	Walker (1992)	83	Hargis et al. (2004)	37	Minniti (1995b)	83	Carretta et al. (2006)	128	Valenti et al. (2011)
38	Alcaino et al. (1994)	84	Brown et al. (2005)	38	Norris & Da Costa (1995)	84	Gratton et al. (2006)	129	Villanova & Geisler (2011)
39	Richtler et al. (1994)	85	Hughes et al. (2007)	39	Fullton (1996)	85	Johnson & Pilachowski (2006)	130	Carretta et al. (2012a)
40	Chaboyer & Kim (1995)	86	Salaris et al. (2007)	40	Minniti et al. (1996)	86	Preston et al. (2006)	131	Gratton et al. (2012b)
41	Ferraro et al. (1995)	87	Barbuy et al. (2009)	41	Shetrone (1996)	87	Sobeck et al. (2006)	132	Gratton et al. (2012c)
42	Fullton et al. (1995)	88	Bergbusch & Stetson (2009)	42	Geisler et al. (1997)	88	Yong et al. (2006)	133	Lardo et al. (2012)
43	Mazzitelli et al. (1995)	89	D'Antona et al. (2009)	43	Gonzalez & Lambert (1997)	89	Wylie et al. (2006)	134	Monaco et al. (2012)
44	Ortolani et al. (1995)	90	Moretti et al. (2009)	44	Smith et al. (1997)	90	Carretta et al. (2007a)	135	Villanova et al. (2012)
45	Samus et al. (1995)	91	Zorotovic et al. (2009)	45	Sneden et al. (1997)	91	Carretta et al. (2007b)	136	Worley & Cottrell (2012)
46	Davidge et al. (1996)	92	Bono et al. (2010)	46	Gonzalez & Wallerstein (1998)				

Table 3.   Available age and recommended chemical abundance references per S05 GGC.
Boldface numbers under the second column denote our the sources of our adopted ages.

NGC ID (1)	Age Reference(s) (2)	Metallicity Reference(s) (3)	Abundance Reference(s) (4)
0104	**1**-6, 8, 18, 24, 31, 40, 43, 50, 56, 60, 63, 70, 75-76, 79, 84, 86-87, 89	1-2, 18, 25, 71, 89, 99, 102	3-4, 11, 15, 21, 25, 38, 65-66, 71-72, 89, 99, 113, 117, 136
1851	**1**-3, 5-6, 21, 27, 37, 40, 50, 53, 56, 60, 70	1-2, 42, 105, 114, 120, 122	105, 114, 120, 122, 131-133
1904	2-3, **5**-6, 16-17, 38, 40, 50, 55-56, 60	1, 22, 42	3-4, 22
2298	**1**, 4-5, 14, 16, 20, 29, 32, 35, 40, 50, 56, 60	1, 29	29
2808	**1**-3, 5-6, 9, 16, 28, 40, 50, 53, 56, 70	1, 42	4, 10, 59, 67, 82-83, 115, 123
3201	**1**-7, 10, 22, 40, 50-51, 56, 60, 74, 80, 92	1, 20, 42	3-4, 10-11, 19, 46
5286	**1**, 4, 45, 91	1	-
5904	**1**-6, 19, 31, 40, 50, 53, 56, 58, 60, 70	1, 30, 41, 55, 63, 108	3-4, 9, 11, 14-15, 27, 30, 32, 41, 44, 55, 57, 63, 101, 106, 108, 118, 124
5927	**1**-4, 47, 52, 68, 84	1-2, 22	22
5946	**2**	1-2	-
5986	**1**-4	1, 42	69
6121	**1**-2, 4-6, 13, 40, 53, 56, 89	1, 20, 25, 33, 37, 49, 100, 108, 111	3-4, 15, 21, 24-25, 28, 49, 78, 96, 100, 106, 108, 116, 125, 129, 134-135
6171	**1**-6, 11-12, 23, 30, 34, 40-41, 48, 60	1, 5	3-4, 12, 126
6218	**1**-2, 4-6, 26, 40, 50, 56, 78, 83	1, 34, 85	4, 56, 62, 69, 85, 91
6235	**2**	1, 60	-
6254	**1**-2, 4-6, 25, 31, 40, 50, 56, 60, 78	1, 35, 97	3-4, 11, 19, 35, 62, 77, 97, 101
6266	2-**3**	1	-
6284	2-**3**	1	-
6304	**1**, 3-4	1, 79	-
6316	-	1-2, 95	-
6333	-	1	-
6342	**2**, 64	1-2, 76	76
6352	**1**, 4-6, 42, 50, 56, 60, 69, 82	1, 22, 110	17, 22, 110
6356	**3**	1-2, 37	-
6362	**1**-6, 14, 56, 62, 65	1, 42	17
6388	**1**, 85, 90	1-2, 96, 121	3, 92, 96
6441	**1**	1-2, 73, 103	84, 93, 103
6522	**3**, 87	1, 109	109
6528	36, **54**, 59, 72, 77, 81, 84	1-2, 70, 76, 87	52-53, 70, 76
6544	**2**	1, 119	-
6553	33, 44, **54**, 57, 71, 75	1, 26, 61, 81	26, 47-48, 53, 61, 81
6569	-	1, 79	128
6624	**1**, 3-5, 39, 69	1-2	128
6626	46, **73**	34, 36	43
6637	**1**-5, 39, 69	1, 36	94
6638	**3**	1, 16	-
6652	**1**-5, 40, 60, 66	1-2	-
6723	**1**-6, 61	1	13, 39
6752	**1**-2, 4-6, 15, 31, 40, 49-50, 56, 60, 70, 79, 84	1, 20, 31, 42, 68, 107	4, 7-8, 11, 15, 24, 38, 40, 54, 64, 68, 72, 75, 80, 88, 90, 104, 107, 112, 130
7078	**1**-6, 40, 50, 56, 60, 70	1-2, 23, 31-32, 45, 86, 98, 111	3-4, 6, 23, 32, 40, 45, 50-51, 58, 74, 86, 101, 127
7089	**1**-4, 67	1-2	101

Table 4.   Ages, [Fe/H], [Mg/Fe], [C/Fe], [N/Fe], and [Ca/Fe] for S05 GGCs. Boldface numbers denote less certain entries (see Appendix for details).

NGC ID (1)	Age (Gyr) (2)	[Fe/H] (dex) (3)	[Mg/Fe] (dex) (4)	[C/Fe] (dex) (5)	[N/Fe] (dex) (6)	[Ca/Fe] (dex) (7)
0104	13.1 ± 0.9	-0.72 ± 0.08	$+0.41 \pm 0.14$	-0.13 ± 0.20	$+0.87 \pm 0.55$	$+0.17 \pm 0.15$
1851	10.0 ± 0.5	-1.17 ± 0.08	$+0.40 \pm 0.10$	-0.36 ± 0.51	$+0.84 \pm 0.46$	$+0.36 \pm 0.09$
1904	$\mathbf{11.7 \pm 1.3}$	-1.58 ± 0.12	$+0.26 \pm 0.07$	-	-	$+0.22 \pm 0.04$
2298	12.7 ± 0.7	-1.95 ± 0.04	$+0.59 \pm 0.20$	-	-	$+0.39 \pm 0.05$
2808	10.9 ± 0.4	-1.14 ± 0.13	$+0.25 \pm 0.18$	-0.50 ± 0.28	$+1.25 \pm 1.06$	$+0.39 \pm 0.14$
3201	10.2 ± 0.4	-1.59 ± 0.20	$+0.36 \pm 0.11$	-0.55 ± 0.23	$+0.56 \pm 0.27$	$+0.20 \pm 0.11$
5286	12.5 ± 0.5	-1.70 ± 0.07	-	-	-	-
5904	10.6 ± 0.4	-1.29 ± 0.08	$+0.33 \pm 0.10$	-0.48 ± 0.26	$+0.68 \pm 0.59$	$+0.28 \pm 0.11$
5927	12.7 ± 0.9	-0.49 ± 0.44	$\mathbf{-0.12}$	-	-	$\mathbf{+0.34}$
5946	$\mathbf{9.7 \pm 1.6}$	-1.29 ± 0.14	-	-	-	-
5986	12.2 ± 0.6	-1.59 ± 0.12	$\mathbf{+0.25}$	-	-	-
6121	12.5 ± 0.7	-1.16 ± 0.09	$+0.50 \pm 0.08$	-0.46 ± 0.28	$+0.65 \pm 0.41$	$+0.30 \pm 0.09$
6171	14.0 ± 0.8	-1.02 ± 0.02	$+0.51 \pm 0.04$	-	-	$\mathbf{+0.06 \pm 0.32}$
6218	12.7 ± 0.4	-1.37 ± 0.12	$+0.46 \pm 0.14$	$\mathbf{+1.18 \pm 0.44}$	-	$+0.31 \pm 0.14$
6235	$\mathbf{9.7 \pm 1.6}$	-1.28 ± 0.31	-	-	-	-
6254	11.4 ± 0.5	-1.53 ± 0.06	$+0.44 \pm 0.13$	-0.77 ± 0.37	$+1.01 \pm 0.45$	$+0.33 \pm 0.11$
6266	$\mathbf{11.6 \pm 0.6}$	-1.18 ± 0.07	-	-	-	-
6284	$\mathbf{11.0}$	-1.26	-	-	-	-
6304	13.6 ± 1.1	-0.45 ± 0.26	-	-	-	-
6316	-	-0.46 ± 0.16	-	-	-	-
6333	-	-1.77	-	-	-	-
6342	$\mathbf{10.2 \pm 0.8}$	-0.55 ± 0.10	$+0.38 \pm 0.01$	-0.34 ± 0.03	-	$+0.38 \pm 0.01$
6352	12.7 ± 0.9	-0.64 ± 0.13	$+0.38 \pm 0.17$	-	-	$+0.18 \pm 0.11$
6356	$\mathbf{15.0 \pm 3.0}$	-0.40 ± 0.12	-	-	-	-
6362	13.6 ± 0.6	-0.99 ± 0.26	$+0.37 \pm 0.16$	-	-	$+0.15 \pm 0.03$
6388	12.0 ± 1.0	-0.55 ± 0.15	$+0.24 \pm 0.12$	-0.66 ± 0.15	-	$+0.00 \pm 0.13$
6441	11.3 ± 0.9	-0.46 ± 0.06	$+0.35 \pm 0.14$	-0.45 ± 0.17	-	$+0.20 \pm 0.17$
6522	$\mathbf{15.0 \pm 1.1}$	-1.34 ± 0.36	$+0.27 \pm 0.10$	-	-	$+0.17 \pm 0.06$
6528	$\mathbf{12.0 \pm 2.0}$	-0.12 ± 0.24	$+0.25 \pm 0.11$	-0.35 ± 0.12	-	$+0.30 \pm 0.09$
6544	$\mathbf{8.8 \pm 1.0}$	-1.40 ± 0.22	-	-	-	-
6553	$\mathbf{12.0 \pm 2.0}$	-0.18 ± 0.03	$+0.32 \pm 0.08$	-0.62 ± 0.10	$+1.15 \pm 0.38$	$+0.20 \pm 0.15$
6569	-	-0.76 ± 0.13	$+0.50 \pm 0.06$	-0.27 ± 0.11	-	$+0.31 \pm 0.04$
6624	12.5 ± 0.9	-0.44 ± 0.07	$+0.42 \pm 0.05$	-0.29 ± 0.20	-	$+0.40 \pm 0.04$
6626	$\mathbf{14.0 \pm 1.1}$	-1.32 ± 0.05	-	-	-	$\mathbf{+0.11 \pm 0.02}$
6637	13.1 ± 0.9	-0.64 ± 0.17	$+0.28 \pm 0.17$	-	-	$+0.20 \pm 0.17$
6638	$\mathbf{12.0}$	-0.95 ± 0.13	-	-	-	-
6652	12.9 ± 0.8	-0.81 ± 0.17	-	-	-	-
6723	13.1 ± 0.7	-1.10 ± 0.07	$+0.44$	-	-	$+0.33 \pm 0.13$
6752	11.8 ± 0.6	-1.53 ± 0.16	$+0.38 \pm 0.15$	-0.45 ± 0.37	$+0.93 \pm 0.63$	$+0.31 \pm 0.09$
7078	12.9 ± 0.5	-2.39 ± 0.14	$+0.36 \pm 0.23$	-0.30 ± 0.36	$+0.84 \pm 0.63$	$+0.31 \pm 0.14$
7089	11.8 ± 0.6	-1.64 ± 0.08	-	-0.62 ± 0.14	-	-

Table 5. [O/Fe], [Na/Fe], [Si/Fe], [Cr/Fe], and [Ti/Fe] for S05 GGCs. Boldface numbers denote less certain entries (see Appendix for details).

NGC ID (1)	[O/Fe] (dex) (2)	[Na/Fe] (dex) (3)	[Si/Fe] (dex) (4)	[Cr/Fe] (dex) (5)	[Ti/Fe] (dex) (6)
0104	$+0.24 \pm 0.20$	$+0.35 \pm 0.22$	$+0.31 \pm 0.12$	$+0.10 \pm 0.08$	$+0.28 \pm 0.12$
1851	$+0.09 \pm 0.26$	$+0.18 \pm 0.31$	$+0.32 \pm 0.11$	-0.00 ± 0.16	$+0.17 \pm 0.06$
1904	$+0.10 \pm 0.19$	$+0.32 \pm 0.25$	$+0.28 \pm 0.03$	-0.28 ± 0.14	$+0.22 \pm 0.10$
2298	-	-	$+0.51 \pm 0.05$	-0.03 ± 0.10	-0.03 ± 0.03
2808	$+0.12 \pm 0.38$	$+0.28 \pm 0.27$	$+0.35 \pm 0.13$	$+0.02 \pm 0.08$	$+0.30 \pm 0.09$
3201	$+0.15 \pm 0.27$	$+0.12 \pm 0.25$	$+0.34 \pm 0.11$	-0.06 ± 0.24	$+0.20 \pm 0.12$
5286	-	-	-	-	-
5904	$+0.15 \pm 0.27$	$+0.19 \pm 0.26$	$+0.31 \pm 0.10$	-0.08 ± 0.19	$+0.22 \pm 0.10$
5927	**+0.33**	**+1.23**	**+0.74**	**-0.11**	**+0.37**
5946	-	-	-	-	-
5986	**+0.65**	**+0.70**	**+0.30**	**+0.15**	**+0.22**
6121	$+0.31 \pm 0.14$	$+0.29 \pm 0.19$	$+0.50 \pm 0.07$	-0.03 ± 0.07	$+0.31 \pm 0.07$
6171	$+0.17 \pm 0.18$	$+0.37 \pm 0.20$	$+0.54 \pm 0.08$	-	$+0.40 \pm 0.10$
6218	$+0.31 \pm 0.34$	$+0.32 \pm 0.27$	$+0.36 \pm 0.07$	-0.04 ± 0.19	$+0.27 \pm 0.13$
6235	-	-	-	-	-
6254	$+0.23 \pm 0.24$	$+0.17 \pm 0.27$	$+0.28 \pm 0.07$	$+0.01 \pm 0.15$	$+0.26 \pm 0.12$
6266	-	-	-	-	-
6284	-	-	-	-	-
6304	-	-	-	-	-
6316	-	-	-	-	-
6333	-	-	-	-	-
6342	$+0.31 \pm 0.02$	-	$+0.37 \pm 0.04$	-	$+0.25 \pm 0.03$
6352	**+0.04**	$+0.19 \pm 0.16$	$+0.27 \pm 0.21$	-0.05 ± 0.07	$+0.23 \pm 0.13$
6356	-	-	-	-	-
6362	-	$+0.25 \pm 0.62$	$+0.43 \pm 0.04$	-0.14 ± 0.28	$+0.38 \pm 0.06$
6388	-0.06 ± 0.25	$+0.42 \pm 0.23$	$+0.30 \pm 0.12$	-0.06 ± 0.14	$+0.20 \pm 0.19$
6441	$+0.09 \pm 0.18$	$+0.41 \pm 0.28$	$+0.36 \pm 0.18$	-0.06 ± 0.20	$+0.32 \pm 0.17$
6522	$+0.49 \pm 0.17$	$+0.04 \pm 0.21$	$+0.25 \pm 0.08$	-	$+0.16 \pm 0.04$
6528	$+0.20 \pm 0.14$	$+0.41 \pm 0.13$	$+0.26 \pm 0.13$	$+0.00 \pm 0.06$	$+0.10 \pm 0.22$
6544	-	-	-	-	-
6553	$+0.36 \pm 0.18$	$+0.30 \pm 0.30$	$+0.23 \pm 0.15$	$+0.04 \pm 0.09$	$+0.18 \pm 0.21$
6569	$+0.48 \pm 0.09$	-	$+0.49 \pm 0.08$	-	$+0.40 \pm 0.04$
6624	$+0.41 \pm 0.14$	-	$+0.38 \pm 0.09$	-	$+0.37 \pm 0.04$
6626	-	-	**+0.60 ± 0.07**	-	**+0.02 ± 0.21**
6637	$+0.20 \pm 0.31$	$+0.35 \pm 0.29$	$+0.45 \pm 0.12$	-	$+0.24 \pm 0.13$
6638	-	-	-	-	-
6652	-	-	-	-	-
6723	-	-	$+0.68 \pm 0.13$	-	$+0.24 \pm 0.15$
6752	$+0.26 \pm 0.25$	$+0.32 \pm 0.26$	$+0.47 \pm 0.19$	-0.13 ± 0.12	$+0.20 \pm 0.11$
7078	$+0.27 \pm 0.23$	$+0.36 \pm 0.34$	$+0.48 \pm 0.20$	-0.23 ± 0.08	$+0.48 \pm 0.20$
7089	-	-	-	-	-
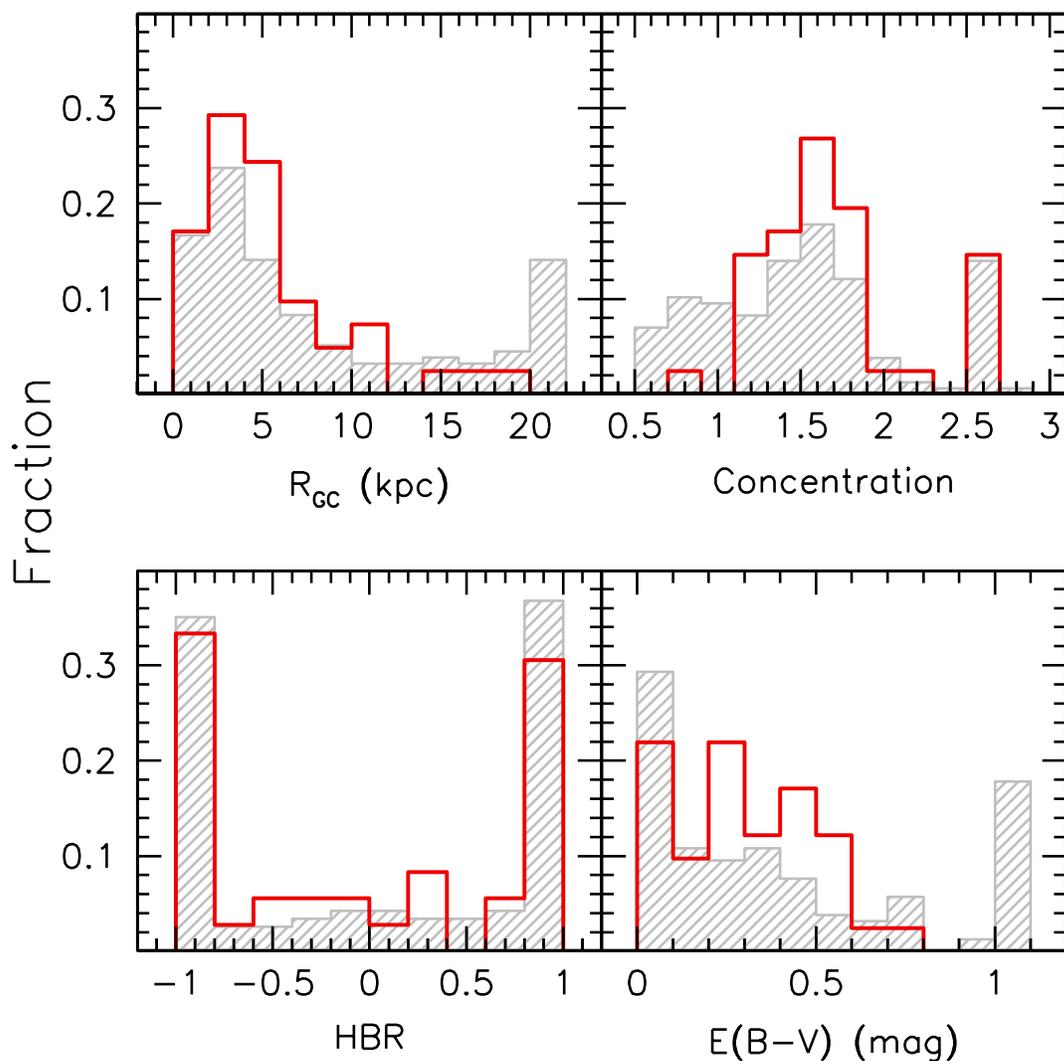
Fig. 1.— Percent distributions of Galactocentric radii [R_{GC}; *upper-left*], concentrations [*upper-right*], horizontal branch ratios [HBR; *lower-left*] and reddenings [$E(B-V)$; *lower-right*] for the Galactic globular cluster (GGC) samples from the full 2010 edition of the Harris (1996, hereafter Ha10) catalogue (grey) and the Schiavon et al. (2005, S05) spectral library (red). Note that the rightmost bins in the upper-left and lower-right panels actually span the (unbounded) ranges of ≥ 22 kpc and ≥ 0.5 mag, respectively. All distributions were created using data from the Ha10 catalogue.
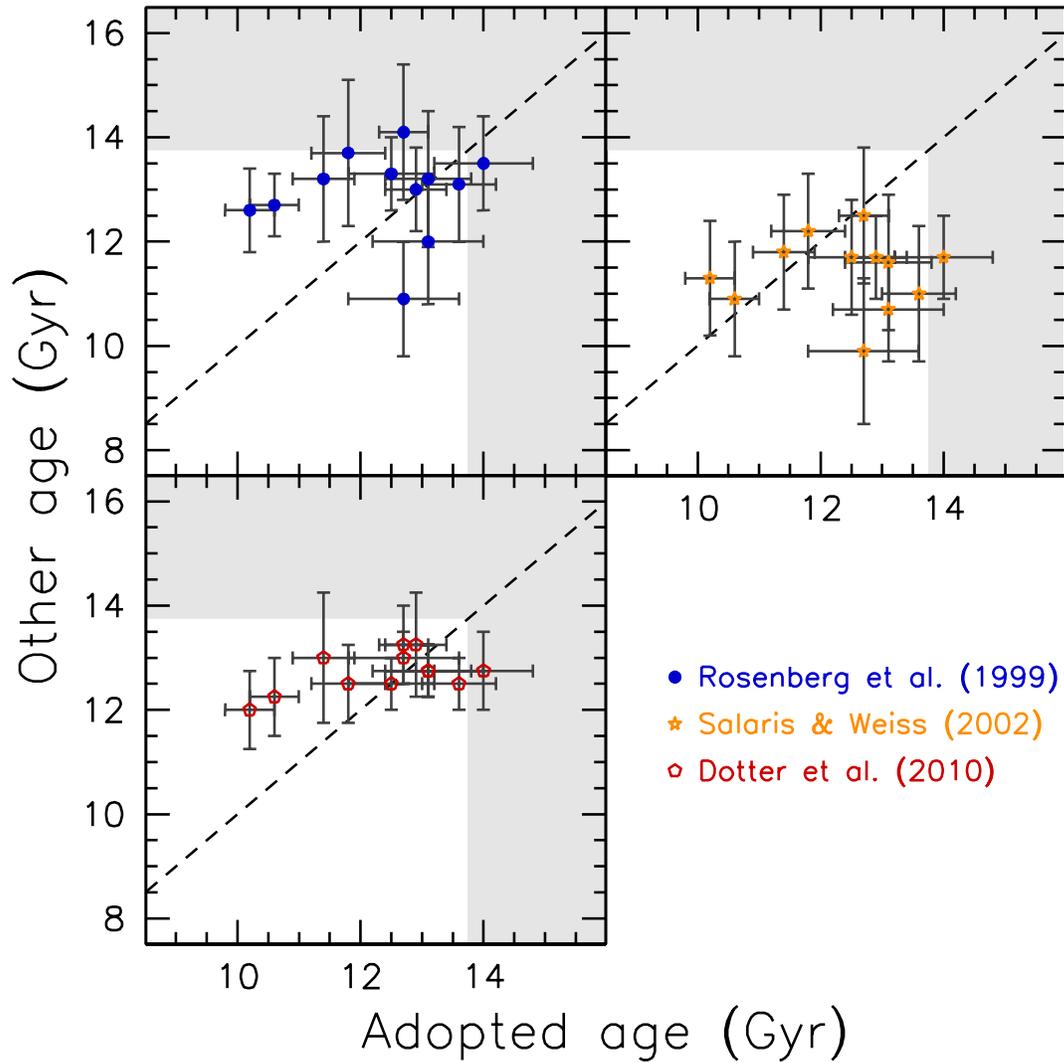
Fig. 2.— Comparison of our adopted ages (x-axis) against similar independent estimates from other homogeneous age compilations (y-axis) for a sub-sample of 12 GGCs from S05 common to Rosenberg et al. (1999), Salaris & Weiss (2002), Dotter et al. (2010) and Marín-Franch et al. (2009, MF09). The dashed line in each panel represents equality between our adopted and other age estimates and the shaded regions demarcate ages in excess of that of the Universe (Komatsu et al. 2011).
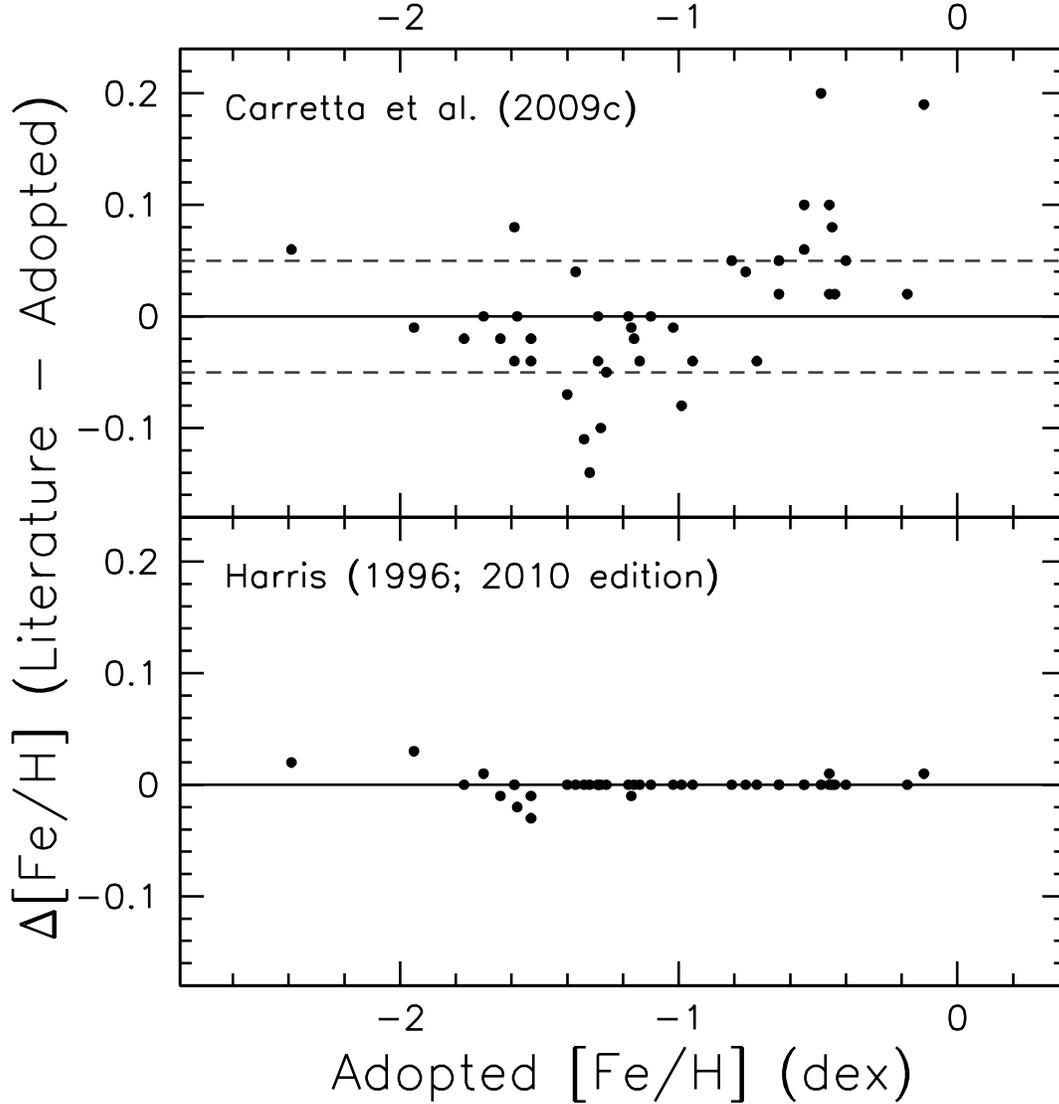
Fig. 3.— Differences between our adopted metallicities for the S05 GGCs against other independent estimates thereof in the literature, either from the Ha10 catalogue (*lower panel*) or Carretta et al. (2009c) (*upper panel*). The differences are plotted against our adopted values in both panels, while the dashed lines in the upper panel outline the 68th-percentile of the distribution about the locus of equality (solid line). The same lines would essentially overlap with equality in the lower panel and are thus omitted therefrom. The median error per point is 0.12 and 0.14 dex in the lower and upper panels, respectively.
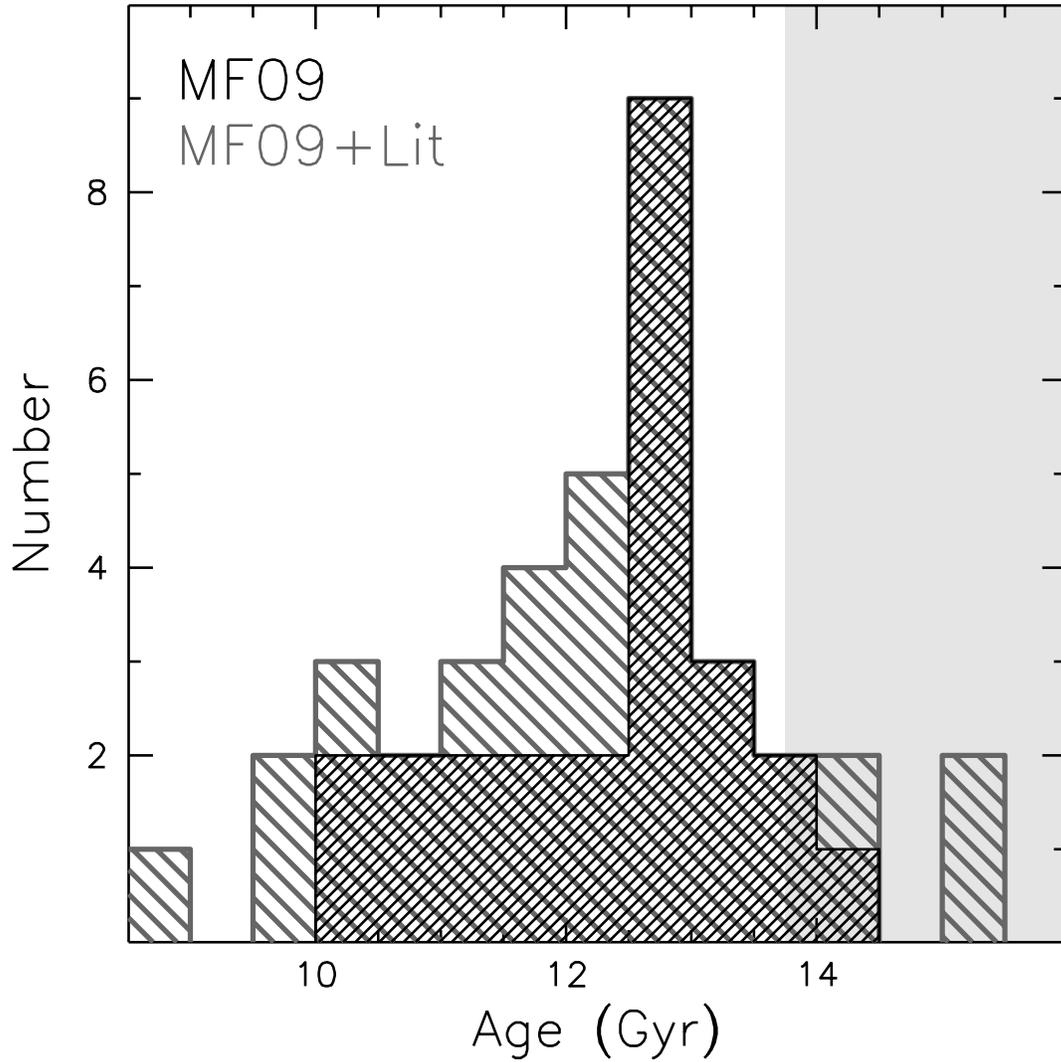
Fig. 4.— Adopted age distribution for the S05 GGC sample based on either the MF09 compilation alone (black), or MF09 plus additional sources of ages from the literature (for those clusters not studied by MF09; dark gray). The shaded region corresponds to ages in excess of that of the Universe (Komatsu et al. 2011).
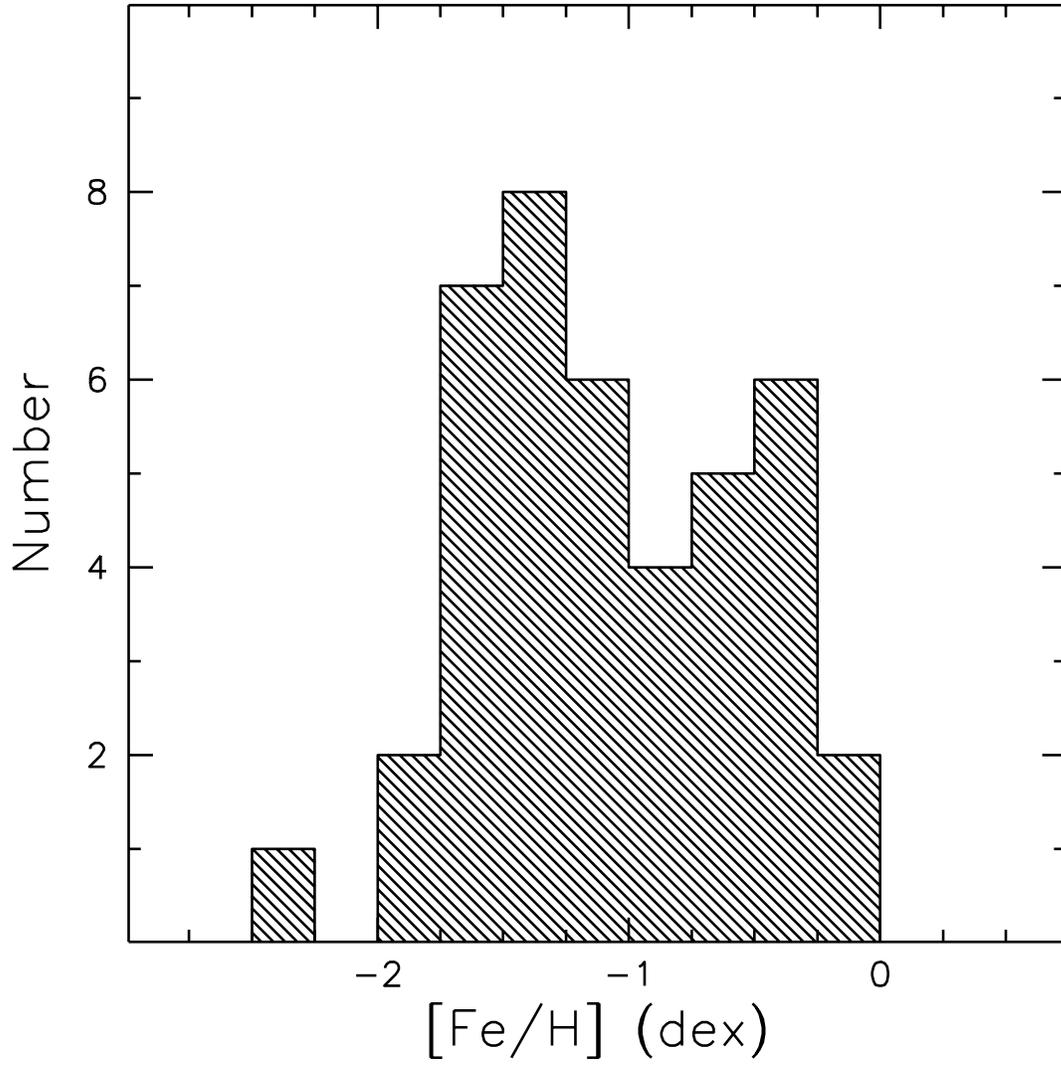
Fig. 5.— As in Figure 4, but for our adopted [Fe/H] values.
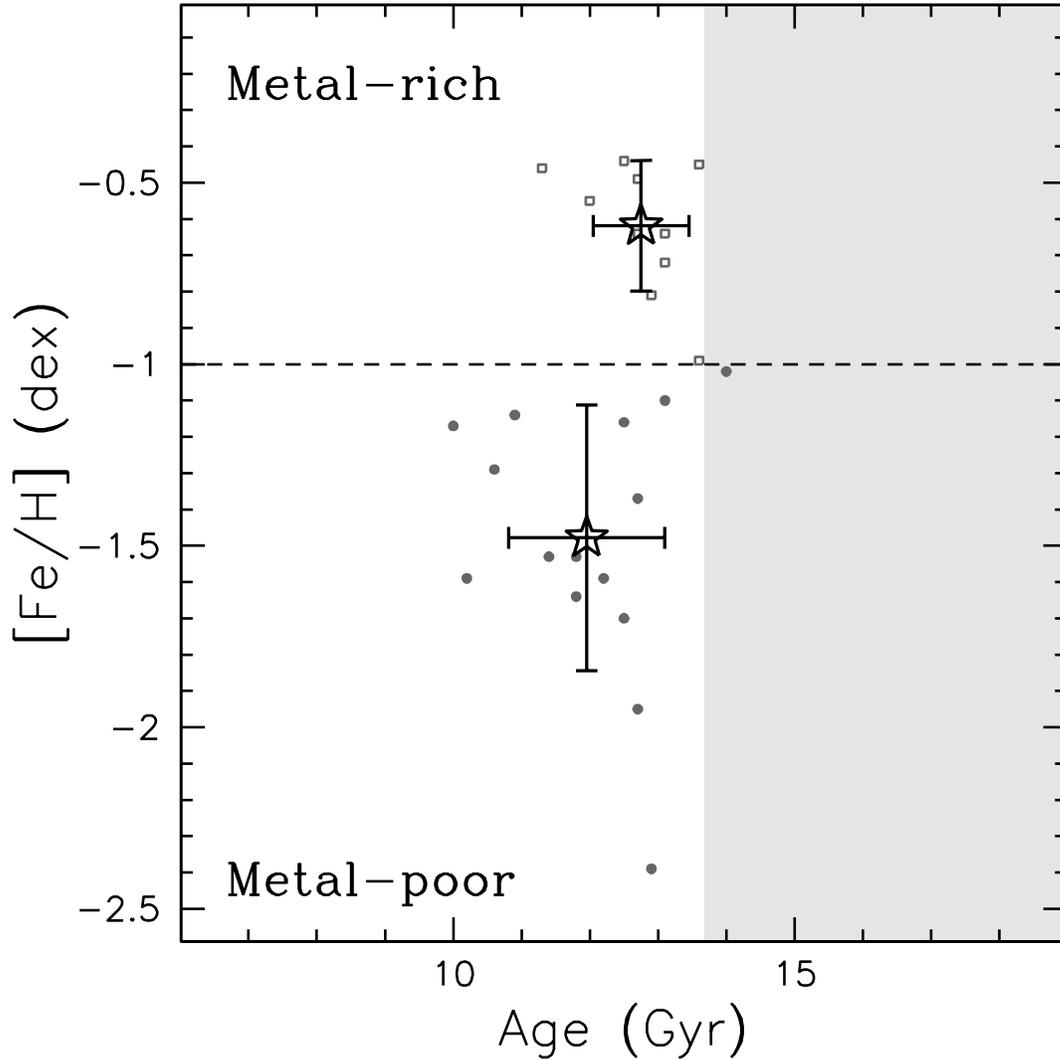
Fig. 6.— Metallicity versus age for S05 GGCs included in the MF09 sample. The mean ages and metallicities (and corresponding rms uncertainties) of the metal-poor (circles) and metal-rich (squares) GGCs in our sample are denoted by the stars and error bars, while the dashed line at [Fe/H] = -1.0 dex roughly marks the transition between these two groups, as seen in Figure 5. The shaded region corresponds to ages in excess of that of the Universe (Komatsu et al. 2011).
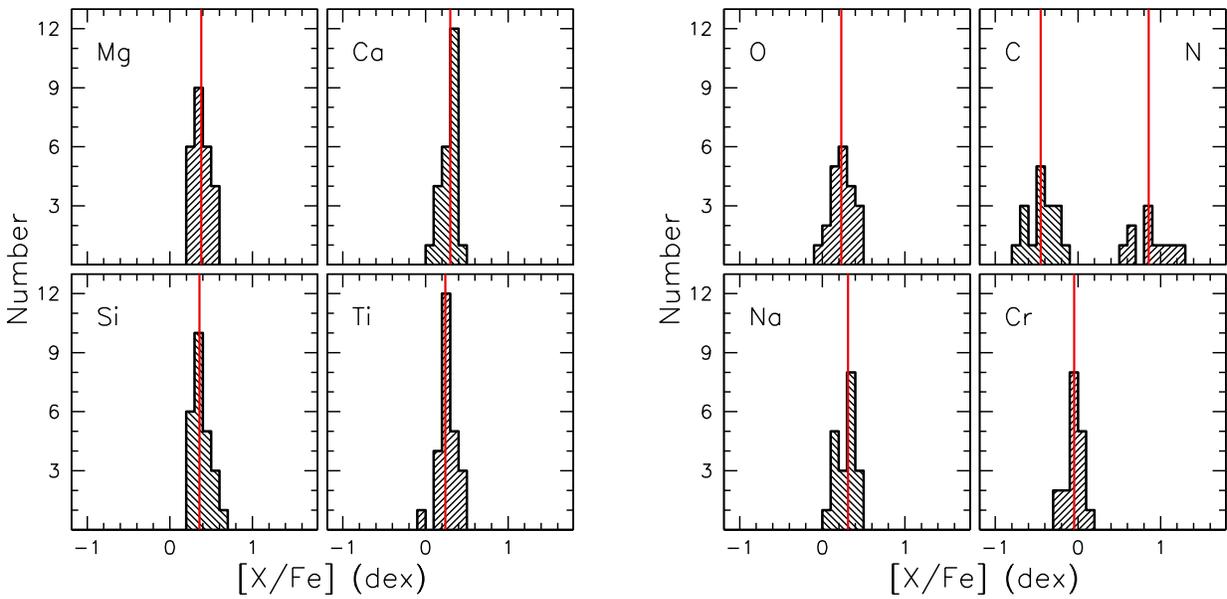
Fig. 7.— As in Figure 4, but for our adopted abundance patterns. The specific abundance ratio plotted in each panel is indicated in the top-left or top-right corner while the median value of each distribution is marked with a red line. Note that less certain entries from Tables 4 and 5 have been omitted from these distributions.
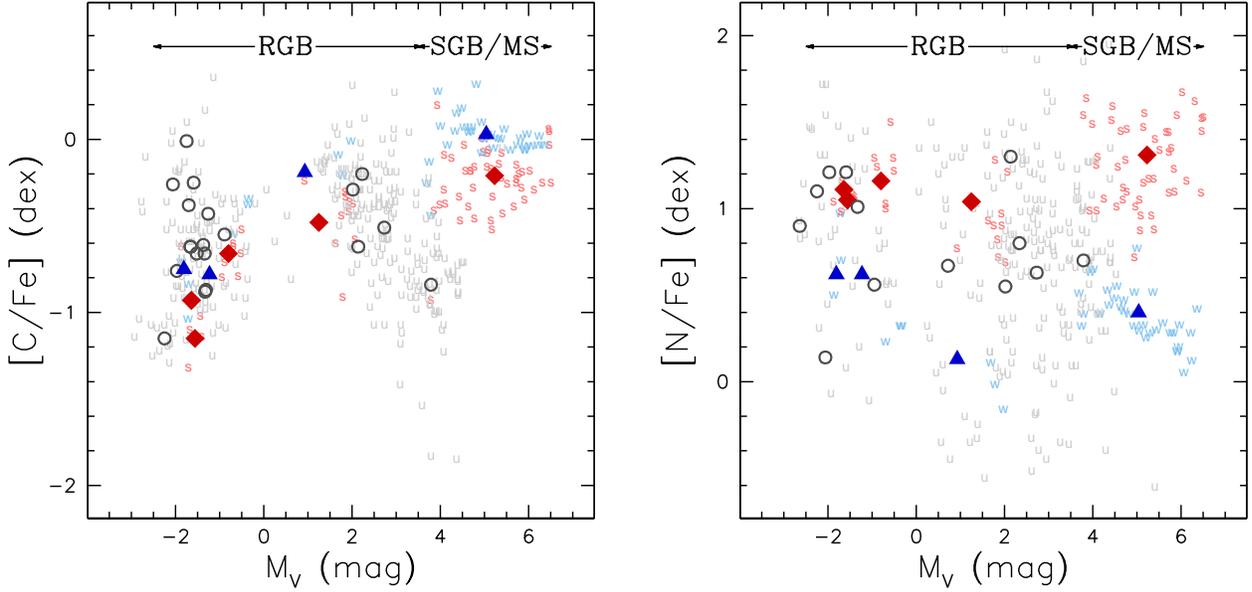
Fig. 8.— Carbon (*left*) and nitrogen (*right*) abundance versus absolute visual magnitude for individual stars belonging to the S05 GGCs (coloured letters). The mean values of the data from the individual studies are represented with the coloured points. The point types (and colours) for both the individual stars and whole samples have been chosen to indicate the corresponding CN-strength: s/diamond (pink/red) if strong, w/triangle (light/dark blue) if weak and u/circle (light/dark grey) if unknown. The horizontal axis has been delineated into zones which roughly correspond to the red giant branch (RGB) and sub-giant branch/main sequence (SGB/MS) phases of stellar evolution present within GGCs.
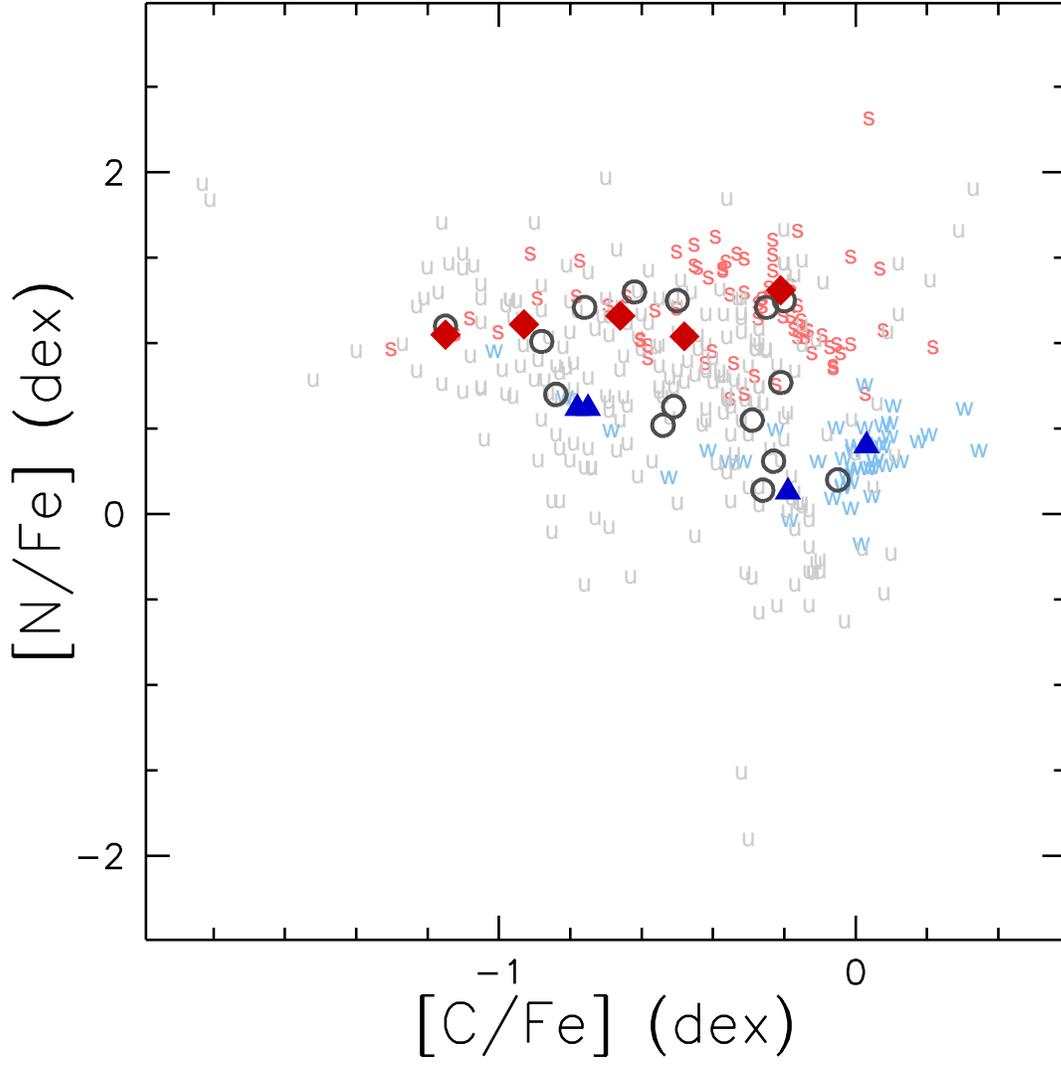
Fig. 9.— As in Figure 8 but in terms of nitrogen abundance versus carbon abundance.
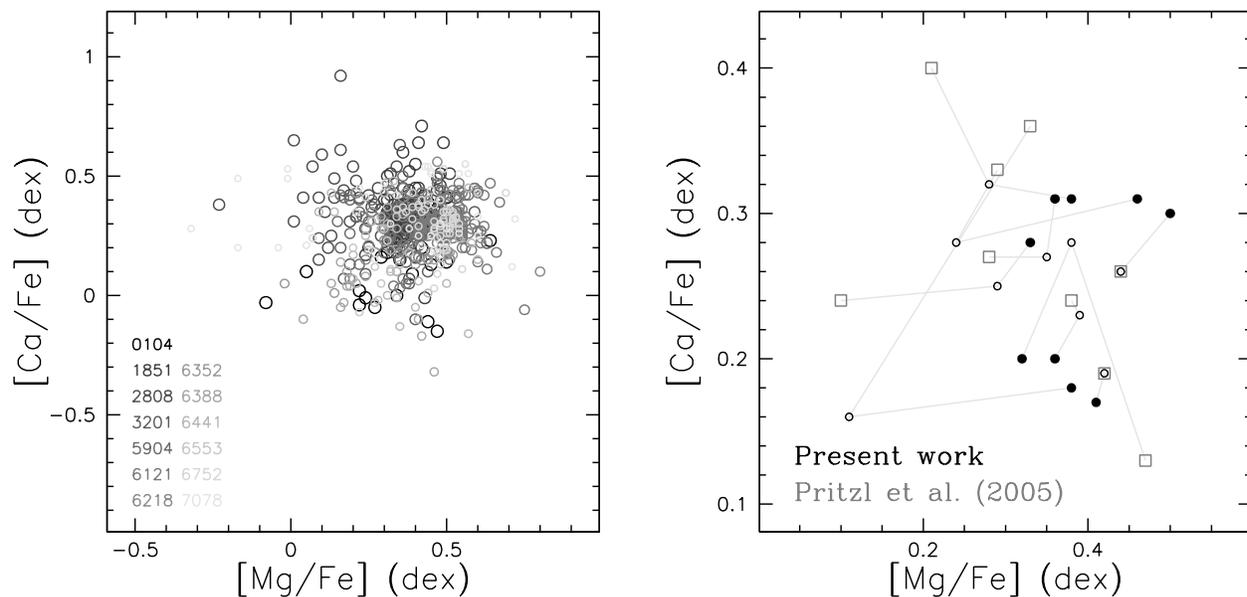
Fig. 10.— Calcium versus magnesium abundance for individual stars (*left*) or whole clusters (*right*) belonging to the S05 sample. In the left-hand panel, data for individual clusters are represented by a unique combination of grayscale shading and point size, with the shading key expressed in the bottom-left corner (numbers refer to NGC IDs of the clusters). The mean abundances of these species are plotted in the right-hand panel for the nine S05 clusters shown at left that overlap with the sample of Pritzl et al. (2005). There, we show the values obtained by these authors (open squares), in the present work (filled circles) and from the same data and method used by Pritzl et al., except without making corrections for choice of log*gf* values nor solar abundance scale (open circles). To help demonstrate the effects that different approaches taken to compilation work such as ours, the different point types are connected by a line for each cluster.
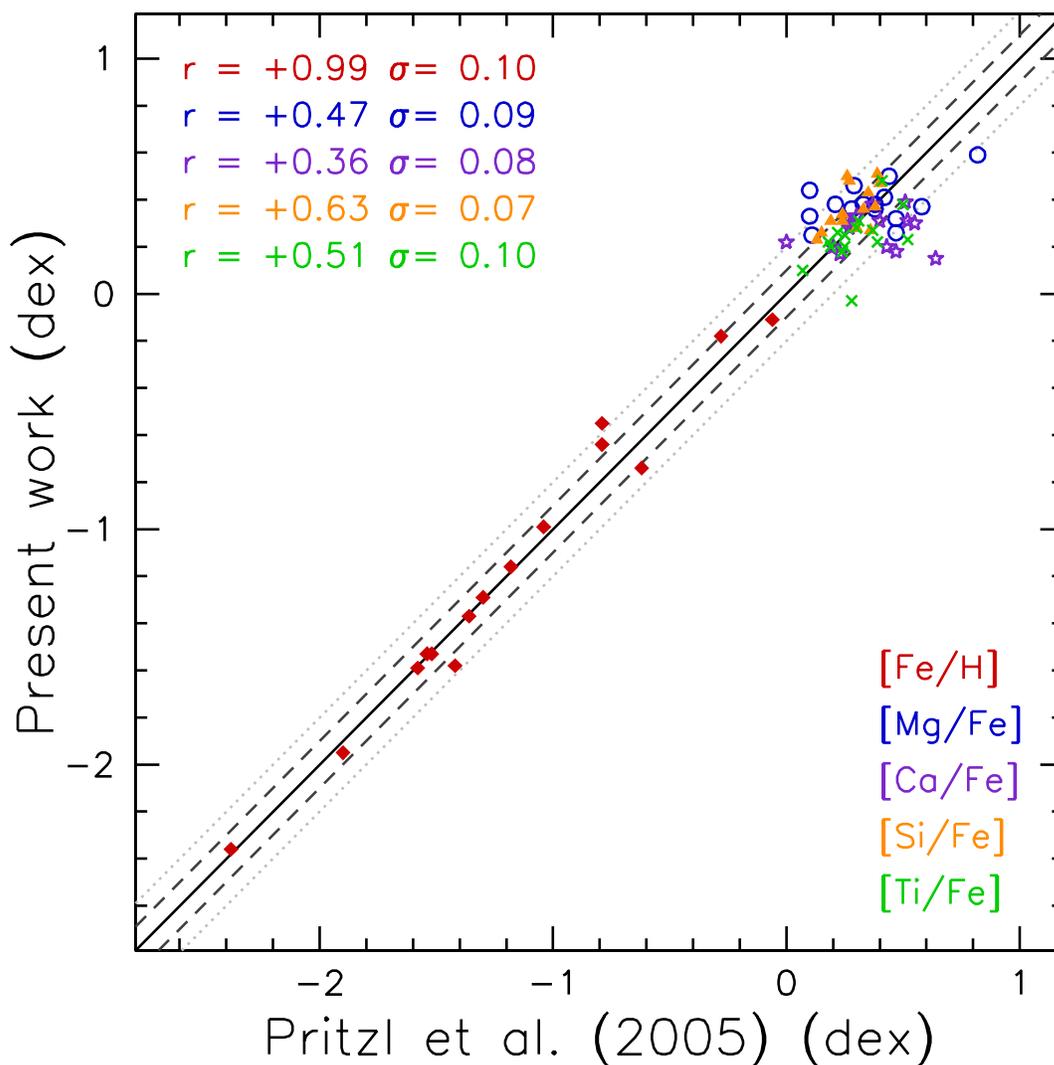
Fig. 11.— Comparison of our adopted metallicities and α-element abundance patterns for GGCs from the S05 sample which overlap with that of Pritzl et al. (2005). The Pearson (linear) correlation coefficient and the 1-σ dispersion (in logarithmic dex units) of a linear least-squares fit between each pair of datasets are indicated at top-left. The dashed and dotted lines correspond to ± 0.1 and ± 0.2 dex offsets from the locus of equality (solid line), respectively.

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A. Notes on Individual Clusters

In this Appendix, we provide on a cluster-by-cluster basis all known sources to us of ages and chemical abundance ratios for each of the S05 GGCs. We also list sources of metallicity information, but restricted to those we have adopted since an exhaustive list for each cluster would be prohibitively large while adding little benefit. Regarding the chemical abundance references, we explicitly identify those included in our compilation and their respective statistical richnesses (i.e. number of measurements, N), outline our justification(s) for any exclusions thereof, and point out instances where we think systematic discrepancies might be an issue. For those clusters in our sample known to harbour multiple stellar populations, we also comment on possible signatures of this phenomenon within our adopted abundance patterns and relate them to other evidence. On the other hand, for the age references we concentrate on comparing the independent measurements against our adopted values or the estimated age of the Universe (13.76 ± 0.11 Gyr; Komatsu et al. 2011) in order to highlight the (sometimes severe) degree of systematic error inherent to this quantity. Pinpointing the various sources of this error would be best accomplished on a per cluster basis though and so is beyond the scope of the present work.

Unless stated otherwise, our adopted ages come from MF09. We omit the ages from Chaboyer et al. (1996) on the grounds that nearly all of them for the S05 clusters exceed the age of the Universe. Also note that the relative ages from De Angeli et al. (2005) refer to the Carretta & Gratton (1997) metallicity scale and were transformed assuming a normalization of 10.9 Gyr. The Buonanno et al. (1998) and Rosenberg et al. (1999) ages were re-cast into absolute terms by adding to them a zeropoint of 15.0 and 13.2 Gyr, respectively. The zeropoint for the ages from Richer et al. (1996) varies from 14.0 Gyr for the most metal-rich clusters to 16.0 Gyr for the most metal-poor ones.

A.1. NGC 0104

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Costar & Smith (1988), Brown & Wallerstein (1992), Alves-Brito et al. (2005), Wylie et al. (2006), Koch & McWilliam (2008), McWilliam & Bernstein (2008) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 0104. The large body of work on the chemical composition of this cluster covers all major evolutionary stages, including the MS (Briley et al. 2004; Carretta et al. 2004a, 2005; Koch & McWilliam 2008; D'Orazi et al. 2010) [$N = 173$], RGB (Pilachowski et al. 1983; Gratton et al. 1986; Brown et al. 1990; Brown & Wallerstein 1992; Norris & Da Costa 1995; Carretta et al. 2004a; Alves-Brito et al. 2005; Carretta et al. 2005; Wylie et al. 2006; Koch & McWilliam 2008; Carretta et al. 2009a,b) [$N = 190$], HB (Alves-Brito et al. 2005) [$N = 1$] and AGB (Brown et al. 1990; Brown & Wallerstein 1992; Wylie et al. 2006; Worley et al. 2009; Worley & Cottrell 2012) [$N = 21$], all of which we fold

into our compiled abundance pattern. Conversely, we excluded the results of Briley et al. (1991, 1996) and Cannon et al. (1998) from the present work on the grounds that they did not provide abundances for the individual stars comprising their respective samples. A plethora of evidence on this cluster strongly suggests that it hosts multiple stellar populations, which includes variations in either the spectroscopic band strengths (CN, CH) or light-element abundances (C, N, O, Na, Mg, Al) of individual stars over a wide range of evolutionary stages (Mallia 1978; Hesser & Bell 1980; Cottrell & Da Costa 1981; Briley et al. 1994, 1996; Carretta et al. 2004a; Campbell et al. 2006; Carretta et al. 2009a,b; D'Orazi et al. 2010; Pancino et al. 2010), distinct photometric main and red giant branch sequences (Anderson et al. 2009; di Criscienzo et al. 2010; Piotto et al. 2012) and radial gradients in both colour and He abundance (Hanes & Brodie 1985; Nataf et al. 2011). From our compilation, we find some support for the notion that NGC 0104 hosts multiple populations via the slightly enhanced rms envelopes on our mean [C/Fe], [N/Fe], [Na/Fe] and [O/Fe] ratios ($\geq$0.2 dex, compared to $\leq$0.15 dex for other species). Given this cluster's well-established abundance anti-correlations (Carretta et al. 2009a), we suggest that systematics between the available abundance measurements of Ca, Si, Cr and Ti may be responsible for weakening the multiple-population signal in our data. Finally, the age of NGC 0104 has been determined in several other studies to date (Hesser et al. 1987; Dorman et al. 1989; Straniero & Chieffi 1991; Chaboyer & Kim 1995; Mazzitelli et al. 1995; Richer et al. 1996; Buonanno et al. 1998; Rosenberg et al. 1999; Zoccali et al. 2001; Brown et al. 2005; Meissner & Weiss 2006; McWilliam & Bernstein 2008; Dotter et al. 2010), the values from which span a range of 12.0-14.7 Gyr for this parameter and are formally consistent with the one we have adopted (13.1 ± 0.9 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 1.1-2.4 Gyr (1.2-1.8σ; VandenBerg 2000; Grundahl et al. 2002; Gratton et al. 2003; Salaris & Weiss 2002; De Angeli et al. 2005; Salaris et al. 2007; Bergbusch & Stetson 2009) [3.9 Gyr (2.9σ) in the case of Salaris & Weiss 1998] or, worse yet, exceed the estimated age of the Universe by 2.7-6.2 Gyr (Harris et al. 1983; Gibson et al. 1999).

A.2. NGC 1851

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Geisler et al. (1997), Villanova et al. (2010), Yong & Grundahl (2008), Yong et al. (2009) and Carretta et al. (2009c, 2011a) to calculate the weighted [Fe/H] for NGC 1851. A large number of studies have also addressed the chemical composition of this cluster, covering nearly all evolutionary stages, including the MS (Lardo et al. 2012) [$N = 64$], SGB (Gratton et al. 2012c) [$N = 77$], RGB (Yong & Grundahl 2008; Yong et al. 2009; Villanova et al. 2010; Carretta et al. 2011a; Gratton et al. 2012b) [$N = 8, 4, 15, 124$ and 12 stars, respectively] and HB (Gratton et al. 2012b) [$N = 91$]; our recommended abundance pattern incorporates all of these results. We omitted Rodgers & Harding

(1987) and Carretta et al. (2012b) from our compilation however on the grounds that neither work provided abundances for the individual stars comprising their respective samples. Our recommended abundance pattern exhibits large rms envelopes about the mean abundance ratios for C (0.51 dex), N (0.46 dex), O (0.26 dex) and Na (0.31 dex), while those for other species are typically ≤0.10 dex. The large abundance scatters in this cluster (partly) reflect its known C–N and Na–O anti-correlations (Yong & Grundahl 2008; Yong et al. 2009; Villanova et al. 2010; Carretta et al. 2010, 2011a) and thus that it harbours multiple stellar populations. Additional evidence of the multiple population phenomenon in NGC 1851 includes its radial colour gradient (Bailyn et al. 1988) and split SGB and RGB (Cassisi et al. 2008; Milone et al. 2008; D'Antona et al. 2009; Han et al. 2009; Lee et al. 2009; Ventura et al. 2009; Carretta et al. 2011b; Piotto et al. 2012). Finally, the age of NGC 1851 has been determined in several other studies to date, the values from a minority of which (Rosenberg et al. 1999; Salaris & Weiss 2002; Meissner & Weiss 2006) span a range of 9.2-10.6 Gyr for this parameter and are consistent with the one we have adopted (10.0 ± 0.5 Gyr). Exceptional cases include measurements which either exceed our adopted value by 1.0-5.0 Gyr (1.1-3.6σ; Sagar et al. 1988; Walker 1992; Chaboyer & Kim 1995; Richer et al. 1996; Sandquist et al. 1996; Buonanno et al. 1998; VandenBerg 2000) or fall below it by 1.2-2.1 Gyr (1.9-2.2σ; Salaris & Weiss 1998; De Angeli et al. 2005). Worse yet, the age from Alcaino et al. (1990a) lies in excess of that estimated for the Universe by 2.2 Gyr (1.1σ).

A.3.   NGC 1904

Following Ha10, we use the measured metallicities from François (1991), Geisler et al. (1997) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 1904. For its recommended abundance pattern, we combine results from the few studies of the chemical abundances of its RGB population (François 1991; Carretta et al. 2009a,b) [N = 72, total]. Other studies of this cluster's chemical composition include Gratton & Ortolani (1989), Fabbian et al. (2005) and Şahin & Lambert (2009) but those are omitted from our compilation on the grounds that their results are at strong odds with those from our adopted references (Gratton & Ortolani), or correspond to an advanced (post-AGB; Şahin & Lambert) or some exotic (extreme HB; Fabbian) stage of stellar evolution. From our compiled abundance pattern, we find that NGC 1904 has significant rms envelopes about its mean [Mg/Fe], [O/Fe] and [Na/Fe] ratios (0.2-0.3 dex) compared to those of other species (≤0.13 dex), which reflects the known Mg-Al and Na-O anti-correlations exhibited by its RGB members (Carretta et al. 2009a,b). These anti-correlations, along with this cluster's extreme HB morphology (Gratton et al. 2010) and radial colour gradient (Cordoni & Auriere 1983; Hill et al. 1996), provide strong evidence for the existence of multiple stellar population(s) within it. Finally, since NGC 1904 was not part of the MF09 sample, we adopt the age estimated for it by Salaris & Weiss (2002, 11.7 ± 1.3 Gyr), but only in a *tentative* sense on the grounds that a sig-

nificant fraction of the latter's estimates are systematically younger than those of the former (Figure 2). Several other age determinations appear in the literature for this cluster (Chaboyer & Kim 1995; Richer et al. 1996; Salaris & Weiss 1998; Rosenberg et al. 1999; Meissner & Weiss 2006), which span a range of 10.1-13.3 Gyr and are consistent with the one we have adopted. Exceptional cases include measurements which either exceed our adopted value by 2.7 Gyr (1.1σ; Buonanno et al. 1998) or fall below it by 2.2 Gyr (1.4σ; De Angeli et al. 2005). Worse yet, the ages from Gratton & Ortolani (1986), Heasley et al. (1986), Alcaino et al. (1994) and Kravtsov et al. (1997) lie in excess of that estimated for the Universe by 2.2-4.2 Gyr.

A.4. NGC 2298

Following Ha10, we use the measured metallicities from McWilliam et al. (1992) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 2298. Our only knowledge of the chemical abundances in this cluster comes from McWilliam et al. (1992), who analysed three of its RGB members. We therefore adopt their results for our compilation. The age of NGC 2298 has been determined in several other studies to date (Alcaino et al. 1990c; Chaboyer et al. 1992; Chaboyer & Kim 1995; Salaris & Weiss 1998, 2002; Dotter et al. 2010), the values from which span a range of 11.7-15.0 Gyr for this parameter and are formally consistent with the one we have adopted (12.7 ± 0.7 Gyr). Exceptional cases concern those measurements which exceed either our adopted value by 2.8 Gyr (1.5σ; McWilliam et al. 1992) or, worse yet, the estimated age of the Universe by 1.3-4.3 Gyr (Alcaino & Liller 1986; Gratton & Ortolani 1986; Janes & Heasley 1988; Richer et al. 1996; Buonanno et al. 1998).

A.5. NGC 2808

Following Ha10, we use the measured metallicities from Geisler et al. (1997) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 2808. For our recommended abundance pattern, we combine results from the many studies which have addressed the chemical composition of this cluster's MS (Bragaglia et al. 2010b) [$N = 2$], RGB (Gratton 1982; Carretta et al. 2003, 2004b; Carretta 2006; Carretta et al. 2006, 2009b) [$N = 1, 81, 20, 20, 120$ and 12, respectively] and HB (Gratton et al. 2011) [$N = 26$]. We exclude the work of Pace et al. (2006) from our compilation on the grounds that the majority of stars in their sample are drawn from an exotic (extreme HB) stage of stellar evolution. NGC 2808 is a special case given that its multiple stellar populations are reflected by many signatures, such as a wide range of CN band strengths amongst its red giants, three distinct MSs, an extreme HB and peculiar colour distribution amongst its blue stragglers (Norris & Smith 1983; D'Antona & Caloi 2004; D'Antona et al. 2005; Lee et al. 2005; Piotto et al.

2007; Bragaglia et al. 2010a; D'Ercole et al. 2010; Glebbeek et al. 2010; Dalessandro et al. 2011; D'Ercole et al. 2012). Our compiled abundance pattern also supports the idea of multiple populations in this cluster via the large rms envelopes on our mean [Mg/Fe], [C/Fe], [N/Fe], [O/Fe] and [Na/Fe] ratios ($\gtrsim$0.2 dex), which we interpret as reflecting the underlying Mg–Al, C–N and Na–O anti-correlations that have been found amongst its member stars of *all* evolutionary phases (Carretta et al. 2006, 2009b; Bragaglia et al. 2010b; Gratton et al. 2011). Finally, the age of NGC 2808 has been determined in several other studies to date (Chaboyer & Kim 1995; Sandquist et al. 1996; Rosenberg et al. 1999; VandenBerg 2000), the values from which span a range of 10.7-12.4 Gyr for this parameter and are consistent with the one we have adopted (10.9 ± 0.4 Gyr). Exceptional cases include measurements which either exceed our adopted value by 2.6-3.1 Gyr (1.5-2.1σ; Richer et al. 1996; Buonanno et al. 1998) or fall below it by 1.2-2.6 Gyr (1.4-2.6σ; Salaris & Weiss 2002; De Angeli et al. 2005; Meissner & Weiss 2006). Worse yet, the ages from Buonanno et al. (1984), Gratton & Ortolani (1986) and Alcaino et al. (1990b) lie in excess of that estimated for the Universe by 2.2-4.2 Gyr.

A.6. NGC 3201

Following Ha10, we use the measured metallicities from Beers et al. (1990), Geisler et al. (1997) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 3201. For our recommended abundance pattern, we combine the results from the many studies that have analyzed the chemical composition of its RGB members: Gratton (1982) [$N = 2$], Pilachowski et al. (1983) [$N = 4$], Gratton & Ortolani (1989) [$N = 3$], Gonzalez & Wallerstein (1998) [$N = 18$] and Carretta et al. (2009a,b) [$N = 149$ and 10, respectively]. Rodgers & Harding (1989) have analysed the Ca abundances of HB stars belonging to this cluster but we omit their result from our compilation given that these authors only provide the mean [Ca/Fe] ratio for their sample. Based on several lines of evidence, including a split RGB (Kravtsov et al. 2010), radial gradients in spectroscopic index strengths (Chun 1988), a bimodal CN distribution amongst its red giants (Smith & Norris 1982) and chemical abundance anti-correlations (Carretta et al. 2009a,b), it has been suggested that NGC 3201 hosts multiple stellar populations. Finding signatures of this phenomenon in our compiled abundance pattern is complicated by the fact that the rms envelopes for the anti-correlated elements (C, N, O, Na; 0.23-0.27 dex) are similar to that of Cr (0.24 dex); the latter's size could be an artifact of systematic bias though between the metallicities determined by the sources of our [Cr/Fe] ratios (Gratton 1982; Pilachowski et al. 1983; Gratton & Ortolani 1989). Finally, the age of NGC 3201 has been determined in several other studies to date (Alcaino & Liller 1981; Cacciari 1984; Chaboyer & Kim 1995; Salaris & Weiss 1998, 2002), the values from which span a range of 9.9-12.0 Gyr for this parameter and are consistent with the one we have adopted (10.2 ± 0.4 Gyr). Exceptional cases include measurements which either exceed our adopted value by 1.0-

5.8 Gyr (1.6-3.3σ; Alcaino et al. 1989; Richer et al. 1996; Buonanno et al. 1998; Rosenberg et al. 1999; Layden & Sarajedini 2003; Bono et al. 2010; Dotter et al. 2010) [3.2 Gyr (5.0σ) in the case of Layden & Sarajedini 2003] or fall below it by 1.2-2.2 Gyr (3.0-3.9σ; De Angeli et al. 2005; Meissner & Weiss 2006). Worse yet, the ages from Samus et al. (1996a) von Braun & Mateo (2001) lie in excess of that estimated for the Universe by 0.24 and 4.2 Gyr, respectively.

A.7. NGC 5286

Little is known about the stellar population(s) of NGC 5286, except for its age and metallicity. Following Ha10, we simply adopt the measured value of this parameter from Carretta et al. (2009c). Alternative determinations of the age of this cluster have been made by Samus et al. (1995), Zorotovic et al. (2009) and Dotter et al. (2010), only the latter of which (13.0 $\pm$ 1.0 Gyr) is consistent with the one we have adopted (12.5 $\pm$ 0.5 Gyr). In both of the other cases, the determinations lie in excess of the estimated age of the Universe by 2.5-3.5 Gyr.

A.8. NGC 5904

Following Ha10, we use the measured metallicities from Sneden et al. (1992), Shetrone (1996), Ivans et al. (2001), Ramírez & Cohen (2003), Yong et al. (2008c) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 5904. The chemical composition of this cluster has been extremely well-studied across nearly all relevant evolutionary stages, including the MS (Ramírez & Cohen 2003) [$N = 6$], SGB (Briley et al. 1992; Cohen et al. 2002) [$N = 51$], RGB (Armosky et al. 1994; Briley et al. 1992; Carretta et al. 2009a,b; Gratton et al. 1986; Ivans et al. 2001; Koch & McWilliam 2010; Lai et al. 2011; Langer et al. 1985; Martell et al. 2008; Pilachowski et al. 1980, 1983; Ramírez & Cohen 2003; Shetrone 1996; Smith et al. 1997; Sneden et al. 1992; Yong et al. 2008a,c) [$N = 276$], HB (Lai et al. 2011) [$N = 2$] and AGB (Ivans et al. 2001; Koch & McWilliam 2010; Lai et al. 2011; Sneden et al. 1992) [$N = 21$]; we fold all of the results from these studies into our compilation. However, we omit the [O/Fe] ratios from Gratton (1987a) since the authors determined them for two different assumptions of their stars' carbon abundances and it is not clear which they prefer. From our recommended abundance pattern, we find that this cluster's carbon, oxygen and sodium abundances are each spread over a range of $\sim$0.3 dex, and $\sim$0.6 dex for its nitrogen abundance. These comparitively large spreads (most other elements have rms envelopes of 0.1 dex) reflect the abundance anti-correlations that have been found amongst this cluster's MS and RGB populations (Osborn 1971; Ramírez & Cohen 2003; Carretta et al. 2009a,b; Lai et al. 2011), a hallmark of the multiple population phenomenon in globular clusters. Additional evidence suggesting that NGC 5904 hosts more than one stellar population is the radial colour

gradient found by Buonanno et al. (1981). Finally, the age of NGC 5904 has been determined in several other studies to date (Sandquist et al. 1996; Jimenez & Padoan 1998; Salaris & Weiss 1998, 2002; Meissner & Weiss 2006), the values from which span a range of 9.9-10.9 Gyr for this parameter and are consistent with the one we have adopted (10.6 ± 0.4 Gyr). Exceptional cases include [concern those] measurements which either exceed our adopted value by 0.9-4.3 Gyr (1.0-2.9σ; Chaboyer & Kim 1995; Richer et al. 1996; Buonanno et al. 1998; Rosenberg et al. 1999; VandenBerg 2000; Dotter et al. 2010) or fall below it by 1.8 Gyr (2.0σ; De Angeli et al. 2005). Worse yet, the ages from Richer & Fahlman (1987) and Straniero & Chieffi (1991) lie in excess of that estimated for the Universe by 2.2-3.2 Gyr.

A.9.   NGC 5927

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), François (1991) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 5927. The generous error on our adopted metallicity (-0.49 ± 0.44 dex) stems from the wide spread (~ 0.8 dex) amongst the input measurements. Our only knowledge of the chemical abundances in this cluster comes from François (1991), who analysed one of its RGB members. As such, we adopt their results in our compilation, but with some reservations since their measured metallicity (-1.08 dex) falls well outside the error on our adopted value for this parameter, while their [Mg/Fe], [Na/Fe] and [Si/Fe] ratios (-0.12, +1.23 and +0.74 dex, respectively) seem suspiciously low. The age of NGC 5927 has been determined in several other studies to date (Fullton 1996; Feltzing & Gilmore 2000; Brown et al. 2005; Meissner & Weiss 2006; Dotter et al. 2010), the values from which span a range of 10.9-13.0 Gyr for this parameter and are consistent with the one we have adopted (12.7 ± 0.9 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 2.7 Gyr (2.5σ; De Angeli et al. 2005) or, worse yet, exceed the estimated age of the Universe by 1.24 Gyr (Samus et al. 1996b).

A.10.   NGC 5946

Little is known about the stellar population(s) of NGC 5946, except for its age and metallicity. Following Ha10, we use the measured values of this parameter from Armandroff & Zinn (1988) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster. These input values are identical though, so we adopt the uncertainty quoted by Carretta to provide some idea of that associated with our metallicity. Since NGC 5946 was not part of the MF09 sample, we adopt the age estimated for it by De Angeli et al. (2005, 9.7 ± 1.6 Gyr), but only in a *tentative* sense on the grounds that the latter's estimates are biased to younger values relative to those of the former.

A.11. NGC 5986

Following Ha10, we use the measured metallicities from Geisler et al. (1997) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 5986. Our only knowledge of the chemical abundances in this cluster comes from Jasniewicz et al. (2004), who analysed two highly-evolved members, one which they hypothesize as being well into its post-AGB phase and experienced a third dredge-up, and the other as just beginning to leave the AGB sequence. As such, we only adopt the latter's abundances into our compilation. Despite the good agreement between the measured metallicity of this star (-1.65 dex) and our adopted value for this cluster (-1.59 ± 0.12 dex), we notice that its [O/Fe], [Na/Fe] and [Cr/Fe] ratios all seem rather large in comparison to those for the rest of the S05 sample. We therefore advise caution when interpreting results based on this single star's abundance pattern. Alternative determinations of the age of NGC 5986 have been made by De Angeli et al. (2005), Meissner & Weiss (2006) and Dotter et al. (2010), the latter two of which span a range of 12.0-13.2 Gyr for this parameter and are consistent with the one we have adopted (12.2 ± 0.6 Gyr). The age determined by De Angeli et al. falls below our adopted value by 2.6 Gyr (3.1σ).

A.12. NGC 6121

Following Ha10, we use the measured metallicities from Beers et al. (1990), Brown & Wallerstein (1992), Drake et al. (1994), Minniti (1995b), Ivans et al. (1999), Marino et al. (2008), Yong et al. (2008c), Takeda et al. (2009) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6121. For our recommended abundance pattern, we combine the results from the many studies of the chemical composition of this cluster's MS/SGB (Monaco et al. 2012) [$N = 91$], RGB (Brown et al. 1990; Brown & Wallerstein 1992; Carretta et al. 2009a,b; D'Orazi & Marino 2010; Drake et al. 1992; Gratton et al. 1986; Ivans et al. 1999; Marino et al. 2008; Smith et al. 2005; Suntzeff & Smith 1991; Villanova & Geisler 2011; Wallerstein et al. 2007; Yong et al. 2008a,c) [$N = 425$], HB (Marino et al. 2011; Villanova et al. 2012) [$N = 28$] and AGB (Ivans et al. 1999) [$N = 10$] populations. Many of the above studies suggest that NGC 6121 plays host to multiple stellar populations on the basis of anti-correlations observed amongst the light-element abundances of its MS, RGB and HB members (Smith et al. 2005; Marino et al. 2008, 2011; Carretta et al. 2009a,b; D'Orazi & Marino 2010; Villanova & Geisler 2011; Villanova et al. 2012; Monaco et al. 2012). In addition, Marino et al. (2008) found that this cluster's RGB is split in colour-magnitude diagrams based, in part, on U−band information. Our compilation also supports the existence of multiple populations in this cluster through the comparatively large rms envelopes on our mean [C/Fe], [N/Fe], [O/Fe] and [Na/Fe] ratios (0.14-0.41 dex), whereas those of other light elements remain below 0.1 dex. Finally, the age of NGC 6121 has been determined in several other studies

to date (Caputo et al. 1985; Chaboyer & Kim 1995; Sandquist et al. 1996; Rosenberg et al. 1999; Salaris & Weiss 2002; D'Antona et al. 2009; Dotter et al. 2010), the values from which span a range of 11.7-13.3 Gyr for this parameter and are consistent with the one we have adopted (12.5 $\pm$ 0.7 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 2.6 Gyr (3.2σ; De Angeli et al. 2005) or, worse yet, exceed the estimated age of the Universe by 2.1 Gyr (1.3σ; Buonanno et al. 1998).

A.13.   NGC 6171

Following Ha10, we use the measured metallicities from Searle & Zinn (1978) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6171. Ha10's value for this parameter can be exactly reproduced if Searle & Zinn's measurement is transformed onto Carretta's scale (-1.00 dex; Harris, *priv. comm.*); we have therefore adopted this transformation here. Nearly all of our recommended abundance pattern for this cluster is based on the results of the few studies that have focussed on the elemental abundances amongst its RGB population: Carretta et al. (2009a,b) and O'Connell et al. (2011) [N = 33, 5 and 13, respectively]. For its Ca abundance, we draw on the mean [Ca/Fe] ratio from Smith & Manduca (1983) with the caveat that it is based on an exotic phase of stellar evolution (RR Lyrae) and that their quoted [Fe/H] (-0.84 $\pm$ 0.25 dex) is systematically lower than (but nevertheless consistent with) that of Carretta et al. (2009c). Smith & Perkins (1982) also measured the mean Ca abundance of NGC 6171, but given that their result is in excellent agreement with that of Smith & Manduca, we opted to omit it from our compilation. Owing to the CN/CH band strength variations (Smith 1988) and a Na-O anti-correlation observed amongst its RGB members (Carretta et al. 2009a,b), NGC 6171 is suspected of hosting multiple stellar populations, a suggestion which is supported by the comparitively large rms envelopes we find on its mean Na and O abundances ($\sim$0.2 dex, compared to $\lesssim$0.1 dex for other species). Finally, the age of NGC 6171 has been determined in several other studies to date (Da Costa et al. 1984; Ferraro et al. 1991; Chaboyer & Kim 1995; Jimenez et al. 1996; Rosenberg et al. 1999), the values from which span a range of 13.5-16.0 Gyr for this parameter and are formally consistent with the one we have adopted (14.0 $\pm$ 0.8 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 1.2-3.6 Gyr (1.1-2.8σ; Salaris & Weiss 1998, 2002; De Angeli et al. 2005; Meissner & Weiss 2006; Dotter et al. 2010) [5.0 Gyr (6.2σ) in the case of Meissner & Weiss 2006] or, worse yet, exceed the estimated age of the Universe by 3.2-6.2 Gyr (Sandage & Roques 1984; Buonanno et al. 1989; Ferraro & Piotto 1992; Ferraro et al. 1995). Note that the age we have adopted for this cluster is statistically consistent with being younger than that of the Universe.

A.14.   NGC 6218

Following Ha10, we use the measured metallicities from Da Costa & Armandroff (1995), Johnson & Pilachowski (2006) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6218. Our recommended abundance pattern for this cluster combines results from several studies that have targetted members of its RGB and AGB phases: Johnson & Pilachowski (2006) and Carretta et al. (2007b, 2009b) [$N = 21$, 79 and 11, respectively; RGB], and Klochkova & Samus (2001), Mishenina et al. (2003) and Jasniewicz et al. (2004) [$N = 3$ total; AGB]. We omit the results of Klochkova et al. (2003) from our compilation on the grounds that they correspond to an advanced stage of stellar evolution (post-AGB); indeed, their abundances for several species, although formally consistent, exhibit (sometimes large) differences from our adopted values. The mean [O/Fe] and [Na/Fe] ratios in our abundance pattern are distinguished by larger rms envelopes (0.34 and 0.27 dex, respectively) compared to those of other species (0.14 dex, in the median) on account of the fact that NGC 6218 is known to exhibit a Na-O anti-correlation (Carretta et al. 2007b), an established hallmark of the multiple populations phenomenon in GGCs. Finally, the age of NGC 6218 has been determined in several other studies to date (Chaboyer & Kim 1995; Richer et al. 1996; Buonanno et al. 1998; Salaris & Weiss 2002; Hargis et al. 2004; Dotter et al. 2010), the values from which span a range of 11.8-14.5 Gyr for this parameter and are formally consistent with the one we have adopted (12.7 $\pm$ 0.4 Gyr). Exceptional cases include measurements which either exceed our adopted value by 1.4 Gyr (1.0σ; Rosenberg et al. 1999) or fall below it by 2.7 Gyr (2.7σ; De Angeli et al. 2005). Worse yet, the ages from Sato et al. (1989) and von Braun et al. (2002) lie in excess of that estimated for the Universe by 2.2-3.2 Gyr ($>3.2\sigma$).

A.15.   NGC 6235

Little is known about the stellar population(s) of NGC 6235, except for its age and metallicity. Following Ha10, we use the measured values of this parameter from Howland et al. (2003) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster. The generous error on our adopted metallicity (-1.28 $\pm$ 0.31 dex) stems from the wide spread ($\sim$0.4 dex) amongst the input measurements. Since NGC 6235 was not part of the MF09 sample, we adopt the age estimated for it by De Angeli et al. (2005, 9.7 $\pm$ 1.6 Gyr), but only in a *tentative* sense on the grounds that the latter's estimates are biased to younger values relative to those of the former.

A.16. NGC 6254

Following Ha10, we use the measured metallicities from Kraft et al. (1995), Haynes et al. (2008) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6254. A large number of studies addressing the abundance pattern of this cluster (predominantly through its RGB population) are found within the literature, the majority of which we incorporate in our compilation. These studies include: Pilachowski et al. (1983) [$N = 3$], Gratton & Ortolani (1989) [$N = 2$], Kraft et al. (1995) [$N = 14$], Mishenina et al. (2003) [$N = 2$], Smith et al. (2005) [$N = 15$], Haynes et al. (2008) [$N = 5$], Martell et al. (2008) [$N = 8$] and Carretta et al. (2009a,b) [$N = 14$ and 147, respectively]. Omitted works include Gratton (1980), Gonzalez & Lambert (1997), Mooney et al. (2001, 2004) and Mishenina et al. (2009) either because they focussed on an advanced/exotic stage of stellar evolution or expressed their abundances relative to another cluster not included in the present work. NGC 6254 is suspected of hosting multiple stellar populations on the basis of CN/CH band strength variations (Smith & Fulbright 1997), large scatters in both [C/Fe] and [N/Fe] ratios at fixed luminosity (Osborn 1971; Smith et al. 2005) and a Na-O anti-correlation observed amongst its RGB members (Carretta et al. 2009a,b). Our adopted abundance pattern for this cluster supports such a notion via the large rms envelopes attached to our mean [C/Fe], [N/Fe], [O/Fe] and [Na/Fe] ratios (0.37, 0.45, 0.24 and 0.27 dex, respectively), whereas other ratios have envelopes $\leq$0.15 dex in size. Finally, while the age of NGC 6254 has been determined in several other studies to date, only that from Salaris & Weiss (2002, 11.8 $\pm$ 1.1 Gyr) is consistent with the one we have adopted (11.4 $\pm$ 0.5 Gyr). The many exceptional cases include measurements which either exceed our adopted value by 1.6-3.8 Gyr (1.2-1.8σ; Buonanno et al. 1998; Rosenberg et al. 1999; Dotter et al. 2010) or fall below it by 1.3-2.0 Gyr (1.1-2.1σ; Salaris & Weiss 1998; De Angeli et al. 2005). Worse yet, the ages from several sources (Hurley et al. 1989; Straniero & Chieffi 1991; Chaboyer & Kim 1995; Richer et al. 1996; von Braun et al. 2002) lie in excess of that estimated for the Universe by 2.2-6.2 Gyr ($>1.1\sigma$).

A.17. NGC 6266

Little is known about the stellar population(s) of NGC 6266, except for its age and metallicity. Following Ha10, we simply adopt the measured value of this parameter from Carretta et al. (2009c). To our knowledge, the age of this cluster has only been estimated by De Angeli et al. (2005, 10.0 $\pm$ 0.6 Gyr) and Meissner & Weiss (2006, 11.0 $\pm$ 0.6 Gyr). Since NGC 6266 was not part of the MF09 sample, we adopt the latter estimate for our compilation on the grounds that the De Angeli ages are biased to younger values relative to those of MF09. We also note that, in this instance, the age estimate from De Angeli et al. is younger than that of Meissner & Weiss by 1.6 Gyr, a difference of 1.9σ.

A.18.   NGC 6284

Little is known about the stellar population(s) of NGC 6284, except for its age and metallicity. Since Carretta et al. (2009c) derive the metallicity of this cluster (-1.31 $\pm$ 0.09 dex) from the 2003 edition of Harris (1996), we simply adopt the corresponding value listed in Ha10 (-1.26 dex), at the expense of not having an error estimate. Smith & Perkins (1982) measured the abundance of calcium in two RR Lyrae stars from this cluster ([Ca/Fe] = +0.48 $\pm$ 0.32 dex), but we omit their result from our compilation since the mean metallicity they quoted for those same stars (-0.91 $\pm$ 0.25 dex) seems anomalously high compared to our adopted value. To our knowledge, the age of NGC 6284 has only been estimated by De Angeli et al. (2005, 9.5 $\pm$ 0.5 Gyr) and Meissner & Weiss (2006, 11.0 Gyr). Since this cluster was not part of the MF09 sample, we adopt the latter estimate for our compilation on the grounds that the De Angeli ages are biased to younger values relative to those of MF09. We also note that, in this instance, the age estimate from De Angeli et al. is younger than that of Meissner & Weiss by 1.5 Gyr, a difference of $\lesssim 3.0\sigma$.

A.19.   NGC 6304

Little is known about the stellar population(s) of NGC 6304, except for its age and metallicity. Following Ha10, we use the measured values of this parameter from Valenti et al. (2005) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster. The generous error on our adopted metallicity (-0.45 $\pm$ 0.26 dex) stems from the wide spread ($\sim$0.3 dex) amongst the input measurements. Alternative determinations of the age of NGC 6304 have been made by Meissner & Weiss (2006) and Dotter et al. (2010), which together span a range of 12.8-13.6 Gyr for this parameter and are consistent with the one we have adopted (13.6 $\pm$ 1.1 Gyr).

A.20.   NGC 6316

Little is known about the stellar population(s) of NGC 6316, except for its metallicity. Following Ha10, we use the measured values of this parameter from Armandroff & Zinn (1988), Valenti et al. (2007) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster.

A.21.   NGC 6333

Little is known about the stellar population(s) of NGC 6333, except for its metallicity. Since Carretta et al. (2009c) derive their value for this parameter (-1.79 $\pm$ 0.09 dex) from the 2003 edition

of Harris (1996), we simply adopt the corresponding [Fe/H] listed for this cluster in Ha10 (-1.77 dex), at the expense of not having an error estimate.

A.22. NGC 6342

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Origlia et al. (2005) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6342. Our only knowledge of the chemical abundances in this cluster comes from Origlia et al. (2005) as well, who analysed four of its RGB members. We therefore adopt their results for our compilation. To our knowledge, the age of NGC 6342 has only been estimated by Heitsch & Richtler (1999, 14.5 $\pm$ 0.4 Gyr) and De Angeli et al. (2005, 10.2 $\pm$ 0.8 Gyr). Since this cluster was not part of the MF09 sample, we adopt the latter estimate for our compilation on the grounds that that from Heitsch & Richtler exceeds the age of Universe by 0.7 Gyr, or 1.8σ. However, we nevertheless regard our adopted value with skepticism as the De Angeli ages are biased to younger values relative to those of MF09.

A.23. NGC 6352

Following Ha10, we use the measured metallicities from François (1991), Carretta et al. (2009c) and Feltzing et al. (2009) to calculate the weighted [Fe/H] for NGC 6352. Our recommended abundance pattern for this cluster also combines results from François (1991) and Feltzing et al. (2009), as well as Gratton (1987b), whom have collectively targetted its RGB [$N = 4$] and HB [$N = 9$] stars. We omit the [O/Fe] data obtained by Gratton (1987a) on the grounds that they were computed for two different [C/Fe] ratios, which itself has yet to be constrained for this cluster. Based on variations observed in the CN/CH band strengths of its RGB members, Pancino et al. (2010) have claimed that NGC 6352 hosts multiple stellar populations. Signatures of this phenomenon are difficult to come by in our adopted abundance pattern however: our [O/Fe] ratio comes from François (1991), whose results correspond to a single star (and are thus statistically ill-defined), while the rms envelopes for our [Mg/Fe] and [Na/Fe] ratios (0.17 and 0.16 dex, respectively) are not remarkably different than those for unaffected species (e.g. 0.21 and 0.13 dex for Si and Ti, respectively). The comparitively large rms envelope on our mean [Ti/Fe] ratio may be explained by Gratton's use of overestimated equivalent widths, small numbers of lines and a different treatment for collisional broadening (Feltzing et al. 2009). Finally, the age of NGC 6352 has been determined in several other studies to date, the values from a minority of which (Fullton et al. 1995; Richer et al. 1996; Dotter et al. 2010) span a range of 13.0-15.2 Gyr for this parameter and are formally consistent with the one we have adopted (12.7 $\pm$ 0.9 Gyr). Exceptional cases include measurements which

either exceed our adopted value by 2.6 Gyr (1.4σ; Buonanno et al. 1998) or fall below it by 1.8-3.3 Gyr (1.3-3.1σ; Salaris & Weiss 1998, 2002; Rosenberg et al. 1999; Pulone et al. 2003). Worse yet, the age from Heasley et al. (2000) lie in excess of that estimated for the Universe by 0.24 Gyr (2.2σ).

A.24. NGC 6356

Little is known about the stellar population(s) of NGC 6356, except for its age and metallicity. Following Ha10, we use the measured values of this parameter from Armandroff & Zinn (1988), Minniti (1995b) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster. To our knowledge, the age of NGC 6356 has only been estimated by Meissner & Weiss (2006, 15.0 ± 3.0 Gyr) and thus we adopt it for our compilation. Note that this result is statistically consistent with being less than the age of the Universe.

A.25. NGC 6362

Following Ha10, we use the measured metallicities from Geisler et al. (1997) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6362. In terms of its abundance pattern, we only adopt the results of Gratton (1987b), whom analysed the chemical abundances of two red giant branch stars belonging to this cluster. The Ca abundance of NGC 6362 was also measured by Smith & Perkins (1982), but we omit this result from our compilation on the grounds that they correspond to an exotic phase of stellar evolution (RR Lyrae), despite the fact that their [Fe/H] and [Ca/Fe] ratios compare well with our adopted values. The age of NGC 6362 has been determined in several other studies to date, the values from a minority of which (Buonanno et al. 1998; Piotto et al. 1999; Rosenberg et al. 1999) span a range of 13.1-15.1 Gyr for this parameter and are formally consistent with the one we have adopted (13.6 ± 0.6 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 1.1-3.6 Gyr ($>1.4\sigma$; Brocato et al. 1999; Salaris & Weiss 2002; De Angeli et al. 2005; Meissner & Weiss 2006; Dotter et al. 2010) or, worse yet, exceed the estimated age of the Universe by 2.4 Gyr (1.5σ; Alcaino & Liller 1986).

A.26. NGC 6388

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Wallerstein et al. (2007), Worley & Cottrell (2010) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for

NGC 6388. Our recommended abundance pattern for this cluster combines the results from the few studies which have focussed on the elemental abundances amongst its RGB population: Carretta et al. (2007c, 2009a) and Wallerstein et al. (2007) [N = 7, 36 and 8, respectively]. The mean [O/Fe] and [Na/Fe] ratios in our abundance pattern are distinguished by larger rms envelopes (0.25 and 0.23 dex, respectively) compared to those of other species (0.14 dex, in the median), likely on account of the fact that NGC 6388 is known to exhibit a Na-O anti-correlation. The small spread in [Mg/Fe] ratios (0.12 dex) however seems at odds with this cluster's purported Mg-Al anti-correlation (Carretta et al. 2007c, 2009a). The light abundance variations observed within NGC 6388, along with its split SGB (Moretti et al. 2009; Piotto et al. 2012) and bimodal HB (Sweigart & Catelan 1998; Busso et al. 2007; Yoon et al. 2008), provide strong evidence that it is home to multiple stellar populations. Alternative determinations of the age of this cluster have been made by Hughes et al. (2007) and Moretti et al. (2009), which together span a range of 11.5-12.0 Gyr for this parameter and are consistent with the one we have adopted (12.0 ± 1.0 Gyr).

A.27.   NGC 6441

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Clementini et al. (2005), Origlia et al. (2008) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6441. Our recommended abundance pattern for this cluster combines the results from the few studies that have focussed on the elemental abundances amongst its RGB population: Gratton et al. (2006), Gratton et al. (2007) and Origlia et al. (2008) [N = 5, 25 and 8, respectively]. Based on the Na-O and Mg-Al anti-correlations exhibited within their respective datasets, these authors argue that NGC 6441 harbours multiple stellar populations, a suggestion which coincides with the popular interpretation of a helium enhancement as the source of its highly extended (bimodal) HB (Sweigart & Catelan 1998; Layden et al. 1999; Busso et al. 2007; Caloi & D'Antona 2007; Yoon et al. 2008). The notion of multiple populations within this cluster is supported by the rather large rms spread in our compiled Na abundance (+0.41 ± 0.28 dex), while systematics may be to blame for the lack of any other abundance signature to this effect (the remaining rms values range from 0.15-0.20 dex). To our knowledge, the only age estimate available in the literature for NGC 6441 is the one we have adopted from MF09.

A.28.   NGC 6522

Following Ha10, we use the measured metallicities from Barbuy et al. (2009) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6522. Our only knowledge of the chemical abundances in this cluster comes from Barbuy et al. (2009) as well, who analysed eight of its RGB

members. We therefore adopt their results for our compilation. To our knowledge, the age of NGC 6522 has only been estimated by Meissner & Weiss (2006, 15.0 ± 1.1 Gyr) and Barbuy et al. (2009, 14.7 ± 0.4 Gyr), both of which exceed the known age of the Universe to significant degrees (1.1 and 2.3σ, respectively). Since this cluster was not part of the MF09 sample, we adopt the former estimate for our compilation, but only in a *tentative* sense on the grounds that it could suffer from unknown systematic errors relative to those of MF09.

A.29. NGC 6528

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Zoccali et al. (2004), Origlia et al. (2005), Sobeck et al. (2006) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6528. The generous error on our adopted metallicity (-0.12 ± 0.24 dex) stems from the wide spread (~ 0.6 dex) amongst the individual measurements. The few studies that have analysed the chemical composition of this cluster so far have focussed on either its RGB (Coelho et al. 2001; Origlia et al. 2005; Zoccali et al. 2004) [$N = 14$, 4 and 2, respectively] or HB (Carretta et al. 2001; Zoccali et al. 2004) [$N = 6$ and 1, respectively] populations. For our recommended abundance pattern, we combine the results from these studies, except for the C, N and Ca abundances from Zoccali, which for each species are identical amongst all three of their stars (and thus suspect). Moreover, Zoccali et al. find sub-solar abundances of Ti for two stars in their sample, which helps inflate the rather large rms envelope on our mean [Ti/Fe] ratio. Finally, since NGC 6528 was not part of the MF09 sample, we adopt the age estimated for it by Bruzual et al. (1997, 12.0 $\pm$ 2.0 Gyr) but only in a *tentative* sense on the grounds that the latter estimate could suffer from unknown systematic errors relative to those of the former. Several other age determinations appear in the literature for this cluster (Richtler et al. 1998; Ortolani et al. 2001; Feltzing & Johnson 2002; Momany et al. 2003; Brown et al. 2005), which span a range of 11.0-13.0 Gyr and are consistent with the one we have adopted. On the other hand, the age estimated by Ortolani et al. (1992) lies in excess of that estimated for the Universe by 0.24 Gyr ($\lesssim 2.2\sigma$).

A.30. NGC 6544

Little is known about the stellar population(s) of NGC 6544, except for its age and metallicity. Following Ha10, we use the measured values of this parameter from Carretta et al. (2009c) and Valenti et al. (2010) to calculate the weighted [Fe/H] for this cluster. The generous error on our adopted metallicity (-1.40 ± 0.22 dex) stems from the wide spread (~ 0.3 dex) amongst the input measurements. Since NGC 6544 was not part of the MF09 sample, we adopt the age estimated for it by De Angeli et al. (2005, 8.8 ± 1.0 Gyr), but only in a *tentative* sense on the grounds that the

latter's estimates are biased to younger values relative to those of the former.

A.31.   NGC 6553

Following Ha10, we use the measured metallicities from Barbuy et al. (1992), Meléndez et al. (2003), Alves-Brito et al. (2006) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6553. For our recommended abundance pattern, we also draw on the above works (excluding Carretta et al.) as well as Barbuy et al. (1999), Cohen et al. (1999) and Coelho et al. (2001), whom have each determined the chemistry of this cluster, largely based on its RGB population (except Coelho et al., who focussed on HB stars). These studies used samples of 1, 5, 4, 2, 5 and 8 stars, respectively. We do not include in our compilation the C or O abundances from Origlia et al. (2002) on the grounds that those results lack a rigorous definition for each of the two stars in their sample. To our knowledge, no evidence exists in the literature to suggest that NGC 6553 harbours multiple stellar populations. The large rms envelopes that we find on this cluster's mean [N/Fe] and [Na/Fe] ratios ($\geq$0.3 dex), however, might be first evidence to this effect. Finally, since NGC 6553 was not part of the MF09 sample, we adopt the age estimated for it by Bruzual et al. (1997, 12.0 ± 2.0 Gyr) but only in a *tentative* sense on the grounds that the latter estimate could suffer from unknown systematic errors relative to those of the former. Several other age determinations appear in the literature for this cluster (Demarque & Lee 1992; Ortolani et al. 1995; Beaulieu et al. 2001; Zoccali et al. 2001), which span a range of 10.5-13.2 Gyr and are consistent with the one we have adopted. On the other hand, the age determined by Guarnieri et al. (1998) lies in excess of that estimated for the Universe by 2.24 Gyr.

A.32.   NGC 6569

Following Ha10, we use the measured metallicities from Valenti et al. (2005) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6569. Our only knowledge of the chemical abundances in this cluster comes from Valenti et al. (2011) who analysed six of its RGB members. We therefore adopt their values for our compilation. We are not aware of any age determinations for NGC 6569 in the literature.

A.33.   NGC 6624

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6624. Our only knowledge of

the chemical abundances in this cluster comes from Valenti et al. (2011), who analysed five of its RGB members. We therefore adopt their results for our compilation. Alternative determinations of the age of NGC 6624 have been made by Meissner & Weiss (2006) and Dotter et al. (2010), which together span a range of 12.0-13.0 Gyr for this parameter and are consistent with the one we have adopted (12.5 ± 0.9 Gyr). In other cases, the determinations either fall below our adopted value by 1.9 Gyr (1.1σ; Salaris & Weiss 2002) or, worse yet, exceed the estimated age of the Universe by 0.2-4.2 Gyr ($\gtrsim 2.2\sigma$; Richtler et al. 1994; Heasley et al. 2000).

A.34.   NGC 6626

Our only solid knowledge about the stellar population(s) of NGC 6626 concerns its metallicity and, to a lesser extent, its age. Following Ha10, we use the measurements of the former parameter from Da Costa & Armandroff (1995) and Minniti (1995a) to calculate the weighted [Fe/H] for this cluster. Gonzalez & Lambert (1997) measured the calcium, silicon and titanium abundance for a highly-evolved and variable (post-AGB, RV Tau) star belonging to this cluster. We *tentatively* adopt their results in our compilation, given the good agreement between their measured [Fe/H] (-1.31 ± 0.10 dex) and the value we have adopted for this parameter (-1.32 ± 0.05 dex). To our knowledge, the age of NGC 6626 has only been estimated by Davidge et al. (1996, 16.0 Gyr) and Testa et al. (2001, 14.0 ± 1.1 Gyr), where the former exceeds the known age of the Universe by 2.2 Gyr. Since this cluster was not part of the MF09 sample, we adopt the latter estimate for our compilation, but only in a *tentative* sense as well on the grounds that it could suffer from unknown systematic errors relative to those of MF09.

A.35.   NGC 6637

Following Ha10, we use the measured metallicities from Minniti (1995a) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6637. In terms of its abundance pattern, we only adopt the results of Lee (2007), whom analysed the chemical abundances of two RGB and three (red) HB stars belonging to this cluster. We omit the Fe, Mg and Si abundances measured by Geisler (1984) on the grounds that they are statistically ill-defined (corresponding to a single star), lack error estimates and favour a much more metal-poor designation for the cluster (-1.21 dex, as opposed to our adopted value of -0.64 dex). Moreover, the Si abundance from Geisler is greater than our adopted value by 0.56 dex (4.7σ). Unfortunately, Lee (2007) failed to notice this discrepancy, making the precise reason(s) for it unclear; increasing Geisler's [Fe/H] value would certainly reduce the discrepancy, but at the expense of introducing a new one between their [Mg/Fe] measurement (+0.21 dex) and that of Lee (+0.28 dex). Lee (2007) found evidence of a Na-

O anti-correlation amongst their sample, which is reflected through the rather large uncertainties we quote for the mean abundances of these two species ($\sim$0.3 dex each) and agrees with the variations/bimodality in the observed CN band strengths of this cluster's RGB population (Geisler 1986; Smith 1989). Finally, the age of NGC 6637 has been determined in several other studies to date, the values from two of which (Meissner & Weiss 2006; Dotter et al. 2010) span a range of 12.5-13.2 Gyr for this parameter and are consistent with the one we have adopted (13.1 $\pm$ 0.9 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 2.5-3.2 Gyr (1.5-2.3σ; Salaris & Weiss 2002; De Angeli et al. 2005) or, worse yet, exceed the estimated age of the Universe by 0.2-4.2 Gyr ($\gtrsim$2.2σ; Richtler et al. 1994; Heasley et al. 2000).

A.36.   NGC 6638

Little is known about the stellar population(s) of NGC 6638, except for its age and metallicity. Following Ha10, we use the measured values of this parameter from Smith & Stryker (1986) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster. Since NGC 6638 was not part of the MF09 sample, we adopt the age estimated for it by Meissner & Weiss (2006, 12.0 Gyr), but only in a *tentative* sense on the grounds that it could suffer from unknown systematic errors relative to the estimates of MF09.

A.37.   NGC 6652

Our only knowledge about the stellar population(s) of NGC 6652 concerns its age and metallicity. Following Ha10, we use the measured values of this parameter from Armandroff & Zinn (1988) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for this cluster. The age of NGC 6652 has been determined in several other studies to date, the values from two of which (Chaboyer et al. 2000; Dotter et al. 2010) span a range of 11.7-13.2 Gyr for this parameter and are consistent with the one we have adopted (12.9 $\pm$ 0.8 Gyr). Exceptional cases concern those measurements which fall below our adopted value by 1.3-4.9 Gyr (1.2-3.6σ; Chaboyer & Kim 1995; Salaris & Weiss 1998, 2002; De Angeli et al. 2005; Meissner & Weiss 2006).

A.38.   NGC 6723

Following Ha10, we simply adopt the measured value of this cluster's metallicity from Carretta et al. (2009c). For its abundance pattern, we combine results from the work of Geisler (1984) and Fullton (1996) whom, respectively, measured the chemical abundances of one and three of its RGB mem-

bers. The only overlap between these two works is with regards to the ratio [Si/Fe], where they together agree that its value lies in the narrow range of $+0.64 - +0.68$ dex[13]. Since Fullton does not provide abundance information on a star-by-star basis, we opt to use their mean [Si/Fe] ratio alone in our compilation on the grounds that it carries an error estimate and is statistically more representative than Geisler's single-star measurement. The age of NGC 6723 has been determined in several other studies to date, the values from two of which (Rosenberg et al. 1999; Dotter et al. 2010) span a range of 12.8-13.2 Gyr for this parameter and are consistent with the one we have adopted (13.1 ± 0.7 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 1.5-2.5 Gyr ($1.0-1.7\sigma$; Salaris & Weiss 2002; De Angeli et al. 2005) [3.1 Gyr (4.4σ) in the case of Meissner & Weiss 2006] or, worse yet, exceed the estimated age of the Universe by 2.4 Gyr (3.4σ; Alcaíno et al. 1999).

A.39.   NGC 6752

Following Ha10, we use the measured metallicities from Beers et al. (1990), Minniti et al. (1993), Geisler et al. (1997), Cavallo et al. (2004), Yong et al. (2008b) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 6752. Our recommended abundance pattern for this cluster folds in results from several sources, the majority of which have focussed on the chemical composition of its RGB members (Bell & Dickens 1980; Carretta et al. 2007a, 2009b, 2012a; Cavallo et al. 2004; Da Costa & Cottrell 1980; Gratton et al. 1986, 2005; Minniti et al. 1996; Norris & Da Costa 1995; Pilachowski et al. 1983; Suntzeff & Smith 1991; Yong et al. 2003, 2005, 2006, 2008b) [$N = 421$], while some others have done likewise for its MS (Gratton et al. 2001; Carretta et al. 2005; Pasquini et al. 2008) [$N = 11$], SGB (Gratton et al. 2001; Carretta et al. 2005) [$N = 9$] and HB (Villanova et al. 2009) [$N = 6$] populations. The significant effort invested in analysing the chemistry of NGC 6752 has yielded many detections of anti-correlations in the abundances of several light elements amongst the members of multiple evolutionary stages (MS/RGB/HB; Cottrell & Da Costa 1981; Cavallo et al. 2004; Carretta et al. 2007a; Gratton et al. 2001; Pasquini et al. 2005; Shen et al. 2010; Villanova et al. 2009; Yong et al. 2005, 2006, 2008a,b,c). This, along with corresponding detections of a photometric split in its MS and RGB (Carretta et al. 2009a, 2011b; Milone et al. 2010), strongly suggest that NGC 6752 harbours more than one stellar population. Our recommended abundance pattern supports the idea of multiple populations within this cluster, based on the large spreads in our compiled [C/Fe] (0.37 dex), [N/Fe] (0.63 dex), [O/Fe] (0.25 dex) and [Na/Fe] (0.26 dex) ratios, compared to those for the other elements we have tabulated (0.12 dex, in the median). Abundance analyses of NGC 6752 which we excluded from our compilation in-

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[13]This agreement may be illegitimate though since Fullton find a metallicity that is lower than that from Geisler by 0.12 dex (1.3σ) and Carretta et al. by 0.16 dex (1.4σ).

clude Gratton (1987a), Glaspey et al. (1989), Pasquini et al. (2005) and Hubrig et al. (2009) either because they did not provide unique results (Gratton, Pasquini), their α-abundances strongly disagree with those from the above works (Glaspey) or their sample corresponds to an exotic stage of stellar evolution (Hubrig). Finally, the age of this cluster has been determined in several other studies to date (Richer et al. 1996; VandenBerg 2000; Salaris & Weiss 2002; De Angeli et al. 2005; Dotter et al. 2010), the values from which span a range of 11.2-13.3 Gyr for this parameter and are consistent with the one we have adopted (11.8 ± 0.6 Gyr). Exceptional cases include measurements which either exceed our adopted value by 1.9-3.0 Gyr (1.2-1.6σ; Chaboyer & Kim 1995; Buonanno et al. 1998; Rosenberg et al. 1999; Gratton et al. 2003) [$\gtrsim 1.2$ Gyr (2.0σ) in the case of Burstein et al. 1986] or fall below it by 2.2 Gyr (1.8σ; Salaris & Weiss 1998). Worse yet, the ages from Straniero & Chieffi (1991), Renzini et al. (1996) and Brown et al. (2005) lie in excess of that estimated for the Universe by 0.7-2.2 Gyr ($>2.2\sigma$).

A.40. NGC 7078

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988), Sneden et al. (1991), Minniti et al. (1993), Armosky et al. (1994), Sneden et al. (1997), Preston et al. (2006), Kirby et al. (2008), Takeda et al. (2009) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 7078. The chemical composition of this cluster has been the subject of numerous studies in the literature, albeit largely focussed on its RGB members (Armosky et al. 1994; Carretta et al. 2009a,b; Cohen 1979; Martell et al. 2008; Minniti et al. 1996; Sneden et al. 1991, 1997, 2000a,b; Sobeck et al. 2011) [$N = 163$], while similar studies of this cluster's other evolutionary stages include Cohen et al. (2005) [$N = 68$, SGB], and Behr (2003), Preston et al. (2006) and Sobeck et al. (2011) [$N = 23$ total, HB]; these results form the basis of our recommended abundance pattern. A number of studies were excluded from our compilation on the grounds that either their analysis concerned an advanced stage of stellar evolution (post-AGB; Bianchi et al. 2001; Mooney et al. 2004), their results could not be transformed into ratios of the form [X/Fe] (Trefzger et al. 1983) or they found highly sub-solar [Mg/Fe] and [Si/Fe] ratios (Jasniewicz et al. 2004). Our compiled data for NGC 7078 show relatively enhanced rms envelopes about the mean abundances for carbon (0.36 dex), nitrogen (0.63 dex) and sodium (0.34 dex), while those for other species are modest (0.08-0.23 dex) in size. We interpret this as a signature of multiple populations within this cluster. A wide variety of other evidence exists to this effect, such as CN/CH band strength variations (Pancino et al. 2010), anti-correlations of light-element abundances (Carretta et al. 2009a,b), the colour spread amongst this cluster's RGB population (Lardo et al. 2011), and a radial colour gradient (Stetson 1994; Lardo et al. 2011). Finally, the age of NGC 7078 has been determined in several other studies to date (Chaboyer & Kim 1995; Rosenberg et al. 1999; VandenBerg 2000; Dotter et al. 2010), the values from which span a range of 13.0-14.1 Gyr for this parameter and

are formally consistent with the one we have adopted (12.9 ± 0.5 Gyr). Exceptional cases concern those measurements which either fall below our adopted value by 1.2-2.5 Gyr (1.2-2.4σ; Salaris & Weiss 1998, 2002; De Angeli et al. 2005) or, worse yet, exceed the estimated age of the Universe by 1.9-3.0 Gyr (1.3-1.9σ; Richer et al. 1996; Buonanno et al. 1998).

A.41.   NGC 7089

Following Ha10, we use the measured metallicities from Armandroff & Zinn (1988) and Carretta et al. (2009c) to calculate the weighted [Fe/H] for NGC 7089. In terms of its abundance pattern, we only adopt the results of Martell et al. (2008), whom analysed the carbon abundances of six RGB stars belonging to this cluster. We omit the Fe, Mg, Ca and Ti abundances measured by Gonzalez & Lambert (1997) on the grounds that they correspond to a single, highly-evolved (post-AGB) star, and thus are likely ill-defined. Despite several lines of evidence which point towards the existence of multiple populations within this cluster, such as its split SGB and RGB, bimodal CN/CH band strengths and a positive radial colour gradient (McClure & Hesser 1981; Smith & Mateo 1990; Sohn et al. 1996; Dalessandro et al. 2009; Lardo et al. 2011; Smolinski et al. 2011; Piotto et al. 2012), the rms spread about its mean [C/Fe] ratio does not appear especially large (0.14 dex). Alternative determinations of the age of NGC 7089 have been made by Meissner & Weiss (2006) and Dotter et al. (2010), which together span a narrow range of 12.5-12.8 Gyr for this parameter and are consistent with the one we have adopted (11.8 ± 0.6 Gyr). In other cases, the determinations either fall below our adopted value by 1.9 Gyr (1.4σ; De Angeli et al. 2005) or, worse yet, exceed the estimated age of the Universe by 2.2 Gyr (Davidge 2000).