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THE NATURE OF THE OPTICAL LIGHT IN SEYFERT 2 GALAXIES WITH POLARIZED CONTINUA

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ABSTRACT

We investigate the nature of the optical continuum and stellar population in the central kiloparsec of the Seyfert 2 galaxies Mrk 348, Mrk 573, NGC 1358, and Mrk 1210 using high signal-to-noise–ratio, long-slit spectra obtained along the radio axis or along the extended high-excitation emission. These four galaxies are known to have polarized continua, including polarized broad lines in Mrk 348 and Mrk 1210, and previous studies indicate featureless continua contributions in the 20%–50% range at $\lambda \approx 5500$ Å. Nevertheless, our measurements of the equivalent widths of absorption lines and continuum ratios as a function of distance from the nuclei show no decrease of the equivalent widths (i.e., no dilution) nor blueing of the spectrum toward the nucleus, as expected if a blue, featureless continuum was present at the nucleus in the above proportions. We investigate one possibility to account for the lack of dilution: that the stellar population at the nucleus is the same as that from the surrounding bulge and dominates the nuclear light. By comparing the nuclear and the extranuclear spectra of each galaxy, we conclude that this hypothesis works for Mrk 348, NGC 1358, and Mrk 1210, for which we find stellar population contributions at the nucleus larger than 90% at all wavelengths. Our approach differs from that adopted in previous studies, where an elliptical galaxy template is used to represent the stellar population of the nucleus. Although the latter may be valid for some galaxies—as, for example, Mrk 573—in several cases the stellar population may be different from that of an elliptical galaxy. We find that a larger stellar population contribution to the nuclear spectra can play the role of the "second featureless continuum" source inferred from previous studies. In particular, stellar population synthesis shows that the nuclear regions of Mrk 348 and Mrk 1210 have important contributions of young to intermediate-age stars ($0–10^8$ yr) not present in templates of elliptical galaxies. In the case of Mrk 1210, this is further confirmed by the detection of a "Wolf-Rayet feature" in the nuclear emission-line spectrum.

Subject headings: galaxies: active — galaxies: nuclei — galaxies: Seyfert — galaxies: stellar content — polarization

1. INTRODUCTION

The development of the unified model for Seyfert galaxies has opened interesting questions regarding the nature of the optical-UV continuum in Seyfert 2 galaxies. This continuum seems to be well understood only in the prototypical Seyfert 2 galaxy NGC 1068 (Antonucci & Miller 1985; Miller, Goodrich, & Mathews 1991), where it is attributed to a combination of a red stellar population contribution plus a blue, featureless continuum (FC) scattered toward us by electrons, and in Mrk 477 (Heckman et al. 1997), where the observed blue continuum is dominated by a dusty starburst. Polarimetric studies by Miller & Goodrich (1990) and later by Tran, Miller, & Kay (1992), Kay (1994), and Tran (1995a, 1995b, 1995c) have revealed polarized lines and continua in a number of additional Seyfert 2 galaxies, indicating the presence of a scattered Seyfert 1 component. However, the low levels of polarization (Miller & Goodrich 1990), the lack of detectable broad lines in the direct spectra (Cid Fernandes & Terlevich 1995; Heckman et al. 1995), and larger polarizations in the broad lines than in the continuum (Tran 1995a, 1995b, 1995c) indicate the existence of another source of continuum not accounted for by the starlight template or by the reflected nuclear component. The origin of the "second featureless continuum" source (FC2), as this extra component became known (Miller 1994; Tran 1995c), is one of the most important current issues in Seyfert 2 studies. The two currently contending scenarios are free-free emission from the scattering region (Tran 1995c) and young stars, as proposed by Cid Fernandes & Terlevich (1992, 1995). The latter model has recently received additional support with the detection of stellar features from young stars in the UV, optical, and near-IR spectra of bright Seyfert 2 galaxies by Heckman et al. (1995, 1997).

When discussing the nature of the optical continuum in active galaxies, one must be aware of the importance of evaluating and removing the starlight "contamination," particularly in Seyfert 2 galaxies, where the stellar component often overwhelms the scattered flux. Indeed, as emphasized by Miller & Goodrich (1990), Antonucci (1993), Kay (1994), and Tran (1995a), the derived polarizations are very sensitive to the adopted stellar population template. The simple fact that different authors obtain very different starlight fractions for the same object (e.g., Kay 1994; Tran 1995a) is a clear demonstration of how critical and uncertain the starlight removal procedure is. In most polarimetric

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studies, as in fact in most optical spectroscopy studies of active galactic nuclei (AGNs) since Koski (1978), the stellar population template used to subtract the stellar contribution is the nuclear spectrum of an elliptical or early type galaxy. Given a library of normal galaxy spectra spanning a sufficiently wide range of stellar population mixtures, this approach will certainly produce a satisfactorily AGN-looking, smooth residual spectrum. However, given the nonuniqueness of the solution, one must always bear in mind that the adopted template may not correspond to the true stellar population of the host galaxy. And even if the adopted template accounts for, say, 80% of the true stellar component, the error induced by not accounting for the remaining 20% may be critical when it comes to interpreting the nature of the residual continuum.

In order to investigate the stellar populations in active galaxies using a different approach, we have recently concluded a study (Cid Fernandes, Schmitt, & Storchi-Bergmann 1998, hereafter Paper I) where we have used long-slit optical spectroscopy of 42 galaxies to measure the variation of equivalent widths (EWs) of several stellar absorption lines, as well as continuum ratios as a function of distance from the nucleus. Our goals were to map the stellar populations in the sample galaxies and to obtain the stellar population characteristics right at the active nucleus via extrapolation of the properties measured in neighboring extranuclear regions. Such an approach has been previously used by Fosbury et al. (1978) and by ourselves in previous works (e.g., Schmitt, Storchi-Bergmann, & Baldwin 1994; Storchi-Bergmann et al. 1995, 1997a).

In Paper I we found that the presence of an FC in the nucleus of Seyfert 1 galaxies was revealed by a blueing of the continuum and by a decrease of the EWs of the absorption lines toward the nucleus. In galaxies with nuclear starbursts or rings of star formation, the same behavior was observed: the star-forming regions present bluer colors and smaller EWs. One unexpected result was the finding that, in the majority of Seyfert 2 galaxies, there is neither a dilution of the EWs nor a blueing of the continuum toward the nucleus, indicating that the FC, if present at the nucleus, contributes with less than $\approx 10\%$ of the flux in the optical waveband. The only clear cases of detection of dilutions and blue continua were the Seyfert 2 galaxies already known to harbor "composite nuclei," with both Seyfert and starburst activity, as evidenced by the emission-line ratios and/or the presence of absorption features of young stars. These results are illustrated in Figure 1, where we show the variation of W(Ca II K), W(G band), W(Mg I + Mg H), and of the continuum ratio $\lambda5870/\lambda4020$ as a function of distance from the nuclei for the Seyfert 1 galaxy NGC 6814, for the galaxy with composite nucleus (Seyfert 2 and starburst) NGC 7130 and the Seyfert 2 galaxy Mrk 348. While the decrease of the EWs and blueing of the continuum is obvious in the two former galaxies, they are not observed in the latter.

In this paper, we investigate the above results more closely for four Seyfert 2 galaxies: Mrk 348, Mrk 573, NGC 1358, and Mrk 1210, since previous works have reported dilution factors up to $\sim 50\%$ for these galaxies. In Paper I we have shown that our method allows the detection of dilutions larger than 5%–10% (which correspond to the uncertainties in the EWs), but for these galaxies we have not detected significant dilutions in the absorption features of the stellar population up to at least $\sim 10''$ from the nucleus. This behavior can be observed in Figure 1 for Mrk 348 and in similar plots for Mrk 573, NGC 1358, and Mrk 1210 (Figs. 17, 21, and 25 from Paper I). We investigate the reason for this lack of dilution and the implications for the nature of the nuclear continuum and stellar population.

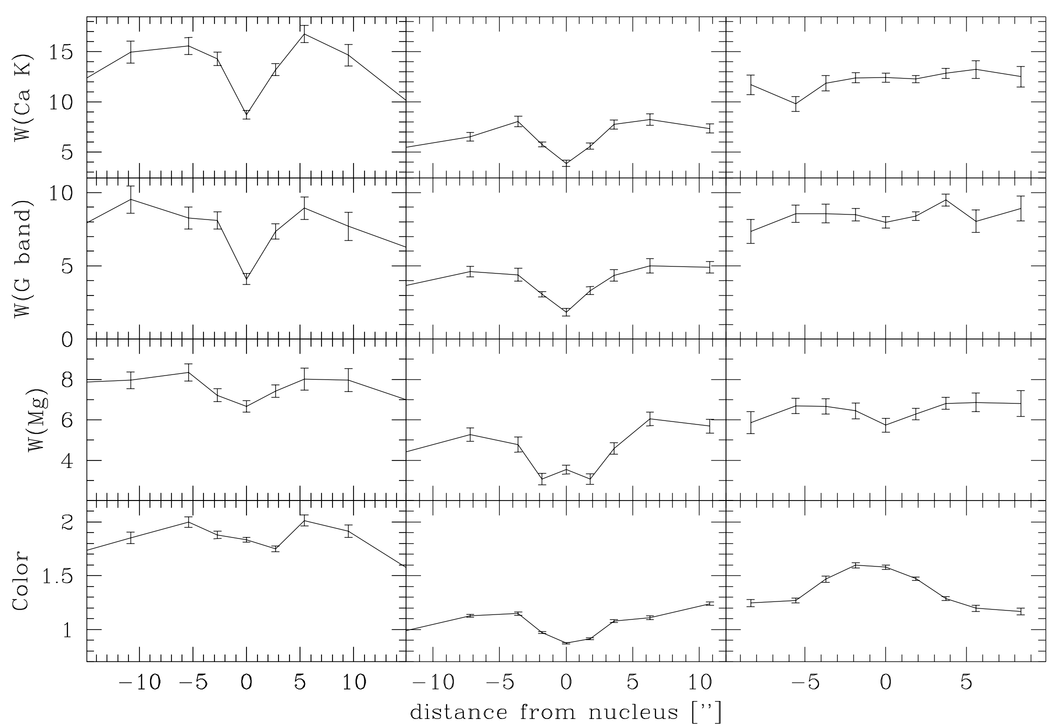

FIG. 1.—*Top to bottom*: Radial variations of the equivalent widths of the absorption features Ca II K (λ3930), G-band (λ4301), Mg I + Mg H (λ5176), and continuum ratio $\lambda5870/\lambda4020$ for the Seyfert 1 galaxy NGC 6814 (*left*), the composite Seyfert + starburst galaxy NGC 7130 (*center*), and the Seyfert 2 Mrk 348 (*right*). (Adapted from Paper I.)

2. THE DATA

The data discussed here have been described in Paper I. In summary, they consist of long-slit spectra obtained with the Cassegrain Spectrograph and Reticon detector at the 4 m telescope of the Cerro Tololo Inter-American Observatory. The pixel size was $\approx 1''$ and the slit width $2''$. For the four galaxies discussed here, the observations were obtained under photometric conditions with a seeing of $\approx 1''$. The slit was oriented along the radio axis and/or along the extended emission, but the observations were scheduled to make this angle coincide with the paralactic angle in order to avoid the effects of differential refraction. The spectral resolution (FWHM of the calibration lamp lines) is ≈ 7 Å. A summary of the observations is presented in Table 1. The spectra were reduced and flux-calibrated using standard procedures in IRAF, and one-dimensional spectra were extracted along the spatial direction in windows of $2'' \times 2''$. Prior to the analysis, the spectra were corrected for the foreground Milky Way reddening, using the empirical selective extinction function of Cardelli, Clayton, & Mathis (1989). The corresponding $E(B-V)$ values are listed in the last column of Table 1 and were extracted from the NASA Extragalactic Database.

3. EXTRANUCLEAR SPECTRA AS POPULATION TEMPLATES FOR THE NUCLEUS

Mrk 348, Mrk 573, NGC 1358, and Mrk 1210 are nearby galaxies whose bulges have effective radii ranging from $6''$ to $36''$, as determined by near-infrared surface photometry (Alonso-Herrero, Ward, & Kotilainen 1996; Heisler, De Robertis, & Nadeau 1996; Xanthopoulos 1996). Thus, the bulge is completely resolved in these galaxies, and spectra extracted at less than $6''$ from the nucleus will still be sampling the bulge stellar population.

We believe that using a stellar population template from the bulge of the same galaxy to represent the stellar population of the nucleus is in principle a more robust approach than adopting a population template from other galaxies, since Paper I shows that the stellar population varies substantially from galaxy to galaxy. The smooth radial variation of the EW of absorption lines found in Paper I also supports this approach. The EWs only show abrupt changes when there is evidence of the presence of a blue stellar population in the starburst galaxies or the rings of star formation or evidence of an FC in the Seyfert 1 galaxies.

Moreover, as pointed out in the Introduction, previous works usually adopt an elliptical galaxy template to represent the stellar population in Seyfert nuclei, whereas recent studies (Wyse, Gilmore, & Franx 1997) show that stellar populations in bulges frequently differ from that in ellipticals. Jablonka, Martin, & Arimoto (1996) show that bulges occupy regions similar to that of ellipticals in the fundamental plane but are displaced toward smaller line strengths. Balcells & Peletier (1994) showed that, although bulges follow a color-magnitude relationship similar to that of ellipticals, they have a larger scatter and are bluer than ellipticals of similar luminosity. The use of an elliptical galaxy template to subtract the stellar population contribution of the bulge of an spiral or lenticular galaxy is thus likely to produce a residual blue continuum due to a "template mismatch" (Cid Fernandes & Terlevich 1992).

These facts, together with the discrepant results obtained by different authors using the traditional elliptical galaxy template method, motivated us to seek an alternative starlight-evaluation technique. In this section we compare the bulge extranuclear spectra with the nuclear spectra of Mrk 348, Mrk 573, NGC 1358, and Mrk 1210 in order to investigate if the former can be used as stellar population templates for the latter.

Two criteria were used to select the windows for the extranuclear spectra: (1) to keep the smallest possible angular distance from the nucleus—always smaller than the effective radius of the bulge—in order to minimize changes in the stellar population characteristics; (2) to ensure that the distance was large enough to avoid contamination from nuclear light due to seeing effects.

The nuclear and extranuclear windows all have sizes of $2'' \times 2''$. In order to construct the extranuclear spectra, we have skipped the windows adjacent to the nucleus and averaged the two extractions centered at $4''$ at both sides of the nucleus, which include light from $3''$ to $5''$ from the nucleus. As the seeing was $\approx 1''$ in the observations, we do not expect significant contamination by nuclear light at these windows. The corresponding average distances from the nuclei at the galaxies are 1.2, 1.4, 1.0, and 1.0 kpc, respectively, for Mrk 348, Mrk 573, NGC 1358, and Mrk 1210.

We compare the nuclear with the extranuclear optical (3500–6000 Å) spectrum of each galaxy in Figures 2–5. As all galaxies present extended emission, we have chopped the emission lines from the extranuclear spectra in order to allow a clearer comparison of the absorption features. An extranuclear spectrum is considered to be an acceptable fit to the nuclear one if the nuclear EWs are reproduced within 10% and the continuum within 5%. At the blue end of the spectra, somewhat larger differences in the continua were allowed ($\approx 10\%$) because of the larger noise in this spectral region. These values correspond to the maximum uncertainties in the measurements of EWs and continua in Paper I. The residuals in the continuum were calculated as averages of the difference spectra (nuclear-extranuclear) in windows avoiding emission lines. The difference spectra are also shown in Figures 2–5.

In all cases, the nuclear continuum is slightly redder than the extranuclear one (see Paper I). Assuming that this is due

TABLE 1

LOG OF OBSERVATIONS

Galaxy	Date	Exposure Time (s)	Position Angle (deg)	$E(B-V)_G$
Mrk 348	1994 Dec 6–7	1800	170	0.060
Mrk 573	1994 Dec 6–7	1800	125	0.008
NGC 1358......	1994 Jan 6–7	900	145	0.025
Mrk 1210.......	1994 Jan 5–6	1800	163	0.018
IC 4889	1992 May 28–29	1800	0	0.045

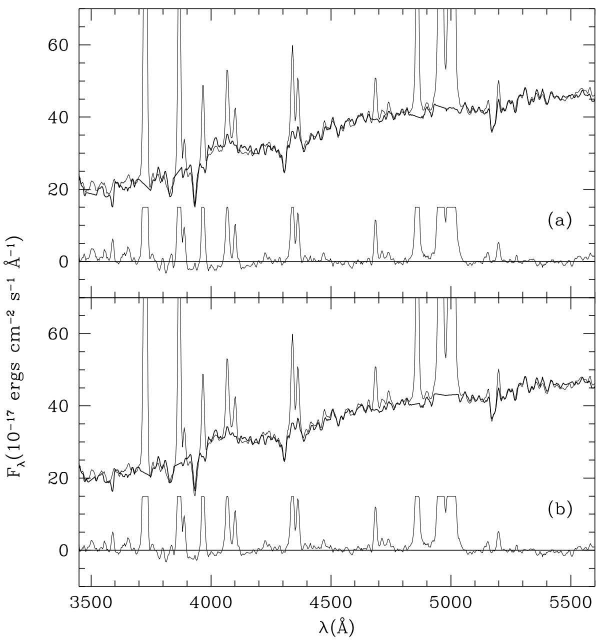

FIG. 2.—Comparison between the nuclear and extranuclear bulge spectra of Mrk 348: (*a*) Nuclear spectrum (*thin line*) plotted on top of the normalized and reddened [$E(B-V)=0.03$] extranuclear bulge spectrum (*thick line*), where the emission lines have been chopped for clarity. The residual between the two is plotted at the bottom of the figure, showing that the nuclear stellar population is well reproduced by that of the bulge. (*b*) Nuclear spectrum (*thin line*) compared with the extranuclear spectrum reddened by $E(B-V)=0.09$, combined with 5% contribution (at 5500 Å) of the FC1 component, represented by a $F_\lambda \propto \lambda^{-1}$ power-law (*thick line*). The residual between the two is plotted at the bottom, showing a slightly improved fit when compared with (*a*). The emission lines in the residual spectra have also been chopped for clarity.

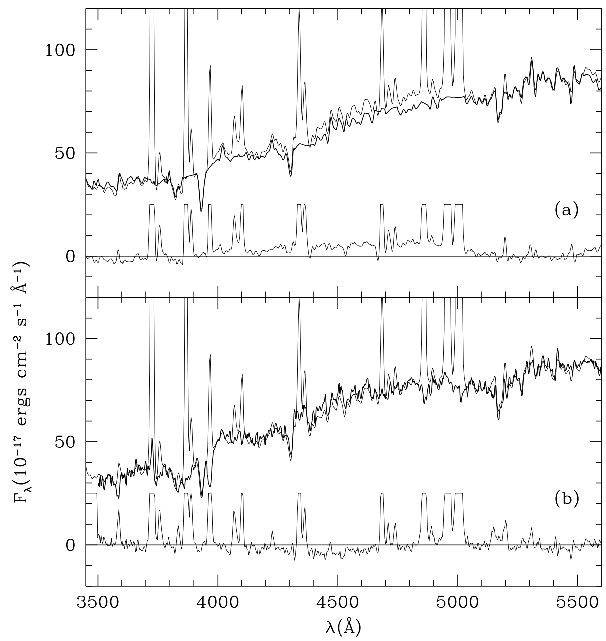

FIG. 3.—Comparison between the nuclear and extranuclear bulge spectra of Mrk 573: (*a*) Nuclear spectrum of Mrk 573 (*thin line*) compared with the normalized and reddened [$E(B-V)=0.10$] extranuclear spectrum (*thick line*), where the emission lines have been chopped for clarity. The residual between the two is plotted at the bottom of the figure. (*b*) Nuclear spectrum (*thin line*) compared with the elliptical template (IC 4889, *thick line*) combined with a $F_\lambda \propto \lambda^{-1}$ power-law, with contributions of 90% and 10%, respectively, to the total flux 5500 Å. The residual between the two is plotted at the bottom, showing a better agreement for case (*b*). The emission lines in the residual spectra have also been chopped for clarity.

to an excess reddening of the nuclear relative to the extranuclear spectra (in agreement with the accepted scenario that the nuclear regions in Seyfert 2 galaxies are dusty), we have reddened the extranuclear spectra by the necessary amount to make the continuum slopes match that of the nuclear spectra. We now discuss the results for each galaxy.

3.1. *Mrk 348*

Figure 2*a* shows the comparison of the nuclear with the reddened [$E(B-V)=0.03$] extranuclear spectrum of Mrk 348 after normalization of the latter to the flux of the nuclear spectrum near 5500 Å, as well as the residual between the two. The nuclear continuum is well reproduced (within 5%) by the extranuclear one after a small reddening of the latter, and, in Paper I, we have also concluded that the equivalent widths of absorption lines are the same within the uncertainties ($\leq 10\%$). These results indicate that the nuclear stellar population can be reproduced by that of the extranuclear spectrum; no extra spectral component seems to be needed within the margins of our matching criteria.

We now compare our results with those obtained by Tran (1995a, 1995b, 1995c). Tran has shown that Mrk 348 presents a Seyfert 1 spectrum in polarized light with a continuum polarization of 5.7% (after starlight correction), increasing to more than twice this value in broad Hα. The stellar component, represented by the elliptical galaxy NGC 821, was found to contribute 73% of the total flux at 5500 Å, while our results suggest a much larger fraction. Tran's analysis of the spectropolarimetry data also showed that

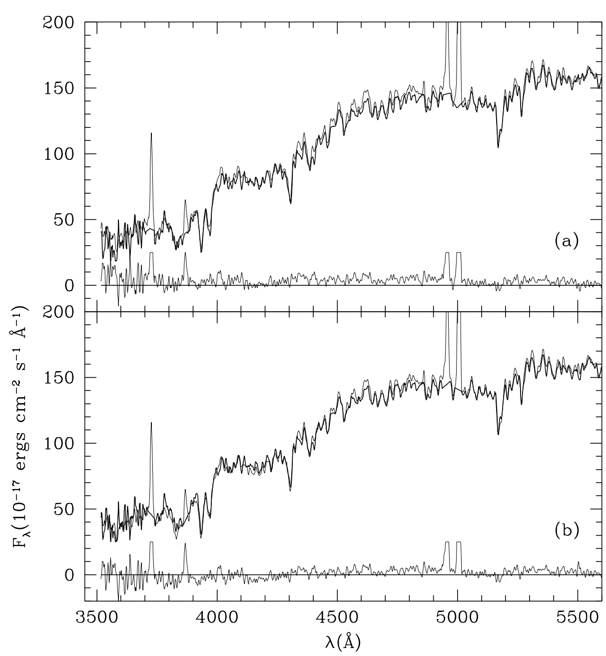

FIG. 4.—(*a*) Nuclear spectrum of NGC 1358 (*thin line*) compared with the normalized and reddened [$E(B-V)=0.10$] extranuclear spectrum (*thick line*), where the emission lines have been chopped for clarity. The residual between the two is plotted at the bottom of the figure. (*b*) Nuclear spectrum (*thin line*) compared with the extranuclear spectrum reddened by $E(B-V)=0.10$ and combined with a 3% contribution (at 5500 Å) of the FC1 continuum, represented by a $F_\lambda \propto \lambda^{-1}$ power-law (*thick line*). The residual between the two is plotted at the bottom. The emission lines in the residual spectra have also been chopped for clarity.

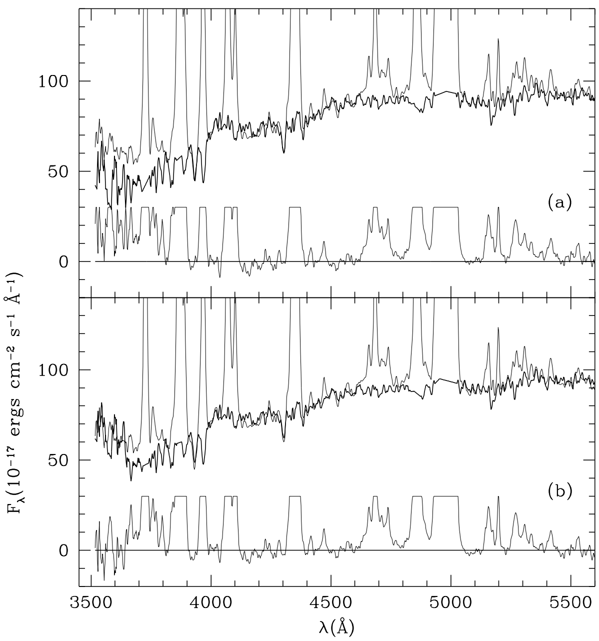

FIG. 5.—(*a*) Nuclear spectrum of Mrk 1210 (*thin line*) compared with the normalized and reddened [$E(B-V) = 0.07$] extranuclear spectrum (*thick line*), where the emission lines have been chopped for clarity. The residual between the two is plotted at the bottom of the figure. (b) Nuclear spectrum (*thin line*) compared with the extranuclear spectrum reddened by [$E(B-V) = 0.15$], combined with the Balmer continuum and a 6% contribution of a FC1 component $F_\lambda \propto \lambda^{-0.7}$. The residual between the two is plotted at the bottom. Notice the better agreement with the new components. The emission lines in the residual spectra have also been chopped for clarity.

the scattered Seyfert 1 component (FC1 in Tran's nomenclature) amounts to 5% of the flux at 5500 Å and that it has a $F_\lambda \propto \lambda^{-1}$ shape. Unlike the starlight fraction, the FC1 strength is not strongly dependent on the choice of template, since Tran's determination takes into account the strength necessary to match the polarization of the continuum to that of the broad lines. Similarly, the λ^{-1} shape is not critically affected by the template, as it is implicit in the polarized spectrum ($P_\lambda \times F_\lambda$). Since we know that a scattered component is present, the spectral decomposition in Figure 2*a* is not physically acceptable because it corresponds to 100% starlight. Yet, as shown below, there is room for a small contribution from the scattered component.

Adopting an $F_\lambda \propto \lambda^{-1}$ shape for the reflected continuum, a contribution of 5% at 5500 Å corresponds to a decrease of ≈5% of W(Mg I + Mg H), somewhat larger for W(*G* band) and up to ≈10% for W(Ca II K), thus within our measurement uncertainties for the EWs. In order to illustrate that both EWs and continuum shape are in agreement with the presence of such a scattered nuclear continuum, we have combined the extranuclear spectrum with an $F_\lambda \propto \lambda^{-1}$ power law in proportions of 95% and 5% at 5500 Å, respectively, and compared this spectrum with the nuclear one. The best reproduction of the nuclear spectrum was obtained when, prior to the combination with the power-law component, we reddened the extranuclear spectrum by an additional $E(B-V) = 0.06$. The result is shown in Figure 2*b*.

The essential difference between Tran's (1995c) results and ours is that, while he attributes the remaining 22% of the photons at 5500 Å to an extra continuum source (FC2), we account for the whole spectrum with either just the extranuclear stellar population template (Fig. 2*a*) or, more realistically, with a combination of this template plus the reflected nuclear spectrum (Fig. 2*b*).

We remark that the slit width used in our observations (2″), is similar to that used by Tran (1995a; 2″.4) and the same used by Kay (1994). The 2″ length of our nuclear extraction window was smaller that the typical 5″–7″ used by Kay; Tran does not give this information, but it is unlikely that it is smaller than ours. We thus rule out the possibility that we have found a larger galaxy contribution due to a larger nuclear window. Instead, the different starlight fractions found by Tran and us stem from the different stellar population templates used. Note that Tran's galaxy fractions are already larger than the ones obtained by Miller & Goodrich (1990) for the objects in common, including Mrk 348 and Mrk 1210. Our results show that an even larger stellar contribution is possible.

3.2. *Mrk 573*

Figure 3*a* shows the comparison of the nuclear spectrum of Mrk 573 with the reddened [$E(B-V) = 0.1$] extranuclear spectrum. In this case, we find some mismatch of the continuum between 4000 and 5000 Å, the reddened extranuclear spectrum having ≥10% less flux than the nuclear spectrum in this spectral region. Mrk 573 has a polarized continuum observed by Kay (1994). Allowing for a few percent contribution of such component (represented by an $F_\lambda \propto \lambda^{-1}$ power law, in analogy with Mrk 348), we get an even worse fit in the 4000–5000 Å region.

We then tried a different stellar population template, obtained from the nuclear spectrum of the elliptical galaxy IC 4889 from our sample of Paper I (thus, observed with the same setup as Mrk 573), combined with the same power-law component above. Figure 3*b* shows that this template, combined with a 10% contribution of the power law at 5500 Å gives a better fit for the continuum and at the same time reproduces the nuclear EW values. This result is in approximate agreement with previous studies, like that of Kay (1994), who derived a stellar population contribution of 80% at 4400 Å, while our results imply a stellar population contribution of 85% at this wavelength.

But how to understand the lack of dilution of the EWs in the nucleus of this galaxy? One possibility is that the stellar population shows a small variation with distance from the nucleus, more evident in the shape of the continuum than in the absorption lines, and that the scattered (power-law) component is *extended*, keeping the EWs approximately at the same values. An extended blue continuum, probably due to scattered light, has indeed been found in near-UV images of Mrk 573 by Pogge & De Robertis (1993) along the ionization cones observed in this galaxy. If this interpretation is correct, spatially resolved spectropolarimetry should reveal a Seyfert 1 spectrum up to a few arcseconds from the nucleus along the cone axis.

3.3. *NGC 1358*

Figure 4*a* shows the comparison of the nuclear spectrum of NGC 1358 with the reddened [$E(B-V) = 0.1$] extranuclear spectrum. The two spectra present <5% differences in the continuum and <10% differences in the EWs, suggesting no contribution by an FC. Nevertheless, Kay (1994) finds a continuum polarization of 1.65% (after starlight subtraction), indicating the presence of a scattered component, albeit weak. She derives a stellar population contribution of 83% at 4400 Å, while our results indicate a larger contribution, of at least 90% at the Ca II K line. Allowing for a contribution of up to 10% of an $F_\lambda \propto \lambda^{-1}$ component in the blue, at 5500 Å this contribution amounts only to $\approx$3%. The fit we obtain for the nuclear spectrum, combining 3% of this component with 97% of extranuclear spectrum at 5500 Å is slightly improved, as illustrated in Figure 4*b*. At 4400 Å the stellar population contribution amounts to $\approx$95%. We note that the 83% starlight fraction found by Kay yields an uncomfortably low polarization for NGC 1358, as compared to the typical values expected in the unified model (Miller & Goodrich 1990). Only for fractions above 95%, and thus within the range of the acceptable stellar population contributions according to our method, would the polarization rise above 10%.

3.4. *Mrk 1210*

Figure 5*a* shows a comparison of the nuclear spectrum of Mrk 1210 with the extranuclear one scaled and reddened by $E(B-V) = 0.07$. The latter is a good reproduction of the nuclear spectrum down to the Ca II K line, with differences in the continuum less than 5% and less than 10% in the EWs. But below 3900 Å, there is an excess continuum in the nuclear spectrum. This continuum could be due to the Balmer recombination continuum of the emitting gas, which is significant in this galaxy because of its strong emission lines. The gaseous temperature, as derived from the [O III] λ4363/λ5007 emission-line ratio, is about 20,000 K. We have then used the corresponding Hβ recombination coefficient and H I continuum emission coefficient from Osterbrock (1989) and the observed Hβ flux (5.38×10^{-14} ergs cm^{-2} s^{-1}) to derive the contribution of the Balmer continuum to the nuclear spectrum. This contribution amounts to $\approx$3% of the total flux at 5500 Å, $\approx$7% at 3700 Å, and 30% for $\lambda < 3646$ Å. We note that a Balmer continuum has also been detected in Mrk 477 (Heckman et al. 1997, hereafter H97), a galaxy in many respects similar to Mrk 1210 (see below).

Mrk 1210 was also observed by Tran (1995a, 1995b, 1995c), who found a polarized continuum contribution of 6% at 5500 Å. As for Mrk 348, this value is derived by Tran as being the one necessary to make the polarization in the continuum agree with that of the broad lines. Tran finds a 75% stellar contribution, while the remaining 19% "nonstellar" continuum is attributed to FC2. The spectral distribution of the scattered continuum is derived to be $F_\lambda \propto \lambda^{-0.7}$. We have then combined this power-law contribution normalized to 6% at 5500 Å, the Balmer continuum described above (3% at 5500 Å), and the extranuclear spectrum normalized to 91% of the nuclear flux at 5500 Å after applying an additional reddening of $E(B-V) = 0.08$. The result is the spectral distribution illustrated in Figure 5*b*, which is an improved fit to the nuclear spectrum. Again, the different stellar fractions obtained by us and previous works result from the different stellar population templates. As for Mrk 348, what Tran (1995c) calls FC2 is somehow included in our stellar population template.

A close look at the nuclear emission-line spectrum shows that this galaxy seems to present a Wolf-Rayet feature, which can be observed in Figure 6*a*. We point out the similarity of the whole complex to that found in Mrk 477 by H97. We identify five narrow emission-lines in this complex: [Fe III] 4658 Å, He II 4686 Å, [Ar IV] 4711,4740 Å, and [Ne IV] 4725 Å, to which we have fitted narrow Gaussians, constraining their FWHM to the average value of the other strong emission lines in the spectrum (720 km s^{-1}). The subtraction of these lines leaves the residual shown in Figure 6*b*, centered around 4670 Å, with flux 1.22×10^{-14} ergs cm^{-2} s^{-1} (and luminosity 3.7×10^{39} ergs s^{-1}).

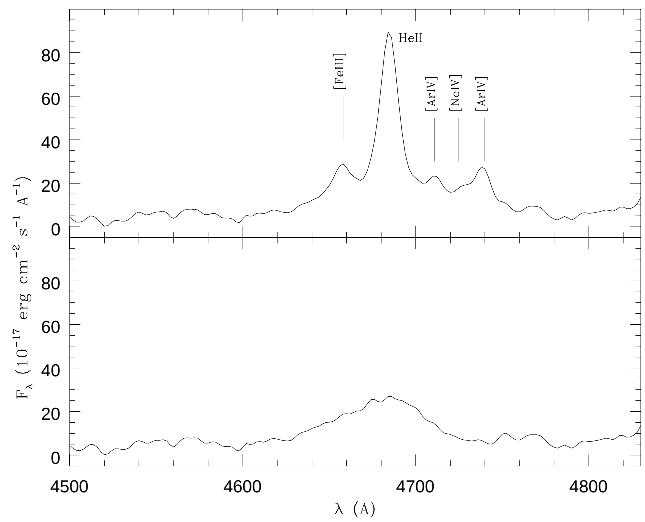

FIG. 6.—(*top*) Spectrum of Mrk 1210 in the region of He II λ4686; (*bottom*) W-R feature: residual after the subtraction of the narrow emission lines Fe [III] λ4658, He II λ4686, [Ar IV] λ4711,40, and [Ne IV] λ4725.

Following the methodology of H97, we have compared our spectrum with those from W-R stars (Smith, Shara, & Moffat 1996; Conti & Massey 1989) in order to estimate the type of W-R stars producing the emission lines. We reach a similar conclusion: that the residual of Figure 6*b* can be identified as broad emission from He II λ4686 and N III λ4640, and the W-R stars in Mrk1210 can be classified as of subtype WN6–7 or later.

In a starburst, the ratio of the flux of the Wolf-Rayet complex to the Hβ flux gives a measure of the relative importance of W-R and O stars (H97 and references therein). In Mrk 1210, this value is $\approx$20%, which is a lower limit, because the Hβ flux includes a contribution from ionization by the AGN. This value is twice the value found for Mrk 477 (H97) before correcting for the contribution from the AGN and indicates the presence at the nucleus of Mrk 1210 of a stellar burst with an age between 3 and 8 Myr (H97; Meynet 1995).

4. POPULATION SYNTHESIS FOR THE STELLAR POPULATION TEMPLATES

Since we have concluded that the difference between the starlight fractions obtained here with respect to those in previous works (particularly for Mrk 348 and Mrk 1210) is due to the different stellar population templates, it is natural to ask: What do our templates have that ordinary elliptical galaxies do not?

In order to answer this question, we have performed a population synthesis analysis using the base of stellar clusters of Bica (1988) and the method described in Schmitt, Bica, & Pastoriza (1996). As input data we have used the EWs of Ca II K, CN, *G*-band, and Mg I + Mg H absorption features, as well as the continuum fluxes at 3660, 4020, 4570, and 6630 Å, all normalized to the flux at 5870 Å.

TABLE 2

POPULATION SYNTHESIS RESULTS[1]

Population Template	10 Gyr	1 Gyr	100 Myr	10 Myr	H II
Mrk 348	45 (36)	45 (50)	5 (8)	4 (5)	1 (1)
NGC 1358...........	64 (55)	34 (42)	2 (3)	0 (0)	0 (0)
Mrk 1210............	53 (42)	24 (25)	21 (31)	2 (2)	0 (0)
IC 4889	79 (72)	21 (28)	0 (0)	0 (0)	0 (0)

[1] Percent contribution of different age bins to the light at 5870 Å (and 4510 Å).

The results of the synthesis are summarized in Table 2. The stellar population of Mrk 573 is represented by the elliptical template from IC 4889, in the last line of the table, while for the other galaxies the results correspond to the extranuclear templates discussed in § 3. The columns of the table show the percentage contribution of the age bins corresponding to 10 Gyr (globular clusters), 1 Gyr, 100 Myr, 10 Myr and H II regions, respectively, to the spectrum at 5870 Å. We also list, between parentheses, the corresponding fractions at 4510 Å.

Inspection of the table shows that in NGC 1358, as in the case of the elliptical galaxy template, the population is composed almost only by the 10 Gyr and 1 Gyr age bins. In Mrk 348 and Mrk 1210, however, there are additional contributions from the younger age bins ($\leq$ 100 Myr), amounting to 10% and 23%, respectively. Since these populations are blue, the corresponding fractions increase for shorter wavelengths, reaching 14% and 33% at 4510 Å, respectively (Table 2).

We thus conclude that the difference between our extranuclear templates and the more commonly used elliptical galaxy spectrum is the presence of a substantial contribution from a 0–100 Myr old population.

A combination of a red bulge, power-law continuum, and young and intermediate-age components has also been found in previous works on the analysis of the optical continuum of active galaxies. Tadhunter, Dickinson, & Shaw (1996), for example, have concluded that an intermediate-age component was required in order to reproduce the optical spectrum of the nearby radio galaxy 3C 321, in addition to a power law and an old bulge component. Using a similar method as used here, Storchi-Bergmann et al. (1997b) have also found a mixture of old bulge, power-law, and "aging starburst" components in the continuum spectrum of the inner region of Cen A. Cid Fernandes & Terlevich (1992) have also suggested that the contribution from young and intermediate-age stars in Seyfert 2 galaxies may have been systematically underestimated because of a "template mismatch" effect. Such a mismatch results from the known difficulty in determining the contribution of early-type stars to the optical spectrum of AGNs (see discussions in Miller & Goodrich 1990; Kay 1994). Further studies suggesting the presence of young to intermediate-age stars in active galaxies are the ones about the strength of the Ca II triplet around 8500 Å (Terlevich, Diaz, & Terlevich 1990) and the infrared work of Oliva et al. (1995).

5. ANALYSIS USING AN ELLIPTICAL GALAXY TEMPLATE

Had we used an elliptical galaxy as a template for Mrk 348 and Mrk 1210, we would have inevitably obtained larger FC contributions. Experiments using the nuclear spectrum of the elliptical galaxy IC 4889 confirm this (see Figs. 7 and 8). In order to match the nuclear spectrum of Mrk 348, a combination of 85% contribution of the elliptical template IC 4889 and a 15% λ^{-1} power-law contribution at 5500 Å would be required. For Mrk 1210, the proportions would be 69% starlight and 28% a $\lambda^{-0.7}$ power law (plus 3% contribution of the Balmer continuum), in better agreement with Tran's (1995a) results.

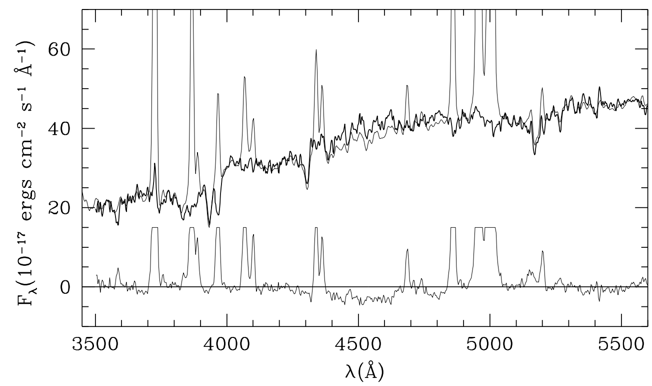

FIG. 7.—*Top*: Comparison of the nuclear spectrum (*thin line*) of Mrk 348 with the elliptical template (*thick line*) combined with a 15% contribution (at 5500 Å) of a λ^{-1} power-law component. *Bottom*: residual between the two, where the emission lines have been chopped for clarity.

It is important to emphasize that the fits obtained with an elliptical galaxy are as good as those obtained with the extranuclear templates! However, these are by no means equivalent choices, since the differences in the starlight fractions imply completely different scenarios for the nature of the residual nonstellar continuum. Which leaves us with the question: How is one to decide which template to use?

While it is not possible to decide a priori which template best suits the true stellar population in the nucleus, we believe that a spectrum extracted from the bulge of the same galaxy should be, in most cases, a better representation of the nuclear stellar population than a spectrum from an external galaxy, whose star-formation history may differ substantially from that of the target galaxy. Furthermore, the much higher FC fractions obtained above with the elliptical galaxy template would imply EWs and color radial gradients if the FC is concentrated in or close to the nucleus—which should be detectable with our method—whereas we find none (Paper I). For example, Figure 1 shows that the *W*(Ca II K) of NGC 6814 decreases by $\approx$40% at the nucleus due to the FC. In the case of Mrk 348,

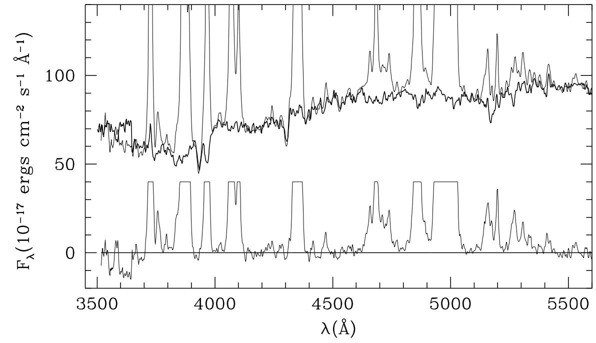

FIG. 8.—*Top*: Comparison of the nuclear spectrum (*thin line*) of Mrk 1210, with the elliptical template (*thick line*) combined with a 28% contribution (at 5500 Å) of a $\lambda^{-0.7}$ power-law component and 3% of the Balmer continuum. *Bottom*: residual between the two, where the emission lines have been chopped for clarity.

for the 15% FC contribution at 5500 Å derived above with the nuclear stellar population represented by the elliptical galaxy template, the FC contribution at the Ca II K line is 33%, while for Mrk 1210 the 28% contribution at 5500 Å corresponds to 45% at the Ca II K line. Such dilutions are comparable to that observed in NGC 6814 and should thus be readily observed.

The only possibility of having an elliptical galaxy template plus an FC at the nucleus and no radial dilution of the absorption lines is if the FC is *extended* and the FC-to-galaxy ratio remains constant throughout the inner regions. In this case our extranuclear spectra would not correspond to the pure stellar population component, since they would be contaminated by the FC (be it FC1, FC2 or both). Testing this possibility will require further observational constraints. Direct imaging in the UV could in principle reveal an extended continuum, as was observed in Mrk 573 (Pogge & De Robertis 1993). Polarization maps would allow testing for the presence of extended scattered light, as well as long-slit spectra obtained at several position angles.

Regardless of its extension, the FC in Mrk 348 and Mrk 1210 is clearly dominated not by scattered light, but by FC2. Tran (1995c) finds that 83% of the FC is due to FC2 in Mrk 348 and 76% in Mrk 1210. The difference between the extranuclear templates of Mrk 348 and 1210 and an elliptical galaxy should thus be essentially due to FC2. According to the synthesis results, this difference is due to young and intermediate-age stars, which we therefore associate with FC2. A conclusive detection of features from such stars would corroborate this idea. The W-R feature in Mrk 1210 confirms the presence of young stars. UV spectroscopy could provide further evidence of this through the detection of Si IV and C IV absorptions, as found in Mrk 477 (H97). In the case of Mrk 348, the evidence for young to intermediate-age stars relies not on a direct detection, but on our population synthesis analysis. UV spectroscopy of this object will be crucial to test this result.

UV spectropolarimetry would also be useful for testing the contribution of young to intermediate-age stars. While the older stellar components should contribute little to the UV emission, the young stars should extend into the UV range along with the scattered AGN component. Since the stellar flux is presumably unpolarized, we expect that Mrk 1210 (and possibly Mrk 348) presents broad UV lines (e.g., C IV λ1550 and Mg II λ2800) with a *larger polarization* than the adjacent continuum. In other words, the "dilution by FC2 effect" found by Tran (1995c) should extend into the UV.

6. SUMMARY AND CONCLUDING REMARKS

We have investigated the nature of the optical continuum and stellar population in the nuclear region of the Seyfert 2 galaxies Mrk 348, Mrk 573, NGC 1358, and Mrk 1210, using long-slit spectroscopic data.

In a previous work (Paper I) we found that none of these galaxies present dilutions in the nuclear EWs of the absorption lines, compared with those of the extranuclear spectra from the bulge of the same galaxy, as would be expected if an FC was present at the nuclei in the proportions found in previous works (20%–50%). We have tested one possibility to account for this lack of dilution: that the nuclear stellar population is the same as the extranuclear one from the bulge, and the FC contribution to the nuclear spectra is smaller than 10% (and thus does not produce enough dilution in the EWs to be detectable with our method). We conclude that this hypothesis works for Mrk 348, NGC 1358, and Mrk 1210.

A larger stellar population contribution can solve several puzzles of Seyfert 2 galaxies: (1) it raises the level of intrinsic polarization, bringing it closer to the values expected in the unified model (Miller & Goodrich 1990); (2) it avoids the problem of overpredicting the strengths of broad lines in the direct spectra (Cid Fernandes & Terlevich 1992, 1995; Heckman et al. 1995); and (3) it allows a compatibilization of the polarizations measured for the broad lines and continua. This last point is implicit in our results, since we have shown that, for Mrk 348 and Mrk 1210, the nuclear spectrum can be adequately fitted with a stellar component plus the scattered continuum at the strengths inferred from spectropolarimetry (Tran 1995a, 1995b, 1995c). Since these are exactly the problems that lead to the idea of an FC2 (Miller 1994), our results suggest that FC2 is the result of an underestimation of the stellar contribution.

Our population synthesis analysis indicates that the larger stellar population contribution found for Mrk 348 and Mrk 1210 relative to that found in previous works is due to the presence of young and intermediate-age stars ($\leq$100 Myr), not accounted for by the more commonly used elliptical galaxy templates. In other words, the FC2 would be due to blue stars in these two cases. For Mrk 1210, the apparent detection of a "Wolf-Rayet" feature confirms this result. These findings, together with results from the recent study by H97 on Mrk 477, suggest that young populations may be common in Markarian Seyferts, being responsible for at least part of the blue continuum in these galaxies (which were discovered precisely because of their blue continuum).

The above results suggest that star formation is an important piece in the AGN puzzle. We speculate that, if there is a causal link between star formation and activity, the $\sim$100 Myr star-formation timescale identified in this paper should be comparable to the duration of the nuclear activity cycle. Since 100 Myr is about 1% of the Hubble time, a causal link between star formation and activity would imply that about 1% of the galaxies should be active. Interestingly, this value seems to agree with current estimates (e.g., Huchra & Burg 1992). Population synthesis for a complete sample of nearby Seyferts could help to put tighter constraints on this link.

We have also tested an elliptical galaxy template, as used in previous works. For Mrk 573, this template gives a better match to the nuclear stellar population than the extranuclear spectrum. The lack of dilution in this case could be due to the presence of an extended scattered continuum (observed in UV images by Pogge & De Robertis 1993). Mrk 348 and Mrk 1210 also present an excess blue continuum when compared with an elliptical template. According to our EW measurements, this continuum should be extended, but, according to the spectropolarimetry by Tran (1995c), only a small part of it is polarized so it is unlikely that it is dominated by scattered light. This result is thus consistent with our finding of an excess blue population in these galaxies relative to an elliptical galaxy.

As a final remark, we note that, as all current FC2 indicators are critically dependent on the starlight correction procedure, unveiling the nature of FC2 will necessarily require a careful examination of the stellar population in the central regions of AGN. With this goal, in a forthcoming paper

(Schmitt, Storchi-Bergmann, & Cid Fernandes 1998) we investigate the stellar content of a sample of 42 active and normal galaxies, via population synthesis as a function of distance from the nuclei, using the extensive data of Paper I.

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REFERENCES

Alonso-Herrero, A., Ward, M. J., & Kotilainen, J. K. 1996, MNRAS, 278, 902
Antonucci, R. R. J. 1993, ARA&A, 31, 473
Antonucci, R. R. J., & Miller, J. S. 1985, ApJ, 297, 621
Balcells, M., & Peletier, R. F. 1994, AJ, 107, 135
Bica, E. 1988, A&A, 195, 76
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Cid Fernandes, R., Schmitt, H. R., & Storchi-Bergmann, T. 1998, MNRAS, in press (Paper I)
Cid Fernandes, R., & Terlevich, R. 1992, in ASP Conf. Ser. 31, Relationships between Active Galactic Nuclei and Starburst Galaxies, ed. A. V. Filippenko (San Francisco: ASP), 241
———. 1995, MNRAS, 272, 423
Conti, P., & Massey, P. 1989, ApJ, 337, 251
Fosbury, R. A. E., Mebold, U., Goss, W. M., & Dopita, M. A. 1978, MNRAS, 183, 549
Heckman, T., et al. 1995, ApJ, 452, 549
Heckman, T. M., Gonzalez-Delgado, R., Leitherer, C., Meurer, G. R., Krolik, J., Wilson, A. S., Koratkar, A., & Kinney, A. 1997, ApJ, 482, 114 (H97)
Heisler, C., De Robertis, M. M., & Nadeau, D. 1996, MNRAS, 280, 579
Huchra, J., & Burg, R. 1992, ApJ, 393, 90
Jablonka, P., Martin, P., & Arimoto, N. 1996, AJ, 112, 1415
Kay, L. 1994, ApJ, 430, 196
Koski, A. 1978, ApJ, 223, 56
Meynet, G. 1995, A&A, 298, 767
Miller, J. S. 1994, in ASP Conf. Ser. 54, The First Mount Stromlo Symposium: The Physics of Active Galaxies, ed. G. V. Bicknell, M. A. Dopita, & P. J. Quinn (San Francisco: ASP), 149
Miller, J. S., & Goodrich, R. W. 1990, ApJ, 355, 456
Miller, J. S., Goodrich, R. W., & Mathews, W. G. 1991, ApJ, 378, 47
Oliva, E., Origlia, Kotilainen, J. K., & Moorwood, A. F. M. 1995, A&A, 301, 55
Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (Mill Valley: University Science Books)
Pogge, R. W., & De Robertis, M. M. 1993, ApJ, 404, 563
Schmitt, H. R., Bica, E., & Pastoriza, M. G. 1996, MNRAS, 278, 965
Schmitt, H. R., Storchi-Bergmann, T., & Baldwin, J. A. 1994, ApJ, 423, 237
Schmitt, H. R., Storchi-Bergmann, T., & Cid Fernandes, R. 1998, in preparation
Smith, L., Shara, M., & Moffat, A. 1996, MNRAS, 281, 163
Storchi-Bergmann, T., Bica, E., Kinney, A. L., & Bonatto, C. 1997b, MNRAS, 290, 231
Storchi-Bergmann, T., Eracleous, M., Livio, M., Wilson, A. S., Filippenko, A. V., & Halpern, J. P. 1995, ApJ, 443, 617
Storchi-Bergmann, T., Eracleous, M., Ruiz, M. T., Livio, M., Wilson, A. S., & Filippenko, A. V. 1997a, ApJ, 489, 87
Tadhunter, C. N., Dickson, R. C., & Shaw, N. A. 1996, MNRAS, 281, 591
Terlevich, E., Diaz, A., & Terlevich, R. 1990, MNRAS, 242, 271
Tran, H. D. 1995a, ApJ, 440, 565
———. 1995b, ApJ, 440, 578
———. 1995c, ApJ, 440, 597
Tran, H. D., Miller, X., & Kay, L. E. 1992, ApJ, 397, 452
Wyse, R. F. G., Gilmore, G., & Franx, M. 1997, ARA&A, 35, 637
Xanthopoulos, E. 1996, MNRAS, 280, 6