ULTRAVIOLET OBSERVATIONS OF STELLAR POPULATIONS IN GLOBULAR CLUSTERS AND GALAXIES

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ABSTRACT. We review some of the contributions made by vacuum ultraviolet observations to our understanding of stellar populations, with emphasis on recent results from the HST and the Astro-1 mission.

1. Introduction

The vacuum ultraviolet is a valuable new window on stellar populations, whose potential is comparable to that of the infrared window so fruitfully exploited over the last 20 years. Access to the UV has been more limited because of the need to place instruments above the atmosphere and their consequent small apertures or limited lifetimes. To date, there have been nine major UV observatories, in terms of number of returned observations: OAO-2, *Copernicus*, ANS, TD-1, IUE, SCAP/FOCA, HST, ROSAT/WFC, and Astro-1; data from the last four of these will reach publication only over the next several years.

Thanks mainly to the remarkable longevity of IUE, a total of about 100,000 UV observations of all types have been made. This is an impressive number, given the technical difficulties. However, in the context of this symposium, the available UV data has somewhat limited scope. First, about 98% of the observations are of individual Galactic stars, not composite systems such as clusters or galaxies. Further, only about 1% is derived from imaging devices or large telescopes capable of reaching objects fainter than the IUE limiting magnitude of $m_\lambda(2000\ \text{Å}) \sim 14$. [1] Finally, only TD-1 made an *all-sky survey*, and this had a limiting magnitude $m_\lambda \sim 9$—comparable to that of the Henry Draper Catalog. Consequently, we know as much about the UV sky today as we knew about the optical sky in 1900! This could quickly change during the 1990's, given favorable funding winds, and we look forward to rich data returns from EUVE, FOCA, Astro-2, the second-generation HST, Spectrum-UV, Lyman/FUSE, and perhaps a deep survey experiment.

The main advantage of the UV for stellar populations problems is its high sensitivity to stellar temperature, which offers greatly improved temperature resolution for a given photometric precision. This also permits the isolation of hot objects from the often dominant cool star background (e.g. in the crowded cores of globular clusters). Further, the UV contains much information on interstellar gas and dust. Finally, the sky background in the UV

[1] Magnitudes are quoted in the monochromatic system, defined as $m_\lambda = -2.5 \log F_\lambda - 21.1$, where $[F_\lambda] = \text{erg s}^{-1}\ \text{cm}^{-2}\ \text{Å}^{-1}$. UV colors used here, such as (1500–2500), are based on such magnitudes.

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is significantly fainter than at longer wavelengths (Henry 1991), providing opportunities for study of very low surface brightness regions.

In this review, I try to give some sense of what UV experiments earlier than 1990 have contributed to our understanding of stellar populations but will concentrate on more recent results from the HST and the Ultraviolet Imaging Telescope (UIT) experiment on the Astro-1 mission. Earlier UV imaging results are covered in more detail in O'Connell (1991); the most comprehensive review of UV spectroscopy is Kondo (1987).

2. The Ultraviolet Imaging Telescope

The Astro-1 Spacelab mission flew for nine days in December 1990. Four experiments were carried: the Broad Band X-ray Telescope, the Hopkins UV Telescope, the Wisconsin UV Photo-Polarimeter Experiment, and the UIT. Despite a number of equipment difficulties, the mission obtained about 40% of its planned observations and reached an efficiency of 80% of the planned exposure time per orbit just prior to its termination due to poor weather at the landing site. As of this writing the UV instruments are scheduled for reflight in 1994. There will be a guest observer program open to the community on Astro-2.

The UIT was designed by a team at Goddard Space Flight Center under the direction of T. P. Stecher. It is a 38-cm telescope with a field of view 40′ in diameter. It carries two image-tube cameras and a total of 11 filters plus a full-field grating. The combination of photocathode and filter response strongly rejects long-wavelength light, so "red leaks" are negligible for most objects. Most observations discussed here were made with the broad-band "FUV" filter (centroid 1500 Å, width 350 Å) or "NUV" filter (2500 Å, 1150 Å). Data is recorded on film and digitized to a 2048^2 pixel format. The stellar limit for a 10-min exposure is $m_\lambda(\mathrm{UV}) \sim 19.5$, or V $\sim$ 23 for a hot, unreddened source.

UIT performed well during the mission. Image FWHM's, attributable mainly to small guidance errors, averaged 3″. A total of 821 of the 2050 planned exposures were made. About half of the exposures have been reduced to date, but only about 50 have received a first-order scientific analysis. Flux calibration is still preliminary.

3. Globular Clusters

Pioneering photometry by OAO-2 and ANS (Welch and Code 1980, van Albada *et al.* 1981) revealed that there is a large range in the integrated UV energy distributions of globular clusters, amounting to over 3 mags in (1500–3300). This was shown to reflect the population and temperature distribution of hot horizontal branch (HB) stars. The bluest clusters are not the most metal poor but are rather "second parameter" clusters whose HB's are bluer than normal for their metal abundance. IUE has obtained the integrated UV spectra of many clusters and some spectra for individual bright stars (reviewed in Castellani and Cassatella 1987). Methods of using integrated spectra to estimate relevant HB parameters (age, abundance, mass loss, rotation, etc.) are still under development (e.g. Nesci 1983, Caloi *et al.* 1985).

Since the hot HB produces no more than ~10% of the integrated optical light (e.g. Buzzoni 1989), the UV will be the only practical means of studying the HB in distant, unresolved clusters. Low S/N spectra are already available for clusters in the Magellanic Clouds (Cassatella *et al.* 1987) and M31 (e.g. Cowley and Burstein 1988, Crotts *et al.* 1990). UV data may settle controversies over the age spread of M31 clusters, but only when HST-quality spectra are obtained. UV observations of more distant cluster systems will be important to place Local Group results in a larger context.

UV imaging can provide a rapid census of the hot star population of resolved clusters. A 30-minute exposure in a broad band with a UIT-sized telescope could detect hot stars up to 9 magnitudes below the HB in a nearby cluster such as M5 (O'Connell 1991). Combined with the natural rejection of cool stars, this sensitivity implies that UV imaging can yield *complete samples* of hot populations. This includes the rapidly-evolving, and therefore rare, types of post-giant branch stars whose evolutionary status is not yet understood (Vauclair and Liebert 1987, Greggio and Renzini 1990). To date, only two large-sample HB studies, based on UV imaging of bright clusters with rockets or balloons, have been published (Bohlin *et al.* 1985, Laget *et al.* 1991).

An excellent example of the ability of UV imaging to penetrate even the crowded cores of clusters is the recent discovery of blue stragglers in the core of 47 Tuc (Paresce *et al.* 1991). Paresce *et al.* obtained HST/FOC images (field size 22″ square) in far-UV bands and found about 20 bright blue objects. In a UV color-magnitude diagram (CMD) these are ~ 1 mag bluer than the warmest HB stars and have locations on the extrapolated main sequence of the cluster. Their density, about 0.05 arcsec^{-2}, is higher than for similar objects in the outer regions of the cluster, leading Paresce *et al.* to conclude they are binaries, formed by interactions, which have been concentrated in the core by mass segregation. It is evident that UV observations will strongly complement the rapidly growing body of ground-based data on modifications of cluster populations through interactions (e.g. Nemec and Cohen 1989, Djorgovski *et al.* 1991).

During Astro-1, UIT obtained good imaging of ω Cen, M79, and NGC 1851. Short exposures of three other clusters have yet to be evaluated. In a 1100 sec exposure of M79 we find a UV-bright center produced either by 2–3 very bright stars or the combined background. Our shorter exposures should permit resolution of individual central sources. We have obtained a UV CMD for 100 objects, which is shown in Fig. 1 together with a ZAHB locus based on Sweigert's (1987) models. Most of the objects cluster around the expected HB locus. (Note that the HB is not actually "horizontal" in this diagram.) We have not yet attempted to use the fit to estimate mean mass or abundance parameters. Interestingly, there are a number of hot objects at or above the extreme tip of the ZAHB locus. Eight have $T_e \sim$ 30,000–150,000. These objects would fall near V $\sim$ 20 and were not present in optical-band CMD's. If they are ZAHB or evolved HB stars, they have envelope masses $\lesssim$ 0.01 $M_\odot$. These are so small that they are not likely to proceed to the normal AGB phase but will rather follow exotic CMD paths involving large T and L excursions (Caloi 1989). Two stars in Fig. 1 are ~ 2 mags brighter than the HB (and several yet brighter may be present in the core). They could be the later stages of such "extreme HB stars" or perhaps post-AGB objects moving blueward from the AGB or down the remnant cooling sequence (e.g. Schönberner 1983).

We observed ω Cen in daylight; our 5 min FUV exposure was excellent, but our NUV frame was contaminated with skyglow. On the FUV frame we detect 1360 stars with $T_e \gtrsim 10,000$ and $m_\lambda(1500) < 19$. The core is fully resolved; the hot objects have an irregular distribution with little central concentration. Using the catalog of Dickens *et al.* (1988), we have constructed a FUV,V CMD for objects in common at $r > 3'$ (about 20% of our sample). As expected, most lie near the HB. However, a significant number scatter up to 3 mags above the HB. We estimate that about 60 stars in the full sample lie above the HB. More such objects would be expected than in M79 since ω Cen is a factor of 10 more luminous. We plan to extend our FUV/optical CMD coverage using new U-band CCD images.

The three brightest objects within $r < 12'$ fall at $m_\lambda(1500) \sim$ 10.2–12.0, implying absolute

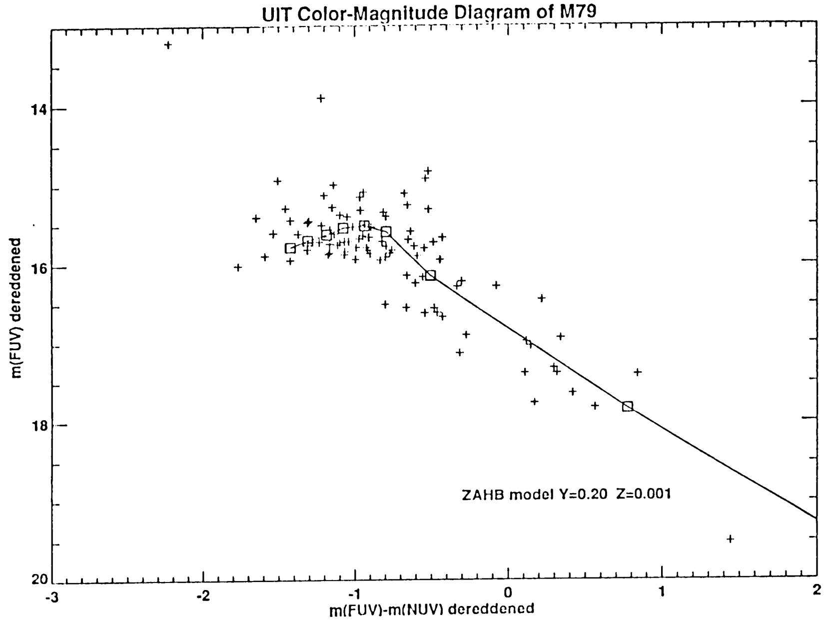

FIGURE 1: Ultraviolet color-magnitude diagram for $r > 40''$ in M79. Magnitudes and colors, defined as in §1, are corrected for extinction. ZAHB models from Sweigart (1987) are plotted; the hottest of these has an envelope mass of 0.01 $M_{\odot}$.

λ1500 magnitudes (corrected for extinction) of –3 to –5. Only the brightest of these (ROA 5701) had been recognized from the ground or had an IUE spectrum available (Cacciari *et al.* 1984). We recently obtained IUE spectra of the two new identifications. All three objects have similar UV SED's, corresponding to $T_e \sim 25,000$, and B-type absorption lines. We believe all are cluster members. Again, they could be P-AGB objects. Interestingly, one of the new identifications falls within the 41″ error box for Einstein IPC source C, which previously had no known optical/UV counterpart.

A UIT-class instrument could quickly survey the brightest 50 globular clusters for such rare, hot objects, creating a sample suitable for making statistical inferences concerning their evolution. Another area for future UV exploration is the white dwarf luminosity function and its implication for remnant cooling physics.

4. Star-Forming Galaxies

The UV has already made considerable contributions to our understanding of systems containing massive OB stars, particularly in the form of IUE spectra. However, recent reviews have covered this area (Kondo 1987, O'Connell 1990a) concerning both populations and the ISM, so I will only briefly discuss some newer developments here.

The far-UV ($\sim$ 2000 Å) continuum measures the mean star formation rate over the last $\sim$ 100 Myr, about 50 times longer than the ionizing continuum ($\lambda < 912$ Å), and hence provides a more representative picture than do emission lines. A compilation by Buat *et al.* (1989) of integrated UV data for spirals, based mainly on SCAP balloon observations, shows that the star formation rate per unit area on this timescale is strongly correlated with the *total* (neutral + molecular) hydrogen surface density but with neither phase separately. They derive a power-law relation with exponent 1.6.

Because UV colors are a strong function of age, the appearance of galaxies depends on the observing wavelength. This is an important issue for assessing the evolutionary state of high redshift systems, which are often imaged in the rest-frame UV and at low S/N. Bohlin *et al.* (1990) recently simulated the appearance of high redshift galaxies based on rocket UV images and illustrated the remarkable "morphological transformations" which can occur: spirals ⇒ E/S0; Sb ⇒ Sc; barred ⇒ unbarred; interacting ⇒ single; single ⇒ multiple.

Recent HST/GHRS spectra have again demonstrated the value of the UV for determining the abundances of hot stars (which cannot be easily done at longer wavelengths owing to the paucity of useful lines). Heap *et al.* (1991) obtained excellent spectra of Melnick 42 in the 30 Dor complex of the LMC. They deduce $Z \sim Z_\odot/4$, $T_e \sim 42,500$, $L_{bol} \sim 2.5 \times 10^6\ L_\odot$, $M \sim 100\ M_\odot$, and a terminal wind velocity of $\sim$ 3000 km s^{-1}.

UIT imaged a number of Local Group and nearby star-forming galaxies. Since unreddened OB stars are $\sim$ 4 mags brighter per unit wavelength in the UV than at V, such images are valuable for tracing star formation histories, investigating the IMF, and identifying important spectroscopic targets. For instance, a 6-min FUV daylight exposure of the 30 Dor complex registered $\gtrsim$ 2000 hot objects fainter than the IUE limit. A 10-min NUV exposure of the disk of M31 is shown in Fig. 2; it includes the massive OB association NGC 206, a number of other OB complexes, and the companion elliptical galaxy M32. We also obtained a good image of the UV-bright plume along the minor axis of M82, presumably a product of forward-scattering by ejected dust grains (Courvoisier *et al.* 1990), and of the cooling flow system NGC 1275. Our preliminary photometry of 1275 indicates that if the IMF is normal, star formation is not occurring now but terminated $\sim$ 50–150 Myr ago.

5. Elliptical Galaxies and Spiral Bulges

The old, high metallicity populations of ellipticals and S0-Sb bulges are not rich in hot HB stars nor, usually, massive OB stars. Nonetheless, the UV can provide important insights here. Two areas are undergoing rapid development.

First, one can use integrated near-UV ($\lambda\lambda$ 2000-3500) spectra to determine their *main sequence turnoff* characteristics, which is crucial to age-dating old populations. It is difficult to extract information on turnoff stars in the optical/IR because their light is blended with cooler dwarfs, subgiants, and giants, which produce over 70% of the light longward of V. By contrast, the turnoff provides $\gtrsim$ 70% of the light in the NUV. As a bonus, the NUV contains many strong absorption lines (see, for example, Burstein *et al.* 1988), which will ultimately yield improved abundance determinations. Because of these advantages, the NUV promises the best near-term improvements in age-dating techniques, which have been a subject of controversy (O'Connell 1986, Renzini 1986).

To extract MSTO information from the NUV, one must first remove the residual effects of the cooler stars plus those of hot HB, UVX (see below), and massive MS populations. This requires long-baseline observations, preferably covering at least 1200–6000 Å. Early

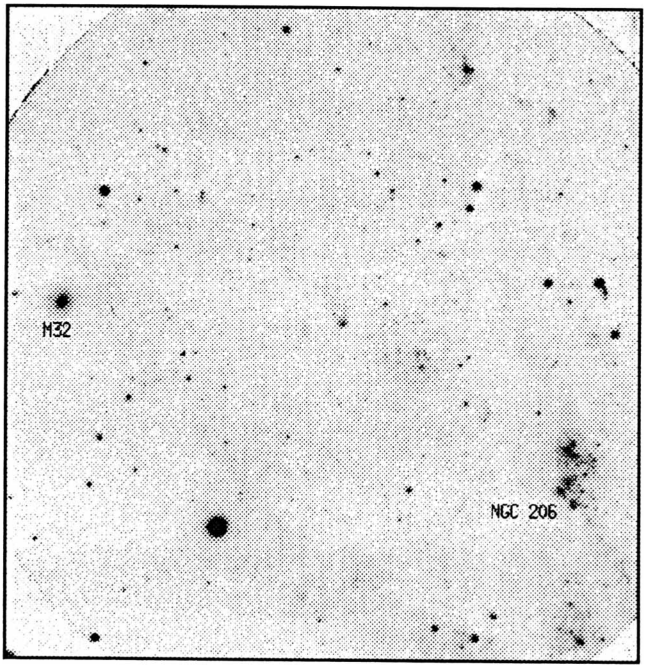

FIGURE 2: UIT image taken with the broad-band NUV filter of a field in M31's disk SW of the bulge. The region shown is 32′ on a side. The OB association NGC 206 and companion E galaxy M32 are marked. The edge of the circular UIT FOV is visible in the corners.

explorations of the problem, based on both "evolutionary" and "optimizing" synthesis techniques, included Wu *et al.* (1980), Gunn *et al.* (1981), and Bruzual (1983); more recent and detailed models include Rocca-Volmerange and Guiderdoni (1988), Buzzoni (1989), Barbaro and Olivi (1989), and Magris and Bruzual (this conference).

M32, which has assumed a key role at this conference as a testing-ground of population modeling, is an important case in point. IUE spectra of the central $\sim 15''$ of M32 indicate a significant contribution by F5-9 stars, presumably (though not definitely) on the main sequence (Bruzual 1983, Burstein *et al.* 1984, Rocca-Volmerange and Guiderdoni 1987, Kjærgaard 1987). An example of the good fits possible with such models is shown in O'Connell (1990b), where a 5 Gyr-old, solar abundance model is compared to the best available IUE spectrum (Burstein *et al.* 1988). Older, lower-abundance models would contain MSTO stars of similar temperatures. However, my preliminary tests of such models do not yield good NUV fits, and nearly all other studies of the optical/IR spectrum of M32 are consistent with $Z \sim Z_\odot$ and a relatively youthful age of 5–8 Gyr for the MSTO (O'Connell 1986, Boulade *et al.* 1988, Bica *et al.* 1990, Davidge 1990). Further refinement of NUV techniques should permit improved age and abundance resolution. The existing results, however, have long seemed entirely consistent with other evidence that elliptical populations are often the product of chaotic and episodic processes extending over a long period. Indeed, that is one of the main themes emerging at this conference.

The UV "rising branch" or excess ("UVX") is a distinct phenomenon affecting the far-UV spectra ($\lambda \lesssim 2000$ Å) of ellipticals and large bulges. It was discovered by OAO-2 (Code 1969) and is manifested by a sharp rise in the energy distribution below 2000 Å, which has a slope equivalent to $T_e \sim 20,000$. Since this is far hotter than the MSTO of old populations ($T_e \lesssim 7,000$), the upturn was a considerable surprise. More recent surveys, especially with IUE, have established that the (1500–V) color of ellipticals varies widely and becomes bluer as metal abundance increases (e.g. Burstein *et al.* 1988). Note that the sense of this relation is *reversed* with respect to the familiar dependence of UBV colors on abundance in old populations.

Since two recent reviews have thoroughly covered both observational and interpretational issues (Burstein *et al.* 1988, Greggio and Renzini 1990), I will not dwell on earlier results. The two main proposals for the source of the UVX are: *(i) massive OB stars*, formed during the past ~ 50 Myr presumably from gas lost during giant branch evolution; and *(ii) low-mass, post-giant branch stars* in advanced evolutionary phases, the descendents of the objects making up the dominant old population. For some time the favored low-mass candidate has been "post-AGB" stars (Schönberner 1983), though it has been recently recognized that these are only one of a plethora of such candidates, others of which (e.g. hot HB, post-EAGB) may fit the data better (see Greggio and Renzini 1990 for details).

The balance of the data prior to 1990 supported the low-mass star interpretation, and the Astro-1 mission has provided yet stronger evidence that massive stars are not the dominant factor in the UVX phenomenon. HUT obtained high S/N spectra covering $\lambda\lambda$ 950–1800 for NGC 1399, the brightest E in the Fornax cluster. The continuum shape and the absence of C IV absorption indicate that massive stars hotter than B0 are absent. The detailed analysis, described by Ferguson at this conference, favors extreme HB stars as the source of the UVX.

UIT images of four objects (the bulges of the Sb spirals M31 and M81, and the E galaxies M32 and NGC 1399) likewise yield little evidence for massive stars. There is none of the structure characteristic of star-forming regions, despite the fact that such are readily visible in the surrounding disks of M31 and M81. All four objects show smooth de Vaucouleurs-type surface brightness profiles in the NUV and FUV to below the level of the night sky. Further, no resolved stars are present in M32 or the M31 bulge. In the bulge, the limit is $m_\lambda(2500) \sim 18.4$ at $r \sim 30''$. This implies that single stars hotter than B1 V or B8 Ia are absent; limits for blended images are cooler. HST imaging would be required to search for individual low-mass objects; PAGB or P-EAGB types would appear in the FUV at $\sim$ 21–24 mag in M31's bulge with a surface density of ~ 0.1–1 arcsec^{-2}.

We have also derived (1500–2500) colors for these four systems. Results are shown in Fig. 3. We caution that these are based on preliminary calibrations and are subject to revision over the next several months. Individual point sources and regions contaminated by disk light (e.g. near M32) have been masked out of the photometry.

The behavior of these systems in the UV is dramatically different from that in the optical/IR, where they exhibit striking homogeneity. First, there are gross differences in their central colors, amounting to a ~ 3 mag range in (15–25) between the bluest system (NGC 1399) and the reddest (M32). Our central colors are in agreement with those based on IUE spectra for objects in common with Burstein *et al.* (1988). Second, all four systems have (15–25) color gradients which are very strong (~ 1 mag over the observed regions)

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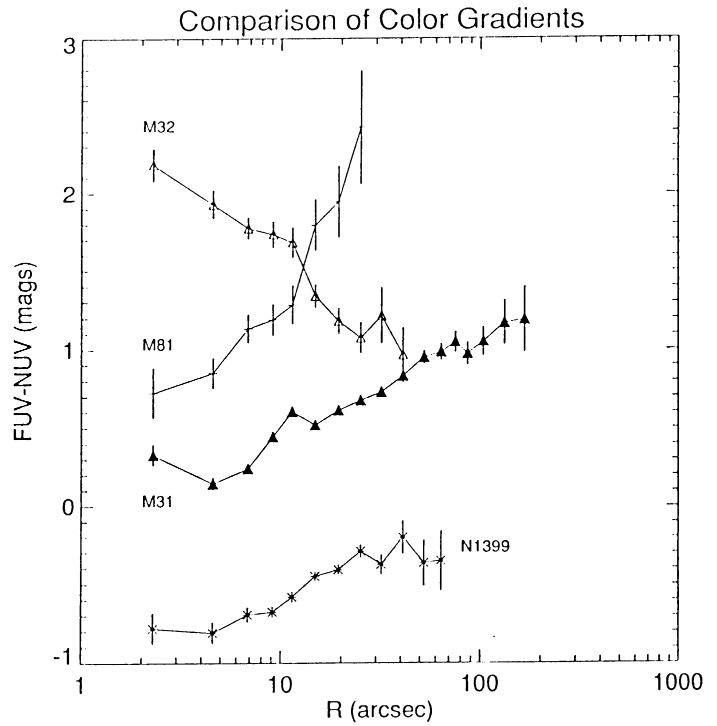

FIGURE 3: UV (1500-2500) colors as a function of radius for four old populations. The plots are truncated where the photometry becomes unreliable. For orientation, normal O7 and A5 main sequence stars would fall at colors of −1.3 and +2.2, respectively; the bluest and reddest globular clusters fall at 0.0 and +2.1.

by comparison to optical/IR gradients ($\lesssim$ few 0.1 mags). The color gradients are smooth from the cores outward. In all objects except M32 the colors become *redder* outward; in M32 they become *bluer*. There were earlier indications of color gradients in IUE spectra for the M31 nucleus (Welch 1982, Deharveng *et al.* 1982), but this is the first evidence for extended gradients of large amplitude.

It is not likely that dust is responsible for the gradients. First, the gradients are similar in the Sb's and the E galaxy NGC 1399 despite a likely major difference in dust content. Second, for the Galactic UV reddening law, the color excess E(15–25) $\sim$ E(B–V) $\lesssim$ 0.1. Instead, it is probable that we are seeing the response of the hot, low mass evolutionary phases which produce the UVX to a decline in metal abundance with radius. The sense observed in the systems other than M32 is the same as the overall UVX/abundance effect found for galaxy centers by Burstein *et al.* (1988). It is consistent with the expectation that giant branch mass loss increases with metal abundance, producing an increase in the net UV luminosity of low-mass remnants (Greggio and Renzini 1990). However, the non-overlap of the NGC 1399 and M31 color profiles in Fig. 3, despite similar optical spectra and line strengths, suggests that the UVX may be sensitive to parameters in addition to metal abundance. A more complex behavior has also been hinted at by the facts that the UVX seems stronger in "boxy" than in "disky" E's (Longo *et al.* 1989) and that S0's have a steeper NUV-luminosity relation than do E's (Smith and Cornett 1982, Kodaira *et al.* 1990).

The UV color gradient in M32 is not explainable as a simple metal abundance effect if the abundances are roughly constant or declining outward, as suggested by optical colors. Because M32 has the lowest mean abundance of the objects studied, its behavior could reflect a phase transition in the dominant type of UVX star. Alternatively, an age gradient, in which the center is younger, would have the correct sense to explain the colors, since it becomes more difficult to produce hot, long-lived post-GB remnants if the MSTO mass is larger (Greggio and Renzini 1990).

6. Conclusion

Important new insights into both young and old stellar populations can be obtained with UV observations. This review has concentrated mainly on systems in or near the Local Group, but rapid progress in covering a much larger volume is possible now that UV telescopes with faint thresholds are available. Ultimately, some of the most interesting applications of UV diagnostics will be to the evolutionary histories of very distant systems in earlier stages of evolution.

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DISCUSSION

LEE: One comment regarding the ω Cen CM diagram. You showed that there is a large scatter in luminosity. I think this is mostly due to the following effects: (1) internal variations in [Fe/H] in ω Cen and the HB luminosity dependence on [Fe/H]; and (2) evolution off the ZAHB, which itself produces a large range in luminosity. One or two stars may be post-AGB, but most in your sample are indeed HB stars.

O'CONNELL: I agree that such effects must be present, and we are in the process of examining the location and frequency of the brighter objects with respect to post-ZAHB evolutionary tracks. We do find objects up to 3–4 mags above the ZAHB, however, and our first impression is that not all of them can be evolved HB stars.

CARRASCO: I suggest that the hot UV bright stars you detect in globular clusters correspond to the same population that exists in the disk and that spectroscopically mimics OB stars of extreme Pop I. These are the so-called "runaway" stars. It has been found that they share the same kinematics as planetary nebulae, indicating that this UV bright population is indeed an evolved one.

O'CONNELL: I can't comment on their relation to the runaway OB stars, but it is certainly true that the IUE spectra of the bright objects in ω Cen look at first glance like those of main sequence B stars. We will make a more detailed comparison soon.

CACCIARI: You mentioned that ages can be derived from UV colors. I would like to make a comment on that. This method, which was applied by Dickens and van Albada about 10 years ago using ANS data for Galactic globular clusters, may be biased by the presence of UV bright stars, such as post-AGB stars. For example, the PAGB star VZ1128 in M3 produces about 20% of the total light at 1500 Å; the same type of star in 47 Tuc would produce about 90% of the 1500 Å light.

O'CONNELL: Yes, it is essential to remove the contaminating effects of very hot stars, as well as the influence of cooler dwarfs and giants. In the case of galaxies, one must remove the long-wavelength tail of the UVX stars. This can be done with some confidence if one has long baseline spectra available. For the hot components, that means data with reasonable S/N down to 1200 Å.

RICH: Have you compared your UV surface photometry for the M31 bulge with the V-band photometry of Kent? Is the UV light profile like the visual or is it more concentrated?

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O'CONNELL: The near-UV profile appears to be very similar to the optical-band profile; the far-UV surface brightness declines faster with r. The (NUV–optical) colors will be affected by UVX contamination as well as by blanketing, and we have not yet tried to disentangle these.

FERGUSON: (1) Can you set any interesting limits on the number of young stars in NGC 1399 from the smoothness of the surface brightness profile? (2) Do any of the UIT exposures of globular clusters go deep enough to pick up the white dwarf cooling sequence?

O'CONNELL: (1) There is possibly some low-level structure in the NGC 1399 images, and we are re-digitizing our data with finer microdensitometer resolution. We think that we may be detecting the brighter globular clusters. (2) Unfortunately, our exposures were too short. We would have needed at least 30-minute exposures, and preferably stacked images from several orbits. Our primary candidate for such studies, 47 Tuc, was also not well placed for long nighttime exposures.

PELETIER: A large fraction of the galaxies in the paper by Burstein *et al.* (1988) showing UV upturns contained active galactic nuclei (e.g. M87, NGC 6166). Is is possible that the "reversed" gradients you find are signs of induced star formation in the inner regions?

O'CONNELL: We don't think so, since in M31, M32, and M81 there is no sign of individual OB stars, associations, or clusters. Also, the objects in the Burstein *et al.* sample which you mention have UV spectra which are significantly *flatter* than those of objects like NGC 1399 or M31. This is probably consistent with the broader range in temperature expected from the upper main sequence in a star-forming system. The steeper spectrum in NGC 1399 probably indicates that low-mass post giant branch stars dominate the UV.

ELLIS: Milliard *et al.* (preprint) present galaxy counts to $m_\lambda(2000) = 19.5$. I find their counts to be above a simple no-evolution expectation, indicating recent changes in the bulk star formation rate. However, their image quality is not as good as the UIT's, and their star/galaxy separation is done in a complex, uncertain way. Will UIT be able to produce UV counts significantly deep to address this?

O'CONNELL: We certainly hope so. We made a number of deep exposures in high latitude fields centered on quasars with this kind of problem in mind.

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