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On the nature of the UV turnup in early-type galaxies*

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Abstract. We study the UV turnup in early-type galaxies from coadded IUE spectra reaching an unprecedented signal to noise ratio. Some spectral groups resulted with strong or moderate UV turnup, while in others it is very weak or absent. We study the relationships of the UV turnup intensity with absolute magnitude, X-ray and Hα luminosities. Galaxies in the strong UV turnup groups are systematically bright, and have high X-ray and Hα emission luminosities; however, some other galaxies with the latter properties do not exhibit a significant UV turnup. The spectral groups with an important intermediate age component are far-UV weak. The contribution from an intermediate age population with varying strength might explain why some red stellar population early-type galaxies present the UV turnup while others do not. The available spectral groups have been further coadded into one with strong UV turnup and another one without it, and we analyse their difference. We compare the spectral slope of the isolated UV turnup with IUE spectra of various hot sources which had been proposed in previous studies to explain it. We conclude that only very hot stars like sdO and sdB subdwarfs, some nuclei of planetary nebulae or DO white dwarfs, have the proper slope to explain the UV turnup. The UV turnup as detected through the IUE aperture is not featureless: it presents absorptions similar to those observed in the galaxies with weak far-UV flux. These features appear to be the λ1400 Å and λ1600 Å ones, characteristic of moderately cool white dwarfs (DA 5), which indicates that these stars are dominant flux contributors between λ1300 – 2000Å in the far-UV weak groups. The cooling time of DA 5 stars together with the evolutionary time since they left the main sequence, imply that they evolved from low-mass stars possibly associated with the initial burst of star formation in early-type galaxies and/or merger events at intermediate ages. On the other hand, two possible scenari are discussed for the origin of the hot component which causes the UV turnup, one related to late stages of normal evolution of low-mass stars, and another related to past nuclear activity events and jets which might have blown away the atmospheres of red giants in the central parts of the galaxies, exposing the hot stellar cores and mimicking a spectral distribution like that of the hottest stars observed.

Key words: galaxies: elliptical and lenticular, cD – galaxies: general – galaxies: stellar content – ultraviolet: galaxies

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1. Introduction

One of the most exciting results provided by observations with the International Ultraviolet Explorer (IUE) Satellite was the UV turnup in early-type galaxies (in this paper, ellipticals and S 0's), i.e. their flux rise shortwards of $\approx \lambda$1800 Å (see Bertola 1986 for a review). Possible interpretations for this phenomenon involved recent star-formation, very hot population II stars such as blue horizontal branch and/or post–AGB stars, as well as genuine nuclear activity (e.g. Bertola et al. 1980; Oke et al. 1981; Bertola & Capaccioli 1982; Nesci & Perola 1985; Burstein et al. 1988).

Bica & Alloin (1988) have investigated the possible nature of the UV turnup in giant ellipticals (gE) on the basis of the continuum distribution of IUE spectra and population synthesis results from the visible and near-IR ranges. They excluded the possibility that a hot stellar component associated with the *old metal-poor* population is responsible for the UV turnup. On the other hand, they concluded that recent star-formation and/or a hot stellar component associated with the *old metal-rich* population were compatible with the UV turnup within the available signal/noise (S/N) ratio of the individual gE's IUE spectra.

Greggio & Renzini (1990) discussed possible theoretical evolutionary channels for the late stages of stellar evolution and their contribution to the integrated spectrum. Depending on mass loss and helium enrichment, which are otherwise uncertain parameters for higher than solar metallicities, old low-mass stars could generate (1) classical post–AGB stars passing through the planetary nebula phase, (2) post-early asymptotic giant branch stars, (3) very hot horizontal branch stars and their progeny, AGB-manqué stars, and (4) post-red giant branch stars. The longest lasting evolutionary phase among these possible channels is the very hot horizontal branch (HB), which appears to have a counterpart in the Galactic disk as the hot subdwarf population (sdO and sdB's). The very hot HB component, together with its progeny, turned out to be a fundamental far-UV flux contributor in the syntheses by Dorman et al. (1995). Rich et al. (1993) detected far-UV rising branches in some metal-rich globular clusters, and they concluded that bright post–AGB stars are inconsistent with the observations. Their work favours less luminous stars as responsible for the rising branches, among which, the very hot HB stars. On the other hand, Magris & Bruzual (1993) carried out population synthesis of elliptical galaxies making use of solar metallicity tracks for post–AGB stages including planetary nebula nuclei and the cooling sequence of white dwarfs. They concluded that bright post–AGB stars dominate the flux, and that the varying intensity of the far-UV flux can be explained by an age effect, in the sense that the post–AGB flux contribution increases from intermediate to old ages.

In addition to the early analyses of IUE spectra of individual galaxies, recently, new observations have been made with the Hopkins Ultraviolet Telescope (HUT) which produced spectra of the giant elliptical NGC 1399 and the bulge of M 31 down to the Lyman limit (Ferguson et al. 1991 and Ferguson & Davidsen 1993). They found significant differences between both spectra which indicated that different components and mixtures of old evolved stars may be occurring. They also found evidence of a significant warm (T≈25 000 K) contribution to the UV turnup. *Hubble Space Telescope* far-UV images of the M 31 bulge and nucleus by King et al. (1992) and Bertola et al. (1995) showed that resolved sources, identified as bright post-AGB stars, do not contribute more than 20% of the integrated far-UV flux. The nature of the unresolved flux sources is not yet clear.

Buson et al. (1993) suggested that the UV turnup might be produced by the component which is also responsible for the radiation which ionises the cold gas and produces emission lines in the nuclear region of early-type galaxies. Recently Binette et al. (1995) have shown that very hot old (post–AGB) stars could be the ionising source in early-type galaxies. They concluded that, provided cold gas is present, a low-level of emission line activity is a natural consequence of the time evolution of the initial starburst, even after a time of $t \approx 10^{10}$ years. Besides, they found a very steep radial decline of the Hα+[NII] surface brightness compared to the stellar continuum surface brightness, which indicates that this gas is confined to the central parts of early-type galaxies. In the present paper we compile X-ray and Hα luminosities for the galaxies with IUE spectra and study their relationship.

In a separate paper (Bonatto et al. 1996, hereafter Paper I) we have gathered the spectra of the early-type galaxies in the IUE library which include normal stellar population galaxies and Active Galactic Nuclei. The AGN and blue stellar population spectra were analysed therein. In the current paper we consider the red stellar population groups in order to isolate the spectrum of the UV turnup and to infer by means of continuum slope arguments which kind of source might be producing this strong rise of the far-UV flux. We also study the implications of the observed absorption features.

This paper is organised as follows: in Sect. 2 we discuss the red stellar population spectral groups obtained in Paper I, and analyse the dependence of the UV turnup on some galaxy properties; in Sect. 3 we study the UV turnup in a scenario where it arises from intermediate–old age and/or metallicity effects; in Sect. 4 we further combine the spectral groups into one with a high UV turnup and another representing a far-UV weak stellar population. We study the wide absorption features in the far-UV and interpret them in terms of white dwarfs of type DA 5, which set important observational constraints on spectral models; in Sect. 5 we obtain the difference spectrum which features out the isolated UV turnup and compare it to a series of IUE spectra of sources which have been proposed in previous studies as possibly causing the UV turnup; in Sect. 6 we discuss a scenario where the UV turnup could be linked to nuclear activity; the concluding remarks of this work are given in Sect. 7.

2. Spectral groups

We gathered the spectra for the present sample from the IUE Uniform Low Dispersion Archive (ULDA Version 4.0), stored at the Instituto Astronômico e Geofísico of the Universidade de São Paulo (IAG–USP). Taking advantage of spectral similarities from the far-UV to the visible/near-IR ranges, we have been able to build up groups containing galaxies which share the same properties. Prior to the grouping procedure, the individual galaxy spectra were corrected for Galactic foreground reddening and for redshift. The grouping procedure produced average spectra with an improved (S/N) ratio, which allowed the study of spectral features in red and blue stellar populations observed in early-type galaxies. Further details on spectra selection and the grouping procedures are to be found in Paper I.

The red stellar population groups are characterised by varying intensities of their UV turnup (Figs. 1 and 2). Hereafter, the IUE réseau mark near λ1790 Å, indicated in Fig. 1, will be clipped out.

In Table 1 we provide information on each group, which are in columns: (1) group designation (from Paper I); (2) average absolute magnitude ($\langle M_B \rangle$); (3) average X-ray luminosity ($\langle L_X \rangle$); (4) average Hα luminosity ($\langle L_{H\alpha} \rangle$); (5) strength of the UV turnup, which can be parameterised by the continuum ratio $C_{\lambda 1242}/C_{\lambda 2646}$; and (6) spectral group derived from the visible/near-IR ranges (Bica 1988). For each group we also give the constituent galaxies (notice that the original groups in Paper I contain a few more galaxies, while here we restrict ourselves to those which have been observed in the SWP region). The sources of X-ray data are: Fabbiano et al. (1992) for *Einstein Observatory* (0.2–3.5 keV) luminosities, and Brinkmann et al. (1994) for *ROSAT* (0.1–2.4 keV) luminosities of the galaxies NGC 4486=M 87 (in spectral group G_N4486) and NGC 4696 (in spectral group G_N1553). As NGC 4486 lies at the center of the Virgo cluster where the X-ray emission is dominated by the hot intracluster medium (Fabricant et al. 1980), the $\langle L_X \rangle$ value

Table 1. Red stellar population groups

Group/ Galaxy	M_B mag	$\log(L_X)$ erg s^{-1}	$\log(L_{H\alpha})$ erg s^{-1}	$C_{\lambda1242}/C_{\lambda2646}$	Spectral Group
G_N4486	-20.9	≤42.27	40.88	3.71±0.10	
NGC 1052	-20.2	40.71	40.26		
NGC 4486	-21.3	≤42.56	41.12		G–E1
G_N4649	-20.9	42.02	≤40.28	3.68±0.15	
NGC 1399	-21.0	42.31	39.08		G–E1
NGC 4406	-21.1	42.24	<40.32		G–E1
NGC 4552	-20.3	40.92	39.52		G–E1
NGC 4649	-21.0	41.51	<40.71		G–E1
G_N4472	-20.9	41.56	≤39.56	2.75±0.20	
NGC 1404	-20.5	41.47	<38.56		G–E5
NGC 1407	-21.3	41.31	<38.60		
NGC 4374	-20.8	41.15	39.56		G–E5
NGC 4472	-21.4	42.06	40.02		G–E1
NGC 4621	-20.2	<40.43	<39.49		G–E1
NGC 7196	-20.6	–	–		
G_N3998	-20.7	41.94	40.25	1.46±0.15	
NGC 3998	-19.3	41.94	40.20		
NGC 4278	-18.8	–	40.29		
IC 1065	-21.7	–	–		
G_N3115	-20.7	<40.57	39.85	1.12±0.12	
IC 3370	-21.7	–	40.49		
NGC 2768	-20.7	–	39.15		
NGC 3115	-20.1	<39.95	*		G–E2
NGC 3379	-20.3	<40.13	39.54		G–E2
NGC 4125	-20.6	–	40.30		
NGC 4350	-18.8	<40.16	*		
NGC 4564	-18.8	<41.08	38.78		
NGC 5670	-21.3	–	*		
G_N1553	-21.4	42.51	40.65	1.11±0.13	
NGC 584	-20.9	<40.69	<40.41		G–E5
NGC 1316	-22.1	41.25	–		G–E5
NGC 1553	-20.8	40.90	–		G–S2
NGC 3311	-21.5	–	39.32		
NGC 4494	-20.7	–	–		
NGC 4696	-22.6	42.98	40.62		
NGC 4697	-21.0	40.97	39.63		G–E5
NGC 4762	-19.9	40.52	*		
NGC 5044	-21.2	43.17	41.13		
NGC 5846	-21.0	42.11	40.50		
NGC 6868	-21.5	–	41.08		G–E5
G_N221	-20.0	40.72	≤39.72	1.16±0.12	
NGC 221	-15.7	–	*		Int. age
NGC 2865	-20.8	–	<38.95		G–E7
NGC 4111	-18.6	–	39.25		
NGC 4382	-20.7	40.72	<40.39		G–E7
NGC 4742	-19.3	–	*		G–E7
G_N4853	-22.2	–	40.53	1.18±0.20	
NGC 4853	-20.8	–	–		
NGC 4874	-22.3	–	–		
NGC 4889	-22.4	–	–		
NGC 6166	-22.6	–	40.53		
NGC 7385	-22.1	–	–		

Table Notes. X-ray data for NGC 4486 and NGC 4696 are from *ROSAT*; the value for NGC 4486 is an upper limit, since this galaxy lies at the center of the Virgo cluster; (–) not available; (*) Hα in absorption or $L_{H\alpha}\approx 0$.

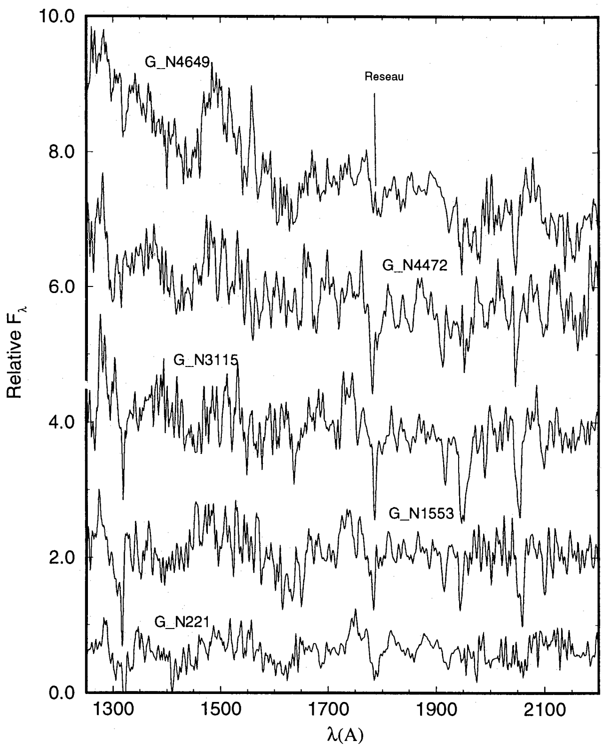

Fig. 1. Groups for red stellar populations in early-type galaxies with varying contribution from the UV turnup. A réseau mark near λ1790 Å is indicated. Flux in F_λ units, normalised at λ2646 Å. Constants have been added to the spectra for clarity purposes, except for the bottom one

for G_N4486 is an upper limit. Group luminosities correspond to the mean of the available values for individual galaxies. Individual M_B's were transformed into luminosities, averaged and transformed back to $\langle M_B\rangle$. The Hα data are from Heckman (1980), Pastoriza, Caon & Macchetto (1995, private communication) and Goudfrooij et al. (1994). No Hα emission was detected in the nucleus of NGC 221=M 32 (Bica et al. 1990). The galaxies NGC 3115 and NGC 4742 have been observed in Bica & Alloin (1987) and no emission lines were found in the detailed analysis carried out by Bonatto et al. (1989).

As our fundamental criteria for grouping are the IUE spectra themselves, some internal range of spectral properties in the visible/near-IR ranges is expected, since galaxy spectral properties are not orthogonal in all wavelength ranges. However, we emphasise that we are dealing with what is called "red stellar population" galaxies, i.e., we excluded H II and blue stellar population starburst galaxies from the groups.

2.1. Dependence of the UV turnup on L_X, $L_{H\alpha}$ and M_B

In Fig. 3 we display the values of $C_{\lambda1242}/C_{\lambda2646}$ *vs.* $\log\langle L_X\rangle$ for each group; no value is available for the group G_N4853. The groups with strong UV turnup (G_N4486 and G_N4649) have a high X-ray luminosity. The group with intermediate UV turnup (G_N4472) has a moderately strong X-ray luminosity, whereas the far-UV weak groups (G_N221 and G_N3115) are about one order of magnitude weaker in L_X. The far-UV weak group G_N3998, containing strong LINERs, in particular NGC 3998 and NGC 4278 which seem to host mini-Seyfert nuclei (Filippenko & Sargent 1985; Heckman 1980; see also Fig. 15 in Paper I), is X-ray bright. Finally, the group G_N1553 is X-ray luminous but is found to be far-UV weak. We conclude that the UV turnup is associated to a high X-ray luminosity, but the reverse does not apply and other X-ray bright galaxies do not necessarily show a UV turnup.

In Fig. 4 we plot $C_{\lambda1242}/C_{\lambda2646}$ *vs.* $\log\langle L_{H\alpha}\rangle$. The conclusions are basically the same as those for the X-ray luminosity,

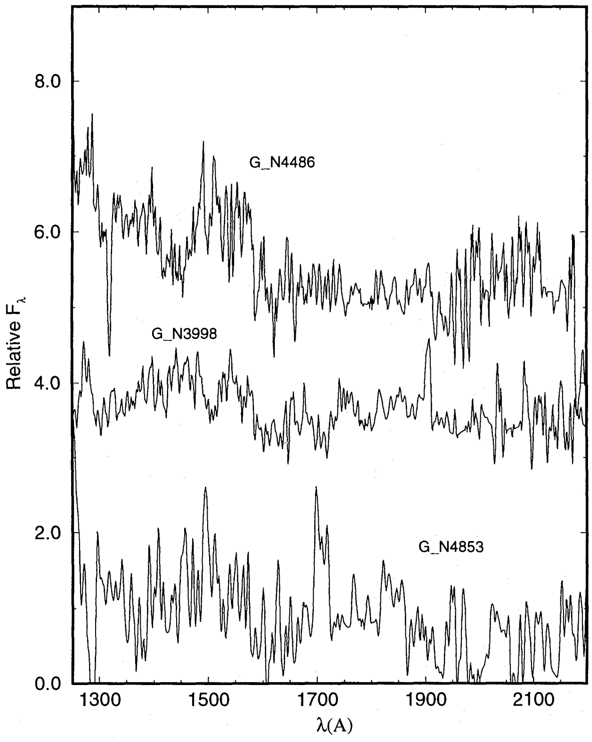

Fig. 2. Complementary groups for red stellar populations in early-type galaxies: the groups G_N4486 (high UV turnup) and G_N3998 contain strong LINERs; the group G_N4853 comprises galaxies considerably more distant than those in Fig. 1, the absence of the UV turnup suggests that it is a nuclear phenomenon. Flux in F_λ units, normalised at $\lambda 2646$ Å. Constants have been added to the spectra for clarity purposes, except for the bottom one

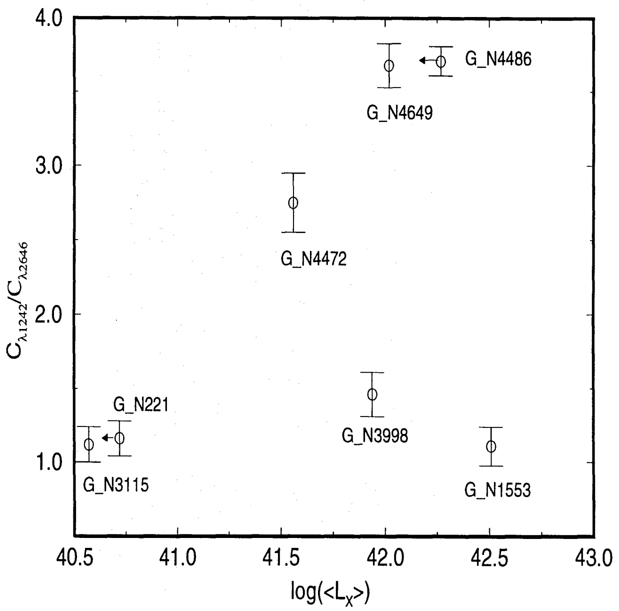

Fig. 3. The strength of the UV turnup plotted against the average X-ray luminosity of each group; arrows indicate upper limit

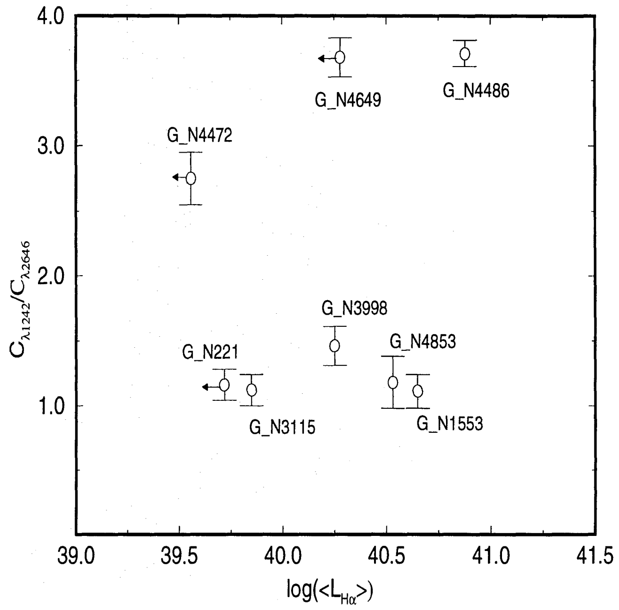

Fig. 4. The strength of the UV turnup plotted against the average Hα luminosity of each group; arrows indicate upper limit

except that the group with intermediate UV turnup (G_N4472) is deficient in Hα emission.

In Fig. 5 we plot the values of $C_{\lambda 1242}/C_{\lambda 2646}$ *vs.* $\langle M_B \rangle$ for each group. The groups with strong or intermediate UV turnup (G_N4486, G_N4649 and G_N4472) contain luminous galaxies, several of them belonging to the Virgo cluster (Paper I). However, the group G_N1553 which is as luminous as those just mentioned is far-UV weak. Its UV turnup is likely diluted by the presence of an intermediate age stellar population (see Sect. 3.4). The other luminous group, G_N4853, formed by distant giant galaxies in the Coma cluster, and the distant luminous galaxies NGC 6166 and NGC 7385, is far-UV weak as well. In this case, we interpret the weakness of the far-UV flux as a distance/aperture dilution effect, since the UV turnup appears to be a nuclear property, rather than associated to the circumnuclear bulge regions (see Sect. 3.2).

We conclude that the UV turnup, as detected through the IUE aperture, is typical of the central regions of some nearby early-type galaxies (up to the distance of the Virgo cluster), and that it is associated with strong X-ray luminosity, but not necessarily with Hα emission; the source responsible for the UV turnup cannot be the only one that ionises the nuclear gas. A possible mechanism for suppressing the UV turnup is flux-dilution in the far-UV spectral range by other components, such as a genuine AGN (Paper I) and/or an intermediate age population (Sect. 3.4).

3. UV turnup: intermediate—old age/metallicity effect?

A wide range of far-UV flux properties is observed in Figs. 1 and 2. The spectral groups G_N4649, G_N4486 and G_N4472 exhibit substantial UV turnups although with different intensities. The group G_N3115 shows a very weak UV turnup, whereas

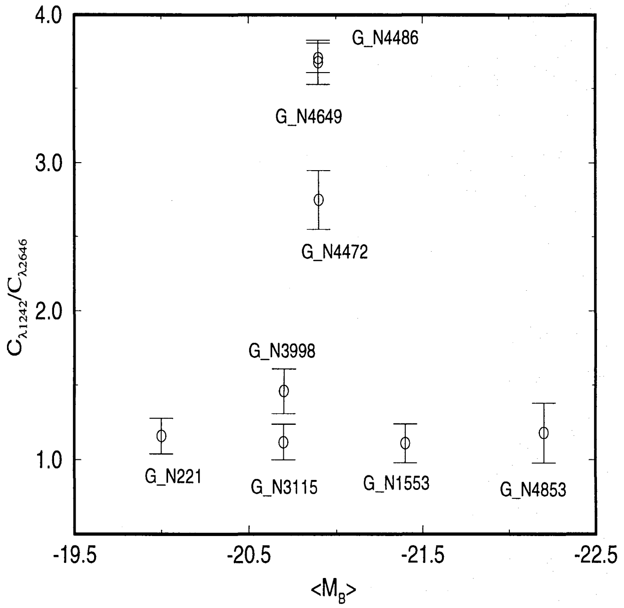

Fig. 5. The strength of the UV turnup plotted against the average absolute magnitude of each group

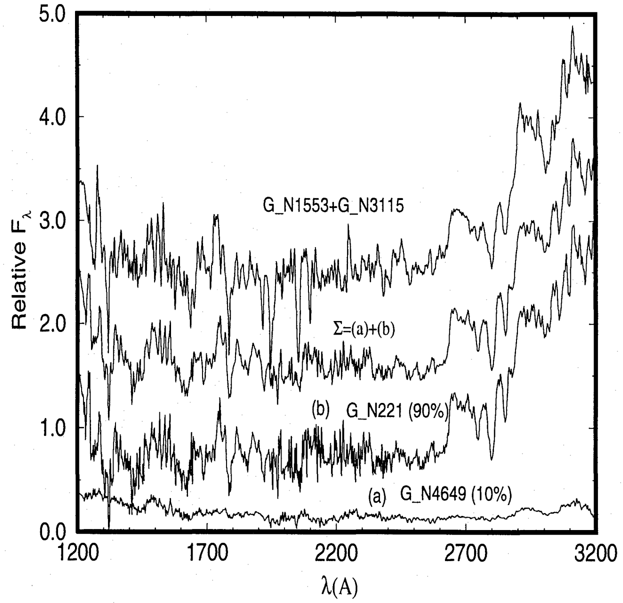

Fig. 6. The strong UV turnup in G_N4649 can be suppressed by the addition of a far-UV weak galaxy spectrum, G_N221. The resulting spectrum looks quite similar to that of a typical far-UV weak stellar population (G_N3115 + G_N1553). Fluxes are in F_λ units, normalised at λ2646 Å. Constants have been added to the spectra for clarity purposes, except for the bottom one

in G_N1553 and G_N221 it is vanishing or even absent. In the far-UV strong groups, the UV turnup is not featureless, at least as detected through the IUE aperture. The absorption features in the UV turnup, in particular the wide depressions around λ1400 Å and λ1600 Å, look similar to those observed in the far-UV weak groups (G_N3115, G_N1553 and G_N221).

3.1. UV turnup: dilution by a UV weak stellar population

In this subsection we carry out an experiment in order to simulate the possible dilution of the UV turnup by the presence of a far-UV weak (red) stellar component. To do so, we use the weakest far-UV flux group G_N221. The results are shown in Fig. 6. Notice that a contribution of ≈ 90% of this far-UV weak spectrum transforms the strong UV turnup of G_N4649 into one like that of the average of groups G_N3115 and G_N1553, which in turn is slightly bluer than G_N221 (Fig. 1).

3.2. UV turnup: aperture-dilution for distant galaxies?

In Fig. 2 we also displayed the group G_N4853 which includes giant ellipticals in the Coma cluster and the distant cD galaxy NGC 6166. The spectrum of this group does not present any UV turnup. All these galaxies are a factor of ≈ 5 more distant than those in the other groups shown in Fig. 1. According to Paper I, the average apertures for each of the latter groups are ≈ 1.0×2.0 kpc, whereas in the distant group G_N4853 it is ≈ 5.0 × 10.0 kpc. We conclude that the UV turnup may be intimately related to the very nucleus, and not a property of the circumnuclear parts of bulges, since giant ellipticals in Virgo (most of the galaxies in groups G_N4649 and G_N4472) exhibit a UV turnup, while giant ellipticals in Coma do not. Notice that gradients have been found in far-UV images of early-type galaxies (O'Connell 1992). Another evidence that the UV turnup is a nuclear phenomenon is the recent HUT spectra of giant ellipticals (Brown et al. 1995): M 60 (NGC 4649) and M 89 (NGC 4552), which are among the strongest UV turnups as observed by IUE, have virtually the same spectral distribution as NGC 3379, which does not have UV turnup. This can be explained by the fact that the HUT aperture is ≈ 3 times larger than that of IUE, and consequently dilution effects are present.

Based on the dilution experiment shown in 3.1, we conclude that large apertures in distant galaxies, by including more flux from the surrounding bulge, may cause the UV turnup to vanish from detection if it is indeed a nuclear phenomenon.

3.3. Galaxies with intermediate age burst.

The red stellar population group G_N221 (Fig. 1) is made up of galaxies for which population syntheses in the visible/near-IR indicated the presence of important intermediate-age components (Bica et al. 1990; Bica 1988): NGC 221 (M 32) appears to have a burst of ≈ 5 Gyr and the galaxies in the E 7 group NGC 2865, NGC 4382 and NGC 4742, a burst of ≈ 1 Gyr. Also included in the group is NGC 4111 (Burstein et al. 1988). It is clear that there is no UV turnup in the spectrum of G_N221, probably because the absence of the UV turnup is characteristic of intermediate age stellar populations (see also Magris & Bruzual 1993).

3.4. Discussion

A fundamental question remains: why does the far-UV flux vary so much among normal nearby early-type galaxies, such as those in Fig. 1? Excluding active and star-forming galaxies, Burstein et al. (1988) found a dependence of the far-UV excess on metallicity by means of the Mg_2 and (1550-V) indices, suggesting that the UV turnup arises from a metallicity effect (see also Bertelli et al. 1989). On the other hand, Magris & Bruzual (1993) found evidence of an intermediate/old age effect based on their solar metallicity models, since intermediate age populations have a lower far-UV flux as compared to older ones, as a result of the faster post-AGB evolution along the tracks for higher core mass stars.

Another possible interpretation of the weakening of the UV turnup, other than an aperture dilution effect (Sect. 3.2), would be dilution by different contributions from an intermediate age component originating in past starburst events, since the reddest spectral group, G_N221 (Sect. 3.3), has an important intermediate age contribution. Interestingly, the second reddest far-UV group, G_N1553, which is intermediate between G_N3115 and G_N221 (Fig. 1), is dominated by galaxies for which the population synthesis in the visible/near-IR (spectral group E 5 in Bica 1988) provided evidence of a small intermediate age excess with respect to the oldest bulges (spectral groups E 1 and E 2): 4 out of the 5 galaxy members of G_N1553 which are in common with Bica (1988), are from the spectral group E 5 (Table 1). This scenario is compatible with the results of Magris & Bruzual's (1993) models.

Mergers of spirals in the early universe or at intermediate ages could have formed many elliptical galaxies (e.g. Zepf & Ashman 1993). In this case, a dispersion in the age of such merger events might explain the varying intensities of the far-UV flux as observed among ellipticals. Such galaxies would populate the lower right region of the sequence in the Mg_2 *vs* (1550-V) diagram of Burstein et al. (1988), because they are far-UV weak, and the intermediate age causes some dilution of the MgI triplet lines (Bica 1988). In addition, depending on the metallicity of the spiral disks involved in the merging, the resulting intermediate age burst could account for some range in Mg_2 index.

We conclude that intermediate/old age effects associated to mergers of spirals (or mergers between a pre-existing elliptical and a spiral), together with metallicity effects resulting therefrom, may explain some of the observed properties of the UV turnup and its host elliptical galaxy.

4. The contribution of white dwarfs to the integrated spectrum

White dwarfs are natural evolutionary consequences of star-formation bursts of intermediate/old age. Thus it is worth looking for spectral signatures of their possible presence in the far-UV.

In order to work with the highest possible (S/N) ratio in the galaxy spectra, we further coadded groups from Figs. 1 and 2, obtaining one average strong and one average weak (or absent) UV turnup spectra. The strong UV turnup group is made up of G_N4486 and G_N4649, which are very similar. We omitted the intermediate intensity group G_N4472 in order to maximise the contrast between the high and low UV turnup groups. The far-UV weak group is composed of G_N3115, G_N1553 and G_N221; in this case, we omitted G_N3998 because of its atypical strong emission lines (Paper I), and G_N4853 because the IUE aperture includes much more circumnuclear flux in those distant galaxies (Sect. 3.2). Following the averaging procedure adopted in Paper I we weighted each component according to the square of its (S/N) ratio. The weights resulted in the relative proportions, at λ2646 Å: for the far-UV strong group, 30% of G_N4486 and 70% of G_N4649, and, for the far-UV weak group, 60% of G_N221, 28% of G_N1553 and 12% of G_N3115. The far-UV strong and weak UV turnup spectra are shown in Fig. 7. Also shown is the isolated UV turnup spectrum, obtained by subtracting the far-UV weak spectrum from that of the far-UV strong group.

Two wide absorption features in the SWP region, centred at $\approx \lambda$1400 Å and 1600 Å, are present both in the far-UV weak and strong spectra (respectively (b) and (a) in Fig. 7). The relative proportions of (a) and (b) in the subtraction (c) intended to minimise the resulting absorption residuals. We searched in the IUE database for sources which presented absorptions at these wavelengths: only relatively cool white dwarfs of types DA 4 and DA 5 exhibit them. Indeed, DA white dwarfs show an absorption feature at λ1600 Å for $T_{eff} <$ 13 500 K and another at λ1400 Å for $T_{eff} <$ 19 000 K (Koester et al. 1985, Nelan & Wegner 1985). They identified the λ1600 Å feature as resonance broadening of Lyα by the hydrogen quasi molecule, and the λ1400 Å feature, as a satellite line to Lyα arising from the hydrogen ion quasi molecule. These features only arise in high gravity conditions, such as those found in white dwarfs.

Using the same method for grouping galaxy spectra (Paper I), we created a library of white dwarf templates making use of the IUE database. It consists of the different subclasses of DO, DB and DA white dwarfs, and the results will be presented elsewhere (Bica, Bonatto & Giovannini 1996). Among all the white dwarf templates, the one representing the DA 5 exhibits similar λ1400 Å and λ1600 Å absorption features, as compared to the far-UV weak galaxy spectrum. A tentative spectral synthesis is presented in Fig. 8. We also use a template of sdB subdwarfs, including PG 0101+039, HD 4539, PG 0856+121, PG 1230+052, PG 1114+072 and PG 2110+127 from Saffer et al. (1994), with atmospheric parameters in the range $26\,200\,K \leq T_{eff} \leq 33\,700\,K$ and $5.63 \leq \log g \leq 5.81$, as well as 11 other sdB stars from Greenstein & Sargent (1974) and Green et al. (1986), with similar IUE spectra as the former. We include the sdB template since it is clear that a component hotter than DA 5 stars is necessary to reproduce the continuum distribution of the far-UV weak galaxy spectrum, and because extreme HB stars (represented by the sdB's in the Galactic field) have been suggested as probable candidates to account for the hot component in galaxies (Dorman et al. 1995, Bertola et al. 1995). The synthesis suggests that DA 5 white dwarfs contribute

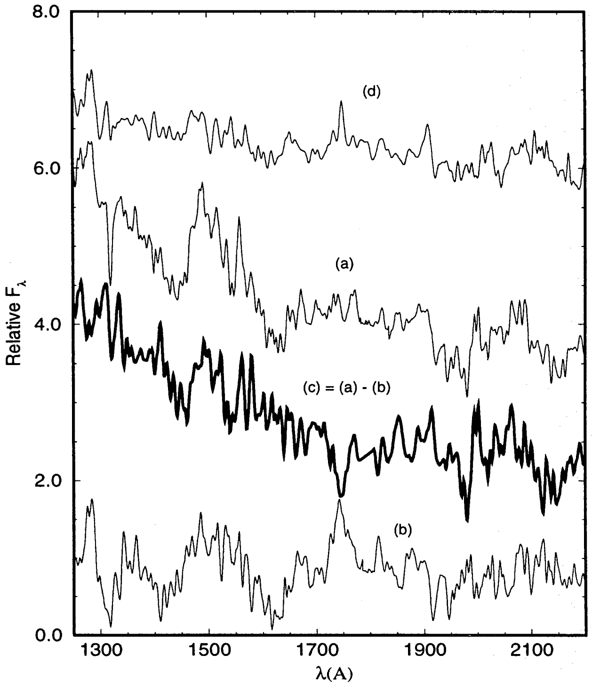

Fig. 7. (a) - Average spectrum of far-UV strong groups; (b) - the same for the far-UV weak groups; (c) - difference spectrum corresponding to the isolated UV turnup, minimising the absorption feature residuals; (d) - average spectrum of the nuclei of the spirals M 31 and M 104 which presents UV turnup but lack the strong white dwarf absorption features

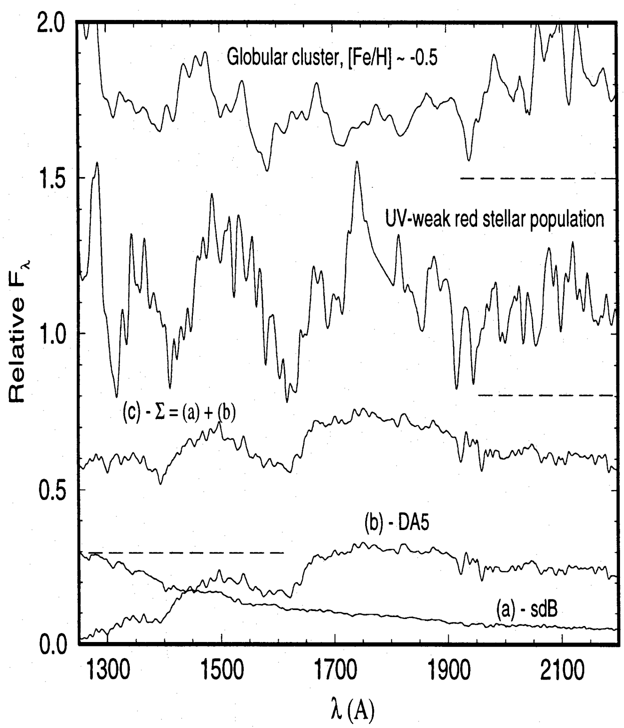

Fig. 8. Spectral synthesis of the far-UV weak red stellar population. Components are: (a) - sdB template (25% of flux contribution at λ1750 Å); (b) - DA 5 white dwarfs (75% of flux contribution at λ1750 Å); (c) - synthetic spectrum. The λ1600 Å and λ1400 Å features are present in (c). Also shown is the spectrum of the metal-rich globular clusters template G2b. Its flux scale has been multiplied by 1.6 with respect to that of the normalisation wavelength λ2646 Å. The dashed lines below each spectrum denotes the true zero level

with $\approx$ 75% of the flux at λ1750 Å. This imposes an important observational constraint to spectral models: in Magris & Bruzual (1993), the white dwarf flux fraction at λ1750 Å corresponds to only $\approx$ 10% in the range 8–16 Gyr. In the M 31 bulge, only $\approx$ 20% of the flux between 1200–2450 Å can be accounted for by resolved sources, which are bright AGB stars (Bertola et al. 1995, King et al. 1992). If the same proportion of bright AGB stars occur in the early-type galaxies, our results suggest that intermediate luminosity candidates like extreme HB stars and their progeny, should be minor flux contributors, since DA white dwarfs appear to be dominant, as indicated by the λ1400 Å and λ1600 Å absorptions.

The above synthesis results suggest that a strong bimodal star formation must have occurred in the past history of early-type galaxies, and allow one to estimate the amount of mass presently stored in white dwarfs (Bressan 1995, private communication). Using a PAGB-white dwarf sequence of a stellar model of 0.546 $M_\odot$ (Schönberner 1983, Koester & Schönberner 1986), the light from DA 4–DA 5 white dwarfs in the range λ1600 − 1800 Å is $\leq$0.1% of the total, consistent with the 10% predicted by Magris & Bruzual (1993), who considered white dwarfs of all temperatures. However, a truncated IMF with a lower cutoff at $\approx$ 1.5 − 2.0 $M_\odot$ would produce after several Gyr, a population dominated by DA 4–DA 5 white dwarfs, implying a bimodality in the star formation rate. In addition, the relative mass in such white dwarf population with respect to that of the *luminous* component of the galaxy can be computed, by assuming that the remaining 25% of the far-UV light comes from PAGB stars, and that white dwarfs were born in the interval 1.5–8 $M_\odot$. The result is $\approx$ 10, which could account for a significant fraction of dark mass.

For comparison purposes we also show in Fig. 8 the most metallic globular cluster template available, G2b ($[Z/Z_\odot] \approx -0.5$), which is made up of NGC 6388, NGC 6441, NGC 6624 and NGC 6637 (Bonatto et al. 1995). It presents obvious similarities with the far-UV weak galaxy spectrum. Two cluster members of G2b (NGC 6624 and NGC 6441) contain X-ray emitting stars, probably accreting binaries, (Bonatto et al. 1995 and references therein). The λ1600 Å feature appears to be present in G2b, which implies the occurrence of DA 5 white dwarfs in these globular clusters. Within the available (S/N) ratio, the λ1400 Å feature is not evident. We measured equivalent widths in the window 1494–1664Å. For the simple model in Fig. 8 we obtained W(λ1600 Å)=28±2 Å, for the far-UV weak stellar population W(λ1600 Å)=56±7 Å, and for the metal-rich globular cluster template W(λ1600 Å)=50±11 Å. In the DA 5 template, W(λ1600 Å)=40±3 Å, which suggests that white dwarf contribution of this type, or a neighbouring one with a somewhat larger W(λ1600 Å), could be even larger in more realistic models using a more complete stellar library.

According to Nelan & Wegner (1985), the λ1600 Å feature is stronger around $T_{eff} \approx$ 10 000 K. The cooling times for white dwarfs to attain such temperatures are ≈ 1 Gyr (Koester & Schönberner 1986), and in order to lower its temperature down to ≈ 4 000 K, additional 4 Gyrs are necessary. Clearly these figures, coupled to the turnoff ages of low-mass stars, suggest that the strong λ1600 Å feature is associated to the initial burst in the early-type galaxies, or perhaps to intermediate age merger events. In the metal-rich globular clusters, they must be a natural evolutionary consequence for ages greater than 10 Gyrs.

As a cautionary note we remind that IUE camera artifacts (Crenshaw et al. 1990) affect the galaxy templates to some extent. However, there are several arguments for the presence of the white dwarf features. *(i)* - the high and low dispersion IUE spectra of the background (Crenshaw et al. 1990) are very similar, although they do not fall on the same camera region. On the other hand, the flat field spectrum has differences, especially around λ1500 Å where it shows a dip. *(ii)* - The excess flux around λ1500 Å in the high and low dispersion background spectra, could be caused by a white dwarf background flux throughout the Galaxy. McCook & Sion's (1987) catalogue contains 1 789 white dwarfs typically closer than ≈ 100 pc from the Sun, most of them DA 4-5. Assuming this local density of white dwarfs (clearly a lower limit, since the catalogue is obviously not complete) as representative for the Galaxy within a few kpc from the Sun, the IUE aperture would collect at least 1–10 Galactic DA white dwarfs in any direction. *(iii)* - a strong argument is that the red stellar population nuclear spectra of the spiral galaxies M 31 (NGC 224) and M 104 (NGC 4594) present UV turnup (we show their average spectrum in Fig. 7 for comparisons), *but lack* the strong λ1400 Å and λ1600 Å features. If the absorptions are entirely camera artifacts, they should be present in both the UV turnups of ellipticals and spirals, which is not the case. HUT spectra of galaxy nuclei (Ferguson et al. 1991, Ferguson & Davidsen 1993, Brown et al. 1995) could provide an independent check, however their (S/N) ratio in the range corresponding to the IUE SWP region is not high enough for a conclusive assertion. Clearly, spectra with an independent telescope/detector with high (S/N) ratio are necessary to settle this issue.

5. Isolating the UV turnup

In the average spectrum of the far-UV strong groups (Fig. 7), both the λ1400 Å and λ1600 Å features are present, which indicates that DA 5 white dwarfs are as well important contributors to this spectrum. We subtracted the far-UV weak spectrum from that of the far-UV strong, trying to minimise the residuals of the λ1400 Å and λ1600 Å features, assuming that the stellar populations are compatible. The resulting hot component (hereafter isolated UV turnup) spectrum is also shown in Fig. 7: the λ1600 Å feature is cancelled out, although a small residual of the λ1400 Å feature remains. The average spectrum of the spirals M 31 and M 104 differs significantly from that of the strong UV turnup early-type galaxy nuclei. Evidence of this was also found by Ferguson & Davidsen (1993).

5.1. Comparison with hot source candidates

In order to investigate which kind of source could be responsible for the isolated UV turnup, we scanned through the IUE database for typical spectra of hot sources already quoted in previous works as possible candidates. For each selected object, we extracted all the available SWP and LWP/R spectra and treated them as explained in Sect. 2.

Among these sources is the strong X-ray emitter and black-hole candidate Cygnus X-1, for which the general shape of the far-UV spectrum of its optical counterpart (HDE 226868) is similar to that of a heavily reddened O 9.7 supergiant (Treves et al. 1980). In order to use Cygnus X-1 in the comparison, we reddening-corrected its spectrum applying a Galactic law (Seaton 1979) and E(B−V)=0.80, which produces a slope comparable to that of the black-hole candidate LMC X-3. This is a lower limit for E(B−V), since some LMC internal reddening may be affecting LMC X-3; indeed, Treves et al. (1980) estimated a somewhat larger value. The observed and corrected spectra of Cygnus X-1 are shown in Fig. 9. The absorption lines marked below the corrected spectrum are interstellar lines as identified in the spectra of other objects (see, e.g. Bahcall et al. 1991), and their presence in Cygnus X-1 is compatible with its observed strong dust absorption. Lines marked above the corrected spectrum are typical of O supergiant stars and originate in the Cygnus X-1 system (Treves et al. 1980). However, the presence of a discontinuity at ≈ λ2150 Å seen in the corrected spectrum is not typical of O stars and might be related to the accretion disk surrounding the black-hole.

We compare in Fig. 10 the IUE spectra of a series of hot sources:

(i) Two groups of subdwarf stars: the sdB template described in Sect. 4, and another one consisting of an average of the 5 hottest ($110\,000K \leq T_{eff} \leq 150\,000K$) sdO's in the sample of Schönberner & Drilling (1984). Some reddening was present in the sdO's as denoted by the λ2200 Å feature. Prior to averaging, the spectra were reddening corrected with Seaton's (1979) law and E(B-V) values in the range 0.05–0.15.

(ii) Two groups of very hot (DO) white dwarfs with effective temperatures above 75 000 K (e.g. Grauer et al. 1992). The group DO 1 is formed by the stars GW Vir, DS Drac and WD 1520, together with 6 other DO stars from McCook & Sion (1987) which presented similar IUE spectra and $T_{eff} \geq$ 100 000 K. The group DO 2 has average $T_{eff} \approx$ 70 000 K, and consists of the stars V817 Her and IR Peg (see Bradley 1993 and references therein), as well as 4 others from McCook & Sion (1987). Further details on these groups are given in Bica, Bonatto & Giovannini (1996).

(iii) The very hot nucleus ($T_{eff} \approx$ 105 000 K) of the planetary nebula NGC 7293 (Schönberner & Drilling 1984).

(iv) The spectra of the cataclysmic variable stars U Gem=HD 64511 and AM Her; both are accreting eclipsing binaries which contain a white dwarf, and are as well dwarf

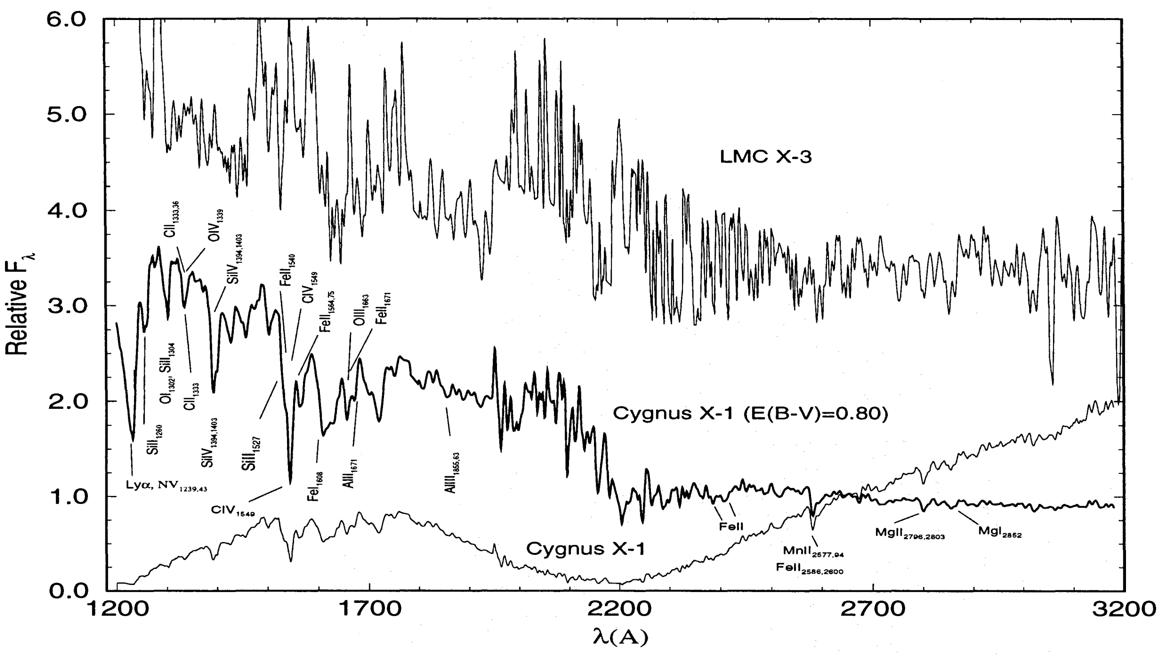

Fig. 9. Black-hole candidate Cygnus X-1 before and after the reddening correction for E(B−V)=0.80. The corrected spectrum turns out to be similar to that of LMC X-3. Flux is in F_λ units normalised at λ2646 Å. A constant has been added to the upper spectrum for clarity purposes

novae (Stockman et al. 1992). From its average IUE spectrum, AM Her presents strong emission lines and appears to be cooler than U Gem.

(v) The averaged spectrum of H II regions in M 101, M 33, LMC and SMC (Bonatto et al. 1995).

(vi) The reddening-corrected spectrum of Cygnus X-1 and the spectrum of the Seyfert 1 nucleus NGC 4151.

Strong emission lines in NGC 4151 and AM Her have been clipped out to facilitate visualisation. The stars in the items *(i)*–*(iv)* are intrinsically faint and consequently are nearby objects for which no significant amount of reddening is expected, except for the sdO's.

It can be concluded from Fig. 10 that among the candidate sources to explain the UV turnup important spectral slope differences occur. This fact can be used to constrain the possibilities.

In Fig. 11 we compare the spectrum of the isolated UV turnup (continuum ratio $C_{\lambda1282}/C_{\lambda1830}$=4.9±1.4) with some reference templates from Fig. 10. It is clear that only very hot sources like the planetary nebula nucleus NGC 7293 ($C_{\lambda1282}/C_{\lambda1830}$=4.3) (and also the sdO and DO white dwarf templates) have the necessary slope. The limiting case acceptable, within (S/N) ratio is the sdB template ($C_{\lambda1282}/C_{\lambda1830}$=3.2). The cataclysmic variables included in this analysis, as well as the H II region template, the Seyfert 1 nucleus, and the black-hole candidate ($C_{\lambda1282}/C_{\lambda1830}$=1.7), have a too mild slope and can be ruled out.

From this slope analysis we conclude that the UV turnup is associated to a stellar component linked to the old/intermediate age stellar population. Typical luminosities of planetary nebula nuclei are ≈ $10^4\,L_\odot$, those of sdO's and sdB's are ≈ $10^2\,L_\odot$, and those of very hot white dwarfs are ≈ $10\,L_\odot$ (Greenstein & Sargent 1974). The planetary nebula nuclei are luminous but short-lived; the sdO and sdB subdwarfs are the most promising candidates, since they are of intermediate brightness and long-lived; finally, the DO white dwarfs are too faint and short-lived. These conclusions have been within reach thanks to the much improved (S/N) ratio of the strong and weak UV turnup spectra as obtained by the averaging process.

It is important to remark that the present results are not at variance with those of Ferguson & Davidsen (1993) and Brown et al. (1995), who found colder components as dominant ones. As discussed in Sect. 3.2, the UV turnup appears to be associated to the very nucleus, and consequently the large HUT aperture dilutes UV turnups when compared to spectra taken with the IUE aperture. Indeed, the HUT spectrum of M 60 (NGC 4649), a strong UV turnup as observed by IUE, turns out to be comparable to that of NGC 3379, which has a very weak (or absent) UV turnup in the IUE aperture.

6. Alternative scenario to the origin of the UV turnup

The occurrence of the UV turnup in some early-type galaxies and not in others (Fig. 1) may be interpreted as a natural consequence of stellar evolution (Sect. 5) coupled to intermediate–old age or metallicity effects (Sect. 3). In this section we suggest an alternative scenario associated to past nuclear activity. The piece of evidence arises from the observation that M 87 (NGC 4486), which dominates the template G_N4486 (Fig. 2), presents a strong UV turnup with essentially the same spectral features and slope as the G_N4649 template (Fig. 1).

M 87 is a radio galaxy (Virgo A) which presents jet and double-lobe structures (Bridle & Perley 1984, and references

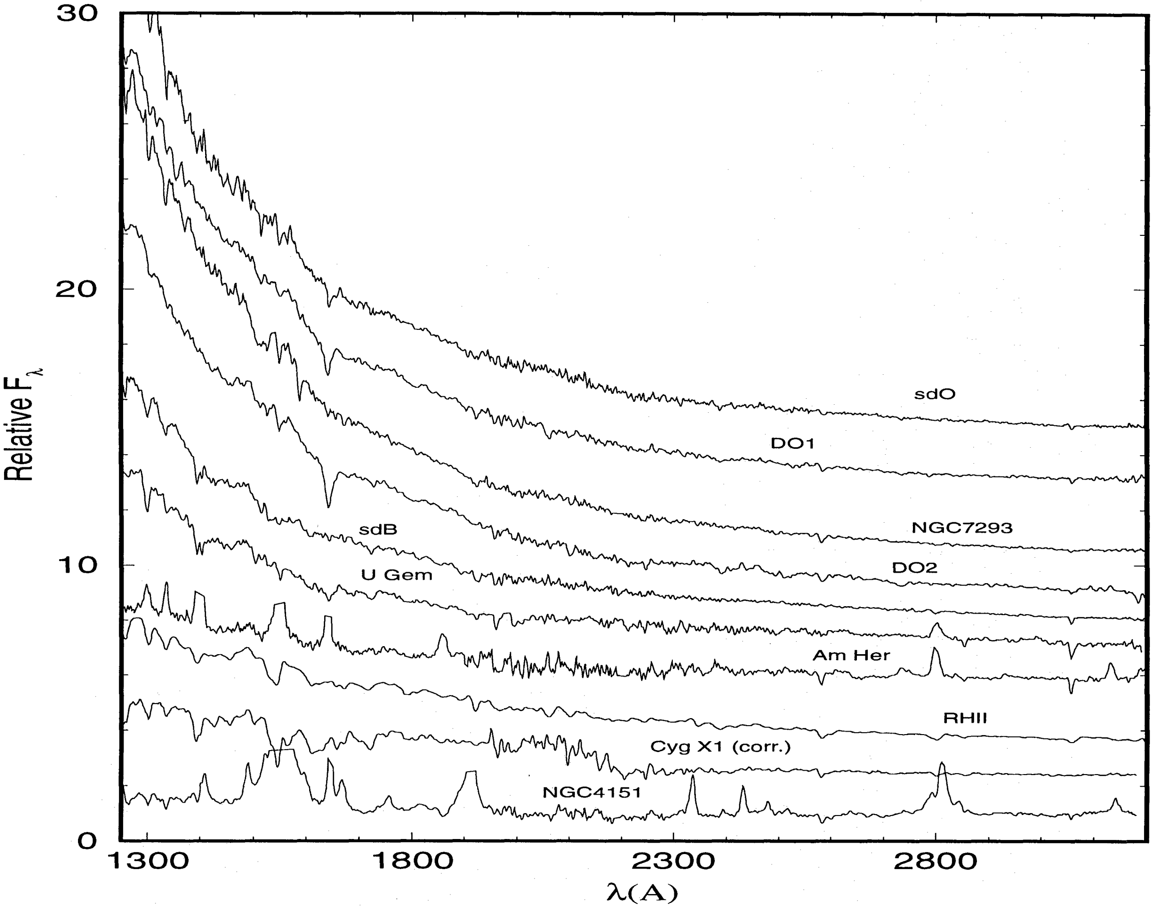

Fig. 10. IUE spectra of objects candidates to explain the UV turnup. Strong emission lines in NGC 4151 and AM Her have been clipped out for the sake of an easy visualisation. Flux is in F_λ units normalised at λ2646 Å. Constants have been added to the spectra for clarity purposes

therein). Tidal disruption of stars by $10^6 - 10^8\,M_\odot$ black-holes can produce winds with the ejected debris, or even double jets aligned with the angular momentum of the debris (Rees 1988). In addition to M 87, Bridle & Perley's (1984) compilation indicates that jets have been detected in NGC 1399 (in the far-UV strong group G_N4649), and in M 84=NGC 4374 (in the far-UV moderately strong group G_N4472). The fact that not every galaxy in the spectral groups with UV turnup has a detected jet or outflow might be related to episodic low intensity nuclear activity, such as those observed in some strong LINERs, and might be explained by chance capture and tidal disruption of stars by a central black-hole (Eracleous et al. 1995, Storchi-Bergmann et al. 1995).

The exposition of the stellar cores or hot inner shells (T≈ 100 000 K) and the spilling of gas into the surroundings would create conditions for photoionisation to explain the observed Hα luminosity in early-type galaxies, as computed by Binette et al. (1995), except that the ionisation source in their models are normal post-AGB stars. One effect of the bipolar outflow in the inner regions of a galaxy is heating surrounding gas to $T \geq 10^6$ K (Königl & Kartje 1994), which can account for the X-ray emission.

What would be the effect of such jets on the extended atmospheres of red giants in the central hundreds of parsecs corresponding to the IUE aperture where the UV turnup is detected?

Blobs associated to jets in the central region of some AGN are known to move at velocities approaching that of the light. The observed spatial shifts of the blobs imply apparent superluminal motions, which are indicative of highly relativistic bulk flows (Muxlow & Wilkinson 1991). Assuming a conservative value for the blob velocity of 100 000 km s^{-1}, and an ejection of 0.5 $M_\odot$, the associated kinetic energy of the blob would be $\approx 7.5 \times 10^{45}$ J. With a typical red giant mass of $\approx 0.8\,M_\odot$ and an envelope mass of $\approx 0.2\,M_\odot$, the kinetic energy of the blob corresponds to $\approx 2.4 \times 10^6$ the binding energy of the envelope. Depending on the efficiency, this process could blow away the envelopes of a considerable number of red giants. Another possible mechanism for blowing away red giant envelopes is the occurrence of a continuous jet (Bridle & Perley 1984). We consider here a jet flow with a mass ejection rate of 0.1 $M_\odot\,yr^{-1}$, velocity of 150 000 km s^{-1}, and opening angle of 5°. For a typical red giant crossing the jet at a distance of 1 pc from the central source, with a velocity of ≈ 200 km s^{-1} (which is a typical value for the central region of giant ellipticals, Terlevich et al. 1981), the jet would transfer to the star an energy equivalent to ≈ 5 times the binding energy of its envelope. The resulting exposed stellar cores would evolve in a similar way as the possible evolutionary channel postulated by Greggio & Renzini (1990), i.e. post-RGB and hot HB stars generated in very metal-rich populations as a consequence of extreme mass-loss conditions during the RGB phase. The hot HB stars are more appealing because they are longer-lived (10^8 yr as compared to $\approx 10^6$ yr, Greggio & Renzini 1990). In such case, the UV turnup would be a stellar effect, however induced by past activity related to jets.

7. Concluding remarks

As compared to previous studies which dealt with individual spectra, our spectral grouping analysis produced higher quality data that allow one to detect absorption features and to determine spectral slopes, which in turn provide important observational constraints to spectral modelling of the far-UV region of early-type galaxies. The main conclusions of this work are as follows:

(i) Galaxies in the strong UV turnup groups are systematically bright, and have high X-ray and Hα emission luminosities; however, some other galaxies with the latter properties do not exhibit a significant UV turnup.

(ii) A distance/aperture effect occurs: the presence of the UV turnup in giant ellipticals in Virgo and its absence in the giant ellipticals in Coma suggest that the UV turnup is diluted when the entrance window is larger, implying that it is related to the nucleus and not to the circumnuclear part of bulges.

(iii) The UV turnup is absent in galaxies presenting intermediate age bursts of star formation (e.g. M 32=NGC 221). Indeed, this effect is theoretically expected (Magris & Bruzual 1993). If bursts in the central regions of early-type galaxies were produced by mergers of spiral galaxies, as suggested by galaxy-interaction models, a dispersion in the age of the mergers in the early universe might naturally explain the varying intensities of the far-UV flux observed in ellipticals. However, metallicity effects in the sense that metal-rich populations having higher mass-loss rates, may produce an enhanced population of hot stars in late stages of stellar evolution through a series of possible evolutionary channels (Greggio & Renzini 1990). Both the metallicity and intermediate/old age effects may be occurring.

(iv) The UV turnup detected through the IUE aperture is not featureless: we find absorption features in the far-UV strong groups G_N4649 and G_N4472 which are similar to those present in the far-UV weak groups G_N3115 and G_N1553. Both groups present the DA 5 white dwarf absorption features at $\approx \lambda 1400$ Å and $\approx \lambda 1600$ Å. The strength of these absorptions observed in the galaxies indicates that DA 5 stars are dominant flux contributors between $\lambda 1300 - 2000$Å. Their cooling time along the white dwarf sequence together with the evolutionary time since they left the main sequence, imply that they evolved from low-mass stars possibly associated with the initial burst of star formation in early-type galaxies and/or merger events at intermediate ages. Spectral models including the white dwarf cooling sequence should be able to reproduce this dominant proportion of white dwarfs.

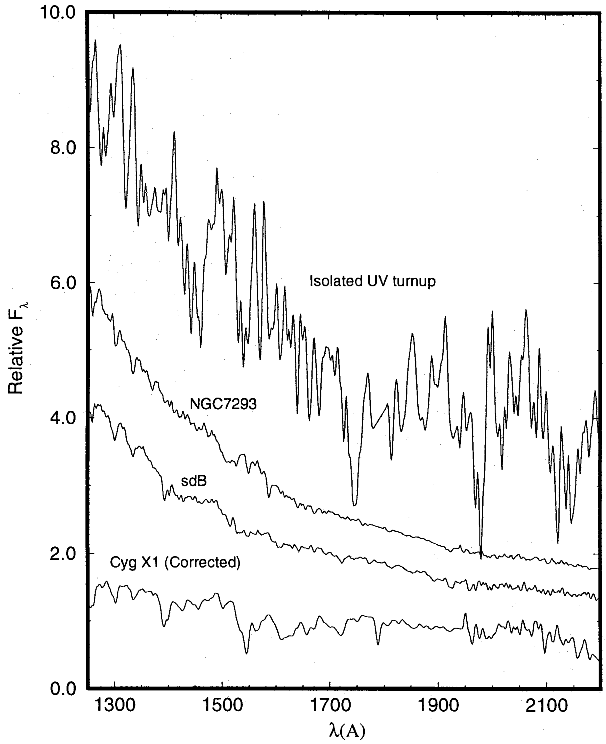

Fig. 11. Spectral slope comparison between the isolated UV turnup and some reference spectra from Fig. 10. The spectra are normalised at $\lambda 1830$ Å, and constants have been added to the spectra, except for the bottom one

(v) A simple synthesis predicts that DA 4–5 white dwarfs may contribute with $\approx 75\%$ of the flux at $\lambda 1750$ Å, with the remaining coming from e.g., hotter PAGBs. In this case, a strong bimodal star formation could have occurred in the past history of early-type galaxies, and the amount of mass stored in white dwarfs would be ≈ 10 times that of the luminous component (Bressan 1995, private communication). This mass locked up in white dwarfs may account for a significant fraction of the dark mass.

(vi) The slope analysis of the isolated UV turnup indicates a stellar origin for the UV turnup. The stellar sources with compatible slope are hot subdwarfs (sdO and sdB), very hot nuclei of planetary nebula and very hot white dwarfs (DO). In a normal stellar evolution scenario, life-time and luminosity arguments favour as best candidates to explain the UV turnup, the sources as in the above order.

(vii) As an alternative scenario, the UV turnup could be linked to past nuclear activity events and jets which might have blown away the atmospheres of red giants in the central parts of the galaxies, exposing the hot stellar cores and mimicking a spectral distribution like that of the hottest stars in advanced stages of low-mass stellar evolution. This scenario is appealing since it provides gas to the interstellar medium which in turn, may be heated to explain some of the observed X-ray emission, and ionised by the exposed cores to explain the Hα emission.

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References

Bahcall, J.N., Jannuzi, B.T., Schneider, D.P., Hartig, G.F., Bohlin, R. & Junkkarinen, V. 1991, ApJ, 377, L5
Bertelli, G., Chiosi, C. & Bertola, F. 1989, ApJ, 339, 889
Bertola, F., Capaccioli, M., Holm, A.V. & Oke, J.B. 1980, ApJL, 237, L65
Bertola, F., 1986 A&A, 22, 22
Bertola, F. & Capaccioli, M. 1982, A&A, 22, 22
Bertola, F., Bressan, A., Burstein, D., Buson, L.M., Chiosi, C. & Serego Alighieri, S. 1995, ApJ, 438, 680
Bica, E., Bonatto, C. & Giovannini, O. 1996, A&AS, in press
Bica, E. & Alloin, D. 1987, A&AS, 70, 281
Bica, E. 1988, A&A, 195, 76
Bica, E. & Alloin, D. 1988, A&A, 192, 98
Bica, E. & Alloin, D. & Schmidt, A.A. 1990, A&A, 228, 23
Binette, L., Magris, C., Stasinska, G. & Bruzual, A. 1994, A&A, 292, 13
Bonatto, C., Bica, E. & Alloin, D. 1989, A&A, 226, 23
Bonatto, C., Bica, E. & Alloin, D. 1995, A&AS, 112, 71
Bonatto, C., Bica, E., Pastoriza, M.G. & Alloin. D. 1996, A&AS, in press (Paper I)
Bradley, P.A. 1993, in *The Second WET Workshop*, ed. E. Meistas & J.-E. Solheim, Baltic Astronomy, 2, 559
Bridle, A.H. & Perley, R.A. 1984, ARA&A, 22, 319
Brinkmann, W., Siebert, J. & Boller, Th. 1994, A&A, 281, 355
Brown, T.M., Ferguson, H.C. & Davidsen, A.F. 1995, ApJ, 454, L15
Burstein, D., Bertola, F., Buson, L.M., Faber, S.M. & Lauer, T.R. 1988, ApJ, 328, 440
Buson, L.M., Sadler, E.M., Zeilinger, W.W., Bertin, G., Bertola, F., Danziger, J., Dejonghe, H., Saglia, R.P. & de Zeeuw, P.T. 1993, A&A, 280, 409
Crenshaw, D.M., Bruegman, O.W. & Norman, D.J. 1990, PASP, 102, 463
Dorman, B., O'Connell, R.W. & Rood, R.T. 1995, ApJ, 442, 105
Eracleous, M., Livio, M. & Binette, L. 1995, ApJ, 445, L1
Fabbiano, G., Kim, D.-W. & Trinchieri, G. 1992, ApJS, 80, 531
Fabricant, D., Lecar, M. & Gorenstein, P. 1980, ApJ, 241, 552
Ferguson, H.C. et al. 1991, ApJ, 382, L69
Ferguson. H.C. & Davidsen, A.F. 1993, ApJ, 408, 92
Filippenko, A.V. & Sargent, W.L.W. 1985, ApJS, 57, 503
Goudfrooij, P., Hansen, L., Jørgensen, H.E. & Nørgaard-Nielsen, H.U. 1994, A&AS, 105, 341
Grauer, A.D., Green, R.F. & Liebert, J. 1992, ApJ, 399, 686
Green, R.F., Schmidt, M. & Liebert, J. 1986, ApJS, 61, 305
Greenstein, J.L. & Sargent, A.I. 1974, ApJS, 259, 28
Greggio, L. & Renzini, A. 1990, ApJ, 364, 35
Heckman, T.M. 1980, A&A, 87, 152
Königl, A. & Kartje, J.F. 1994, ApJ, 434, 446
King, I. et al. 1992, ApJ, 397, L35
Koester, D., Weidemann, V., Zeidler-K.T., E.-M. & Vauclair, G. 1985, A&A, 142, L5
Koester, D. & Schönberner, D. 1986, A&A, 154, 125
Magris, G.C. & Bruzual, G.A. 1993, ApJ, 417, 102
McCook, G.P. & Sion, E.M. 1987, ApJS, 65, 603
Muxlow, T.W.B. & Wilkinson, P.N. 1991, MNRAS, 251, 54
Nelan, E.P. & Wegner, G. 1985, ApJ, 289, L31
Nesci, R. & Perola, G.C. 1985, A&A, 145, 296
O'Connell, R.W. 1992, in "The stellar populations of galaxies", IAU Symp. 149, eds. B. Barbuy & A. Renzini (Dordrecht: Kluwer), 233
Oke, J.B., Bertola, F. & Capaccioli, M. 1981, ApJ, 243, 453
Rees, M. J. 1988, Nature, 333, 523
Rich, R.M., Minniti, D. & Liebert, J. 1993, ApJ, 406, 489
Saffer, R.A., Bergeron, P., Koester, D. & Liebert, J. 1994, ApJ, 432, 351
Schönberner, D. 1983, A&A, 103, 119
Schönberner, D. & Drilling, J.S. 1984, ApJ, 278, 702
Seaton, M.J. 1979, MNRAS, 187, 73p
Stockman, H.S., Schmidt, G., Berriman, G., Liebert, J., Moore, K.C. & Wickramasinghe, D.T. 1992, ApJ, 401, 628
Storchi-Bergmann, T., Eracleous, M., Livio, M., Wilson, A. S., Filippenko, A. V. & Halpern, J. P. 1995, ApJ, 443, 617
Terlevich, R., Davies, R.L., Faber, S.M. & Burstein, D. 1981, MNRAS, 196, 381
Treves, A. et al. 1980, ApJ, 242, 1114
Zepf, S.E. & Ashman, K.M. 1993, MNRAS, 264, 611

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