A survey of Low Luminosity Compact sources and its implication for evolution of radio-loud AGNs. II. Optical analysis

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ABSTRACT

This is the second in a series of papers concerning a new sample of low luminosity compact (LLC) objects. Here we discuss the optical properties of the sample based on Sloan Digital Sky Survey (SDSS) images and spectra. We have generated different diagnostic diagrams and classified the sources as high and low excitation galaxies (HEG and LEG, respectively). We have studied the jet-host interactions, relation between radio and optical line emission and evolution of the radio source within a larger sample that included also the published samples of compact steep spectrum (CSS), gigahertz peaked spectrum (GPS) sources and FR II and FR I objects. The optical and radio properties of the LLC sample are in general consistent with brighter CSS and large-scale radio sources, although the LLC objects have lower values of $[\text{O III}]$ luminosity than the more powerful CSS sources ($L_{1.4 \text{ GHz}} > 10^{25}$ \text{ W Hz}^{-1}$). However, when LLC are added to the other samples, HEG and LEG seem to follow independent, parallel evolutionary tracks. Regarding ionization mechanisms, LLC and luminous CSS objects behave like FR II sources, while FR I seem to belong to a different group of objects. Based on our results, we propose the independent, parallel evolutionary tracks for HEG and LEG sources, evolving from GPS - CSS - FR.

Key words: galaxies: active – galaxies: evolution – galaxies: quasars: emission lines

1 INTRODUCTION

The compact radio sources consist of two population of objects: the gigahertz-peaked spectrum (GPS) and compact steep spectrum (CSS) sources. These are considered to be young and evolve into large radio objects, FR I/FR II (Fanti et al. 1993; Readhead et al. 1996; O’Dea 1998, for a review). The GPS sources are considered to be entirely contained within the extent of the narrow-line region (≤ 1 kpc). Unbeamed, symmetric GPS sources have been classified as Compact Symmetric Objects by Wilkinson et al. (1994). CSS sources are thought to extend to the size of the host galaxy (≤ 20 kpc). Compact radio sources are the ideal for learning more about the relation between formation and evolution of the host galaxy, the trigger of the activity and its effect on the nuclear regions and ISM of the host galaxy.

Once the nuclear activity and radio source are triggered, the small-scale jets expand through the natal cocoon, driving outflows in the emission line gas (fast outflows and jet-cloud interactions). In some cases the interaction of the radio jets with the ISM can disrupt the jet and change the morphology and luminosity of the source (Kaiser & Best 2007). In large radio sources, the emission line activity is connected with black hole mass, fuelling mechanism and type of the accreting gas (Hardcastle et al. 2007; Buttiglione et al. 2010). However the morphological division of large radio objects into FR I and FR II does not correspond to low/high excitation division: FR Is show typically faint optical nuclei and low excitation spectra, while among FR IIs we have both low and high excitation galaxies. The spectroscopic analysis of GPS/CSS sources - progenitors of large FR I/FR II objects - can allow to derive their accretion properties at times close to the jet launching.

In GPS/CSS sources, the jet is still crossing the ISM and the interaction with the ISM is stronger than in large radio sources. Observations of the ionized gas in GPS and CSS sources show the presence of such interactions (Holt et al. 2000, 2001; Labiano et al. 2003). Therefore, other ioniza-
tion mechanisms must be taken into account, such as jet-induced shocks or precursor photoionization. Furthermore, some radio sources show traces of star formation associated with a hidden radiatively efficient active nucleus. Tasse et al. (2008) also argue that the low luminosity radio activity is associated with re-fuelling of massive black holes. Most of the GPS and CSS sources known so far are powerful objects and the clue to solve the evolution puzzle can be the analysis of less powerful compact sources.

In this paper we will investigate the characteristics of the optical properties of 29 out of 44 low luminosity CSS sources selected from the FIRST survey. We compare these with more powerful compact objects and FR I and FR II large sources.

2 OPTICAL DATA

The sample of Low Luminosity Compact (LLC) sources has been selected from the FIRST survey and observed with MERLIN at L-band and C-band. The selection criteria and the radio properties of the sample were discussed and analysed in Kunert-Bajraszewska et al. (2010), hereafter Paper I. All of the LLC sources are nearby objects with redshift $z < 0.9$.

Optical data are available for 29 LLC sources and have been obtained from the Sloan Digital Sky Survey (SDSS) Data Release 7 (DR7: Abazajian et al. 2009). DR7 includes fits for all the emission lines in the spectra. However, the SDSS pipeline has problems fitting multi-component lines such as Hα+[NII] doublet or lines with both broad and narrow components. In these cases, we fitted the lines using TOPCAT and the Splot task in IRAF.

DR7 data are not corrected of Galactic extinction. We have applied the Cardelli et al. (1989) extinction law to correct for it, using the E(B-V) values listed in NED. Table I lists the line fluxes, corrected for Galactic extinction, for each source with available SDSS spectra.

To improve our statistics, we completed the sample of compact sources by taking CSS/GPS sources with available spectroscopic and radio data from the literature: 28 CSS/GPS sources were taken from Labiano et al. (2007) and 8 low luminosity CSSs were taken from Buttiglione et al. (2009a). Moreover we performed spectroscopic analysis of CSS objects from Fanti et al. (2001) and Marecki et al. (2003) samples (combined sample, Table A) and discussed them in Appendix A. Their radio properties were already used in the statistical studies presented in Paper I. However, the SDSS data are available for only 14 objects from the combined sample. To explore evolution with size (i.e. age) we also included the [O III] line luminosities of available 114 large sources from the revised 3C sample of FR I and FR II sources (LRL sample: Laing et al. 1983, Buttiglione et al. 2009b, and Willott et al. 1999).

Throughout the paper, we assume a cosmology with $H_0=71\text{ km s}^{-1}\text{ Mpc}^{-1}$, $\Omega_M=0.27$, and $\Omega_{\Lambda}=0.73$ (Spergel et al. 2003). Distances were calculated using the astronomy calculator by Wright (2006).

3 NOTES ON INDIVIDUAL SOURCES

In this section we describe the main features in the SDSS optical images and spectra of the LLC sample. The HEG/LEG classification is based on the line ratios observed in the SDSS spectra and the Buttiglione et al. (2010) definitions. Our sample shows that all sources with log $[\text{O III}]\lambda\lambda3727,3729/[\text{O III}]\lambda5007 \lesssim 0.2$ are LEG while those with log $[\text{O III}]\lambda\lambda3727,3729/[\text{O III}]\lambda5007 \gtrsim 0.2$ are HEG (Figure 2 and Table 1). The data suggests that the [O III]$\lambda5007/H\beta$ can be used to distinguish between HEG and LEG: HEG show log $[\text{O III}]\lambda5007/H\beta \gtrsim 0.75$ while LEG show log $[\text{O III}]\lambda5007/H\beta \gtrsim 0.75$. Based on these criteria, we assigned a HEG/LEG classification for those sources where we could measure only the $[\text{O III}]\lambda\lambda3727,3729/[\text{O III}]\lambda5007$ ratio. These sources are marked with **.

0025+006. HEG. The source shows extended (~20 kpc) emission and a bright nucleus. The image suggest a possible tail towards NW.

0754+401. HEG. The image shows an extended (~10 kpc) source with a bright nucleus with a possible arm or tail at ~10 kpc towards the NE.

0810+077. LEG. Very elongated (~40 kpc, NW-SE) galaxy with a bright nucleus, possibly a disk galaxy. The radio source is perpendicular to the longest optical axis (Paper I). This behaviour has been observed before in e.g. 3c 236 (O’Dea et al. 2001, Tremblay et al. 2010).

0821+321. Very extended source (~60 kpc) with a faint nucleus. The image shows two bright emission regions towards NE (at ~15 kpc) and SW (at ~25 kpc), embedded in the extended emission.

0835+373. Compact source with a faint nucleus.

0846+017. HEG. Diffuse source with a faint nucleus. The image suggest possible extended emission towards W (~20 kpc).

0850+024. The image shows extended emission (~30 kpc) suggesting an elongated (SE-NW) galaxy or an optical jet. However, the radio jet is oriented EW (Paper I). The spectrum is consistent with AGN or stellar continuum. It seems to have a Lyα break but it is on the border of the spectrum. The emission line ratios suggest possible HII (star forming) galaxy. However, this is based on limits.

\footnote{http://www-astro.physics.ox.ac.uk/~sr/grimes.html}
0851+024. LEG*. The image shows a diffuse and faint source with a bright compact object at \( \sim 50 \text{kpc} \) SE. The optical sources are not necessarily related.

0907+049. The image shows two bright merging sources embedded in extended emission. The separation between the nuclei amounts to \( 20 \text{kpc} \). The extended emission has a size of \( \sim 50 \text{kpc} \). The Western component shows an elongated NE-SW structure while the East component is a compact object. The probable radio jet however, is aligned NS (Paper I). The optical image shows a bright, faint source south of the system at \( \sim 60 \text{kpc} \) with some diffuse emission between them. Kopylov et al. (1993) already suggested that 0907+049 was a member of a group of galaxies.

0914+504. The optical image shows a compact source. The spectra shows broad [Mg II] at 2800 and a powerlaw continuum consistent with a QSO.

0921+143. LEG. Large system (\( \sim 50 \text{kpc} \)) with a bright nucleus. The image shows two bright, compact regions at \( \sim 20 \text{kpc} \) towards W and E, and a fainter compact region at \( \sim 30 \text{kpc} \). The image suggests a merging system in a very crowded field.

0923+079. HEG*. The image shows two close-by (\( \sim 10 \text{kpc} \)) bright compact sources. The radio emission corresponds to the E component. The spectra shows a flat continuum with broad H\( \beta \) and possibly H\( \alpha \). However the former is right in the border of the spectrum. The spectrum therefore suggests a Sy1 or QSO. There are also hints of faint [Mg II] at 2800 and [Ne V] at 3425 emission lines. However, the S/N is too low in this region. The radio maps show also a very compact source, consistent with the optical classification (Paper I).

0931+033. LEG. The optical image shows a bright \( \sim 20 \text{kpc} \) source with a bright nucleus and a small (\( \sim 7 \text{kpc} \)) tail towards SE, and very elongated, jet-like \( \sim 40 \text{kpc} \) emission towards NW. The radio map, however, shows a compact source with no jet present (Paper I).

0942+355. HEG. The optical image shows a compact source (\( \sim 12 \text{kpc} \)) with weak extended emission surrounding it and a faint tail towards NW. The orientation of the tail is aligned with the radio jet (Paper I).

1007+142. LEG. The image shows a very extended source (\( \sim 50 \text{kpc} \)) with a bright nucleus and a bright compact region at \( \sim 8 \text{kpc} \) for the center, towards W. However, the radio structure (\( 2.3 \text{kpc} \)) is oriented NS (Paper I).

1037+302. LEG. Extended (\( \sim 24 \text{kpc} \)) asymmetric galaxy, showing a tail towards NE. The radio structure (\( 2.6 \text{kpc} \)) is however perpendicular to this structure (Paper I). This behaviour has been observed before in e.g. 3c 236 (O’Dea et al. 2001; Tremblay et al. 2010). The optical image also show two compact regions on the E and W sides of the source.

1053+505. HEG*. The spectrum looks clearly as a QSO, with a strong powerlaw and bright broad [Mg II] at 2800 and H\( \beta \) emission. The image shows a compact bright source, consistent with the QSO classification. The radio map shows a 5.8 kpc structure, unresolved in the optical image (Paper I).

1140+058. HEG*. The image shows a compact source. The spectrum shows faint powerlaw continuum with broad emission lines, suggesting a QSO and consistent with the core-jet radio morphology observed (Paper I).

1154+435. HEG*. The image and radio map show a compact source. The spectrum shows clear powerlaw continuum with bright, broad emission lines, consistent with a QSO. The emission line ratios suggest a possible HII (star forming) source. However, the data fall in in the HEG/HII limit. 1156+470. The image shows a small source with some diffuse emission around and no clear nucleus. There are a few aligned knots of emission towards NW, extending \( \sim 20 \text{kpc} \). This structure is aligned with the smaller 3.6 kpc radio structure (Paper I).

1308+451. Extended (\( \sim 35 \text{kpc} \)) source with a very complex structure and several bright compact regions and suggests an interacting system in a very crowded field. The image shows a bright \( \sim 10 \text{kpc} \) NW-SE jet-like structure aligned with the smaller radio structure (Paper I).

1321+045. The image shows an extended (\( \sim 40 \text{kpc} \)) source with a faint nucleus and two bright knots towards NW embedded in the extended region. The radio jet however, is perpendicular to this structure (Paper I). This behaviour has been observed before in e.g. 3c 236 (O’Dea et al. 2001).

1359+525. The image shows an extended galaxy (\( \sim 30 \text{kpc} \)) with a faint nucleus, several bright knots around it and a possible small (\( \sim 10 \text{kpc} \)) companion.

1402+415. HEG*. The image shows a faint compact galaxy (\( \sim 20 \text{kpc} \)). The spectrum shows no traces of AGN.

1407+363. HEG. The image shows a very elongated system (\( \sim 70 \text{kpc} \)) consisting of three bright regions aligned NS and connected by diffuse, extended emission. The radio source position corresponds to the central region (Paper I). The image also suggests a faint tail connected to a fourth knot, SW of the system.

1411+553. The image shows a faint compact galaxy (\( \sim 15 \text{kpc} \)). The spectrum shows no traces of an AGN.

1418+053. The image shows a faint \( \sim 15 \text{kpc} \) source with two faint knots of emission towards SW at \( \sim 22 \) and \( 30 \text{kpc} \). The spectrum shows no traces of an AGN.

1506+345. The image shows an extremely extended, elongated (\( \sim 45 \text{kpc} \), NE-SW) galaxy with resolved dust lanes, bright emission knots and a large (\( \sim 25 \text{kpc} \)) diffuse tail towards N, leaving the galaxy from the E, where the brightest structure is. The spectrum however, corresponds to the central, fainter region. The radio map shows also a complex structure but smaller source. Previous observations have identified this source as an interacting system (Paper I).

1532+303. The image shows a very faint source with a possible double component. SDSS estimates a redshift of \( z=0.0009 \). However, the spectrum is extremely noisy and, based on the faint small source in the image, the redshift is probably larger.

1542+390. HEG*. The image shows a very small faint source (\( \sim 10 \text{kpc} \)).

1550+444. The image shows an extended (\( \sim 20 \text{kpc} \)) source with a faint nucleus and a possible merging companion SW. The radio map shows a 5 kpc NS structure (Paper I).

1558+536. LEG*. The image shows a NS elongated galaxy (\( \sim 20 \text{kpc} \)) at the radio source coordinates, with a closeby (\( \sim 15 \text{kpc} \)) compact, bright companion (towards NE), suggesting interaction. The radio map shows a 3.6 kpc long structure, aligned with the optical emission (Paper I).

1601+528. LEG*. The image shows an extended (\( \sim 40 \text{kpc} \)) source with bright nucleus and a bright compact region (at \( \sim 10 \text{kpc} \) towards SW) in a crowded field.

1610+407. LEG. The image shows an extended (\( \sim 15 \text{kpc} \)) source, slightly elongated EW, with a bright nucleus. The
orientation is consistent with the small (2.6 kpc) radio source (Paper I).

1641+320. HEG*. The image shows two bright compact sources separated by ~25 kpc, suggesting interaction. The spectrum shows a clear powerlaw and broad emission lines, consistent with a QSO. Brotherton et al. (1999) identified this system as a two interacting QSO. The SDSS spectrum corresponds to the southern one.

Summing up, the radio-selected LLC sample shows a wide variety of optical structures: 22 sources (63%) show extended emission, 13 sources (37%) are compact or unresolved, and 16 sources (46%) show a possible merger or complex structures in the image. Only 4 sources (11%) show radio-optical alignment. The radio-optical alignment is usually seen in CSS (e.g., de Vries et al. 1997, 1999, Axon et al. 2002) and large radio sources (McCarthy et al. 1987). However, the radio jets in our sample are mostly small (\(\lesssim 5\) kpc) and too young to have affected the ISM and show traces of jet-induced ionization (therefore alignment).
Table 1. Emission lines measurements and spectroscopic classification of LLC sources

| Source Name | Class       | $z$ | $E(B-V)$ | $\lambda$2800 | $\lambda$3425 | $\lambda$3727 | $\lambda$3787 | $\lambda$4363 | $\lambda$4959 | $\lambda$5007 | $\lambda$6300 | $\lambda$6548 | $\lambda$6584 | $\lambda$6614 | $\lambda$6731 |
|-------------|-------------|-----|----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 0025+006    | HEG         | 0.1 | 0.02     | –              | –              | –              | 142            | 20             | –              | 14             | 44             | 128            | –              | 51             | 82             |
| 0754+401    | HEG         | 0.07| 0.05     | –              | –              | –              | 69             | 14             | –              | 3              | 13             | 60             | 171            | –              | 38             |
| 0810+014    | LEG         | 0.11| 0.02     | –              | –              | 60             | –              | 3              | 7              | 10             | 22             | 18             | 45             | 58             | 104            |
| 0835+373    | LEG         | 0.4 | 0.04     | –              | –              | 7              | –              | –              | 1              | 1              | 3              | –              | *              | *              | –              |
| 0846+010    | LEG         | 0.35| 0.04     | –              | –              | 11             | –              | –              | 3?             | 7              | 21             | –              | 3              | 14             | 17             |
| 0850+024    | –           | 0.46| 0.04     | –              | –              | 14             | –              | –              | 4              | 4              | 12             | –              | 1              | 15             | 2              |
| 0851+024    | LEG*        | 0.4 | 0.04     | –              | –              | 2              | –              | –              | 1              | –              | –              | –              | –              | –              | –              |
| 0914+504    | –           | 0.63| 0.01     | 1              | –              | 2              | –              | –              | –              | –              | –              | –              | –              | –              | –              |
| 0921+143    | LEG         | 0.14| 0.03     | –              | –              | 65             | –              | 4              | –              | 11             | 7              | 18             | 38             | 38             | 80             |
| 0923+079    | HEG*        | 0.44| 0.05     | –              | 12             | 3              | 7n             | 18             | 53             | –              | –              | –              | –              | –              | –              |
| 0931+013    | LEG         | 0.23| 0.03     | –              | 25             | –              | –              | –              | 3              | 5              | 12             | 5              | 23             | 20             | 51             |
| 0942+355    | HEG         | 0.21| 0.01     | –              | 8              | 17             | 10             | –              | 7              | 26             | 76             | –              | 38             | 26             | 45             |
| 1007+124    | LEG         | 0.21| 0.04     | –              | 23             | –              | –              | 1              | 3              | 4              | 4              | 5              | 15             | 11             | 28             |
| 1037+302    | LEG         | 0.09| 0.02     | –              | 59             | –              | –              | –              | 9              | 17             | 22             | 22             | 50             | 46             | 132            |
| 1053+505    | HEG*        | 0.82| 0.02     | 114            | 5              | –              | 18             | 4n             | 5              | 14             | –              | –              | –              | –              | –              |
| 1140+058    | HEG*        | 0.5 | 0.03     | 9              | 20             | –              | –              | –              | 2n             | 16             | 50             | –              | –              | –              | –              |
| 1154+435    | HII/HEG*    | 0.23| 0.01     | –              | 13             | 31             | 25             | 4n             | 19n            | 55             | 61             | 6              | 13             | 61n            | 30             |
| 1308+451    | –           | 0.39| 0.02     | –              | 12             | –              | –              | –              | –              | –              | –              | –              | –              | –              | –              |
| 1321+045    | –           | 0.26| 0.03     | –              | 11             | –              | –              | –              | –              | –              | –              | –              | –              | –              | –              |
| 1339+525    | –           | 0.12| 0.01     | –              | 14             | –              | –              | –              | –              | –              | –              | –              | –              | –              | –              |
| 1402+415    | HEG*        | 0.36| 0.02     | –              | 3              | –              | –              | –              | 2              | 4              | –              | –              | 19             | –              | –              |
| 1407+363    | HEG         | 0.15| 0.01     | –              | 16             | –              | –              | –              | 9              | 25             | 7              | 14             | 25             | 29             | 17             |
| 1411+553    | –           | 0.28| 0.02     | –              | 3              | –              | –              | –              | –              | –              | –              | –              | –              | –              | –              |
| 1418+053    | –           | 0.46| 0.04     | –              | –              | –              | –              | –              | 3              | –              | –              | –              | –              | –              | –              |
| 1542+390    | HEG*        | 0.55| 0.02     | –              | 3              | –              | –              | –              | 3              | 7              | –              | –              | –              | –              | –              |
| 1558+536    | LEG*        | 0.18| 0.01     | –              | 22             | –              | –              | –              | 5              | 7              | 7               | 11             | 21             | 22             | –              |
| 1601+528    | LEG*        | 0.11| 0.02     | –              | 11             | –              | –              | –              | 4?             | –              | –              | 40             | 20             | 85             | 34             |
| 1610+407    | LEG         | 0.15| 0.01     | 62             | –              | 4              | –              | 11             | 13             | 34             | –              | 32             | 49             | 70             | 51             |
| 1641+320    | HEG*        | 0.59| 0.03     | 19             | 6              | 21             | 7              | 2n             | 5n             | 3              | 12n            | 25             | 79             | –              | –              |

Description of the columns: (1) source name; (2) spectroscopic classification (see text for details), '*' means the classification is based on the $[O II]\lambda\lambda 3727,3729/[O III]\lambda 5007$ ratio only; (3) redshift; (4) galactic extinction; Rest of columns: flux for each line. '*' - The line is present but on the edge of the spectrum (and unfittable). '?' - Low S/N, questionable detection. n = narrow b = broad Wavelengths are in ˚A. Flux in $10^{-16}$ erg s$^{-1}$ cm$^{-2}$. 
4 DISCUSSION

Optical data are available for most of the radio sources. However, some data have too low signal-to-noise ($\lesssim 3$) and could not be analysed. We measured emission line fluxes of the LLC sources (Table I) and sources from [Fanti et al. 2001] sample and [Marecki et al. 2003] sample for which available spectroscopic data exist (Appendix, Table A). Discussion on optical properties of CSS sources is then based on the results presented in Fig. 1 and 2. The radio properties of the sample have been discussed and analysed in the Paper I.

4.1 Spectroscopic properties of LLC sources

We have classified the LLC sources in HEG and LEG following the criteria described in Buttiglione et al. (2010) (Table I). However, not all sources in the sample had the necessary lines measured.

It is worth mentioning that LLC HEGs show a $\sim 10$ times higher $[O\text{ III}] \lambda 5007$ luminosities than LLC LEGs. HEG show $L_{[O\text{ III}]} > 10^{41.1}$ erg s$^{-1}$, while LEG $L_{[O\text{ III}]} < 10^{41.1}$ erg s$^{-1}$. This effect is not only present in our sample but also in Buttiglione et al. (2010).

Both HEG and LEG show similar numbers of quasars and galaxies. However, all broad line objects (25% of the LLC sample, 0923+079, 1053+505, 1140+458, 1154+435, 1641+320) are quasars and have been classified as HEG. Large sources showing broad line emission (30% of the 3CR sample) also fall under the HEG class. They all show a broad H$_β$ component. 1154+435 shows broad H$_β$, and H$_α$ emission. 1641+320 shows broad H$_β$, and H$_α$. All broad line objects (and only these) have $[O\text{ III}]$ luminosity $>10^{42}$ erg s$^{-1}$.

The radio morphologies of 1154+435 and 1641+320, are core-jet and asymmetric double objects. The radio source 1037+302 has been classified as a young FR I by Buttiglione et al. (2009b). The radio structure is a candidate for a fader (Paper I).

Six of the LLC sources have low $[O\text{ III}]$ luminosity values ($< 10^{41}$ erg s$^{-1}$): 0810+077, 0851+024, 0921+143, 1007+142, 1037+302, 1558+536. These are both galaxies and quasars, all of them classified as LEG. Among them we have core-jet and asymmetric double objects. The radio source 1037+302 has been classified as a young FR I (Giroletti et al. 2005), and 1558+536 with its breaking up radio structure is a candidate for a fader (Paper I).

The radio morphology of LLC HEG and LEG do not correspond to a difference in their emission line properties indicating that similar radio structures can be formed in both classes.

4.2 Spectroscopic diagnostic diagrams

We have used the ITERA (Groves & Allen 2010) tool to generate emission line diagnostic (or BPT, after Baldwin et al. 1981) diagrams and compare the emission line ratios ($[O\text{ II}]\lambda\lambda 3727,3729/[O\text{ III}]\lambda 5007$, $[O\text{ III}]\lambda 5007/\text{H}β$, $[O\text{ I}]\lambda 6300/\text{H}α$, $[\text{S II}]\lambda\lambda 6726,6731/\text{H}α$ - versus $[\text{N II}]\lambda 6583/\text{H}α$) of the CSS HEG and LEG sources in our sample (Fig. 2) with predictions of starburst (Kewley et al. 2001), Dopita et al. (2007), Levesque et al. 2010, dust, dustfree AGN (Groves et al. 2010), and shock (Allen et al. 2008) models. Our results are roughly consistent with the 3CR sample studied by Buttiglione et al. (2010). However, our sample tend to show higher $[\text{N II}]\lambda 6583/\text{H}α$, $[\text{S II}]\lambda\lambda 6726,6731/\text{H}α$ and $[\text{O I}]\lambda 6300/\text{H}α$ but similar $[O\text{ III}]\lambda 5007/\text{H}β$ to the Buttiglione et al. (2010) sample.

None of the recent (<10 Myr) star formation models is consistent with the data. The sources could be too weak to induce star formation or the gas has not had time yet to cool down and form stars in the regions affected by the jet.

The higher ionization parameter and the presence of the precursor in HEG, suggest a difference in the strength of the shocks and jet-ISM interactions in HEGs and LEGs. Strong shocks (which show higher U and higher contribution from the precursor gas, e.g. Allen et al. (2008)) are present in HEGs while weaker shocks are characteristic for LEGs.

Concerning the environment, both HEG and LEG are present at all gas densities and metallicities and are well reproduced by both dusty and dust-free AGN models. However, HEGs tend to show slightly lower metallicities, and higher magnetic parameter (ratio of the magnetic field to the density, see Groves & Allen 2010 for details). The data also suggest stronger radiation fields in LEG environments although the measurements are not conclusive (most of the $[\text{O I}]\lambda 6300/\text{H}α$ data are limits).

4.3 Emission lines - radio correlation

We have compared the $[O\text{ III}]$ luminosity with the radio properties for LLC sources, and expanded the sample with other CSS sources (Buttiglione et al. 2009a,b, 2010; Willott et al. 1999), GPS sources (Labiano et al. 2005) and FR I and FR II objects (Buttiglione et al. 2009b, Willott et al. 1999).

The whole sample shows that, for a given size or radio luminosity, HEG sources are brighter than LEG in the $[O\text{ III}]$ line (Table I, Table A, Fig. 3B) by a factor of $\sim 10$.

The LLC objects follow the same correlation between $[O\text{ III}]$ luminosity and radio power, as the rest of the sample (Figure 3A). In Figure 3A we plotted the same sources in the plane $[O\text{ III}]$ luminosity versus linear size which can be interpreted as a picture of radio source evolution. As we already showed and discussed in Paper I the LLC objects occupy the space in radio power versus linear size diagram below the main evolutionary path of radio objects. Although we have optical data for 29 out of 44 LLC sources this trend is also visible in Figure 3B.

We suggest that some of the low luminosity sources might be short-lived objects, and their radio emission may be disrupted several times before becoming FR II.

The previously reported correlation (Labiano 2008a) between $[O\text{ III}]$ luminosity and size of the radio source for CSS and GPS sources (although not very strong, the correlation coefficient is $0.35$) is breaking up when including LLC objects (correlation coefficient equals to 0.11, Fig. 3B). It is also significant that CSS sources causing this effect are LEGs (Fig. 3B). This break up could be due to a sample selection effect since the Labiano (2008a) data was collected from the available literature samples which were created for different purposes and different selection criteria. The radio
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jet could only enhance the [O III] emission in HEGs, as these sources seem to be more powerful than LEGs.

Moreover, all sources (compact and large) classified as HEGs, have [O III] luminosities $\gtrsim 10^{41}$ erg s$^{-1}$ while all LEGs fall below this limit and show stronger jet contributions in the BPT diagrams. (Fig. II-d). It has been discussed (Buttiglione et al. 2010) that the differences between LEGs and HEGs are related to a different mode of accretion: LEGs are powered by hot gas while HEGs require the presence of cold accreting material. The fact that only CSS HEGs seem to follow the correlation between [O III] luminosity and size of the radio source for CSS/GPS sources (Labiano 2008) can be connected with the above findings. According to Labiano (2008) the expansion of the radio source through the host ISM could be triggering or enhancing the [O III] line emission through direct interaction. The presence of the cold structures (i.e. molecular torus or Broad Line Region) in HEGs could be responsible for higher gas excitation, and consequently for higher [O III] line emission and Hα line emission. Considering Hα line luminosities of CSS sources we also found a division among them: CSS HEGs have higher Hα line luminosities than CSS LEG objects (Table I and Table A). This correlation has been earlier found for large scale FR Is and FR IIs (Buttiglione et al. 2010). However, in the case of CSS and GPS sources, more data are needed to confirm the correlation and study its possible implications.

A recent paper (Garofalo et al. 2010) suggest that the HEG/LEG nature of a radio galaxy could be related to the black hole spin instead of the different accretion mechanism (e.g. Hardcastle et al. 2007). However, the definitions of high and low excitation sources used in these two
Figure 2. Selected BPT diagrams for the sample of LLC sources. We show the best fitting models to the sample. From left to right and top to bottom: [N II]λ6583/Hα dustfree AGN (Z=4, N=10000), [O I]λλ6300/Hα dustfree AGN (Z=1, N=1000), [O II]λλ3727,3729/[O III]λ5007 dustfree AGB (Z=1 N=1000), and [S II]λλ6726,6731/Hα dusty AGN (Z=2, N=1000). The remaining BPT diagrams and the colour version of this figure are available online.

papers are slightly different than the definitions used by Buttiglione et al. (2010) and adopted for our sample. While searching for HEG and LEG differences in the samples we used, we also found that they show differences in X-ray emission. LEGs have X-ray luminosities below $10^{42}$ erg/s while HEG X-ray emission cover a wider range (from $0.1 \times 10^{42}$ to $1.4 \times 10^{42}$ erg/s, e.g. Evans et al. 2006, Hardcastle et al. 2003, Tenishev et al. 2003, Massaro et al. 2010). Although there is an overlap around $10^{42}$ erg/s, there are no LEGs with X-ray luminosities higher than $10^{42}$ erg/s. We see the same behaviour in [OIII]λ50007 luminosity (with a similar overlap around $10^{41}$ erg/s, see Figure 1 c and d). A detailed study about the origin of the HEG and LEG X-ray properties is however beyond the scope of this paper.

Figure 1 shows that the division for HEGs and LEGs described for FR II/FR I sources by Buttiglione et al. (2010) is also visible among CSS sources (i.e. earlier phases of AGN evolution). The FR II HEG and CSS HEG, as well as the FR II LEG and CSS LEG show a wide range of radio powers, but it seems they follow different [O III] luminosity versus radio power correlation. FR I sources could be completely different group of objects concerning the photoionization, or follow the LEG [O III] luminosity versus radio power correlation. As has been noted by Buttiglione et al. (2010) all FR Is for which they were able to derive a spectral type are LEGs. We considered separately the populations of HEGs and LEGs and we have obtained the following linear correlations (plotted in Fig. 1c):

- **HEG (FR II+CSS):**
  \[
  \log L_{[OIII]} = 0.59(\pm 0.07) \times \log L_{4.85 \text{ GHz}} + 26.77(\pm 1.75)
  \]

- **LEG (FR I+FR II+CSS):**
  \[
  \log L_{[OIII]} = 0.67(\pm 0.08) \times \log L_{4.85 \text{ GHz}} + 23.69(\pm 2.12)
  \]

- **LEG (FR I+FR II):**
  \[
  \log L_{[OIII]} = 0.81(\pm 0.07) \times \log L_{4.85 \text{ GHz}} + 19.79(\pm 1.76)
  \]

Based on the analysis above, we propose a scenario
where the differences in the nature of LEG and HEG (accretion mode or black hole spin) are already visible in the CSS phase of AGN and determine the evolution of the source (i.e., CSS$_{LEG}$ evolve to FR$_{LEG}$, CSS$_{HEG}$ evolve to FR$_{HEG}$). The main evolution scenario (GPS-CSS-FR II) was proposed years ago [Fanti et al. 1992; Readhead et al. 1996]. However, once the HEG/LEG division is included, these sources seem to evolve in parallel; GPS$_{LEG}$ → CSS$_{LEG}$ → FR$_{LEG}$ and GPS$_{HEG}$ → CSS$_{HEG}$ → FR$_{II}$HEG. Concerning LEG, it is still not clear if CSS$_{LEG}$ would evolve directly to FR$_{II}$LEG or go through a FR$_{III}$LEG phase before the FR$_{II}$LEG.

As discussed in Paper I there should also exist a group of short-lived CSS objects with lower radio luminosities. These short-lived CSSs could probably show the low [O III] luminosities seen in FR Is.

The nature of the division for HEGs and LEGs among radio galaxies is still a debated issue and waiting for an answer. It seems that the radio and ionized gas luminosities of radio galaxies are determined by the properties of central engine: black hole spin (Garofalo et al. 2010), rate (Willott et al. 1999) or mode of accretion (Hardcastle et al. 2006; Buttiglione et al. 2010). In the last case the authors working on the large scale FR IIs and FR Is speculate that HEGs are powered by accretion of cold gas (provided probably by the merger with a gas rich galaxy), while LEGs accrete hot material. As we have just shown, the HEG/LEG division is present also among the young radio galaxies: CSS and GPS galaxies. We speculate that the differences in central engine of radio galaxy can occur at the beginning of the activity phase. However, as we discuss in Paper I, many of the low luminosity CSSs can be short-lived objects and undergo the CSS phase of evolution many times, as they are able to escape from the host galaxy and evolve further. The ignition of the activity can be caused by different mechanisms, major or minor mergers or instabilities in the accretion flow (Czerny et al. 2009). Depending on the ignition mechanism the radio galaxy can return as LEG or HEG. The comparison of the properties of LLC sources with different ionization models suggest also that jet-ISM interactions play an important role on producing HEG (through strong shocks in the ISM) or LEG excitation levels (weaker shocks). However, spectroscopic observations of larger sample of CSS and GPS sources and also studying their environmental properties are needed to give more certain conclusions.

5 SUMMARY

In this paper, we present and discuss the optical properties of Low Luminosity Compact sources, based on SDSS images and spectra. The sample and its radio properties are presented in Paper I. The comparison of the LLC sources with luminous CSSs and large radio sources has given a wider view of how LLC objects fit to the general radio source scenario.

Using the emission line ratios, we classified the LLC sources as HEGs and LEGs. For the same size and radio luminosity, HEGs are 10 times more luminous in [O III] than LEGs. This behaviour is also present in brighter CSS and large radio sources. Furthermore, LLC HEGs and LEGs fall above and below $L_{[OIII]} = 10^{41.1} \text{ erg/s}$, respectively. All sources with with broad line emission in their spectra are HEG. They are also the most luminous objects in our sample ($L_{[OIII]} > 10^{42} \text{ erg/s}$).

We have compared the [O III] luminosity with radio power linear size for the LLC sample, bright CSS and large radio sources. The correlation reported for bright GPS/CSS and large sources, between [O III] luminosity and radio size, disappears when LLC objects are included, mainly because to CSS LEGs. This effect could be to result of a previous sample selection effect. However, it is also possible that the radio jet could only enhance the [O III] emission in HEG, which show a stronger jet contribution to the ionization of the ISM than LEG.

The distribution of the LLC sample in the plots is consistent with the correlations found for CSS and large radio sources, although LLC sources have lower [O III] luminosities. However, when the samples are separated into HEGs and LEGs, they seem to follow different correlations. Furthermore, the HEG/LEG classification in the LLC, bright CSS and large-scale sources is independent of radio power and size. Concerning the radio morphology, CSS behave like FR II sources at all radio powers, suggesting that the differences in the mode of accretion (or black hole spin) between LEG and HEG sources is already visible in the CSS phase. According to BPT diagrams generated for LLC sources, HEGs have stronger shocks than LEGs, which can indicate differences in their environment.

Based on these results, we suggest that HEG and LEG follow different (and parallel) evolutionary tracks during the whole life of the radio source: GPS$_{LEG}$ → CSS$_{LEG}$ → FR$_{LEG}$ and GPS$_{HEG}$ → CSS$_{HEG}$ → FR$_{HEG}$. We could still be missing the precursors of the large FR I sources. However, short-lived CSS could probably show the low [O III] luminosities seen in FR I and give some clues as to their origin.

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REFERENCES

Abazajian et al., 2009, ApJS, 182, 543
Allen, M. G., Sparks, W. B., Koekemoer, A., et al., 2002, ApJS, 139, 411
Allen, M. G., Groves, B. A., Dopita, M. A., Sutherland, R. S., Kewley, L. J., 2008, ApJS, 178, 20.
Axon, D. J., Capetti, A., Fanti, R., Morganti, R., Robinson, A., Spencer, R., 2000, AJ, 120, 2284
Baldwin, J. A., Phillips, M. M., Terlevich, R., 1981, PASP, 93, 5
Brotz, M. S., Gregg, M. D., Becker, R. H., Laurent-Muehleisen, S. A., White, R. L., Stanford, S. A., 1999, ApJ, 514, L61
Buttiglione S., Capetti, A., Celotti, A., Axon, D. J., Chiaberge, M., Macchetto, F. D., Sparks, W. B., 2010, A&A, 509, 5
Buttiglione S., Capetti, A., Celotti, A., Axon, D. J., Chiaberge, M., Macchetto, F. D., Sparks, W. B., 2009b, A&A, 495, 1033
Buttiglione, S.; Capetti, A.; Dallacasa, D.; D'Odorico, V.; Giovannini, G., 2009a, AN, 330, 237
Cardelli, J. A., Clayton, G. C., Mathis, J. S., 1989, ApJ, 345, 245
Chambers, K. C.; Miley, G. K.; van Breugel, W. 1987, Nature, 329, 604
Chiaberge, M., Macchetto, F. D., Sparks, W. B., et al. 2002, ApJ, 571, 247
Czerny, B., Siemiginowska, A., Janiuk, A., Nikiel-Wroczyński, B., Stawarz, L., 2009, ApJ, 698, 840
Dopita, M. A., Fischera, J., Sutherland, R. S., Kewley, L. J., Leather, C., Tuffs, R. J., Popescu, C. C., van Breugel, W., Groves, B. A., 2006, ApJS, 167, 177.
Evans, D. A., Worrall, D. M., Hardcastle, M. J., Kraft, R. P., Birkinshaw, M., 2006, ApJ, 642, 96
Fanti, C., Fanti, R., Dallacasa, D., et al. 1995, A&A, 302, 317
Fanti, C., Pozzi, F., & Dallacasa, D., et al. 2001, A&A 369, 380
Garofalo, D., Evans, D. A. & Sambruna, R. M., 2010, arXiv:1004.1166
Giroletti, M., Giovannini, G., & Taylor, G. B. 2005, A&A 441, 89
Groves, B. A & Allen, M. G. 2010, arXiv:1002.3372
Groves, B. A., Dopita, M. A., Sutherland, R. S., 2004, ApJS, 153, 75
Hardcastle, M. J.; Evans, D. A.; Croston, J. H., 2007, MNRAS, 376, 1849
Hardcastle, M. J.; Evans, D. A.; Croston, J. H., 2006, MNRAS, 370, 1893
Holt, J., Tadhunter, C. N., & Morganti, R., 2009, MNRAS, 400, 589
Holt, J., Tadhunter, C. N., & Morganti, R., 2006, AN, 327, 147
Hutchings, J. B., Crampton, D., Johnson, A., 1995, AJ, 109, 73
Kaiser, C. R., & Best, P. N. 2007, MNRAS 381, 1548
Kewley, L. J., Dopita, M. A., Sutherland, R. S., Heisler, C. A., Trevena, J., 2001, ApJ, 556, 121
Kewley, L. J., Groves, B.; Kauffmann, G. Heckman, T. 2006, AJ, 372, 961
Kopylov A. I., Goss, V. M., Pariiskii, Yu. N., Soboleva, N. S., Zhielenkova, O. P., Tempirova, A. V., Vitkovski, V. V., Naugel’Naya, M. N., Verkhodanov, O. V., 1995, Arp, 39, 543.
Kunert-Bajraszewska, M., Gawroński, M. P., Labiano, A., Siemiginowska, A., 2010, MNRAS, in press (Paper I)
Kunert-Bajraszewska, M., Marecki, A., & Thomasson, P. 2006, A&A 450, 945
Labiano, A., 2008a, A&A, 488, 59
Labiano, A., O’Dea, C. P., Barthel, P. D., et al. 2008b, A&A, 477, 491
Labiano, A., Barthel, P.D., O’Dea, C.P., et al., 2007, A&A, 463, 97
Labiano, A., O’Dea, C.P., Gelderman, R., et al., 2005, A&A, 436, 493
Levesque, E. M., Kewley, L. J., Larson, K. L., 2010, AJ, 139, 712
Laing, R. A., Riley, J. M., & Longair, M. S. 1983, MNRAS 204, 151
Marecki, A., Kunert-Bajraszewska, M., & Spencer, R. E., 2006, A&A 449, 985
Marecki, A., Niezgoda, J., Wlodarczak, J., Kunert, M., Spencer, R. E., & Kus, A. J., 2003, PASA 20, 42
Massaro,F., Harris, D. E., Tremblay, G., Axon, D., Baum, S., Capetti, A., Chiaberge, M., Gilli, R., Giovannini, G., Grandi, P., Macchetto, F. D., O’Dea, C., Risaliti, G., Sparks,W., 2010, arXiv:1003.2438
McCarthy, P. J.; van Breugel, W.; Spinrad, H.; Djorgovski, S. 1987, ApJ, 321, L29
Morganti, R., Tadhunter, C. N., Dickson, R., Shaw, M. 1997, A&A, 326, 130
O’Dea, C. P., et al. 2001, AJ, 121, 1915
O’Dea, C. P., 1998, PASP, 110, 493
Rawlings, S., Saunders, R., Eales, S. A., Mackay, C. D. 1989, MNRAS, 240, 701
Readhead, A. C. S., Taylor, G. B., Xu, W., et al. 1996, ApJ, 460, 612
Spergel, D. N., Verde, L., Peiris, H. V., Komatsu, E., Nolta, M. R., Bennett, C. L., Halpern, M., Hinshaw, G., Jarosik, N., Kogut, A., Limon, M., Meyer, S. S., Page, L., Tucker, G. S., Weiland, J. L., Wollack, E., Wright, E. L., 2003, ApJS, 148, 175.
Tasse, C., Best, P. N., Rttgering, H., Le Borgne, D., 2008, A&A, 490, 893
Tengstrand, O., Guainazzi, M., Siemiginowska, A., Fonseca, Kunert-Bajraszewska & Labiano
A survey of Low Luminosity Compact sources

Bonilla, N., Labiano, A., Worrall, D. M., Grandi, P., Piccioni, E., 2009, A&A, 501, 89
Tremblay, G. R., O’Dea, C. P., Baum, S. A., Koekemoer, A. M., Sparks, W. B., de Bruyn, G., Schoenmakers, A. P., arXiv:1004.0388
de Vries, W. H., O’Dea, C. P., Baum, S. A., Barthel, P. D. 1999, ApJ, 526, 27.
de Vries, W. H., O’Dea, C. P., Baum, S. A., Sparks, W. B., Biretta, J., de Koff, S., Golombek, D., Lehner, M. D., Maccio, F., McCarthy, P., Miley, G. K., ApJS 110, 191.
de Vries, N., Snellen, I. A. G., Schilizzi, R. T., Mack, K.-H., Kaiser, C. R., 2009, A&A, 498, 641
Wilkinson, P. N., Polatidis, A. G., Readhead, A. C. S., Xu, W., Pearson, T. J., 1994, ApJ, 432, L87
Willott, C. J., Rawlings, S., Blundell, K. M., & Lacy, M. 1999, MNRAS, 309, 1017
Wright, E. L., 2006, PASP, 118, 1711.

APPENDIX A: COMBINED SAMPLE OF CSS SOURCES

The spectroscopic data are available for 14 CSS sources from the combined sample (Table A1). The HEG/LEG classification was possible for only 3 of them.

Notes on individual sources

0800+472. HEG*. The image shows a compact source (~16 kpc) with a possible eastern companion ~50 kpc. The spectrum shows a powerlaw continuum and broad [Mg II]λ2800 emission, consistent with a QSO. The radio map shows a compact source (~4 kpc), consistent with the QSO optical classification.

0809+404. HEG*. The image shows a compact source (~12 kpc) with a possible tail towards W, consistent with the faint component in the radio map (Fanti et al. 2001).

1141+466. The image shows an extended source (~20 kpc) with a bright nucleus and bright emission knots in a very crowded field.

1201+394. The image shows a compact source (~16 kpc), slightly elongated towards NW, consistent with the orientation of the radio structure (Fanti et al. 2001).

1241+411. HEG. The image shows an extended source (~40 kpc) with a bright nucleus.

1343+386. The optical data show a bright compact source (~20 kpc) with a clear powerlaw and bright broad emission lines, suggesting a QSO.

1445+410. The image shows an extended source with a bright nucleus. There is no clear evidence of the ~20 kpc radio structure (Fanti et al. 2001) in the optical image.

0801+4303. The optical data show a bright compact source (~30 kpc) with a clear powerlaw and bright broad emission lines, suggesting a QSO.

0853+291. The optical data show a bright compact source (~30 kpc) with a clear powerlaw and bright broad emission lines, suggesting a QSO.

1251+308. The optical data show a bright compact source (~30 kpc) with a clear powerlaw and bright broad [Mg II]λ2800 emission, suggesting a QSO. The radio map shows a small source with a very structured ~5 kpc long jet oriented SE-NW (Marecki et al. 2006).

1315+396. The optical data show a bright compact source (~30 kpc) with a clear powerlaw and bright broad emission lines, suggesting a QSO. The radio map shows a very small (~0.03 kpc) jet oriented EW (Kunert-Bajraszewska et al. 2004).

1502+291. The optical data show a bright compact source (~30 kpc) with a clear powerlaw and bright broad emission lines, suggesting a QSO.

1619+378. The image shows a compact faint source suggesting a possible QSO. The spectrum shows only one clear line, with broad wings. If it is [Mg II]λ2800, then the source is at redshift z = 1.2734. However, this line could be affected by a possible break in the continuum. It also shows no clear traces of the expected AGN powerlaw. The radio map (Marecki et al. 2006) shows a 0.5'' (~4 kpc at z=1.2734) jet oriented NE-SW, which does not show up in the optical image.

1632+391. The spectrum shows a clear powerlaw with bright broad emission lines, consistent with a QSO. The image shows a two component source, separated ~30 kpc. The W component is compact and bright while the E component is fainter and extended. The E component was classified as a compact blue cluster by Hutchings et al. (1995). The radio map (Marecki et al. 2006) shows a ~6 kpc jet oriented NE-SW at the coordinates of the compact source, which does not show up in the optical image.

Summing up, 9 sources (64%) are compact or unresolved, 5 sources (36%) show extended emission, and 1 source (7%) shows a possible merger or complex structure. Only 2 sources (14%) show radio-optical alignment.
Table A1. Emission lines measurements and spectroscopic classification of the combined sample of CSS sources - part I.

| Source Name | Class | $z$ | $E(B-V)$ | $[\text{Ly}\alpha]$ | $[\text{C IV}]$ | $[\text{He II}]$ | $[\text{C III}]$ | $[\text{Mg II}]$ | $[\text{O II}]$ | $[\text{Ne III}]$ |
|-------------|-------|-----|----------|----------------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|
| 0800+472 HEG* | 0.51 | 0.04 | – | – | – | 48 | 22 | 8 |
| 0809+404 HEG* | 0.55 | 0.05 | – | – | – | 16 | – | – |
| 1141+466 | – | 0.12 | 0.02 | – | – | – | – | 32 | – |
| 1201+394 | – | 0.45 | 0.03 | – | – | – | – | 2 | – |
| 1241+411 HEG | 0.25 | 0.02 | – | – | – | – | 18 | 4 | – |
| 1343+386 | – | 1.85 | 0.01 | – | 67 | – | 32 | 36 | – | – |
| 1445+410 | – | 0.2 | 0.02 | – | – | – | – | 3 | – |
| 0801+303 | – | 1.45 | 0.04 | – | – | 3 | 42 | 28 | 3 | – |
| 0853+291 | – | 1.09 | 0.03 | – | – | 28 | 18 | 18 | 4 | – |
| 1251+308 | – | 1.31 | 0.02 | – | – | – | – | 5 | – | – |
| 1315+396 | – | 1.56 | 0.01 | – | 48 | – | 38 | 26 | – | – |
| 1502+291 | – | 2.28† | 0.02 | 87 | 41 | – | 12 | 8 | – | – |
| 1619+378 | – | 1.27 | 0.01 | – | – | – | – | 4 | – | – |
| 1632+391 | – | 1.09 | 0.01 | – | – | – | – | 21 | 14 | 2 | – |
| Avg. Error | – | – | – | 8% | 7% | 30% | 12% | 19% | 8% | 8% |

Description of the columns: (1) source name; (2) spectroscopic classification, '*' means the classification is based on the $[\text{O II}]\lambda 3727,3729/[\text{O III}]\lambda 5007$ ratio only; (3) redshift, † - this is a new value from the SDSS; (4) galactic extinction; Rest of columns: flux for each line in $10^{-16} \text{erg s}^{-1} \text{cm}^{-2}$. Spectral information are taken from SDSS. Sources are taken from Fanti et al. (2001) sample (first part of the table) and from Marecki et al. (2003) sample. There is a small overlap of this two sample that is why the overlapping sources are included only in a first part of the table.

Table A1. Emission lines measurements and spectroscopic classification of the combined sample of CSS sources - part II

| Source Name | $H_\delta$ | $H_\gamma$ | $H_\beta$ | $[\text{O III}]$ | $[\text{O III}]$ | $[\text{O I}]$ | $[\text{N II}]$ | $\text{H}_{\alpha}$ | $[\text{N II}]$ | $[\text{S II}]$ | $[\text{S II}]$ |
|-------------|---|---|---|----------------|----------------|-----------|-------------|-----------------|-------------|-------------|-------------|
| 0800+472 | 2 | – | – | 28 | 85 | – | – | – | – | – | – |
| 0809+404 | – | 2 | 7 | 19 | 57 | – | – | – | – | – | – |
| 1141+466 | – | 4 | 4 | 1 | – | – | – | 14 | 22 | 41 | 15 | 9 |
| 1201+394 | – | – | – | – | – | – | – | 2 | – | – | – |
| 1241+411 | – | 5 | 19 | 55 | – | – | – | 37 | 32 | 53 | 15 | 7 |
| 1343+386 | – | – | – | – | – | – | – | – | – | – | – |
| 1445+410 | – | – | – | 3 | – | – | – | 18 | – | – | – |
| 0801+303 | – | – | – | – | – | – | – | – | – | – | – |
| 0853+291 | – | 6 | – | – | – | – | – | – | – | – | – |
| 1251+308 | – | – | – | – | – | – | – | – | – | – | – |
| 1315+396 | – | – | – | – | – | – | – | – | – | – | – |
| 1502+291 | – | – | – | – | – | – | – | – | – | – | – |
| 1619+378 | – | – | – | – | – | – | – | – | – | – | – |
| 1632+391 | – | – | – | – | – | – | – | – | – | – | – |
| Avg. Error | 31% | 44% | 19% | 15% | 7% | 13% | 24% | 16% | 11% | 12% | 17% |

Description of the columns: (1) source name; (2) spectroscopic classification, † means the classification is based on the $[\text{O II}]\lambda 3727,3729/[\text{O III}]\lambda 5007$ ratio only; (3) redshift, † - this is a new value from the SDSS; (4) galactic extinction; Rest of columns: flux for each line in $10^{-16} \text{erg s}^{-1} \text{cm}^{-2}$. Spectral information are taken from SDSS. Sources are taken from Fanti et al. (2001) sample (first part of the table) and from Marecki et al. (2003) sample. There is a small overlap of this two sample that is why the overlapping sources are included only in a first part of the table.