THE ASTRONOMICAL JOURNAL, 117:2213–2225, 1999 May

THE INTEGRATED SPECTRA OF M32 AND OF 47 TUCANAE: A COMPARATIVE STUDY IN THE MID-ULTRAVIOLET WITH *IUE*

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Received 1998 December 17; accepted 1999 January 20

ABSTRACT

Low-resolution mid-UV spectra of M32 and 47 Tuc have been extracted from the *IUE* archival database, along with spectra of 41 F and G dwarfs with well-determined atmospheric parameters and integrated spectra of 24 Galactic globular clusters. We have used five mid-UV spectral indices defined by Fanelli et al. to constrain the stellar content of M32 and 47 Tuc and to make a comparative study between the two stellar systems. In the case of 47 Tuc, the bulk of the mid-UV light is shown to come from the main-sequence turnoff stars, with much smaller (but significant) contributions coming from red horizontal-branch stars, red giants, and A stars (presumably, blue stragglers). In contrast, M32 is shown to have no significant contribution from a red horizontal-branch population, has a more metal-rich main-sequence turnoff, and has a significantly larger hot star contribution than is inferred to be present in 47 Tuc. These inferences are consistent with conclusions obtained from integrated light studies of M32 and 47 Tuc in the blue.

Key words: galaxies: evolution — galaxies: individual (M32) — galaxies: stellar content — globular clusters: individual (47 Tucanae)

1. INTRODUCTION

The Local Group elliptical galaxy M32 has played a key role in evolutionary studies of the stellar populations in elliptical galaxies. Due to its unusually high surface brightness nuclear region, M32 offers the best opportunity to obtain a high signal-to-noise ratio integrated spectrum of an elliptical galaxy nucleus that is almost entirely free of emission-line contamination. In addition, the fact that its central velocity dispersion is only ∼80 km s^{-1} allows for integrated light studies to be carried out at relatively high spectral resolution (2.5 Å FWHM). Consequently, many diagnostic spectral features, especially in the blue, which are compromised by Doppler broadening in giant ellipticals, can be reliably quantified in the spectrum of M32.

In addition to its unique potential for integrated light studies, M32 also provides an excellent opportunity in terms of resolving individual stars in an elliptical galaxy, thereby obtaining direct information on stellar populations that can be compared to inferences from integrated spectra. Ground-based studies (Freedman 1989, 1992; Davidge & Nieto 1992; Elston & Silva 1992) have succeeded in resolving the bright end of the giant branch (GB). Recently, *Hubble Space Telescope* (*HST*) imaging down to the horizontal-branch level has been carried out by Grillmair et al. (1996) in a field 1′–2′ from the center of M32.

The results of the above studies, while still somewhat controversial, generally indicate that there is a large intermediate-age stellar population (i.e., with an age of roughly half the Hubble time) in the central regions of M32. O'Connell (1980) first proposed the presence of such an intermediate-age population to explain the strengths of Balmer lines in the integrated spectrum of M32. All subsequent integrated light studies have consistently found that one cannot satisfactorily describe the integrated light of M32 with a single-age and single-metallicity stellar population. The controversy has largely centered over uniquely disentangling the affects of a spread in metallicity as opposed to a spread in age on the integrated spectrum, a feat that is very difficult to accomplish in a reliable manner. Nevertheless, most subsequent integrated light studies of M32 (e.g., Burstein et al. 1984; Rose 1985; Rocca-Volmerange & Guiderdoni 1987; Boulade, Rose, & Vigroux 1988; Davidge 1990; Bica, Alloin, & Schmidt 1990; Hardy et al. 1994), including the most recent one (Jones & Worthey 1995), have concluded that an intermediate-age population is present in the nucleus of this galaxy. This conclusion has been bolstered by the color-magnitude diagram (CMD) studies, which have also claimed direct evidence for intermediate-age stars (Davidge & Nieto 1992; Elston & Silva 1992; Freedman 1992). However, considerable uncertainties still remain in stellar evolution models, in population synthesis models (based on the stellar evolution models), and in the spread in metal abundance (and possible nonsolar abundance ratios) such that it may be still difficult to unambiguously determine a luminosity-weighted mean age for M32 based on the integrated light studies (e.g., Renzini & Buzzoni 1986).

A way to circumvent some of the difficulties involved in accurately modeling the integrated light of M32 is to compare its spectrum with the integrated spectrum of another, similar, stellar system whose properties are better understood and whose stellar population is homogeneous in age and metallicity. By working differentially, some of the problems involved in absolute age determinations can be avoided. Furthermore, differences in integrated light properties can be easier to interpret in terms of reference stellar libraries, as opposed to directly fitting line indices and spectral energy distributions. Bica & Alloin (1986) and Burstein et al. (1984) have especially emphasized the utility of comparing the integrated spectra of galaxies with those of Galactic star clusters. In the case of elliptical galaxies, metal-rich Galactic globular clusters offer an excellent opportunity to provide a reference stellar system. The metal-rich globular cluster 47 Tuc has an exceptionally high core surface brightness, thus providing a stellar system that can be studied in integrated light at a signal-to-noise ratio that matches M32. In fact, Rose (1994) already exploited this situation in his comparative study of M32 and 47 Tuc in the blue spectral region.

In this paper we compare the integrated light of M32 and 47 Tuc in the mid-UV using archival spectra from the *International Ultraviolet Explorer* (*IUE*). The advantage in turning now to the mid-UV in comparing M32 and 47 Tuc is that the main-sequence turnoff (MSTO) light should make its maximum contribution to the integrated light of these relatively old and metal-rich stellar systems in the mid-UV wavelength interval. An early characterization of the UV-optical color of M32 by Burstein et al. (1984), followed by subsequent studies of *IUE* spectra of M32 in the mid-UV (Rocca-Volmerange & Guiderdoni 1987; Kjaergaard 1987; Burstein et al. 1988 and references therein; Buson, Bertola, & Burnstein (1990); Worthey, Dorman, & Jones 1996) have indeed established the dominance of MSTO light there. To make an effective comparison between M32 and 47 Tuc requires a reference framework of mid-UV stellar spectra, which is available from the *IUE* archive. Fanelli et al. (1990) laid the groundwork for such a spectral database by analyzing the spectra of a large number of stars with observed *IUE* spectra and defined a number of diagnostic spectral indices that are used as the basis for our present study. At the time of the Fanelli et al. (1990) study, a sample of bright F stars with high-quality and homogeneous abundance determinations was not available, thereby restricting the degree to which they could evaluate the effect of metallicity in their spectral indices. As has been mentioned above, to convincingly sort out the thorny question of age versus metallicity in M32 requires a full understanding of the effects of metallicity on the spectra of MSTO stars in intermediate and old populations (i.e., F stars). Subsequent to the Fanelli et al. (1990) paper, a study has been carried out by Edvardsson et al. (1993) of a large number of F and early G stars in the Galactic disk, covering a range in metal abundance. As a result, a truly homogeneous and high-quality set of metal abundance determinations for F stars of a variety of metallicity has been provided. Fortunately, a substantial number of the Edvardsson et al. (1993) stars have also been observed with *IUE*. Hence in this paper we can revisit the metallicity effect on the Fanelli et al. (1990) spectral indices in more detail.

The outline of the paper is as follows: In § 2, we discuss the *IUE* stellar database that is used for the present study, as well as the spectra of M32, 47 Tuc, and also a library of other Galactic globular cluster spectra. In § 3, we present the results for the stellar library, with particular attention to the effect of metallicity on the Fanelli et al. (1990) spectral indices for the Edvardsson et al. (1993) F star sample, and in § 4, we briefly discuss the sequence of globular cluster spectra. In § 5, a detailed comparison is made between the mid-UV spectra of M32 and 47 Tuc, using the observed behavior of the spectral indices from § 3, as a guide to understanding the differences found between M32 and 47 Tuc. Our conclusions are stated in § 6.

2. *IUE* OBSERVATIONAL DATABASE

2.1. *Stellar Database*

The key stellar database for our study consists of archival *IUE* low-resolution spectra with the long-wavelength camera of the FG dwarfs that are in common with the Edvardsson et al. (1993) list. Of 189 Edvardsson et al. (1993) stars, 50 have been observed with *IUE* at low spectral resolution in the mid-UV. We dropped seven stars with poor-quality *IUE* spectra and two subgiants, hence the final list consists of 41 FG dwarfs with good-quality *IUE* spectra. Most of these stars were observed only once with *IUE*, but a few of them were observed twice or more, in which case the best quality data were chosen according to the *IUE* quality flag and visual examination. The final list of these stars is given in Table 1. The stellar parameters $T_{\rm eff}$ and [Fe/H] given in Table 1 were obtained from Edvardsson et al. (1993), while the $B-V$ colors and V magnitudes were obtained from Hoffleit (1982) or from the on-line *Hipparcos* Catalog. The typical error in [Fe/H] is ∼0.1 dex (Edvardsson et al. 1993). Since all of the Edvardsson et al. (1993) stars are bright, hence nearby, stars, the effect of interstellar extinction on the mid-UV spectrum should be negligible, and thus no extinction correction was made for these stars.

In addition to the database in common with the Edvardsson et al. (1993) sample, we augmented our library of FG dwarfs with other *IUE* archival spectra from the Fanelli et al. (1990) sample, which have $0.4 < B-V < 0.7$, known [Fe/H] values, and are not already in the Edvardsson et al. sample. These stars are listed in Table 2. Furthermore, to enable us to carry out a crude spectral synthesis of 47 Tuc and M32 in integrated light, we augmented the stellar library with a number of stars covering other regions of the HR diagram that may make significant contributions to their mid-UV integrated spectra. Specifically, we extracted several archival spectra of solar metallicity GK giants, "metal-poor" giants (with [Fe/H] ~ -0.7), and several A5–A7 dwarfs (to simulate the effect of blue stragglers). Finally, to simulate the effect of the red horizontal branch (RHB) in 47 Tuc, we obtained a single 3 minute exposure (LWP31779) of the field RHB star HD 79452 in the mid-UV with the long-wavelength camera on 1995 January 12. HD 79452 is a G5III star with [Fe/H] of -0.85 (Helfer & Wallerstein 1968) and thus appears to be a local field counterpart to the RHB stars in "metal-rich" Galactic globular clusters such as 47 Tuc and M71.

2.2. *Globular Cluster Database*

From a search of the *IUE* archival database 32 Galactic globular clusters were identified that have been observed by *IUE* in their core regions. After checking the quality of the data, we selected 24 clusters with good-quality mid-UV data. Most of the clusters have only a single observation, but for the ones with multiple observations, the co-added spectra were used. Of particular note, we found seven individual spectra for 47 Tuc. In Table 3 are listed the globular clusters selected for this study, along with their integrated $B-V$ colors (not corrected for reddening) and $E(B-V)$ values, taken from Peterson (1993), and their [Fe/H] values, taken from Djorgovski (1993). Since the *IUE* aperture of $10'' \times 20''$ covers a fairly large region of the cores of most clusters, the spectra are representative of the integrated mid-UV light of cluster cores. All of the spectra were individually corrected for interstellar extinction by using the Cardelli, Clayton, & Mathis (1989) reddening curve, as updated in the near-UV by O'Donnell (1994), with the $E(B-V)$ as obtained from Peterson (1993), and an assumed value of total-to-selective absorption of 3:1.

From the *IUE* archive we also extracted five spectra of the elliptical galaxy M32. These spectra were also dered-

TABLE 1

EDVARDSSON ET AL. (1993) FG DWARFS

Star	$B-V$	[Fe/H]	C26−30	2609/2660	2828/2923	Mg II 2800	Mg I 2852	Ca II (S)
HD 4307	0.60	−0.28	1.71	1.21	0.58	1.12	0.41	...
HD 4614	0.57	−0.31	1.36	1.08	0.38	0.87[a]	0.38	0.159
HD 16673	0.52	0.02	1.34	0.94	0.44	0.93	0.37	0.216
HD 22001	0.40	−0.11	0.94	0.63	0.18	0.71	0.15	...
HD 22879	0.55	−0.84	1.08	0.84	0.42	1.29	0.39	...
HD 39587	0.59	−0.03	1.51	0.97	0.52	0.78	0.39	0.307
HD 43318	0.50	−0.17	1.35	1.05	0.37	1.02	0.23	...
HD 55575	0.58	−0.28	1.57	1.11	0.55	1.14	0.40	Low
HD 61421	0.42	−0.02	1.14	0.84	0.29	...	0.22	0.187
HD 69897	0.47	−0.26	1.21	0.96	0.36	1.04	0.28	0.154
HD 76151	0.67	0.01	1.73	0.93	0.66	0.72	0.60	0.261
HD 76932	0.53	−0.82	1.05	0.90	0.33	1.28	0.33	...
HD 82328	0.46	−0.20	1.18	0.98	0.32	1.00	0.22	0.181
HD 86728	0.66	0.10	2.00	0.95	0.73	0.91	0.56	0.156
HD 95128	0.61	0.01	1.62	0.81	0.61	...	0.41	0.165
HD 102870......	0.55	0.13	1.56	0.99	0.49	0.95[a]	0.33	Low
HD 106516......	0.46	−0.70	0.92	0.70	0.27	1.10	0.25	0.209
HD 109358......	0.59	−0.19	1.58	1.06	0.40	...	0.41	0.177
HD 110897......	0.55	−0.59	1.37	1.09	0.47	1.15	0.43	0.159
HD 114710......	0.57	0.03	1.71	1.11	0.55	0.92	0.41	0.200
HD 114762......	0.54	−0.74	1.17	0.90	0.43	1.17	0.33	...
HD 115383......	0.59	0.10	1.48	0.79	0.51	0.84	0.43	0.312
HD 115617......	0.71	−0.03	2.03	0.97	0.74	0.87	0.69	0.161
HD 128620......	0.71	0.15	1.90	0.96	0.71	...	0.43	...
HD 141004......	0.60	−0.04	1.75	1.25	0.59	1.01	0.39	0.159
HD 142373......	0.56	−0.52	1.45	1.12	0.46	1.23	0.35	0.144
HD 142860......	0.48	−0.16	1.37	1.00	0.33	1.03	0.28	0.156
HD 143761......	0.60	−0.26	1.64	1.21	0.63	1.07	0.45	0.148
HD 153597......	0.48	−0.17	1.29	0.97	0.31	0.86	0.30	0.218
HD 157089......	0.55	−0.59	1.35	1.04	0.51	1.17	0.40	...
HD 157214......	0.62	−0.41	1.56	1.11	0.72	1.07	0.58	0.156
HD 165908......	0.52	−0.56	1.14	0.98	0.31	1.11	0.31	...
HD 173667......	0.46	−0.11	1.20	0.85	0.38	0.84	0.17	0.190
HD 187691......	0.55	0.09	1.72	1.07	0.51	1.02	0.34	0.148
HD 201891......	0.51	−1.06	0.95	0.75	0.32	1.17	0.31	...
HD 207978......	0.42	−0.66	0.95	0.73	0.17	0.96	0.21	0.153
HD 208906......	0.50	−0.72	1.09	0.97	0.32	1.10	0.31	...
HD 215648......	0.50	−0.32	1.34	1.04	0.33	1.07	0.26	0.141
HD 216385......	0.48	−0.25	1.33	1.04	0.33	1.05	0.23	0.142
HD 217014......	0.67	0.06	1.98	1.00	0.73	0.91	0.52	0.155
HD 222368......	0.51	−0.17	1.46	1.09	0.38	1.05	0.28	0.152

[a] Adjusted Mg II 2800 values from Fanelli et al. 1990.

TABLE 2

FANELLI ET AL. (1993) FG DWARFS

Star	$B-V$	[Fe/H]	C26−30	2609/2660	2828/2923	Mg II 2800	Mg I 2852	Ca II (S)
HD 1461	0.68	0.33	2.01	0.98	0.71	0.87	0.55	...
HD 14802	0.60	0.00	1.78	1.14	0.56	1.05	0.38	...
HD 27561	0.41	0.15	1.18	0.81	0.23	0.77	0.22	...
HD 30455	0.62	−0.18	1.60	1.16	0.65	1.16	0.49	...
HD 48682	0.56	0.15	1.73	1.08	0.52	0.99	0.39	0.158
HD 90508	0.60	−0.23	1.65	1.16	0.59	1.13	0.22	0.167
HD 152792......	0.65	−0.38	1.69	1.23	0.55	1.19	0.43	...
HD 187923......	0.65	0.06	1.85	1.13	0.71	1.09	0.51	...
HD 197076......	0.63	−0.08	1.83	1.13	0.66	0.99	0.49	0.171
HD 210027......	0.44	−0.10	1.16	0.90	0.21	0.91	0.21	...
HD 217877......	0.58	−0.31	1.71	1.21	0.57	1.07	0.34	...
HD 224930......	0.67	−0.90	1.52	1.05	0.66	1.12	0.69	0.178

TABLE 3

Galactic Globular Clusters

Cluster	$B-V$	$E(B-V)$	[Fe/H]	C26−30	2609/2660	2828/2923	Mg II 2800	Mg I 2852
NGC 104	0.88	0.04	−0.71	1.35	0.88	0.55	1.06	0.45
NGC 362	0.78	0.04	−1.28	0.74	0.53	0.29	0.67	0.20
NGC 1904......	0.64	0.01	−1.69	0.40	0.29	0.12	0.45	0.11
NGC 2808......	0.90	0.24	−1.37	0.60	0.65	0.31	0.67	0.15
NGC 5139......	0.80	0.15	−1.59	0.50	0.37	0.10	0.51	0.12
NGC 5272......	0.69	0.01	−1.66	0.85	0.48	0.19	0.70	0.10
NGC 5904......	0.71	0.03	−1.40	0.59	0.47	0.28	0.50	0.21
NGC 6093......	0.84	0.20	−1.64	0.39	0.29	0.16	0.45	0.10
NGC 6205......	0.67	0.02	−1.65	0.45	0.31	0.13	0.44	0.13
NGC 6266......	1.19	0.50	−1.28	0.51	0.42	0.24	0.54	0.22
NGC 6284......	1.01	0.28	−1.40	0.40	0.28	0.16	0.54	0.12
NGC 6293......	0.96	0.36	−1.92	0.46	0.27	0.13	0.35	0.14
NGC 6341......	0.62	0.02	−2.24	0.40	0.17	0.10	0.29	0.11
NGC 6388......	1.18	0.34	−0.60	1.10	0.82	0.49	0.73	0.23
NGC 6441......	1.27	0.42	−0.53	1.39	1.42	0.72	0.83	0.41
NGC 6624......	1.11	0.28	−0.37	0.94	0.48	0.60	0.96	0.45
NGC 6637......	1.02	0.18	−0.59	1.15	0.82	0.50	0.98	0.26
NGC 6681......	0.72	0.06	−1.51	0.46	0.27	0.16	0.49	0.18
NGC 6715......	0.85	0.15	−1.42	0.60	0.44	0.17	0.56	0.20
NGC 6752......	0.67	0.04	−1.54	0.42	0.33	0.20	0.55	0.11
NGC 6864......	0.87	0.16	−1.32	0.89	0.58	0.11	0.62	0.29
NGC 7078......	0.68	0.05	−2.17	0.47	0.23	0.12	0.33	0.12
NGC 7089......	0.67	0.02	−1.58	0.45	0.32	0.12	0.49	0.16
NGC 7099......	0.60	0.05	−2.13	0.31	0.20	0.02	0.32	0.09

dened according to the above reddening curve for $E(B-V) = 0.08$, where we have adopted the reddening to M32 advocated by Burstein et al. (1984). The composite of the five dereddened M32 spectra is compared with that of the seven dereddened 47 Tuc spectra in Figure 1.

2.3. *Mid-UV Spectral Indicators*

In their comprehensive paper on the mid-UV behavior of stellar spectra, Fanelli et al. defined more than 10 spectral indices for their large sample of long-wavelength camera *IUE* spectra. After checking our data we found that the Fanelli et al. indices most useful for the FG dwarfs are the Mg II 2800 and Mg I 2852 equivalent width indices, the 2609/2660 and 2828/2923 spectral break indices, and the C26−30 color. The latter color is formed from bandpasses at 2600 and 3000 Å that are each 200 Å wide.

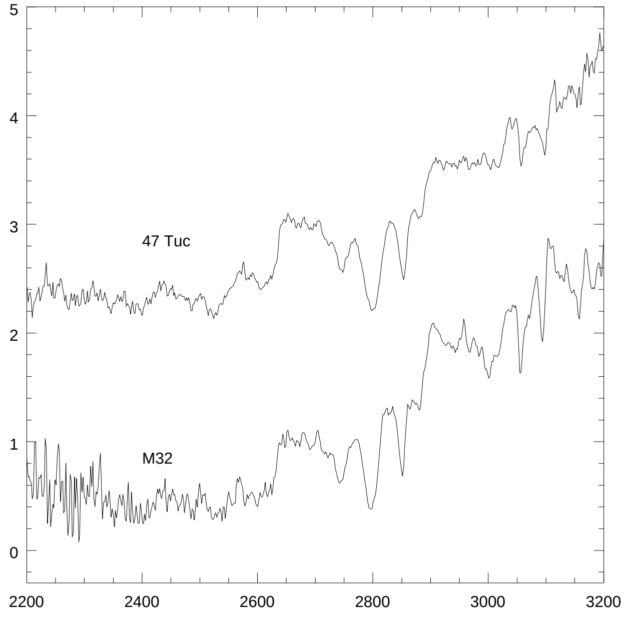

Fig. 1.—Dereddened *IUE* mid-UV spectra of M32 and 47 Tuc plotted in relative intensity units with the 47 Tuc spectrum offset for ease of comparison.

There are 11 stars in the Edvardsson et al. (1993) sample that also have published index values in Fanelli et al. (1990). This overlap allowed us to check how closely our determinations of Fanelli et al. indices agree with the actual Fanelli et al. (1990) published values. We obtained essentially indistinguishable results as Fanelli et al., except in the case of the Mg II 2800 index, for which we obtain a systematically larger value by 0.07, and with a scatter of ±0.03. This small offset does not present a problem, especially since we do all Mg II 2800 index calculations within our own measuring system. However, there are two Edvardsson et al. stars (HD 4614 and HD 102870) for which we did not measure Mg II 2800 values, due to a bad pixel, but for which Fanelli et al. (1990) did provide values. We added 0.07 to the Fanelli et al. values and used those adjusted values in Table 1.

Errors in the spectral indices of the Edvardsson et al. (1993) and Fanelli et al. (1990) stars clearly vary from one star to another, depending upon the exposure level in a particular spectrum. However, to obtain a general estimate of the typical errors in spectral indices for these stars, we looked at a subsample for which multiple observations exist in the archive. We calculated the rms scatter in the spectral indices for each star for which multiple observations exist and then determined the average rms error for the sample. We find that the typical error in the five indices considered in this paper is roughly ±0.03, except for the Mg II 2800 index, for which we find a typical error of ∼ ±0.06.

Errors in the spectral indices of 47 Tuc and M32 were also directly estimated from the dispersions in the index values obtained from the multiple spectra of each of these objects, seven in the case of 47 Tuc and five in the case of

M32. The final error for each index was then the dispersion divided by the square root of the number of exposures. For a few indices it was found that one value deviated by more than 3 σ from the other values. In that case we rejected the one discordant value in calculating the mean index and its error. Data on the spectral indices of 47 Tuc and M32, and on their errors, is presented in Table 4. It can be seen there that the errors are small, typically ± 0.02 for 47 Tuc and slightly larger for M32.

Errors in the spectral indices of the other Galactic globular clusters are not so well defined, especially since there is a considerable range in quality from one cluster spectrum to another and because there were not enough multiple observations to obtain a good representative error. In addition, although for most of the clusters the aperture of the *IUE* spectrograph encompasses a large fraction of the core radius of the cluster, in a few cases the aperture size is small enough that sampling errors could be a problem. Thus for the most part the sample of globular cluster indices is used here to define a principal sequence, with little quantitative handle on the source of scatter around that sequence.

Finally, as was pointed out by Fanelli et al. (1990) and further investigated by Smith et al. (1991), the Mg II 2800 index is sensitive to emission fill-in from chromospheric activity in young stars. Because this index will be seen below to be particularly effective for population studies, it is important to isolate a restricted sample of the Edvardsson et al. and Fanelli et al. stars for which data on chromospheric activity indicates little problem with emission fill-in. We used the mean S index in the Duncan et al. (1991) database on Ca II emission measurements to flag stars with enhanced activity levels. All stars with $S > 0.18$ were excluded from our restricted sample. For reference, the solar activity level is ~ 0.18 on average, while the Hyades, Pleiades, and Praesepe are typically ~ 0.3–0.5. Hence our restricted sample should be almost free from emission contamination in the Mg II 2800 index, except that a few stars for which no Duncan et al. (1991) S-measurements are available, might have high activity levels and were not excluded from the sample. The other indices discussed below do not appear to be appreciably affected by chromospheric activity.

3. RESULTS FOR FG DWARFS

Given the extremely homogeneous and high-quality nature of the Edvardsson et al. (1993) sample, we can now reexamine the effects of effective temperature and metal abundance on the mid-UV spectra of F and early G stars. As mentioned in § 1, such an analysis has implications for the study of stellar populations in integrated light. In the remainder of this section we plot the behavior of the five Fanelli et al. (1990) indices used in this study for the restricted F and early G spectral range. Hence we focus on the behavior of the indices in this narrow spectral range and only make qualitative summaries as to their behavior at other spectral types. To see plots of these indices over a full range of spectral types, the reader is referred to the Fanelli et al. (1990) paper.

In Figure 2*a* are plotted the C26−30 color indices versus $T_{\rm eff}$ for the entire sample of Edvardsson et al. (1993) stars for which we found *IUE* spectra. Different symbols correspond to different metallicity intervals. The strong temperature and metallicity dependence of this index is evident from the figure. In Figure 2*b* the C26−30 color is plotted against $B-V$ color, producing a similar result. However, due to the dependence of $B-V$ itself on [Fe/H], which is caused by line blanketing, a weaker metallicity dependence is evident.

Fanelli et al. (1990) and Smith et al. (1991) demonstrated that the Mg II 2800 index rises monotonically from early-type stars up through the late F stars and then declines toward later spectral type. The fact that this index peaks so sharply among the late F stars, which is the spectral type of the MSTO of solar abundance intermediate age (i.e., ~ 5 Gyr old) populations is potentially useful as a diagnostic tool for establishing the presence of intermediate-age stars. Furthermore, Fanelli et al. and Smith et al. showed that chromospheric activity in young stars contaminates the Mg II 2800 index with emission fill-in. Thus if a stellar framework is to be established for understanding the integrated Mg II 2800 index in intermediate- to old-age stellar populations, it is important to select only those stars that do not suffer from high levels of chromospheric activity. Consequently, in discussing the Mg II 2800 index, we have eliminated from consideration all Edvardsson et al. (1993) and Fanelli et al. (1990) stars whose chromospheric activity levels, as monitored by the S index, exceeds that of the Sun, which has a mean value of ~ 0.18. In Figure 3*a* are plotted the 28 Edvardsson et al. (1993) stars with low (or unknown) activity levels versus $B-V$ color. To further increase the number of stars, in Figure 3*b* we have added in the 12 Fanelli et al. (1990) stars with known [Fe/H] that satisfy the chromospheric activity level criterion. As was pointed out in Fanelli et al. (1990) and further noted in Smith et al. (1991), there is a well-defined inverse metallicity effect on

TABLE 4

INDICES FOR M32, 47 TUCANAE, AND COMPOSITE POPULATIONS

Object	C26−30	26009/2660	2828/2923	Mg II 2800	Mg I 2852
47 Tuc: observed indices	1.33 ± 0.02	0.91 ± 0.02	0.58 ± 0.01	1.05 ± 0.01	0.44 ± 0.02
47 Tuc: optimum model	1.34	0.94	0.49	1.03	0.42
M32: observed indices	1.49 ± 0.03	0.79 ± 0.06	0.49 ± 0.03	0.76 ± 0.02	0.39 ± 0.04
M32: optimum model (without PAGB)	1.41	0.81	0.52	0.79	0.38
M32: optimum model (with PAGB)	1.40	0.80	0.52	0.76	0.38
Solar MSTO	1.54	1.13	0.45	1.02	0.34
Metal-poor MSTO	1.19	1.00	0.39	1.19	0.36
Solar RGB	2.64	0.89	1.06	0.64	0.91
Metal-poor RGB	2.44	1.06	0.99	0.92	0.78
RHB	2.10	1.35	0.90	1.09	0.57
BS (A5V–A7V)	0.41	0.42	0.04	0.41	0.16
Metal-poor globular cluster	0.47	0.33	0.15	0.50	0.15

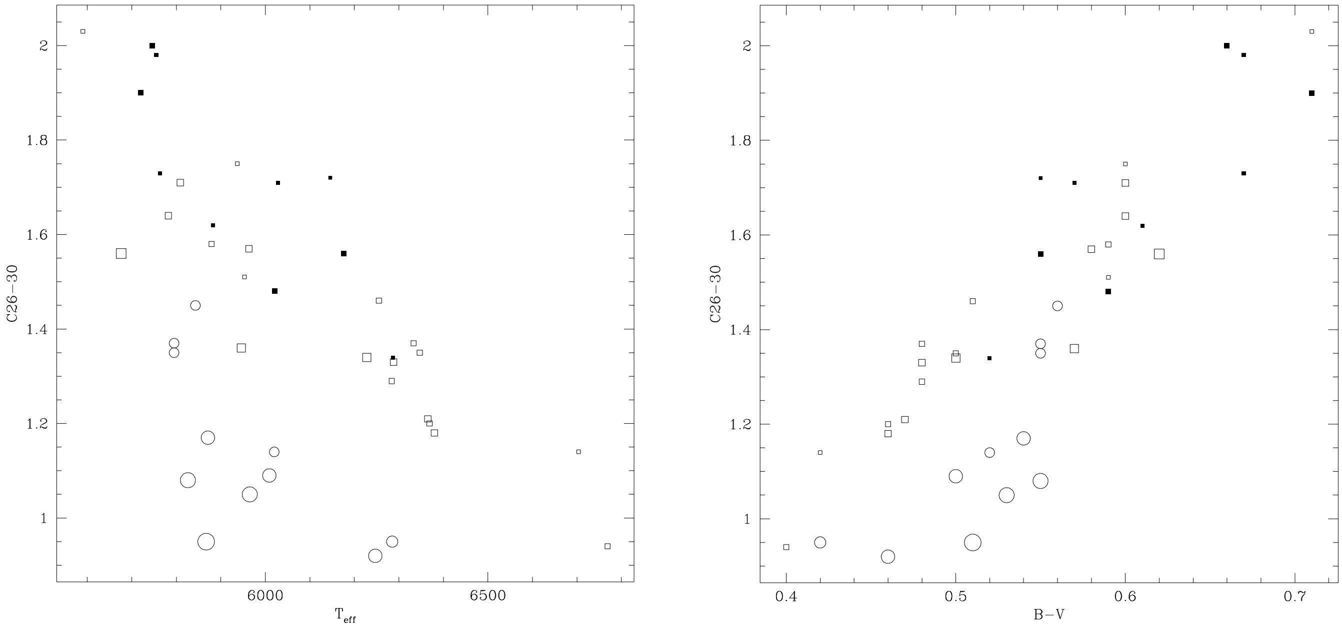

FIG. 2*a*

FIG. 2*b*

FIG. 2.—(*a*) C26 − 30 index plotted versus $T_{\rm eff}$ for Edvardsson et al. stars. Different symbols correspond to different metal abundances. Filled symbols indicate above solar metallicity, while open symbols denote below solar metallicity. Open squares are for stars with 0.0 ≥ [Fe/H] ≥ −0.5; open circles have [Fe/H] < −0.5. The size of the symbol indicates the degree of nonsolar metallicity of the star for its particular symbol; the larger the symbol, the more nonsolar is the metal abundance. (*b*) C26 − 30 index plotted versus $B-V$ for Edvardsson et al. (1993) stars. The symbols are as in (*a*).

Mg II 2800 near its peak value for $B-V \sim 0.55$, i.e., Mg II 2800 is actually higher for lower metallicity stars. This *inverse* metallicity dependence, which amounts to ∼0.25 in the Mg II 2800 index of late F and early G dwarfs, thus provides a constraint on the metallicity of the MSTO stars in the integrated light of intermediate- and old-age galaxies and star clusters.

The other three Fanelli et al. (1990) indices are plotted versus $B-V$ in Figures 4*a*–4*c* for all 41 Edvardsson et al. (1993) stars. In Figures 5*a*–5*c* the same indices are plotted for the low chromospheric activity sample of 28 Edvardsson et al. (1993) stars and 12 Fanelli et al. (1990) stars. The 2828/2923 break index and the Mg I 2852 index closely tracks $B-V$, with no metallicity separation, in the $B-V$ region covered by these stars. Fanelli et al. (1990) showed that in fact these two indices track $B-V$ out to $B-V \sim 1.0$ before flattening out and then dropping at higher $B-V$ values. The 2609/2660 index shows similarity in behavior to

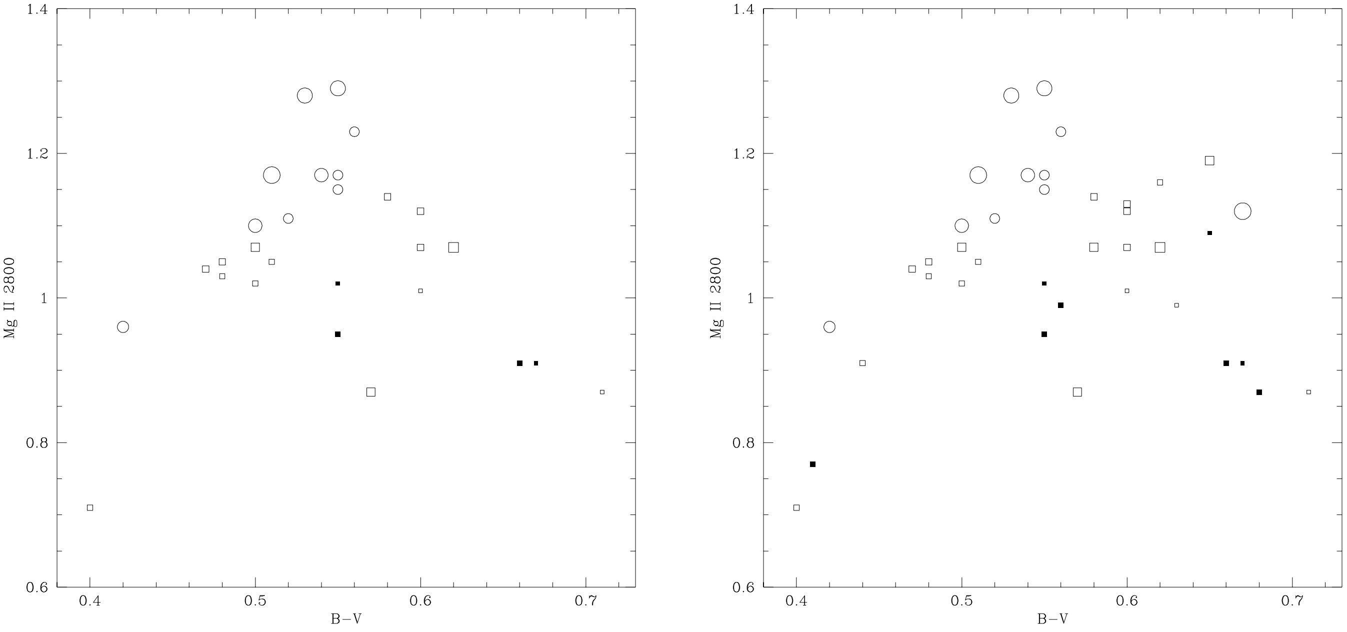

FIG. 3*a*

FIG. 3*b*

FIG. 3.—(*a*) Mg II 2800 index plotted versus $B-V$ for Edvardsson et al. (1993) stars with low chromospheric activity. Same symbols as in Fig. 2*a*. (*b*) Mg II 2800 index plotted versus $B-V$ for both Edvardsson et al. (1993) and Fanelli et al. (1990) stars with low chromospheric activity. Same symbols as in Fig. 2*a*.

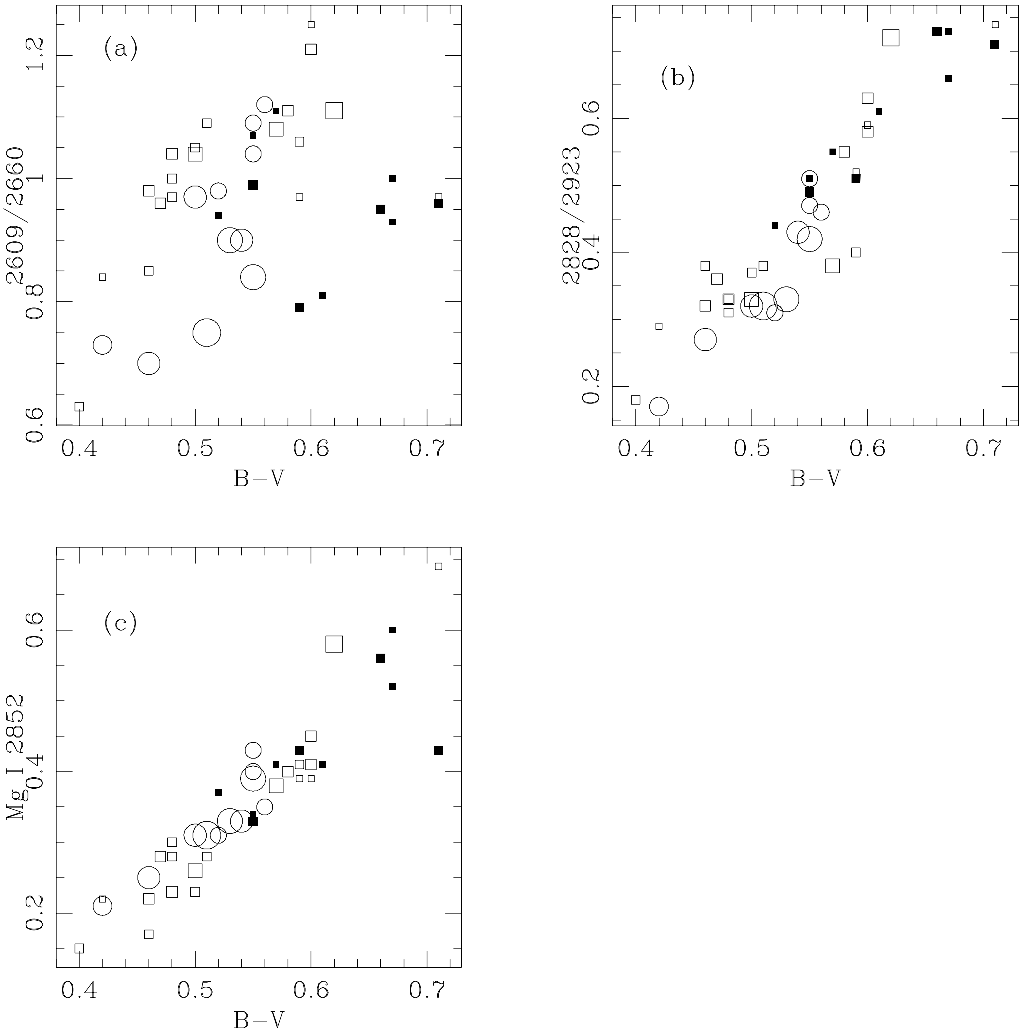

FIG. 4.—(*a*) 2609/2660, (*b*) 2828/2923, and (*c*) Mg I 2852 indices are plotted versus $B-V$ for all Edvardsson et al. (1993) stars. The symbols are as in Fig. 2*a*.

Mg II 2800, in that it peaks among the early G stars, at $B-V \sim 0.6$, and then drops toward higher $B-V$, a trend that is seen over a larger $B-V$ range in Fanelli et al. (1990). There is a large amount of scatter around the general relation, but no clear trend with metallicity, and certainly no indication of the kind of inverse metallicity trend seen in the Mg II 2800 index. There is also no clear signature of an influence from chromospheric activity on the 2609/2660, 2828/2923, and Mg I 2852 indices.

4. RESULTS FOR GALACTIC GLOBULAR CLUSTERS

Since the primary goal of this paper is to compare in detail the mid-UV spectra of M32 and 47 Tuc, before making that comparison we first consider 47 Tuc in the context of other Galactic globular clusters. Specifically, is 47 Tuc representative of "metal-rich" Galactic globulars? To answer this question we have plotted spectral indices of the archival sample of Galactic globulars versus their [Fe/H] values. We thus evaluate whether the integrated indices exhibit monotonic behavior with [Fe/H] and whether 47 Tuc exhibits behavior typical for a "metal-rich" cluster.

Given the important role that the Mg II 2800 index will play in the subsequent comparison between M32 and 47 Tuc, we begin with that index. In Figure 6 are plotted the Mg II 2800 indices of the Galactic globular clusters versus their known [Fe/H] values. The index exhibits a monotonic rise with [Fe/H] up to the [Fe/H] of 47 Tuc; at higher metallicity it flattens out and then drops to lower values. This behavior can be readily understood from the previous discussion of the stellar indices, where it was found that the Mg II 2800 indices of dwarfs rises with increasing $B-V$ until it peaks at $B-V \sim 0.55$ and then declines toward higher $B-V$. Furthermore, the peak value of Mg II 2800 at $B-V = 0.55$ depends inversely on the stellar metallicity. In comparison, the MSTO of a ∼15 Gyr population is at $B-V \sim 0.38$ for $[\mathrm{Fe/H}] = -1.5$, and rises to $B-V \sim 0.55$ at $[\mathrm{Fe/H}] = -0.7$, then increases to higher $B-V$ for higher metallicity. Thus we can explain the dependence of the integrated Mg II 2800 indices of globular clusters very simply in terms of the Mg II 2800 dependence of their MSTO, i.e., there is no necessity to bring in the horizontal-branch properties of the clusters to explain the overall observed trend in Mg II 2800 with [Fe/H]. However, at a given [Fe/H] there is considerable scatter in Mg II 2800 among individual clusters. How much of this scatter may result from differences in horizontal-branch morphology, as opposed to observational error, is difficult to assess, given the poor knowledge of the observational errors for the globular clusters. To look for the influence of horizontal-

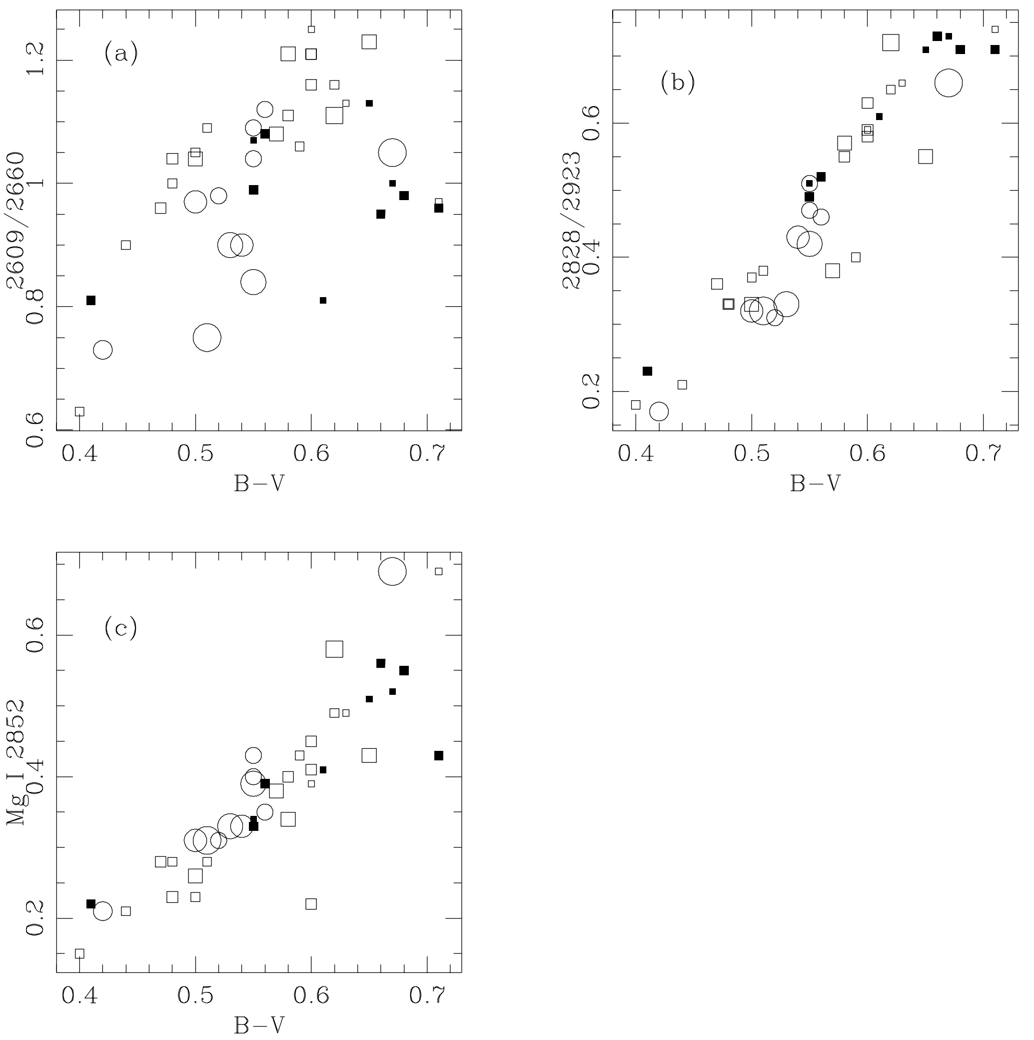

FIG. 5.—(*a*) 2609/2660, (*b*) 2828/2923, and (*c*) Mg I 2852 indices are plotted versus $B-V$ for both Edvardsson et al. (1993) and Fanelli et al. (1990) stars with low chromospheric activity. The symbols are as in Fig. 2*a*.

branch morphology, we examined pairs of clusters with large horizontal-branch morphology differences, especially those clusters in the "intermediate" metallicity range, $-1.6 < [\mathrm{Fe/H}] < -1.2$, for which the second-parameter problem in globular cluster horizontal-branch morphology is so pronounced. We used the $(B-R)/(B+V+R)$ parameter of Lee, Demarque, & Zinn (1994) to characterize the cluster horizontal-branch morphologies. While on the one hand, NGC 5272 has a higher Mg II 2800 index and redder horizontal branch than NGC 6093 and NGC 6205, on the other hand NGC 2808 has higher Mg II 2800 and bluer horizontal branch than NGC 5904. NGC 362 also has a higher Mg II 2800 and bluer horizontal branch than NGC 6266. Thus no consistent correlation between horizontal-branch morphology and Mg II 2800 is evident from our data.

In contrast to Mg II 2800, the 2828/2923 index shows the most monotonic stellar behavior in the sense that the index systematically increases toward later spectral type, only flattening out at $B-V = 1.0$ and then eventually dropping beyond $B-V \sim 1.2$ (cf., Fig. 8*b* of Fanelli et al.). A plot of 2828/2923 versus metallicity in Figure 7 reveals that the globular clusters also appear to exhibit a monotonic behavior with [Fe/H]. Thus again we can readily explain the mid-UV indices of Galactic globular clusters primarily in terms of the MSTO contribution to their integrated light.

Plots of the other mid-UV spectral indices versus [Fe/H] also show a basic trend with metallicity. In summary, the Galactic globular clusters have mid-UV indices that for the most part correlate well with [Fe/H]. However, at the "metal-rich" end (i.e., above $[\mathrm{Fe/H}] = -0.7$), the trend between index and [Fe/H] is not so clear, especially for the Mg II 2800 index. Furthermore, in all cases 47 Tuc appears to show behavior characteristic of the other "metal-rich" globulars, thus it can be used as a representative benchmark for M32.

5. MID-UV COMPARISON OF M32 AND 47 TUCANAE

We now turn to the main goal of this paper, a comparison of the mid-UV spectra of 47 Tuc and M32. A look at the spectral indices of these two objects, as listed in Table 4, reveals typical differences of ~ 0.1 for all but Mg II 2800, where the difference of 0.3 is much larger. Given the small errors in the indices of both 47 Tuc and M32, even differences at the 0.1 level are significant and thus perhaps indicate fundamental differences between the "metal-rich" globular cluster and the elliptical galaxy. To understand the 47 Tuc versus M32 comparison, in what follows we first

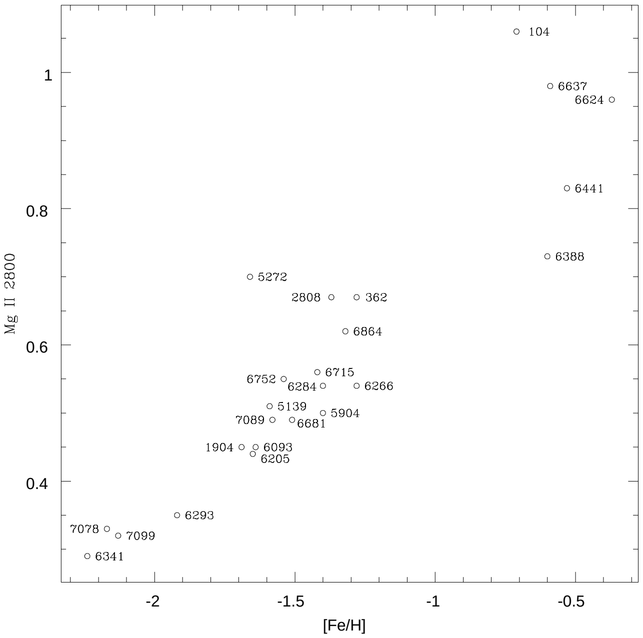

FIG. 6.—Mg II 2800 indices plotted versus [Fe/H] for the Galactic globular clusters.

make a simple model of 47 Tuc and demonstrate how the mid-UV spectral indices place tight constraints on that model. Then we make a similar examination of M32, with emphasis on the ways in which M32 differs from 47 Tuc.

5.1. *Model for 47 Tuc*

To interpret the nature of the spectral indices in 47 Tuc, we have generated a number of composite spectra using the stellar library. A simple model can be made for 47 Tuc by assuming that its integrated mid-UV light is contributed to by four populations: an MSTO population with [Fe/H] ∼ −0.7, a GB population of similar metallicity, an RHB population, and a blue straggler (BS) component that has been detected in the core of 47 Tuc by Paresce et al. (1991) and Guhathakurta et al. (1992). We have constructed these four populations by taking the composite spectrum of seven late F dwarfs with [Fe/H] ∼ −0.7 to represent the MSTO component, the composite of four late G giants with [Fe/H] ∼ −0.7 to represent the GB component, the spectrum of HD 79452 to represent the RHB component, and the composite of five A5–A7 stars to represent the BS component. Spectral indices for these four components are given in Table 4 and are listed as "Metal-poor MSTO," "Metal-poor RGB," "RHB," and "BS," respectively. To evaluate the relative contributions of these four components to the models of 47 Tuc, the four composite spectra were normalized to unity in a bandpass at 2640–2720 Å. Thus all subsequent statements to the effect that a particular component contributes a certain percentage of the mid-UV light refers to the percentage of light at 2680 Å. Note that since 47 Tuc does not show an upturn in the UV beyond 1500 Å, it is not necessary to include a very hot star component in our models for this cluster. In Figure 8 the spectrum of 47 Tuc is plotted along with the spectra of the four components that form the basis for the modeling of 47 Tuc.

We have produced a variety of composite model spectra for 47 Tuc using various combinations of the four principal components described above (metal-poor MSTO, metal-poor RGB, RHB, and BS). We find that the optimum model, in terms of producing as close a match as possible to the observed indices of 47 Tuc, combines 7% of the light from the RGB, 8% of the light from the RHB, 7% from a BS component, and the remaining 78% from the metal-poor MSTO. Varying the contributions of any of the three minor components by much more than ∼2% leads to a significant worsening in agreement between observed and model indices for 47 Tuc. For instance, we obtain essentially equally good agreement between the model and the observed 47 Tuc indices with a model consisting of 5% RGB, 10% RHB, 5% BS, and 80% metal-poor MSTO, but we cannot push the RHB contribution much above 10%

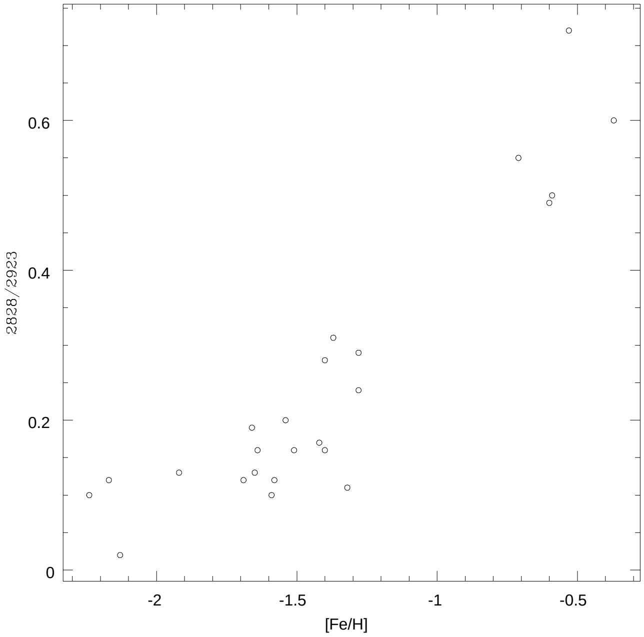

FIG. 7.—2828/2923 indices plotted versus [Fe/H] for the Galactic globular clusters.

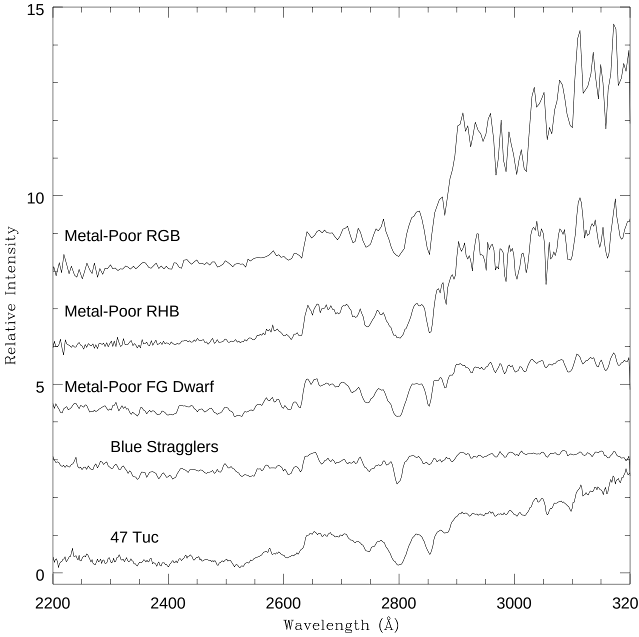

FIG. 8.—Mid-UV spectra of 47 Tuc and of the four component stars that have been used to model the integrated light of the cluster.

without incurring significant discrepancies. The spectral indices for the optimum 47 Tuc model are listed in Table 4, below the observed indices. It can be seen that the agreement between observed and model indices is good, given the rather simple nature of the model, with the one exception being a discrepancy of 0.09 between model and observation in the case of the 2828/2923 index. This discrepancy is perhaps an indication that one or more of the stellar components used in the models is too crude an approximation to the population that it is supposed to represent. This may be especially relevant for the BS component, which is represented here by a composite of solar neighborhood (hence solar metallicity) A5–A7 dwarfs.

To illustrate how the Fanelli et al. (1990) indices effectively constrain the contributions of the four principal components to the integrated UV light of 47 Tuc, we make the following observations: First, the very high value of Mg II 2800 observed in 47 Tuc implies that the contributions to the mid-UV light from the RGB and BS stars must be small, i.e., the combination of MSTO and RHB components must dominate. It also confirms a fact that has long been known from the observed CMD of 47 Tuc (cf., Hesser et al. 1987), viz., that the MSTO of 47 Tuc occurs in the late F stars. Because the Mg II 2800 index is so strongly peaked in the late F stars, if we try to reproduce the integrated Mg II 2800 index of 47 Tuc with MSTO stars that are significantly earlier or later than late F, we cannot produce a high enough Mg II 2800 index. Similarly, if we replace the [Fe/H] ~ -0.7 MSTO with a solar MSTO, we are unable to reproduce the observed Mg II 2800 index of 47 Tuc. Note that due to the vertical nature of the turnoff in the CMD (i.e., the piling up of many stars with the same color and spectral type) and to the fact that the turnoff stars are the bluest main-sequence stars, the MSTO dominates the main-sequence contribution to the mid-UV light, as it was shown to do in the blue (cf, Rose 1985).

A second important constraint is obtained from the $C26-30$ color, which can then be used to properly balance the MSTO contribution versus that of the RHB (with a slight contamination from the BS versus RGB balance). The fact that the observed $C26-30$ color of 47 Tuc is much closer to the metal-poor MSTO composite than it is to the RHB thus implies that the MSTO contributes much more strongly to the mid-UV light of 47 Tuc than the RHB, which again comes as no surprise, given the properties of 47 Tuc's CMD, and inferences about the balance of MSTO and RHB/RGB light in the blue that were discussed in Rose (1994).

Third, the 2609/2660 break index demonstrates that there must be *some* contribution from a BS population. Since all of the other components have 2609/2660 indices that are higher than the observed value for 47 Tuc, the only way to reproduce the 47 Tuc value is to include a small BS component. Note that the 2609/2660 break index is particularly effective in constraining the RHB population, since the latter has such an exceptionally high value of 2609/2660.

Finally, both the 2828/2923 and Mg I 2800 indices can be used to establish the balance between dwarf (MSTO and BS) and giant (RGB and RHB) contributions, since the former have lower values for these indices than the latter. Again, it is clear from the index values in Table 4 that the mid-UV light of 47 Tuc is primarily contributed by dwarfs.

The inferred contributions of MSTO, BS, and RHB/RGB stars to the integrated light of 47 Tuc at 2680 Å can be compared with that determined from previous integrated light studies at optical wavelengths. Such a comparison is made in the Appendix, where good consistency is found between the contributions to the integrated light deduced at both optical and UV wavelengths.

To summarize, simple models for the integrated spectrum of coeval single-metallicity population such as 47 Tuc are quite adequate to explain the basic features of the integrated mid-UV spectrum. Furthermore, the subset of Fanelli et al. (1990) spectral indices used here are effective at tightly constraining the relative contributions of the various model components to the integrated mid-UV spectrum of 47 Tuc. Moreover, the relative contributions determined from the UV analysis are in good agreement with those determined at optical wavelengths.

5.2. *Model for M32*

In comparing the mid-UV indices of M32 with that of 47 Tuc, the most important differences are that:

1. While the $C26-30$ color of M32 is slightly redder than that of 47 Tuc, the other four spectral indices in M32 are lower than in 47 Tuc.
2. While three of the latter four indices differ by only ~ 0.1 from M32 to 47 Tuc, the Mg II 2800 index of M32 is 0.3 lower than in 47 Tuc.

Thus to reproduce the integrated mid-UV indices of M32 it is apparent that we require a greater contribution from stars that have lower Mg II 2800 indices than in the case of 47 Tuc. There are three ways to produce a lower Mg II 2800 index. First, we can eliminate the metal-poor RHB population that makes a significant contribution to 47 Tuc, i.e., we can replace the 47 Tuc RHB with the "clump" stars that are characteristic of the core helium-burning phase of stars in solar metallicity intermediate-age open clusters such as M67. The redder clump stars, which are late G giants, do not have the high Mg II 2800 index of the field RHB star HD 79452. Second, we can increase the metallicity of the MSTO stars to solar or near solar. Such an approach makes use of the fact that the Mg II 2800 index peaks at metallicity [Fe/H] ~ -0.7 and then declines with higher metallicity. Third, we can utilize an MSTO population that is either earlier or later than the $B-V \sim 0.55$ F8 dwarf that dominates the integrated mid-UV light of 47 Tuc.

An additional point to consider in regard to the Mg II 2800 index of M32 is that recent studies have produced considerable evidence for non-solar abundance ratios in elliptical galaxies, with [Mg/Fe] enhanced over the solar value, particularly in massive ellipticals (Worthey 1998 and references therein; Tantalo, Chiosi, & Bressan 1998; Casuso et al. 1996). However, M32 appears to have a solar value of [Mg/Fe]; hence we do not consider this problem further. Note that *if* [Mg/Fe] were enhanced from the solar value in M32, it would in fact increase the difficulty of reproducing the low observed Mg II 2800 index.

To model M32 we begin by eliminating the metal-poor RHB component that was so necessary to successfully reproduce the 47 Tuc Mg II 2800 index. This appears to be an unavoidable first step toward reproducing the low Mg II 2800 index of M32, i.e., achieving the low Mg II 2800 index is already difficult given the constraints of the other indices, but adding in a substantial fraction of the evolved star light in the form of an RHB makes the task essentially impossible. After eliminating the RHB component (i.e., replacing it with a later giant contribution that corresponds to a "clump" giant), we then turn to a solar metallicity MSTO near $B-V = 0.55$. In principle we could also explore earlier and later MSTO populations, but for the simple modeling exercise conducted here we restrict the possibilities to replacing the RHB and to using the higher metallicity MSTO. Three representative stellar components are used. First, a composite solar abundance MSTO was produced from five late F dwarfs with [Fe/H] within ± 0.15 of solar. Next, a GB spectrum was produced from the composite of four solar abundance red giant stars. This GB spectrum is meant to simulate the entire luminosity-weighted mean evolved star light in M32, i.e., includes the clump stars as well as the mean RGB. The final component was produced from the composite of six metal-poor Galactic globular clusters, with $[\mathrm{Fe/H}] \sim -1.5$. The purpose of this component is to simulate the small contribution in the blue from "hot" stars (i.e., with spectral type A) that Rose (1985, 1994) inferred to be present on the basis of the Ca II index. Specifically, Rose (1985) found that the hot star population that produces the effect on the Ca II index in the blue can be modeled by a $\sim 8\%$ contribution at 4000 Å from a metal-poor Galactic globular cluster, i.e., a population with $[\mathrm{Fe/H}] = -1.5$. This in fact is very close to the contribution from such a population that is expected in the case of the closed-box model of chemical enrichment. Alternatively, the A star light could be due to BSs or to a young (<2 Gyr) population. In that case, we can replace the metal-poor globular cluster (MPGC) component with the same A5–A7V component that was used in the 47 Tuc models. Since the mid-UV indices of the MPGC and BS composite spectra are very similar, either one is possible as a contributor to M32. We have used the MPGC component because the simple chemical enrichment picture indicates that it should be present, and the recent *HST* CMD of Grillmair et al. (1996) does in fact provide evidence for a contribution from such metal-poor stars, although at a lower level than expected from the simple closed-box chemical evolution model. Similarly, Worthey et al. (1996) have proposed that the amount of metal-poor population present in the nuclei of M31 and M32 is deficient by at least a factor of 2 from the simple model. The spectra of M32 and the MPGC, solar abundance MSTO, and solar GB components are plotted in Figure 9, and their spectral indices are given in Table 4, where they are listed as "M32: observed indices," "Metal-poor globular cluster," "Solar MSTO," and "Solar RGB," respectively.

A variety of combinations of the above MSTO, GB, and MPGC components were tried, and it quickly became apparent that we could either fit the C26−30 color, in which case the 2609/2660, 2828/2923, and Mg II 2800 model indices were significantly discordant with the observed values, or we could fit the latter indices, in which case the model color was too blue by nearly 0.1 mag. Since there are still uncertainties in the flux calibration of *IUE* data at nearly this level (Massa & Fitzpatrick 1998), as well as uncertainty in the reddening to M32 (some estimates, e.g., McClure & Racine 1969; Ferguson & Davidsen 1993, indicate that $E_{B-V} = 0.11$ instead of 0.08, which would remove our color discrepancy), we chose to optimize on the smaller passband indices. In that case, the closest match to M32 was achieved with a mixture of 60% MSTO, 11% GB, and 29% MPGC. The indices of this "optimum" model are compared with those of M32 in Table 4, where the model indices are referred to as "M32: optimum model (without PAGB)."

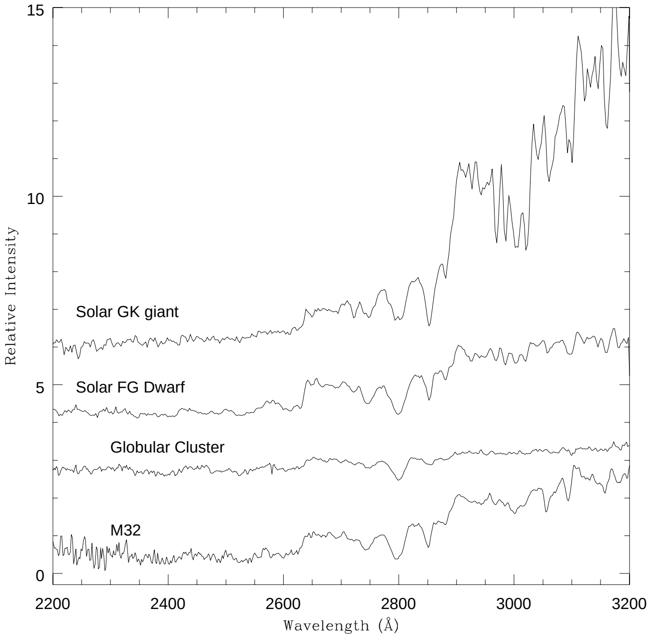

FIG. 9.—Mid-UV spectra of M32 and of the three components that have been used to model the integrated light of the galaxy.

One particular deficiency of the above three-component model is that it ignores any contribution from very hot stars. While Burstein et al. (1988) have shown that M32 represents an extreme case of an elliptical galaxy with little of the UV upturn beyond 1500 Å that is so prevalent in the more massive ellipticals, nevertheless they propose that some contribution from a postasymptotic giant branch (PAGB) population is present in the UV spectrum of M32. There is considerable debate in the literature as to whether PAGB stars dominate the UV upturn or whether other very hot, highly evolved stars are more important (e.g., Bressan, Chiosi, & Fagotto 1994), but here we follow the prescription of Burstein et al. (1988). Specifically, they synthesized the composite spectrum of a PAGB population from evolutionary models of a 0.565 $M_{\odot}$ star during its PAGB phase. Blackbody spectra were calculated at various T_{eff} intervals along the evolutionary path and then weighted according to the bolometric luminosity and evolutionary timescale of each interval [cf. § IV(*b*)(ii) of Burstein et al. 1984]. The resulting composite PAGB spectrum, if normalized to dominate the light at 1500 Å, can be seen in Figure 7 of Burstein et al. (1988) to contribute $\sim 10\%$ of the integrated light at 2680 Å, which is thus a substantial contribution.

We consequently found an optimum model for M32 in which, along with the three components already mentioned above, 10% of the light at 2680 Å was contributed by the PAGB population. The composite spectrum of this PAGB population was kindly provided by Dr. David Burstein and is the same spectrum used for the Burstein et al. (1988) paper. The spectral indices for the resulting four-component optimum model for M32 are given in Table 4 [listed as "M32: optimum model (with PAGB)"], where they can be compared with those of the three-component model and to the observed indices for M32. In this four-component solution, the mixture is 67% MSTO, 11% GB, 12% MPGC, and 10% PAGB and provides a satisfactory solution in all indices except for the above-mentioned discrepancy in the C26 − 30 color index.

To summarize, on the basis of the above modeling, several conclusions can be reached:

1. Although superficially similar in the mid-UV, given their similar C26 − 30 colors, there are substantial differences between M32 and 47 Tuc. This conclusion is based primarily on their very different Mg II 2800 indices. The mid-UV situation is reminiscent of the comparison between M32 and 47 Tuc in the blue, where they have indistinguishable $B - V$ colors, but differences in several spectral indices indicate major population differences (Rose 1994).

2. While the high Mg II 2800 of 47 Tuc discussed earlier forced us to conclude (in agreement with its known CMD and metallicity) that 47 Tuc has a substantial red horizontal-branch and that its metal abundance is a good deal less than solar, opposite conclusions are reached in the case of M32. Its low Mg II 2800 index rules out any significant contribution from an RHB component as in 47 Tuc and also points strongly toward a metal-rich (i.e., solar) MSTO.

3. There is a significantly greater contribution to the mid-UV light of M32 from "hot" (i.e., mid-A and hotter) stars than for that of 47 Tuc. Specifically, only about 7% of the mid-UV light of 47 Tuc comes from these stars, while the fraction is approximately 25% in the case of M32. In the case of 47 Tuc, the 7% mid-A star contribution is consistent with the number of BSs found in the *HST* CMD of the cluster. In the case of M32 the ∼25% contribution is more plausibly connected with both the expected metal-poor population and with the PAGB (or other UV-bright) population that dominates the flux at 1500 Å.

6. CONCLUSIONS

The most important conclusion from our study is that, despite similarities in mid-UV colors of M32 and 47 Tuc, the detailed mid-UV spectral indices indicate major differences in the populations of these two systems, thereby reinforcing a conclusion that has been reached at visible wavelengths as well. The crude modeling carried out here has characterized the primary differences between M32 and 47 Tuc, namely a lack of RHB stars in M32, a higher mean metal abundance for its mid-UV light, and a more substantial contribution from hot stars. To make further progress, a detailed population synthesis of the mid-UV spectrum of M32 is needed, which requires the assembly of a stellar spectral library from the *IUE* archival database covering a large range in effective temperature and luminosity for a variety of metallicities. In principle, such a comprehensive modeling of M32 would lead to a further refinement of the picture developed above.

Finally, although a detailed comparison between the best-studied metal-rich globular cluster and the best-studied elliptical galaxy serves as an important benchmark in comparing globular clusters with early-type galaxies, it is clearly necessary to place these two objects within the larger framework of globular clusters and early-type galaxies in general. This latter subject is considered in Ponder et al. (1998), where the mid-UV properties of a sample of elliptical galaxies are compared with those of Galactic and M31 globular clusters.

We sincerely thank Yoji Kondo, Willem Wamsteker, and Armin Theissen for arranging the key observation of HD 79452. Useful discussions with Dr. David Burstein are also gratefully acknowledged. This research was supported by NSF grant AST 93-20723 and STScI grant GO-06585.03-95A to the University of North Carolina.

APPENDIX

The inferred contributions of MSTO, BS, and RHB/RGB stars to the integrated light of 47 Tuc at 2680 Å can be compared with that determined from previous integrated light studies at 4000 Å (Rose 1994). In the Rose (1994) paper it was found that ∼45% of the light at 4000 Å comes from main-sequence stars, and ∼55% comes from giants, both RGB and RHB. This assessment was found to be in basic agreement with the Hesser et al. (1987) CMD and luminosity function for 47 Tuc. To compare the inferred proportions of MSTO and other light at 2680 Å with that found at 4000 Å, we need to know the 2680/4000 flux ratios of the BS, MSTO, and RGB/RHB components. These were determined by using the *IUE* spectra to assess the flux ratio from 2600 to 3300 Å and then using the Gunn & Stryker (1983) spectrophotometry (electronically available from the NASA Astronomical Data Center) to calculate the 3300 Å–to–4000 Å flux ratio. Specifically, the flux ratios between 2600 and 4000 Å for BS, MSTO, and combined RHB/RGB components were found to be 4.9, 10.3, and 71, respectively. Using these flux ratios, we infer from the BS, MSTO, and RGB/RHB contributions of 7%, 78%, and 15%, respectively, to the integrated light at 2680 Å that they should contribute 1.7%, 42%, and 56% of the light at 4000 Å, respectively. These predictions are clearly in good agreement with the determinations of Rose (1994). In fact, the agreement between inferences about the integrated light at 2680 Å with those at 4000 Å is suprisingly good, given the large (and somewhat uncertain) 2680–4000 Å flux ratios of the various stellar components. In addition, on the basis of the Ca II index (which is described in Rose 1994), Rose (1994) found that BS stars must contribute less than a few percent of the integrated light at 4000 Å, which is consistent with the inferred contribution of 1.7% at 4000 Å that we find from the 7% BS contribution at 2680 Å. In addition, Rose (1994) calculated from the number of BS stars found by Guhathakurta et al. (1992) that the BS stars should contribute ∼1.5% of the light at 4000 Å, which agrees with our assessment derived from the 2680 Å constraint. Thus the inferences that we have made in this paper about the relative contributions to the integrated light at 47 Tuc from various stellar components is in good agreement from similar work done at 4000 Å and also agrees with direct determinations from the CMD of 47 Tuc.

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