Spectral synthesis of the nuclear regions of Seyfert 2 and radio galaxies

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ABSTRACT

We present the results of an optical spectral synthesis analysis for the nuclei of 20 Seyfert 2 and four radio galaxies, using a base of stellar population templates of different ages and metallicities and a power-law continuum. Compared with the stellar population of elliptical galaxies, we find that Seyfert 2s usually have a smaller contribution from old metal-rich stars (age 10 Gyr, $Z \gtrsim Z_{\odot}$), and a larger contribution from stars with ages of 100 Myr. We also find that the contributions from stars with ages $\lesssim 10$ Myr and from a power-law continuum are small, rarely exceeding 5 per cent. These results show that the general assumption of elliptical galaxies as stellar population templates for these objects is incorrect, also implying that the excess blue continuum frequently found in their nuclear spectra is probably due to this template mismatch. We find a considerable contribution from 100-Myr-old stars (≈ 5 per cent), which can be interpreted from the point of view of models where the fuelling of the AGN is carried out by interactions/mergers.

Key words: galaxies: active – galaxies: nuclei – galaxies: Seyfert – galaxies: stellar content.

1 INTRODUCTION

From the point of view of spectral studies of active galactic nuclei (AGN), starlight is an unwanted but unavoidable pollution. Removing the stellar component is the most critical and uncertain step when analysing optical spectra of AGN, since it strongly affects the residual 'pure' nuclear spectrum, particularly in the continuum. This would be reason enough to study the impact of different starlight evaluation techniques. Another reason why this step deserves further attention is that the starlight 'pollution' contains valuable information on the stellar population of the host galaxy, which might reveal links between the nuclear activity phenomenon and the star formation history in the nuclear regions of AGN.

In this paper we explore both these issues by using an adaptation of stellar population synthesis techniques, so successfully applied to the study of normal galaxies (e.g. Bica 1988; Schmidt, Bica & Alloin 1990; Jablonka, Alloin & Bica 1990, 1992; Bonatto et al. 1998), to determine the stellar population and the contribution from a featureless continuum (FC) to the nuclear spectrum of AGN. Our main motivations were the intriguing results of Cid Fernandes, Storchi-Bergmann & Schmitt (1998, hereafter Paper I), where we measured equivalent widths (Ws) of several absorption lines and continuum fluxes from long-slit spectra of a sample of 42 Seyferts, LINERs, normal and radio galaxies (nearly 500 spectra in total).

The analysis of the radial variation of the Ws in Seyfert 2s and radio galaxies showed surprisingly little or no signs of dilution in the nucleus, implying an FC contribution to the nuclear spectrum of less than 10 per cent in the optical range. Later, Storchi-Bergmann, Cid Fernandes & Schmitt (1998, hereafter Paper II) presented a detailed spectral decomposition of four individual Seyfert 2s, confirming that the contribution from a nuclear FC is of the order of 10 per cent or less. These results contrast with the much larger FC fractions (20–50 per cent) usually found in the literature. The origin of this discrepancy traces back to the fact that most authors use an elliptical galaxy spectrum as a template for the nuclear stellar population, a method pioneered by Koski (1978). It is thus crucial to establish how appropriate this procedure is, since it is still widely employed in AGN studies.

FC strengths play an important role in several aspects of AGN research (line–continuum correlations, polarization, etc.). As an example we mention the current controversy over the origin of the so-called 'second featureless continuum' component (FC2) in Seyfert 2s (Miller 1994; Cid Fernandes & Terlevich 1995; Heckman et al. 1995, 1997; Tran 1995b). Indeed, judging from the results of Storchi-Bergmann et al. (1998), the whole issue of FC2 might rest upon a question of alternative FC determination methods, which are ultimately related to different choices of stellar population templates.

In this paper we present results from a spectral synthesis of the nuclear regions of 20 Seyfert 2s and four radio galaxies, using spectra in the wavelength range $\lambda\lambda 3500$–7000 Å and a synthesis code to quantify the contribution of stars of different ages and metallicities and an FC to the nuclear spectrum of these objects.

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the case of H II regions, only one more galaxy has a contribution larger than 1 per cent: NGC 7582 (6 per cent). Regarding the FC component, contributions larger than 5 per cent were only found for two Seyfert 2s: NGC 5135 and Mrk 1210. Even taking into account the ambiguity between the H II and FC components, it is clear that FC fractions larger than 5–10 per cent are rare.

Considering the case when the fluxes are normalized to the flux at λ3660 Å (Fig. 1, right panel), we can see that the percentage contribution from old metal-rich stars is smaller, while the contribution from younger stars, which are bluer, is larger. The general trends seen for the spectra normalized at λ5870 Å are also seen here, including the difference between the AGN and the elliptical spectra.
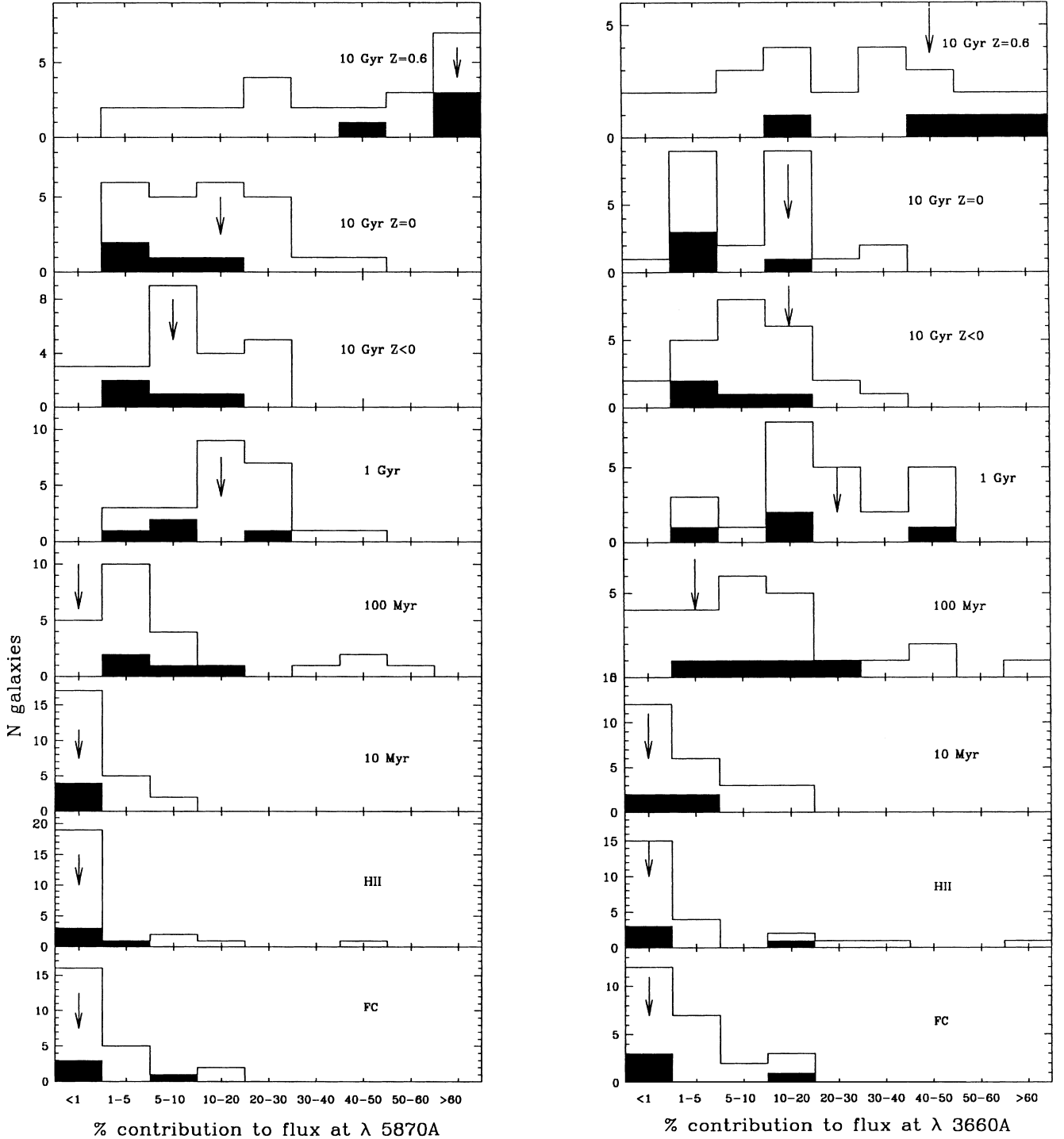
Figure 1. Histogram of the contribution of different age and metallicity components, normalized to the light at λ5870 Å (left) and λ3660 Å (right). The filled histograms represent the radio galaxies, the open ones represent the cumulative histogram of Seyfert 2s and radio galaxies, and the arrows represent the ellipticals. The panels show, from top to bottom, the contribution from stars with age 10 Gyr and $Z/Z_\odot = 0.6$ to the light at λ5870 Å; stars with age 10 Gyr and $Z/Z_\odot = 0.0$; the sum of stars with age 10 Gyr and $Z/Z_\odot = -1.0$ and -2.0; the sum of the three metallicity bins of stars with age 1 Gyr; the sum of the two metallicity bins of stars with age 100 Myr; the sum of the two metallicity bins of stars with age 10 Myr; H II regions; and the FC ($F_\nu \propto \nu^{-1.5}$).

Table 2. Synthesis results.

Name	10 Gyr $Z/Z_\odot = 0.6$	10 Gyr $Z/Z_\odot = 0.0$	10 Gyr $Z/Z_\odot < 0$	1 Gyr	100 Myr	10 Myr	H II	FC	$E(B-V)$
NGC 1358	73	1	0	26	0	0	0	0	0.14
NGC 1386	56	15	7	12	8	0	0	0	0.33
NGC 3081	53	13	7	21	2	4	0	0	0.14
NGC 5135	2	2	9	4	46	6	17	14	0.42
NGC 5643	6	6	6	47	35	0	0	0	0.51
NGC 6300	33	28	26	11	2	0	0	0	0.43
NGC 6890	13	28	14	37	0	6	0	2	0.35
NGC 7130	5	13	20	3	9	2	44	4	0.24
NGC 7582	10	9	16	12	42	0	6	5	0.60
Mrk 348	19	43	20	13	0	2	0	3	0.07
Mrk 573	70	8	4	13	4	1	0	0	0.01
Mrk 607	62	10	5	17	6	0	0	0	0.14
Mrk 1210	23	24	7	26	0	5	6	10	0.09
CGCG 420 − 015	50	17	10	19	4	0	0	0	0.33
IC 1816	21	26	17	30	4	0	0	2	0.19
IRAS 11215 − 2806	27	37	20	12	4	0	0	0	0.12
MCG-05-27-013	56	18	13	13	0	0	0	0	0.27
Fairall 316	88	2	0	7	3	0	0	0	0.17
ESO 417-G6	39	23	8	27	3	0	0	0	0.13
ESO 362-G8	25	3	0	21	51	0	0	0	0.47
3C 33	81	4	3	5	7	0	0	0	0.14
PKS 0349 − 27	75	11	5	7	2	0	0	0	0.04
PKS 0634 − 20	66	5	2	25	2	0	0	0	0.34
PKS 0745 − 19	46	7	12	3	18	0	5	9	0.36

The contributions are normalized to the flux at λ5870 Å. The last four rows are the radio galaxies.

Also, the number of galaxies that now show some contribution (> 1 per cent) from ≤10-Myr-old stars or from a FC increases to ≈50 per cent, or 25 per cent if we consider only those galaxies where these components contribute more than 5 per cent.

The results for the elliptical galaxy IC4889 and the templates E1 and E2 are very similar, so their average synthesis results are shown as arrows in Fig. 1. Not surprisingly, the most noticeable characteristic of their stellar populations is a dominant contribution from old metal-rich stars and almost no contribution from young stars. The 10-Gyr and $Z/Z_\odot = 0.6$ component contributes more than 60 per cent to the light at 5870 Å, while the $Z/Z_\odot = 0$ component contributes 10–20 per cent. Stars with age 10 Gyr and $Z/Z_\odot < 0$ contribute with 5–10 per cent and 1-Gyr-old stars contribute 10–20 per cent, while the contribution from components of age 100 Myr and younger is smaller than 1 per cent. Note that these results agree closely with those of Bica (1988).

Comparing the stellar population synthesis results for Seyfert 2s with those for elliptical galaxies, we can see that they differ considerably in most cases, but can be meaningful for some galaxies. The contribution of 10-Gyr-old stars with $Z/Z_\odot \gtrsim 0$ to the spectrum of Seyfert 2s is generally smaller than that obtained for ellipticals. The contribution from low-metallicity stars with age 10 Gyr, as well as stars with age 1 Gyr, to the spectrum of Seyfert 2s is usually equal to or larger than that in ellipticals, though there are exceptions. The largest difference, however, occurs in the lower age bins, particularly that corresponding to 100 Myr. Fig. 1 shows that whereas in ellipticals such stars contribute less than 1 per cent to the flux at λ5870 Å, only five of the Seyfert 2s studied have such a small contribution. The contributions from stars with age 10 Myr and H II regions are also skewed towards values larger than those found in ellipticals, but to a lesser extent than for 100-Myr-old stars.

The stellar population mixtures in three of the four radio galaxies are similar to that of ellipticals, which is expected, since their host galaxies are ellipticals. There is some difference in the contribution from stars of age 100 Myr, which is larger in radio galaxies than in ellipticals, and in the contribution from stars with age 1 Gyr and stars with age 10 Gyr and $Z/Z_\odot = 0$, which is smaller than in ellipticals. PKS 0745 − 19 shows different results, with a smaller contribution of 10-Gyr-old, high $Z/Z_\odot$ stars and larger contributions of the younger populations, which could be due to the fact that it is in the middle of a cooling flow (Cardiel, Gorgas & Aragón-Salamanca 1995).

5 DISCUSSION

The results presented in the previous section are in sharp contrast with the traditional view (e.g. Koski 1978) that the spectra of Seyfert 2s are essentially composed of an old stellar population plus an underlying FC. We have shown that: (1) Seyfert 2s present a wide range of stellar population characteristics and thus cannot be adequately represented by a single starlight template; (2) there are substantial differences between the stellar populations of Seyfert 2s and elliptical galaxies, particularly regarding the contribution from stars with age 10 Gyr and $Z/Z_\odot = 0.6$, and stars with age 100 Myr; (3) the contribution of age ≤10 Myr stars and an FC is small, rarely exceeding 10 per cent of the light at λ5870 Å.

Of particular interest in our analysis are the results for Mrk 1210, Mrk 348, Mrk 573, Mrk 607, NGC 1358 and 3C 33. All these galaxies have been previously studied by other authors, who have determined FC fractions using the more traditional procedure of adopting the spectrum of an elliptical galaxy (or the bulge of a normal spiral) as a starlight template. According to Tran (1995a), for instance, the FC accounts for 25 per cent of the light at λ5500 Å in Mrk 1210, while in Mrk 348 it contributes 27 per cent. Our results for Mrk 1210 show that the FC contributes only ≈10 per cent of the light at λ5870 Å, while stars with age 10 Myr or younger contribute

11 per cent – note that these percentage contributions are approximately constant over the 5500–5870 Å interval. For Mrk 348 we find only ≈3 per cent contribution from an FC and ≈2 per cent from young stars. For 3C 33, Koski (1978) found a 19 per cent FC contribution to the light at λ5500 Å, while the synthesis yields less than 1 per cent from either an FC or young stars. For Mrk 573, Mrk 607 and NGC 1358, Kay (1994) estimated FC fractions at λ4400 Å of 20, 10 and 17 per cent, respectively. Our results show only a 1 per cent FC for Mrk 573 and even less for NGC 1358 and Mrk 607, while young stars contribute ≈2 per cent to the spectrum of Mrk 573 at λ4510 Å and < 1 per cent for NGC 1358 and Mrk 607.

In order to check if the smaller FC contribution found by us is real, or if it is just due to the spectral synthesis technique used, we have repeated the spectral synthesis allowing only FC contributions, at λ5870 Å, larger than 25 per cent for Mrk 1210 and Mrk 348, 20 per cent for 3C 33 and Mrk 573, 15 per cent for NGC 1358 and 10 per cent for Mrk 607. These values are close to the ones found by other authors in the literature. With the exception of Mrk 1210, it is not possible to find combinations that would fit the observed spectra for the windows previously used.

We have also repeated this test for all galaxies in the sample, allowing only a minimum FC or H II region contribution of 5 per cent at λ5870 Å. Again, for most of the galaxies, the results of this forced synthesis yield poorer χ^2 than that of using all possible contributions of the FC or the H II region, indicating that these components contribute less than 5 per cent to the spectrum. The exceptions are the galaxies with a circumnuclear starburst, for which the results obtained by forcing a larger contribution from these components give a better χ^2. Owing to the ambiguity of the H II regions and FC component, they also show a better fit when we force a larger contribution of this component.

The above discrepancy between our results and those obtained by other authors is exacerbated by the fact that our spectra were obtained with an aperture 2–4 times smaller than those used by the above authors, which should lead to even larger FC fractions, contrary to what is seen. On the other hand, the synthesis results for Mrk 348, Mrk 1210 and NGC 1358 are in good agreement with those obtained in Paper II, where a spectral decomposition using an extranuclear extraction as a stellar population template for the nucleus was carried out, leading to the conclusion that the FC contribution was smaller than 10 per cent for these three galaxies at λ5870 Å. Furthermore, the small contributions from an FC or young stars found in the synthesis fit nicely with the main result of Paper I, namely that for most of these galaxies the nuclear Ws are similar to the extranuclear ones, indicating no dilution of the nuclear absorption features, which would be expected if an FC or a blue stellar population were present at the nucleus. The results presented here are thus not isolated, but entirely consistent with the previous findings of Papers I and II. Taken together, these results suggest that previous measurements of the FC contribution to the nuclear spectrum of Seyfert 2s have been overestimated owing to the use of an inadequate stellar population template.

In summary, our spectral synthesis analysis shows that the usual assumption that the nuclear stellar population of Seyfert 2 galaxies can be represented by an elliptical galaxy template is not necessarily correct. With the exception of the radio galaxies, most of the Seyfert 2s do not have as large a contribution from old metal-rich stars as ellipticals do. Elliptical galaxies have deep absorption lines (large Ws), which, when compared with the spectrum of Seyfert 2s, create the impression that these lines are diluted by a large proportion of an FC. What actually happens is that Seyfert 2s and ellipticals have different stellar populations.

The main difference obtained for 19 of the 24 galaxies, when normalized at λ5870 Å, or 16 of 24 when normalized at λ3660 Å, is the larger contribution of 'intermediate-age' stars of age ≈100 Myr to the spectrum of Seyfert 2s and radio galaxies, compared with ellipticals. This result points to some sort of connection between star formation and nuclear activity, which we speculate can be related to the process of fuelling the AGN. Several models explain the fuelling of the nuclear engine in terms of galaxy interactions or mergers (Byrd et al. 1986; Byrd, Sundelius & Valtonen 1987; Lin, Pringle & Rees 1988; Hernquist & Mihos 1995). According to these models, the interaction between two galaxies brings the gas to the nuclear region (inner 100 pc), where it is shocked and compressed, producing a starburst and feeding the nucleus. The starburst phase starts 100–300 Myr prior to the feeding of the nuclear engine and can spread throughout this period. This time-scale agrees with the larger contribution from 100-Myr-old stars found in the synthesis, as well as with the contribution from younger populations found in some of the galaxies.

Finally, we would like to discuss the implications of our results to the nature of the FC2. We conclude that this component is due, in most of the cases, to a template mismatch, as most of the previous works used elliptical templates to subtract the stellar population contribution from the nuclear spectrum of AGN, overestimating the amount of FC. As shown here, the role of the FC2 can be played by stars with age 100 Myr. Elliptical galaxies have < 1 per cent contribution from 100-Myr-old stars, while, for 19 of the 24 AGN studied here, the contribution from these stars to the light at λ5870 Å is larger than 1 per cent (or for 9 of 24 galaxies if we consider contributions larger than 5 per cent). In a few cases the FC2 can also be due to stars with age ≤10 Myr, which also contribute less than 1 per cent to the light at λ5870 Å in ellipticals. In four of the 24 galaxies, stars with age < 10 Myr contribute > 5 per cent (or 9 of 24 if we consider galaxies with a contribution > 1 per cent).

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