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The interstellar Na I strength versus reddening relationship: its incidence on stellar population synthesis*

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Summary. We study the equivalent width W of the Na I D lines in 41 globular clusters with reddening $0 \leqq E(B-V) \leqq 1.11$ and a wide spatial distribution in the Galaxy. Contributions to the line absorption from the stellar and interstellar components are separated via comparisons with the Ca II K and the Mg I b lines. The value W(Na I) is found to be enhanced for reddened clusters. The relationship between interstellar Na I and $E(B-V)$ presents a steeper slope for globular clusters than that derived for stars in the solar neighborhood.

In view of stellar population synthesis in galaxies, we study the age and metallicity effects in the W(Na I) vs W(Mg I) plane by means of 15 Magellanic Cloud and 3 Galactic open clusters. For solar and lower than solar metallicities a large excess E(Na I) can be produced only by interstellar line absorption.

We also analyze 154 normal and 11 active galactic nuclei. We find that the Na I line is enhanced with galaxy inclination in spirals. Very metallic early type galaxies deviate from a linear relationship in the W(Na I) vs W(Mg I) plane. This excess of the Na I absorption can be equally accounted for by, (i) an interstellar contribution from the central regions and/or an extended halo compatible with the existing H I detections in early type galaxies, and (ii) an enhancement of W(Na I) with respect to W(Mg I) in the atmospheres of very metal rich late type stars as suggested by synthetic spectra computations.

Key words: interstellar Na I – globular clusters – galactic inclination effects

1. Introduction

The existence of a correlation between the line strength of interstellar Na I and the continuous extinction of starlight by interstellar grains is an evidence that gas and dust are generally associated in the interstellar medium (Spitzer, 1948). Indeed, observations of stars at intermediate and high galactic latitudes indicate that the column density of interstellar Na I is correlated with $E(B-V)$ (Hobbs, 1974). However, spatial variations of this relationship are observed in the Galaxy. In nearby disc regions the equivalent width of interstellar Na I in spectra of stars situated behind or within dense clouds are smaller than those of more distant stars with the same amount of reddening, arising from a long pathlength through relatively diluted interstellar material. This is due to Na I depletion from the gas in dense clouds, where most of the heavy elements must be locked on grains (Cohen, 1973). The very strong Na I D lines with respect to Mg I b, observed in some galaxies indicate an interstellar line absorption much stronger than in Galactic stars having the same amount of reddening; this could be explained by a larger sodium abundance or a higher gas to dust ratio in the central regions of these galaxies (Véron-Cetty et al., 1982).

We study the interstellar Na I D line vs reddening relationship using Galactic globular clusters (GGC) which present over stars, the advantage of a wide spatial distribution in the Galaxy. Indeed the lines of sight to our sample of GGC probe the interstellar medium through the outer halo, the bulge as well as the disc. Thus, they could potentially provide an average relationship for the Galaxy. We also discuss the derived relation with respect to a set of 165 normal and active galaxies.

The observations are presented in Sect. 2. We discuss in Sect. 3 the method for separating the stellar from the interstellar Na I D absorption components, the construction of the interstellar line strength versus reddening relationship and its interpretation in terms of interstellar matter in the solar neigborhood. We also present in Sect. 4 the age and metallicity effects in the W(Na I) : W(Mg I) plane, on the stellar component. In Sect. 5 we apply these results to a set of normal and active galaxies, some of which showing a large Na I excess absorption with respect to that expected from the stellar population. Concluding remarks are given in Sect. 6.

2. The observational data set

The observations of 41 globular and 3 open Galactic clusters, as well as 15 Magellanic Cloud clusters and 165 galaxies are part of a program for population synthesis in galaxies using integrated spectra of star clusters. The observations were carried out in January, July, November 1984 and May 1985 with the IDS attached to the Boller and Chivens spectrograph at the European Southern Observatory (ESO), La Silla, 1.52 m telescope. For large angular size objects a scanning procedure was used. The dispersion was 224 Å/mm in the range 3700, 8200 Å, with 11 Å resolution. Reductions were made using the IHAP system at ESO (Garching)

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* Based on observations collected at the European Southern Observatory, La Silla, Chile

Table 1

S1	Type	Galaxy			$b/a^\star$	Date	Exp (min)	Slit (kpc)	W(Mg I) (Å)	W(Na I) (Å)
		M_{BT}	A_B	V_R						
NGC3783	SBa(r)I	−20.81	0.21	2790	0.81	85 May 14	16	1.2×1.9	0.0	0.0
NGC7469	Sabpec	−23.10	0.05	4890	0.74	84 Nov 18	16	2.5×3.9	<0.2	0.1
IC4329A	S0/a ⋆	−21.70 ⋆	0.12	4815 ⋆	0.32	85 May 16	20	1.9×3.2	0.0	2.7

Observed parameters are from Sandage and Tammann (1981) except when denoted by an asterisk; then they are from de Vaucouleurs et al. (1976). For homogeneity, $H_0 = 50\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$

and Institut d'Astrophysique de Paris. Exposure time, area covered by the observations, slit dimension as well as physical properties – age, metallicity, reddening – have been given previously for each cluster (Bica and Alloin, 1986a). The equivalent widths W(Ca II K), W(Mg I b) and W(Na I D), measured from windows respectively 44, 40 and 34 Å wide are to be found in Table 1 of Bica and Alloin (1986b). For 154 normal galaxies as well as 7 Seyfert 2, and 1 Seyfert 1 objects with spectrum around 6000 Å dominated by the stellar component, we give morphological and photometric parameters, details on the observational conditions and resulting measurements for W(Na I D) and W(Mg I b) in a paper to come (Bica and Alloin, 1986c). Finally, we provide in Table 1 observational results for 3 Seyfert 1 type galaxies with negligible stellar contribution.

For such a study, excellent sky cancellation is required, owing to the atmospheric Na I D emission lines. We tested our sky subtractions by searching for residuals at [O I] 5577 Å, which, in the night sky emission is about a factor two stronger than the total Na I D line and lies in a nearby spectral region very little disturbed by absorption lines. In 51 star cluster spectra, no [O I] residual could be distinguished against the noise or the eventual weak intrinsic absorptions. In four cases, detections are suspected (1 absorption and 3 emissions) but their weakness implies Na I residuals less than 0.1 Å. In three cases, NGC 1866, 4833 and 5024, an [O I] residual was found in emission from which we infer Na I residuals of 0.15, 0.20 and 0.25 Å respectively. These objects are marked with a colon in Figs. 2, 3 and 4. In one case NGC 6171, a strong residual was found and this object was then excluded from the analysis in Figs. 2a and 2b. Note that the galaxy spectra cannot be affected by sky emission as long as $V_R > 700\ \mathrm{km\,s^{-1}}$.

3. The interstellar *W*(Na I) versus reddening relationship for Galactic globular clusters

In addition to their wide spatial distribution in the Galaxy, globular clusters are useful in the study of the interstellar Na I vs reddening relation because they have equal ages within the precision of the determinations (Vandenberg, 1983; Janes and Demarque, 1983). Consequently, differences observed among integrated spectra of GGC are in first order due to metallicity. We compare in Fig. 1 the Na I and Mg I lines in 3 pairs of cluster spectra, with moderately rich, intermediate and poor metallicity downward. Within each pair the clusters differ by large amounts in reddening. To make the line strength comparison easier, the continuous distribution has been dereddened. The noticeable enhancement of Na I observed in the more reddened objects can only be explained in terms of interstellar gas Na I absorption. Equal cluster ages allow the comparison not only of metallic lines in the same wavelength range like Na I and Mg I, but also of lines further away to the blue like Ca II K. We have plotted W(Na I) as a function of W(Mg I) and W(Ca II K) respectively in Figs. 2a and 2b, classifying the clusters into three reddening groups: $0 \leq E(B-V) \leq 0.20$, $0.21 \leq E(B-V) < 0.50$ and $0.51 \leq E(B-V) \leq 1.11$. In spite of the rather large spread, some separation among the points is observed; linear regressions and their attached r.m.s. deviations in the three groups confirm that these differences are significant. As a check, we have plotted W(Mg I) vs W(Ca II) in Fig. 2c. No trend for a separation is seen contrarily to what happens in the plots in Figs. 2a and 2b. Yet, an interstellar absorption is known to occur in the Ca II K line, its equivalent width being of the same order as that of Na I (e.g. Cohen, 1973). We do not detect it simply because in composite stellar populations W(Ca II K) is generally a factor 5 stronger than W(Na I). The Mg I triplet cannot be increased by an interstellar contribution since essentially all the interstellar lines arise from ground level transitions (Münch, 1968). Is is worth noticing that the group with negligible $E(B-V)$ in Fig. 2 does not contain any metal rich cluster. This is due to the fact that all metal rich GGC are concentrated towards the central regions of the Galaxy, at low Galactic latitudes and hence present a considerable reddening (Zinn, 1980; Bica and Pastoriza, 1983).

In order to somehow quantify the interstellar Na I vs reddening relationship, we define in Figs. 2a and 2b the pure stellar population relations for W(Na I) vs W(Mg I) and W(Na I) vs W(Ca II). For this we use the regressions deduced for the group with negligible reddening, a small slope correction being introduced from the reddened groups which cover a wider range in metallicity. An average excess E(Na I) with respect to W(Mg I) and W(Ca II) has been derived for each cluster; they are plotted against $E(B-V)$ in Fig. 3. The slope and dispersion of this relation can be understood in terms of a combination of different interstellar matter properties, as derived from interstellar line equivalent widths and reddening in solar neighborhood stars (Cohen, 1973, 1974, 1975; Cohen and Meloy, 1975). In order to compare those observations to ours, obtained with a lower dispersion, we selected stars having both D_1 and D_2 Na I measurements. Although the original conclusions of their papers were mostly based upon the less saturated D_1 component, they remain unchanged using $D_1 + D_2$ for the present star group. We also use data from Hobbs (1969, 1974). We show in Fig. 3 various zones filled in by stars from the Galactic plane: (i) within or behind dense dark clouds, (ii) more distant stars for which the line of sight goes through the low density intercloud medium, as well as, (iii) intermediate and high latitude stars (some of them might even be Halo members). Cloud stars exhibit weaker E(Na I) than do the more distant ones with the same

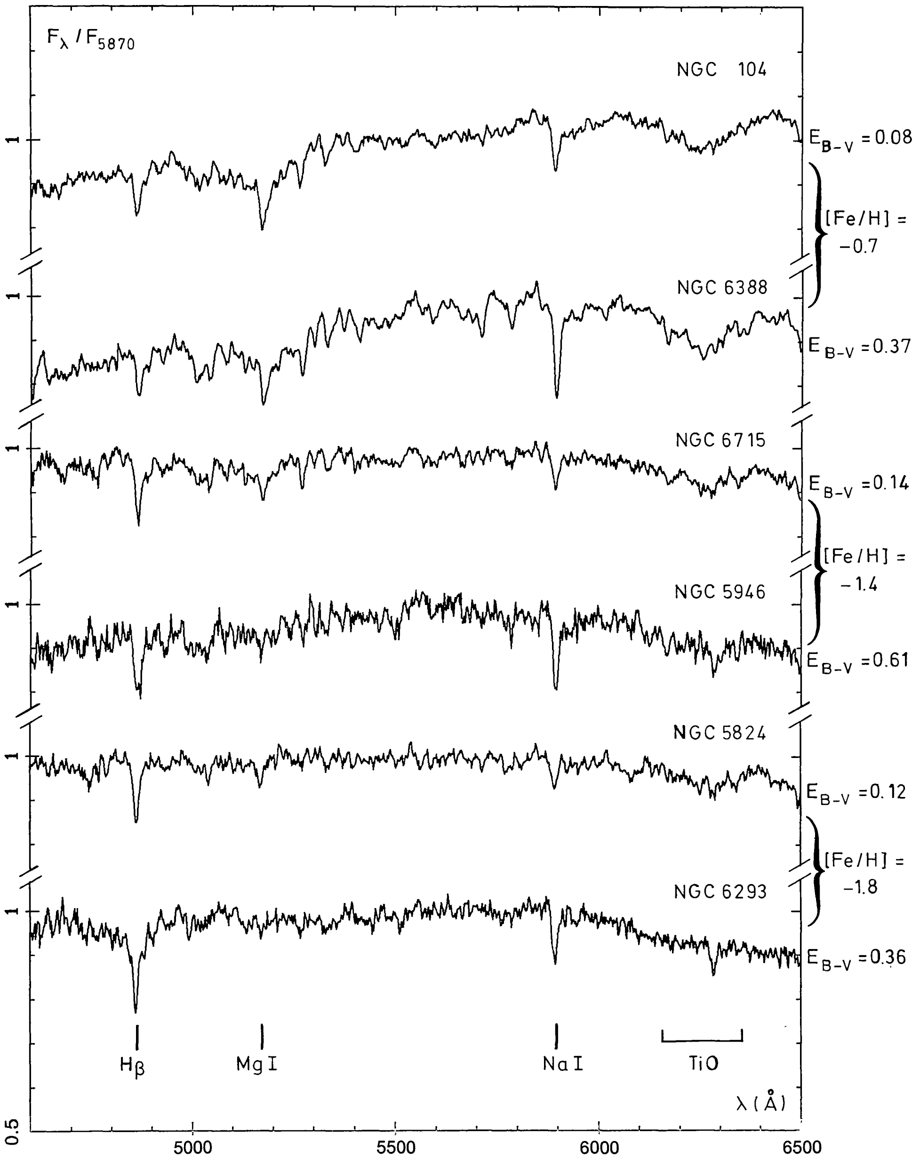

Fig. 1. Comparison of the relative strengths of the Na I and Mg I lines in pairs of GGC of similar metallicity, which differ by their amount of reddening. The Na I enhancement can only result from interstellar gas contribution

amount of reddening. This results from Na I depletion in the gas cloud where most of the heavy elements must be locked in dust grains (Cohen, 1973). The reddening for intermediate and high latitude stars arises most probably from a disc layer with half-thickness 100 pc. The line-strengths indicate that gas must be present as far as 1 kpc or more above the plane (Cohen, 1974; Cohen and Meloy, 1975).

With respect to stars, the GGC relation presents a steeper slope although a similar scatter. For our three reddening groups, we provide in Table 2 the mean solar distance $\langle d_\odot \rangle$ and the mean distance above the Galactic plane $\langle Z \rangle$, derived from Bica and Pastoriza (1983). The steeper global slope for the GGC is explained by their much longer pathlengths through the interstellar medium. As a matter of fact, most stars in this subset are within 1 kpc from the Sun, none exceeding 2.5 kpc, while the nearest GGC lies at $d_\odot \simeq 4$ kpc and the smallest mean distance in our reddened groups is $\langle d_\odot \rangle = 7.3$ kpc. Saturation effects in the lines, although certainly present do not affect this conclusion. Indeed, different systematic velocities and velocity dispersions of the gas clouds and the low density intercloud medium through various subsystems in the Galaxy are to be found along the lines of sight to GGC. The spread in the relation can be assigned, at least in part, to the different amount and physical conditions of the interstellar material intercepted towards each particular cluster. A typical globular cluster in the low reddening group is a distant outer halo object at high Galactic latitude with E(Na I) and $E(B-V)$ similar to the ones associated with intermediate and high latitude stars. The values of E(Na I) for these clusters, whose pathlength crosses both the local dust patches and the gaseous disc layer, indicate that the upper limit for Galactic gas contamination in the Na I window for galaxies having $V_R < 1000\ \mathrm{km\,s^{-1}}$, is 1 Å. In most cases however, this contribution should not exceed 0.5 Å. The group of clusters with $0.21 \leqq E(B-V) \leqq 0.50$ corresponds to typical low latitude bulge objects. They show a stronger E(Na I) than the local stars with the same $E(B-V)$, this being probably the result of a longer pathlength through the interstellar matter above the plane. Clusters from the last group, with $0.51 \leqq E(B-V) \leqq 1.11$, lie at smaller values of $\langle Z \rangle$ and $\langle d_\odot \rangle$ than the previous

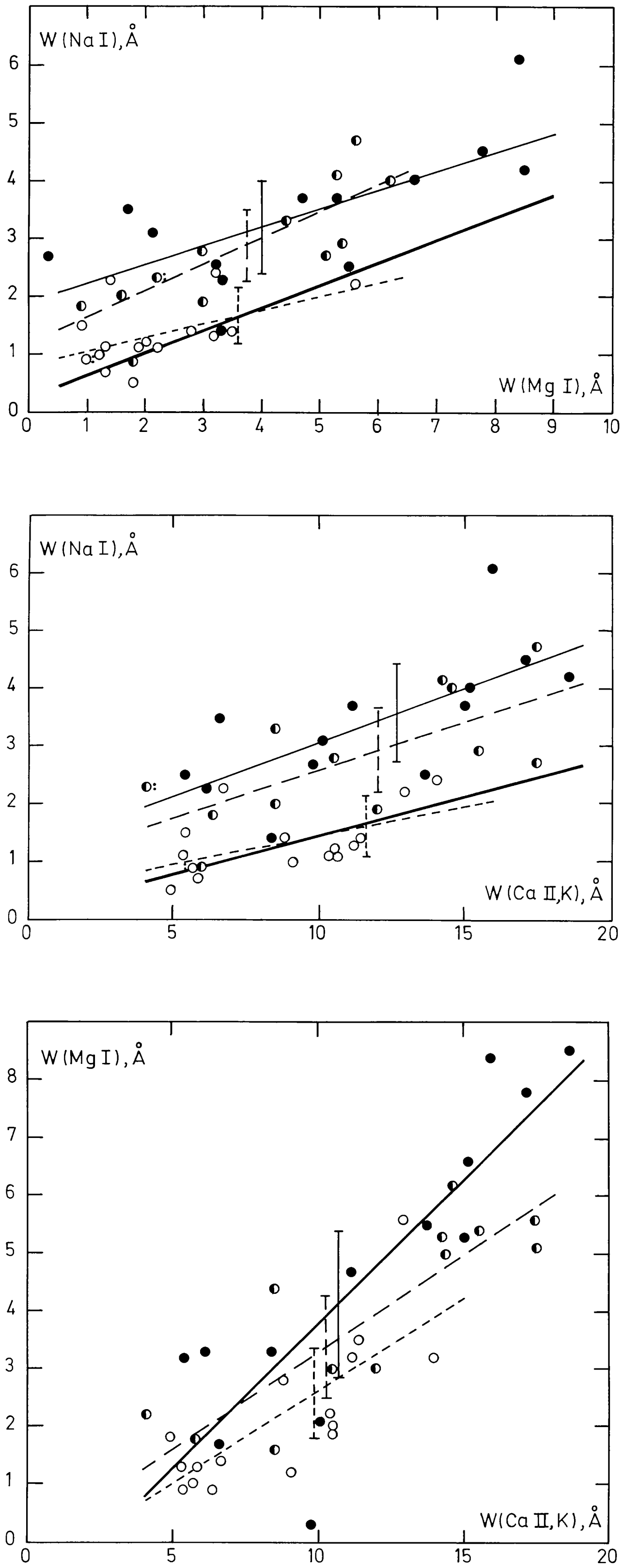

Fig. 2a–c. Comparison of metallic lines in GGC for three reddening groups: open circles, $0 \leq E(B-V) \leq 0.20$, semi-filled dots, $0.21 \leq E(B-V) \leq 0.50$, and black dots, $0.51 \leq E(B-V) \leq 1.11$. The corresponding linear regressions and r.m.s. deviations are represented respectively by a dotted line, an interrupted line and a thin solid line. The thick solid line in Figs. 2s and 2b is the adopted relationship, free from gas contamination

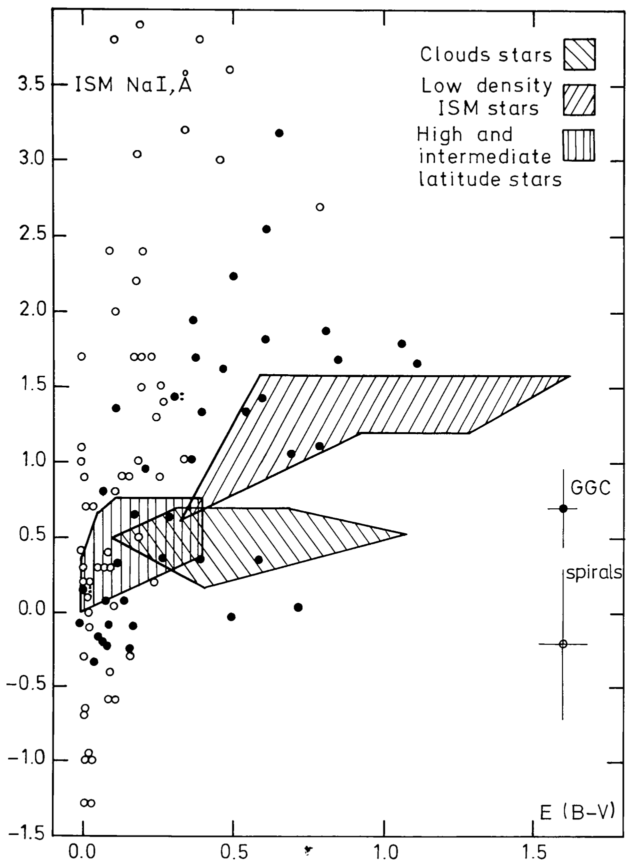

Fig. 3. The interstellar gas component of Na I vs reddening for GGC (black dots) as compared to Galactic stars with various line of sight properties. Open circles present inclined spirals ($b/a \leq 0.75$) where the excess $\mathscr{E}$(Na I) and $\mathscr{E}(B-V)$ are given with respect to nearly face-on spiral templates of similar stellar population (Sect. 5)

Table 2

Group No.	$E(B-V)$	N	$\langle d_{\odot} \rangle$ (kpc)	$\langle Z \rangle$ (kpc)	$\langle E(\text{Na I}) \rangle$ (Å)
1	0–0.20	15	14.6 ± 8.6	6.3 ± 4.4	0.13 ± 0.47
2	0.21–0.50	13	8.5 ± 3.4	1.3 ± 0.7	1.13 ± 0.70
3	0.51–1.11	13	7.3 ± 2.3	0.8 ± 0.7	1.52 ± 0.82

ones, a result in agreement with their large reddening. The line of sight to these clusters at very low Galactic latitude crosses on average a larger number of dense clouds so that their reddening grows much faster than does E(Na I). This explains why the two groups of intermediate and high reddening are almost undistinguishable in Figs. 2a and 2b.

4. Age and metallicity effects in the W(Na I) vs. W(Mg I) plane

In view of stellar population synthesis in galaxies, we study the effects of age and metallicity in the W(Na I) vs W(Mg I) plane using the pure stellar population relationship derived in Fig. 2a and the results from the integrated spectra of intermediate age and blue Magellanic Cloud clusters, as well as Galactic open clusters from

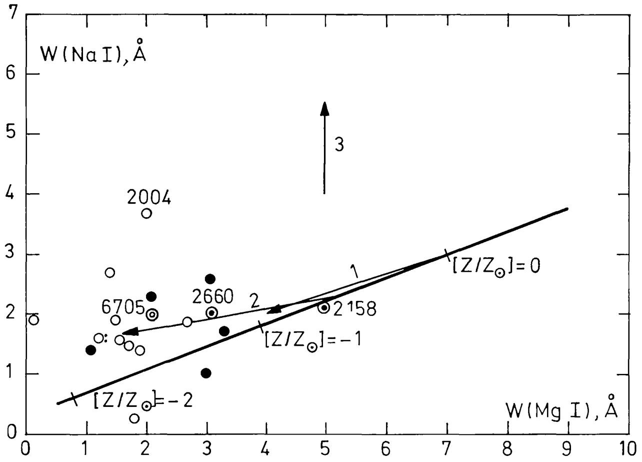

Fig. 4. Age and metallicity effects on W(Na I) and W(Mg I). The gas-free relation for GGC from Fig. 2a is labelled with metallicity. Black dots and open circles are for red and blue Magellanic Cloud clusters respectively. Encircled black dots and encircled empty dots are for red and blue Galactic open clusters. Vector 1 illustrates an age shift of 1.5 10^{10} yr at constant $[Z/Z_\odot]=0$. Vector 2 illustrates an age shift of 1.65 10^{10} yr at constant $[Z/Z_\odot]=-0.5$. Vector 3 shows the direction of interstellar gas contamination

Bica and Alloin (1986a, 1986b). In Fig. 4, the pure stellar population relation for the globular cluster isochrone is labelled with $[Z/Z_\odot]$. This demonstrates the effect of metallicity variations within the old clusters: as expected, both metallic lines Mg I and Na I become weaker for low metallicities. The vector labelled 1 corresponds to an age variation from a GGC to a red GOC about 10^9 yr, both with solar metallicity. The two 10^9 yr old GOC, NGC 2158 and 2660 present considerable reddening ($E(B-V)\simeq 0.40$), so that W(Na I) certainly contains some interstellar contribution. These considerations make it still more difficult to interpret the W(Na I) enhancement in terms of age variation. The vector labelled 2 corresponds to an age change from a GGC to the mean locus of blue LMC clusters, for a constant $[Z/Z_\odot]=-0.5$. The W(Na I) measurements for LMC clusters may also contain some interstellar contribution around 0.5 Å due to the Galactic and MC gas clouds (York, 1982). So, the intrinsic vector is more probably parallel to the GGC sequence. This is due to the fact that the blue turn-off points for these clusters contribute similarly to the underlying continuum owing to the wavelength proximity of these lines, while not to the line absorption. This is also supported by the position in Fig. 5, of NGC 5102, an S0 galaxy with a spectrum dominated by a population younger than in other early type galaxies. The abnormal position of the LMC blue cluster NGC 2004 in Fig. 4 results from a large TiO contribution to the Na I window as expected for an enhanced supergiant population in this cluster, 10^7 yr old (Bica and Alloin, 1986a). An age variation at constant solar metallicity from a GGC to the blue Galactic open cluster NGC 6705 is also essentially parallel to the GGC sequence. We conclude that for solar or lower than solar metallicity a strong enhancement of Na I *D* can only be produced by interstellar gas absorption.

5. Position of galaxies in the plane W(Na I) vs W(Mg I)

Measurements of W(Na I) and W(Mg I) for our sample galaxies (Bica and Alloin, 1986c) are plotted in Figs. 5a through 5d, corresponding respectively to types E-S0, S0/Sa-Sa, Sab-Sb and Sbc-Sc. We also recall in these figures the gas-free relation derived in Sect. 3 for GGC. The strong-lined early type galaxies (Fig. 5a) depart from the linear extrapolation of the GGC relationship, in the sense that for large W(Mg I) values, a 2 Å excess is observed in Na I. It can also be noticed that this effect tends to be stronger for higher luminosities. We also checked the presence of other contributors to the absorption in the Mg I and Na I windows. Using local continua, we estimated that for E and S0 galaxies, 50% of the absorption in the Mg I window is due to MgH, while TiO is responsible for 25% of the absorption in the Na I window. This implies even stronger relative excess of Na I with respect to Mg I. Such an excess might be explained by a larger interstellar gas content in the more massive galaxies or by an intrinsic population effect.

A stellar population effect could result from a variable giants to dwarfs ratio among galaxies. Another possible explanation is a larger increase rate of W(Na I) with respect to W(Mg I) for metallicities higher than solar, which could be associated with the different mechanisms responsible for the absorption in the wings of these lines. According to this latter hypothesis, for massive galaxies which are metal enriched (Faber, 1973), W(Na I) might increase more rapidly than W(Mg I) with metallicity in the stars contributing most to the galaxy light, an alternative to be explored. On the other hand, variations in the dwarfs to giants ratio seemed to be a promising assumption because dwarf stars show larger W(Na I) values than giants of the same spectral type (Spinrad, 1962). However, detailed population synthesis using solar metallicity stars, in some cases SMR stars, and fitting spectral features over a wide wavelength interval, do not allow a huge dwarfs contribution. Indeed, large Na I residuals remain in the best fit models for strong-lined galaxies like M31 and M81 (Spinrad and Taylor, 1971; Faber, 1972; Pritchet, 1977).

We can investigate the explanation of the 2 Å excess in W(Na I) with respect to W(Mg I) in terms of the relative increase rates of W(Na I) and W(Mg I) with metallicity. We compare our galactic observations to synthetic spectra of K0 giant and dwarf stars representing best the stellar groups which dominate the 5000–6000 Å flux in early type galaxies (Pickles, 1985). The models consist of computed profiles of the Mg I triplet and Na I doublet lines for a grid of values: $T_{\rm eff}=4710$ °K, $\log g=2.2$ and 4.5, and $[Z/Z_\odot]=0.6$, 0, −1 and −2 (Cayrel de Strobel and Cayrel, 1986). Atmosphere models are from Gustafsson et al. (1975), Bell et al. (1976) and Gustafsson (1982). A description of the actual profile computation is given in Cayrel et al. (1985). Results are displayed in Fig. 6 where we compare W(Na I) and W(Mg I) computed from model atmospheres to those of GGC and for galaxies as derived from the mean relation in Fig. 5a assuming $[Z/Z_\odot]=0.6$ in strong-lined galaxies (Bica and Alloin, 1986a). In the dwarf models, we observe a trend for W(Na I) increasing more rapidly than W(Mg I) in the interval $0.0\leqq[Z/Z_\odot]\leqq 0.6$. The increase of W per metallicity interval is presented in percentage, in the upper part of Fig. 6: giant stars present a W(Na I) increase rate which is consistent with that observed for galaxies, although the amplitude variation is less for giants. We conclude from this study that W(Na I) grows faster than W(Mg I) for metallicities above solar, both in dwarfs and giants. This is probably due to the fact that the damping in the Mg I triplet wings is essentially collisional while that in the Na I doublet wings is radiative.

Following Spinrad (1962) we can estimate the amount of interstellar gas required to produce an equivalent width of the Na I *D* lines: $W_\lambda=\pi l N\lambda^2 e^2 f/mc^2$, where l is the pathlength, N the number density of neutral Na atoms, $\lambda=5893$ Å and $f=1$. Typical values for the gas density in the Galaxy are $N_{\rm H}=0.1\,{\rm cm}^{-3}$ and

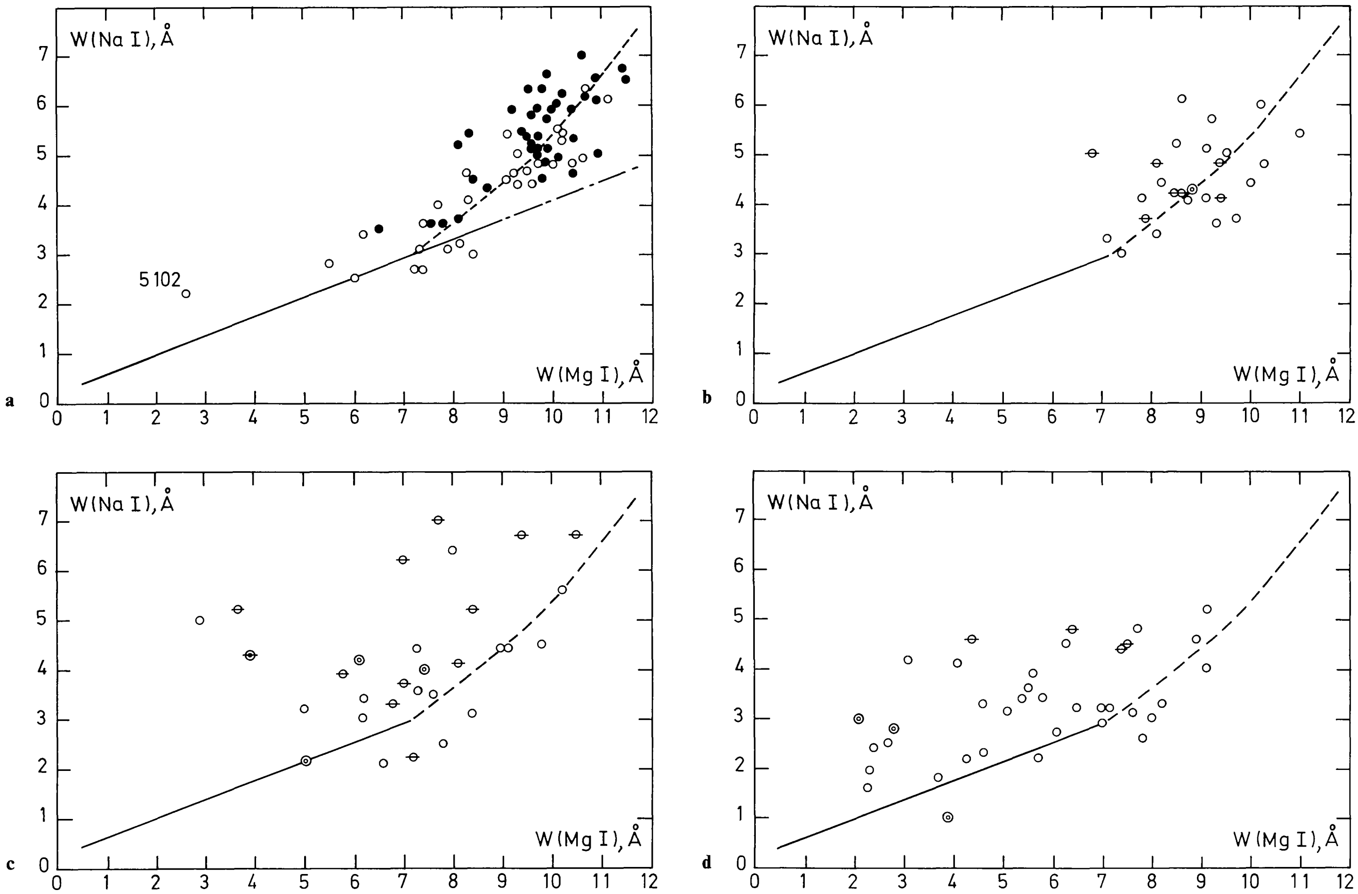

Fig. 5a–d. Line-strength comparisons for respectively E-S0 (**a**), S0 /Sa-Sa (**b**), Sab-Sb (**c**), and Sbc-Sc (**d**) galaxies. In **a**, black dots and open circles are respectively for galaxies with $M_v \leqq -21$ and $M_v > -21$. In Figs. **b** through **d**, open circles and barred circles denote respectively little and highly inclined ($b/a \leqq 0.50$) spirals. Encircled symbols are for Seyfert galaxies whose spectrum is dominated in the visible range by the stellar population component. We have recalled with a solid line the gas free GGC relationship from Fig. 2a, while the dashed-line is the mean relation for early type galaxies from Fig. 5a

$N_H = 8\,cm^{-3}$ respectively for the intercloud medium and the clouds (Allen, 1973). Assuming $N_H = 1\,cm^{-3}$ for a line of sight intercepting both kinds of medium, a solar sodium abundance Na/H = 1.8 10^{-6} (Allen, 1973) and the ionization degree of Na in an H I region to be $N_i/N_0 = 1500$ (Spinrad, 1962), we obtain $N = 1.2\ 10^{-9}\,cm^{-3}$. In order to reproduce the observed 2 Å excess in early type galaxies, the pathlength should then be of 1.8 kpc. Under simple assumptions for the gas distribution, a 1.8 kpc pathlength results in a total gaseous mass of about 6 $10^7 M_\odot$. This value is in agreement with the H I content detected in some massive E and S0 galaxies; it is also compatibele with most of the upper limits for the undetected ones, although in some cases the upper limits are only $M_{H\,I} \leqq 5\ 10^6 M_\odot$ (Knapp et al. 1985; Wardle and Knapp, 1986). We recall however that $M_{H\,I} \sim 10^6 M_\odot$ is the typical H I content found in dwarf early type galaxies in the Local Group, such as NGC 185 and NGC 205. This simple estimate suggests that, if the gas is to be responsible for the 2 Å excess in W(Na I), it has to be most probably extended. Indeed, extended H I gas is observed in the elliptical NGC 1052 (Van Gorkom et al., 1986). On the other hand, would the gas be confined to a small volume, its density should be around that found in Galactic clouds; very high density gas is likely to be associated with dust and then Na would probably be depleted (Sect. 3). In this extreme case, a strong E(Na I) is not expected anymore. The presence of high density gas clouds in the nuclear regions of some early type galaxies is suggested by the detection of dust lanes or complexes (Sparks et al., 1985).

Galaxies of later types (Figs. 5d to 5d) show three effects as follows: (i) the increasing contribution from hot stars in the spectra shifts the points in the W(Na I) vs W(Mg I) plots towards smaller values, as does also a nonstellar continuum in active galaxies, (ii) the cases of strong W(Na I) enhancement in the two last groups (Figs. 5c and 5d) are preferentially associated with inclined galaxies, (iii) last, the lower envelope for W(Na I) coincides roughly with that for early type galaxies and that for GGC from Figs. 5a and 2a.

The shifts described in (i) are consistent with the age effects in the plane W(Na I) vs W(Mg I), as derived for young star clusters in Sect. 3. This is also the case of the blue S0 galaxy NGC 5102 in Fig. 2a. Such age effects are not expected to produce significant enhancement of W(Na I) with respect to W(Mg I), as shown in Sect. 3.

In order to study the effects of inclination on W(Na I) in spirals, we have applied a template method for deriving the internal reddening due to galaxy inclination (Bica and Alloin, 1986c). For a given inclined spiral, it consists in selecting from the nearly face-on galaxies ($b/a \geqq 0.75$), templates showing a similar stellar population. The selection criterion is the minimization of differences in

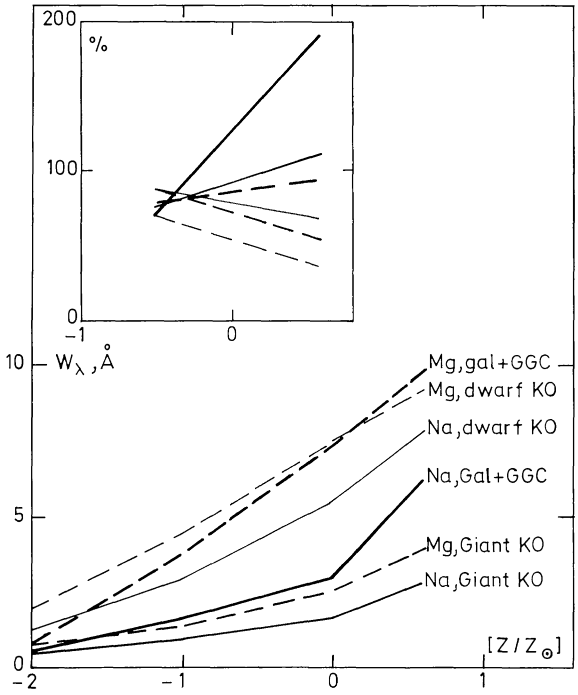

Fig. 6. The equivalent widths of Na I (solid line) and Mg I (dashed-line) as a function of metallicity. Thick lines correspond to GGC plus early type galaxies, thin lines to the synthetic spectrum of a K0 giant star and very thin lines to that of a K0 dwarf star. In the upper inset, we show the percentage increase of equivalent width per metallicity interval, with the same conventions

W(Ca II K), *W*(*Gb*), *W*(Mg I) and *W*(TiO). Metallic features in the blue insure a same content in younger age components, those in the red a same metallicity (Bica and Alloin, 1986a). Due to a possible emission, Balmer lines are not suitable for this analysis. The method is described extensively and the templates found for each inclined galaxy are given in Bica and Alloin (1986c). Although rather similar populations may, in some cases, exist in early or late spiral types, we have restricted our search to templates within 1.5 morphological class intervals. We also include in the present analysis the three Seyfert 1 galaxies with negligible stellar content (Table 1). Then, NGC 3783 was adopted as the nearly face-on template. As an illustration of the method applied to a Seyfert and a normal galaxy, we provide in Fig. 7 the reddened and dereddened spectra of a very inclined galaxy, together with the respective templates. By comparing each galaxy to the face-on template in its group, we derive the internal reddening $\mathscr{E}(B-V)$ required to produce a continuous distribution similar to that of the template, and we estimate the Na I and Mg I excess $\mathscr{E}$(Na I) and $\mathscr{E}$(Mg I) as $W_{gal} - W_{templ}$.

Galactic nuclear regions, as seen through the spectrograph slit, are however a spatial average over zones possibly composite with respect to the population content and reddening distribution. A population effect is not expected to affect much the averaged observations, due to strong luminosity gradients which are as a rule present in the nuclear regions of massive galaxies of all morphological types. On the other hand, the situation is different in the case of an inhomogeneous reddening. A mixture of highly reddened to reddening-free regions produces a composite reddening law which departs from the normal one, even if the individual regions along the line of sight themselves obey a normal reddenning law. For the sake of simplicity we have assumed in the present study that a normal reddening law was still valid. When applied to the reddened nuclei in our sample, it allows to reproduce the continuum distribution of the respective templates, at least over the 4000 Å wavelength range considered (Fig. 7). This indicates that an eventual composite law does not depart significantly from the normal one, in turn suggesting highly peaked distributions around the best fit value of $E(B-V)$.

Results for the whole sample of inclined spirals are shown in Fig. 8. One observes that $\mathscr{E}$(Na I) increases with inclination, due to the gas component in the disc. As a test we have displayed $\mathscr{E}$(Mg I) which is null as mean. We also show $\mathscr{E}(B-V)$ resulting from inclination, which tends to be larger for low values of b/a, although this effect is not as conspicuous as that occuring for $\mathscr{E}$(Na I). This is in agreement with observations of the Milky Way revealing that dust and gas are mostly contained in layers with halfthickness 100 pc and 1 kpc respectively (Cohen, 1974; Cohen and Meloy, 1975). We compare the excess in Na I and the reddening due to inclination in galaxies, with GGC and stars in Fig. 3. This confirms the result that some galaxies have a strong $\mathscr{E}$(Na I) with respect to Galactic stars of the same $E(B-V)$ (Véron-Cetty et al., 1982). However, the template method used in our study as well as the results for GGC in Sect. 3 suggest that the Na I excess results from long paths through inclined discs rather than from metal rich gas in the central regions of galaxies.

We can look for galaxies with a large amount of gas not located in a disc, by plotting the residuals of W (Na I) with respect to the mean relation in Fig. 5, for the elliptical and S0 galaxies, as well as the nearly face-on spirals having $b/a \geqq 0.75$ (Fig. 9). Large positive residuals would be an indication of atypical gas content, either in the central regions or in an extended halo. This seems to be the case for the spiral NGC 986, and to as lesser extent for NGC 1316 and 2442. As already noticed by Véron-Cetty et al. (1982), NGC 986 shows dust lanes associated with the nucleus; NGC 1316 also presents dust lanes (Baade and Minkowski, 1954), as well as NGC 2442, but in this case the galaxy seems to be more inclined than suggested by the axial ratio which is large owing to asymmetric arms (Sersic, 1968).

Finally, we observe that the lower enveloppe for spirals (Figs. 5b to 5d) coincides with that for E and S0 galaxies (Fig. 5a). This suggests a common origin in all galaxies, for the linearity departure of *W*(Na I) at large *W*(Mg I) values.

6. Concluding remarks

The main conclusions of this study are as follows:

1. The absorption Na I *D* line is enhanced in reddened Galactic globular clusters.
2. The stellar and interstellar components of the Na I *D* lines are separated via comparisons with Mg I *b* and Ca II K lines.
3. The derived interstellar *W*(Na I) versus reddening relationship for GGC shows a stronger slope than that for Galactic stars. This arises essentially from longer pathlengths through the interstellar medium outside the Galactic plane. The characteristics of the lines of sight to GGC are interpreted in terms of the various properties of the interstellar gas along the lines of sight to stars in the solar neighborhod.
4. A comparison of GGC with Magellanic Cloud and Galactic open clusters in the plane *W*(Na I) : *W*(Mg I) indicates that age and metallicity effects cannot produce a relative enhancement of Na I with respect to Mg I for solar and lower than solar metallicities.
5. The Na I line is enhanced with inclination in spirals.

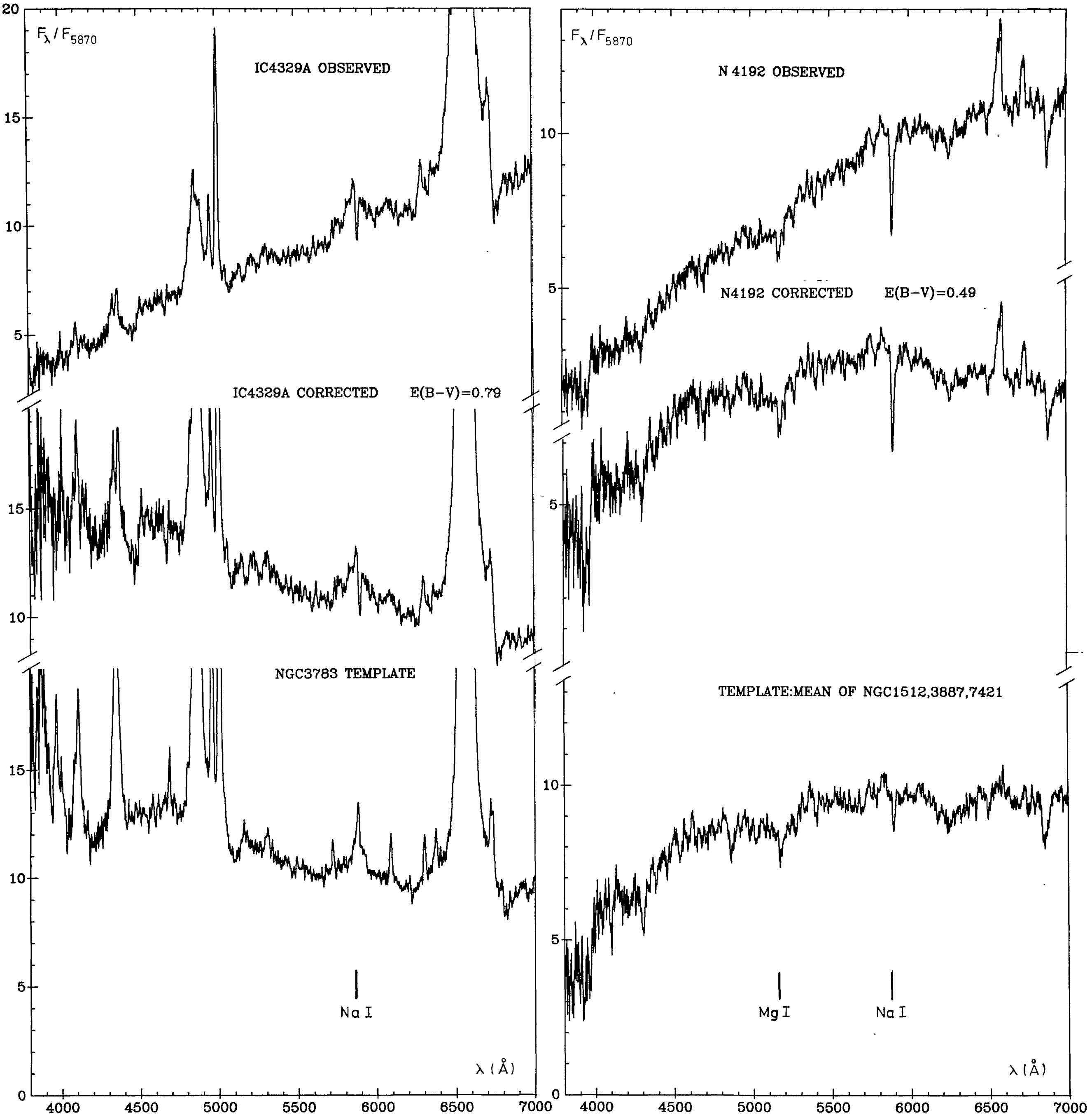

Fig. 7. Spectra of inclined spirals with their respective nearly face-on templates. Left: Seyfert 1 with negligible stellar population contamination; Right: normal galaxy. Dereddened spectra are also shown. Notice the strong NaI excess in the inclined galaxies. The spectra are normalized to $F_\lambda = 10$ at $\lambda = 5870$ Å

6. Very metallic early type galaxies deviate from a linear relationship in the W(Na I) : W(Mg I) plane. This excess in the Na I absorption could be accounted for in different ways:

(i) An interstellar contribution from the central regions and/or from an extended halo compatible with some existing H I detections in early type galaxies,

(ii) An enhancement of W(Na I) with respect to W(Mg I) in the atmospheres of very metal rich late type stars as suggested by synthetic spectra computations.

7. We conclude that the Na I D lines are not of a straightforward use in stellar population synthesis, owing to their contamination by the interstellar contribution. This contribution

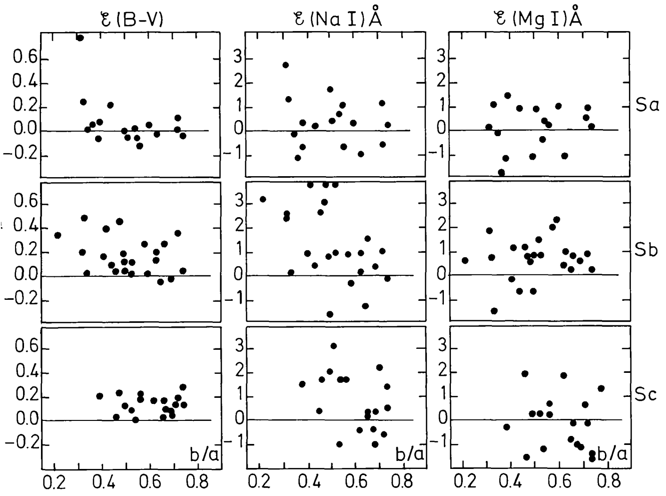

Fig. 8. The Na I excess found for inclined spirals ($b/a \leqq 0.75$), with respect to nearly face-on spiral templates of similar stellar population, as a function of the inclination

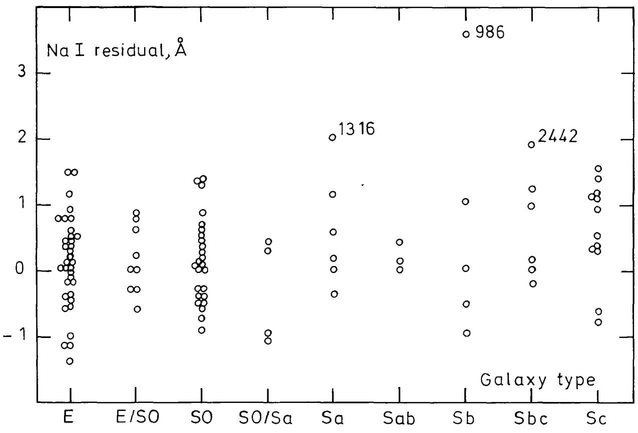

Fig. 9. Residuals in the Na I line, with respect to the GGC plus early type galaxies relationship (Figs. 5a through 5d), for early type galaxies and nearly face-on spirals ($b/a > 0.75$) in our sample

can be substantial, even larger than the stellar one, in spiral galaxies highly inclined.

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