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The stellar populations of nearby radiogalaxies

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Abstract. We present results on a sample of 7 nearby luminous radiogalaxies ($z < 0.08$, $P_{178\mathrm{MHz}} \gtrsim 10^{25}$ W Hz^{-1} Sr^{-1}), which mostly correspond to the FR II class. In two cases, Hydra A and 3C 285, the Balmer and λ4000 break indices constrain the spectral types and luminosity classes of the stars involved, revealing that the blue spectra are dominated by blue supergiant and/or giant stars. The ages derived for the last burst of star formation in Hydra A are between 7 and 40 Myr, and in 3C 285 about 10 Myr. The rest of the narrow-line radiogalaxies (four) have λ4000 break and metallic indices consistent with those of elliptical galaxies. The only broad-line radiogalaxy in our sample, 3C 382, has a strong featureless blue continuum and broad emission lines that dilute the underlying blue stellar spectra.

1. Introduction

In recent years direct evidence that star formation plays an important role in Active Galactic Nuclei (AGN) has been gathered [13][5][2][7] through the detection of stellar atmospheric features that indicate that most of the UV-NIR light coming from the nuclei of Seyfert 2 and LINERs is dominated by young starbursts. The evidence of these starbursts strongly supports some kind of Starburst-AGN connection. However, it is still to be demonstrated that starbursts play a key role in *all* kinds of AGN.

One of the most stringent tests *to assess if all AGN have associated enhanced nuclear star formation* is the case of lobe-dominated radio-sources, whose host galaxies have relatively red colours when compared to other AGN varieties. In this paper we address the stellar content associated with the active nuclei of a sample of FR II radiogalaxies, the most luminous class of radiogalaxies which possess the most powerful central engines and radio-jets [11]. The presence of extended collimated radio-jets, which fuel the extended radio structure over $\gtrsim 10^8$ yr, strongly suggests the existence of a supermassive accreting black hole in the nuclei of these radiogalaxies. This test addresses the question of whether AGN that involve conspicuous black holes and accretion processes also contain enhanced star formation.

2. Spectra and analysis

Our sample of radiogalaxies was extracted from the 3CRR catalogue [8] with the only selection criteria being edge-brightened morphology, which defines the FR II class of radiogalaxies and redshift $z < 0.08$. Six out of a complete sample of ten FR II radiogalaxies that fulfill these requirements were randomly chosen. In addition to this sub-sample of FR IIs, we observed the unusually luminous FR I radiogalaxy Hydra A (3C 218). This has a radio luminosity which is an order of magnitude above the typical FR I/FR II dividing luminosity.

Spectroscopic observations of this sample were performed using the double-arm spectrograph ISIS mounted in the 4.2m William Herschel Telescope in 1997 November 7–8 and 1998 February 19–20.

2.1. Line and continuum measurements

The CaT index was detected in all of the objects, although in three cases (3C 285, 3C 382 and 4C 73.08) it was totally or partially affected by residuals left by the atmospheric band corrections and the measurement of its strength was thus precluded. For the remaining cases, the strength was measured in the rest-frame of the galaxies against a pseudo-continuum [13]. The values corrected for velocity dispersions (202 – 292 km/s) range between 6.2 and 7.0 Å.

Stellar populations can be dated through the measurement of the λ4000 or Balmer breaks. In intermediate to old populations the discontinuity at λ4000 results from a combination of the accumulation of the Balmer lines towards the limit of the Balmer absorption continuum at λ3646 (the Balmer break) and the increase in stellar opacity caused by metal lines shortwards of λ4000.

Table 1 lists the values of the λ4000 break index, Δ4000Å, measured in the spectra of the 6 narrow-line radiogalaxies and the elliptical galaxy in our sample. This excludes 3C 382, which has a spectrum dominated

Table 1. Break indices

object	original spectra Δ4000Å mag	bulge-subtracted spectra Δ4000Å mag	D	λ_1 Å
3C 98	2.1			
3C 192	1.9			
Hydra A	1.4	1.2	0.26–0.28	3746–3752
3C 285	1.6	1.0	0.48–0.53	3740–3746
4C 73.08	2.2			
DA 240	2.2			
NGC 4374	2.3			

by a strong blue continuum and broad-emission lines, and shows very weak stellar atmospheric features and no break. We adopted a definition [4] which quantifies the ratio of the average flux-level of two broad bands, one covering the break (3750-3950) and one bluewards of the break (4050-4250).

Hydra A and 3C 285 have spectra which are much bluer than those of normal elliptical galaxies. In order to quantify better the strength of the break and the ages of the populations derived, we have performed a bulge subtraction using as template the spectrum of NGC 4374, scaled to eliminate the G-band absorption of the radiogalaxies. Since the velocity dispersion of the stars in NGC 4374 and in the radiogalaxies are comparable inside the spectral resolution of our data, no further corrections were needed. The G-band absorption is prominent in stars of spectral types later than F5 and it is especially strong in types K. Thus, by removing a scaled template of NGC 4374, we are isolating the most massive stars ($M \gtrsim 1 M_{\odot}$) in the composite stellar population of the radiogalaxies. Fig. 1 shows the bulge subtractions obtained on these two radiogalaxies.

We measured on the bulge-subtracted spectra Δ4000Å and also the Balmer break index as defined by the classical $D\lambda_1$ method of stellar classification [12]. The latter quantifies the Balmer discontinuity in terms of the logarithmic difference of the continuum levels (D) and the effective position of the break (λ_1). The method places a pseudo-continuum on top of the higher order terms of the Balmer series in order to measure the effective position of the discontinuity. The functional dependences on the effective temperature and gravity of the stars are sufficiently different for D and λ_1 to satisfy a two-dimensional classification.

The $D\lambda_1$ method could only be reliably applied in the cases of Hydra A and 3C 285. For the other radiogalaxies, the bulge-subtractions led to results that did not allow the identification of the absorption features and/or the break in an unambiguous way due to the resulting poor S/N.

3. Discussion

3.1. Comparison with elliptical galaxies and population synthesis models

The radiogalaxies 3C 98, 3C 192, 4C 73.08 and DA 240 have indices of the order of 1.9 to 2.3, which overlap with those of normal E galaxies, $\Delta 4000\text{Å} = 2.08 \pm 0.23$. These values correspond to populations dominated by stars of *ages 1 to 10 Gyr old*, if one assumes coeval population synthesis models [9].

However, Hydra A and 3C 285 have indices in the range 1.4 to 1.6, typical of coeval populations which are 200 to 500 Myr old. Once the bulge population is subtracted, the Δ4000Å indices of Hydra A and 3C 285 decrease to 1.2 and 1.0 respectively, which are typical of systems younger than about 60 Myr.

Hamilton [4] found a sequence of increasing Δ4000Å from B0 to M5 stars, with values from 1 to 4 mag respectively. A comparison with the sequence he found leads us to conclude that the break in the bulge subtracted spectrum of Hydra A is dominated by B or earlier type stars while that of 3C 285 is dominated by A type stars. The index Δ4000Å does not clearly discriminate luminosity classes for stars with spectral types earlier than G0.

The equivalent width of the H10 absorption line in these two radiogalaxies give further support to the interpretation of the Balmer break as produced by a young stellar population. In Hydra A we find after bulge subtraction EW(H10)$\approx$ 3.9Å, which, according to synthesis models [3] gives ages of 7 to 15 Myr for an instantaneous burst of star formation, and 40 to 60 Myr for a continuous star formation mode, in solar metallicity environments. In the case of 3C 285, EW(H10)$\approx$ 6Å would imply an age older than about 25 Myr for a single-population burst of solar metallicity.

3.2. The blue stellar content

A better estimate of the spectral type and luminosity class of the stars that dominate the break in Hydra A and 3C 285 comes from the classification of Barbier and Chalonge. In Fig. 2 the solid squares connected by lines

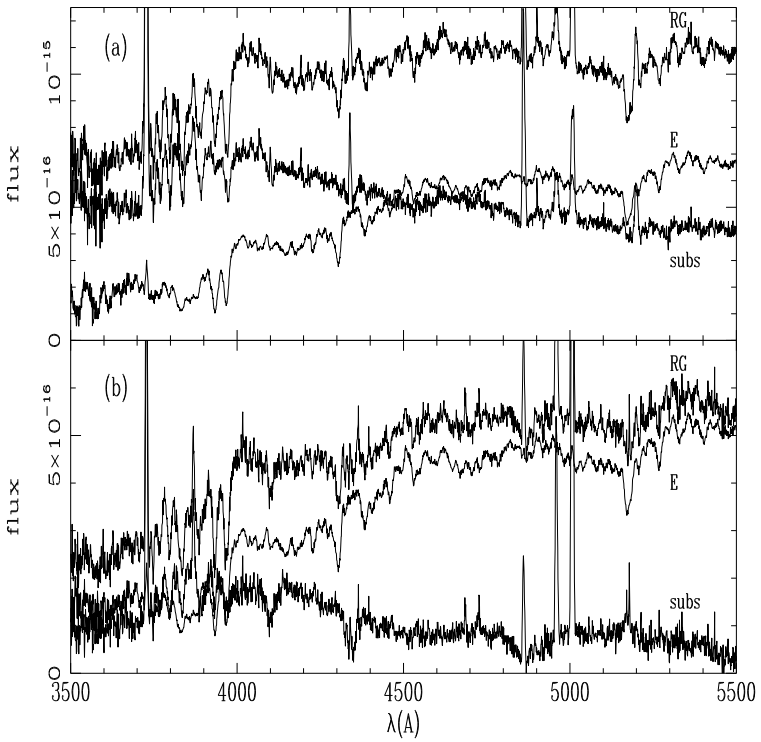

Fig. 1. Bulge-subtraction for (a) Hydra A and (b) 3C 285. We show the original spectra of the radiogalaxy (RG), the scaled template spectra of the bulge population (E), and the resulting bulge-subtracted spectra (subs).

represent the maximum range of possible $D\lambda_1$ values measured in these radiogalaxies.

The Balmer break index is sensitive to the positioning of the pseudo-continuum on top of the higher order Balmer series lines, which in turn is sensitive to the merging of the wings of the lines, enhanced at large velocity dispersions. In order to assign spectral types and luminosity classes to the stars that dominate the break, therefore, it is not sufficient to compare the values we have obtained with those measured in stellar catalogues. The values measured for the radiogalaxies can be corrected for their intrinsic velocity dispersions; we have chosen instead to recalibrate the index using template stars of different spectral types and luminosity classes convolved with gaussian functions, until they reproduce the width of the Balmer lines observed in the radiogalaxies (FWHM$\approx$ 12.5Å). We used the B0 to A7 stars from a stellar library [6], which were observed with 4.5Å resolution. The values of the $D\lambda_1$ indices measured in these broadened stars are represented in Figure 2 by their respective classification. By comparison we also plot the grid traced by the locus of unbroadened stars [12]. The broadening of the lines shifts the original locus of supergiant stars from the $\lambda_1 \lesssim 3720$Å range to the $3720 \lesssim \lambda_1 \lesssim 3740$Å range, occupied by giant stars in the original (unbroadened) classification. Giant stars, in turn, shift to positions first occupied by dwarfs. Most dwarfs have Balmer line widths comparable to those of the radiogalaxies, and thus their locus in the diagram is mostly unchanged.

The value of the D index indicates that the recent burst in *Hydra A is dominated by B3 to B5 stars*, and the effective position of the Balmer break (λ_1) indicates that *these are giant or supergiant stars*, respectively. These stars have masses of 7 and $20M_\odot$. From the stellar evolutionary tracks of massive stars with standard mass-loss rate at $Z_\odot$ or $2Z_\odot$ we infer that these stars must have *ages between 7 to 8 Myr (B3I) and 40 Myr (B5III)*. Note that the B4V stars in Figure 2, near the location of Hydra A, cannot originate the break and at the same time follow the kinematics of the nucleus: the stars producing the Balmer absorption lines are dynamically decoupled from those producing the metallic lines [10]. Any dwarf star located in the stellar disk of Hydra A would show absorption lines that have been broadened beyond the 12.5Å of FWHM we measure in this radiogalaxy, and its position would have been shifted further into larger values of λ_1.

The location in the $D\lambda_1$ plane of 3C 285 indicates that the break is produced by A2I stars. These are $15M_\odot$ stars. Again, *ages of 10 to 12 Myr* are found for the last burst of star formation in this radiogalaxy. The interpretation

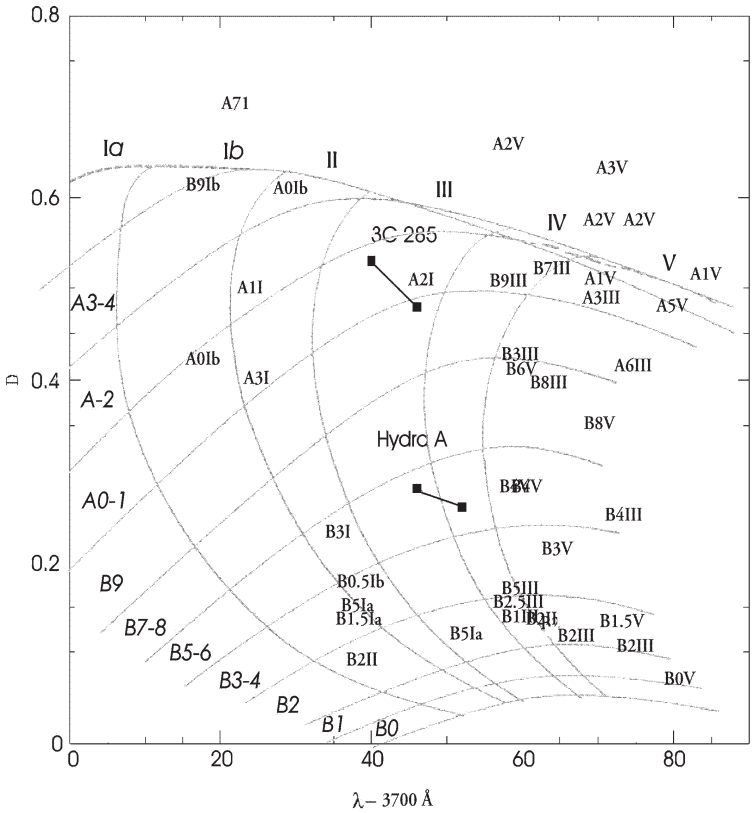

Fig. 2. Barbier and Chalonge index plane. The location of the range of values for 3C 285 and Hydra A is indicated by solid squares and connecting lines. We have also plot the indices measured in the stellar library, that have been broadened to mimic the width of the Balmer lines in the radiogalaxies., represented by their corresponding spectral type and luminosity class (*e.g.* A2I). The grid of solid lines traces the original locus of unbroadened stars. The big symbols at the edges of the grid represent the correspondance into spectral classes and luminosity classes of the frame defined by the grid.

of the blue excess in terms of A type stars is further supported by the detection of the Ca II H line in the bulge-subtracted spectrum.

3.3. The red stellar content

We have measured the CaT in a control sample of elliptical galaxies. We find that the range of CaT in elliptical galaxies, 5 to 7.5Å, comprises the range of values of the radiogalaxies.

Mixed populations of young bursts which contain red supergiants, superposed on old populations can also yield values of the CaT[1] between 4 and 8Å. Since metal rich giant stars have CaT values ranging from 6 to 9Å we regard our observations of the CaT index in radiogalaxies, as being compatible with ages 1 to 15 Gyr.

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