Spectroscopy of Blue Compact Galaxies *

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Blue Compact Galaxies (BCGs) are gas-rich systems undergoing very massive starburst events which involve the entire galaxy. We performed a spectroscopic study of 12 BCG in order to determine metallicities and helium content. Some objects show presence of broadened emission lines, probably due to internal motion of the interstellar medium, caused by intense stellar winds and supernova explosions.

Key words: galaxies: abundances – compact galaxies – ISM – starbursts – HII regions

AAA subject classification: 132, 152, 158

1. Introduction

Blue Compact Galaxies (BCGs) are gas-rich systems undergoing a very massive burst of star formation. Since their discovery in 1970 by Sargent and Searle, they were called *isolated extragalactic HII regions*, because their spectra resemble those of giant HII regions such as 30 Dor in the LMC. Today, the most widely accepted denomination is “HII galaxies”, because their appearance is completely dominated by the HII region at their center. In almost all cases the HII region is superimposed to an underlying dwarf galaxy, and this is the reason why we call them BCGs. Their appearance on Palomar photographic plates is quite always stellar-like as size, with a fuzzy structure and no dominant nucleus (see Fig. a) but there are remarkable exceptions (Fig. b).

It is generally believed that BCGs are very young objects, due to their high content of neutral hydrogen, with gas fraction $\sim 0.1 \div 0.5$ of the total mass, and very low metallicities (from $1/3$ to $1/70$ of the solar value). For this reason these galaxies are claimed to be the best laboratory for the study of primordial helium content (Y_p) via the determination of the oxygen content (see Campbell (1992) for a review). The knowledge of Y_p is crucial in verifying predictions of the standard big bang nucleosynthesis theory, in particular the baryon-to-photon ratio, and the lifetime of the neutron τ_n (Pagel et al. 1992). We performed high resolution spectral analysis of 12 BCGs, in order to determine their metallicities and helium content. In Section 2 we present the sample of galaxies under study, in Section 3 we describe the data reduction. Several objects of the sample present evidence of broadening of emission lines, and this will be discussed in details in Section 4. Finally, a summary of the results is presented in Section 5.

2. The sample

A substantial part of blue emission line objects found in objective prism surveys for quasar search (e.g. UM, Case, FBS, SBS, HES) and in surveys for galaxies with emission lines (Zw and Mrk) is formed by BCGs. The galaxies we studied are 12 metal-deficient objects chosen from a complete sample of emission line galaxies assembled from an objective prism survey carried out with the 1m ESO Schmidt telescope as a key project “Hamburg/ESO Survey for bright QSOs” (HES). With a magnitude limit $m_v \sim 18$, the HES provides a well-defined sample of low luminosity

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Fig. 1. (a) Contour map of *he1300-0833*; the other objects in the field are stars. (b) Countour map of *he1155-0953*; note the four brilliant knots of emission (see also Fig. 3[up]). Images are taken from the uncompressed Digitized Sky Survey through SkyView; square sides are roughly 3 arcmin.

galaxies with high-excitation spectra and strong emission lines in a sky region defined by $10^{\text{h}} \leq \alpha \leq 13^{\text{h}}03^{\text{m}}$ and $-15^{\circ} \leq \delta \leq -5^{\circ}$.

All objects whose low dispersion spectra on the objective prism plates showed strong emission lines and a weak continuum were classified using short exposure spectra taken with the 1.52-mESO telescope. This follow-up spectroscopic work allowed to define a complete sample of ~ 20 BCGs (other emission-line objects such as Seyfert galaxies, massive starburst galaxies or quasars being removed).

The subsequent spectroscopy we carried out in this work will allow us to give accurate abundances of O, N and S. The completion of this program can increase the number of galaxies with well measured He abundances, and provide crucial data for testing modern cosmological models for the standard Big Bang nucleosynthesis.

Campbell (1992), analyzing all available data of BCGs, found a large physical dispersion in the O/H-He/H relation used to infer the abundance of primordial helium (Y_{p}). She requested more high-quality data for BCGs in the range $7.0 \leq 12 + \log(\text{O}/\text{H}) \leq 8.0$. The metallicity of the sample spans from 1/5 to 1/20 solar, and this locates our BCGs in the gap cited by Campbell.

The most extensive survey until now is that of Campbell et al. (1984; 32 objects). There are also 12 objects studied by Kunth & Sargent (1983). Izotov and collaborators (1994; 1996) have studied 10 + 3 BCGs.

The object under study are those listed in Table 1.

Table 1. The sample of BCGs

Object	R.A. (B1950.0)	Dec	Date	Observing time	Slit width	P.A.
he1046-1513	10 ^h 47 ^m 00.0 ^s	-15° 13' 22"	24/04/95	60 ^m	2".5	90°
he1153-1609	11 53 00.6	-16 09 08	23/04/95	45 ^m	2".5	90°
he1155-0953	11 55 11.5	-09 53 45	25/04/95	45 ^m	2".5	90°
he1155-1311	11 55 50.8	-13 11 37	25/04/95	60 ^m	2".5	90°
he1203-2644	12 03 25.0	-26 44 11	25/04/95	30 ^m	2".5	90°
he1233-1047	12 33 04.1	-10 47 33	25/04/95	60 ^m	2".5	45°
he1247-1115	12 47 01.7	-11 15 19	23/04/95	45 ^m	2".5	90°
he1256-1458	12 56 54.7	-14 58 11	23/04/95	30 ^m	2".5	90°
he1300-0833	13 00 08.0	-08 33 48	23/04/95	45 ^m	2".5	90°
he1320-2724	13 20 59.6	-27 24 03	24/04/95	45 ^m	2".5	90°
he1328-2511	13 28 30.6	-25 11 55	23/04/95	45 ^m	2".5	90°

The observations were carried out at the 1.52m telescope at ESO, and we had three nights out of four of excellent weather with a mean seeing of 0.7 arcsec.

Fig. 2. Blue (a) and red (b) part of the spectrum of *he1320-2724*. Several emission lines, typical of HII region spectra, are shown.

3. Data reduction

Our spectra were bias corrected, flatfielded, wavelength calibrated with He–Ar lamps and flux calibrated with spectrophotometric standard stars. Then fluxes were corrected for atmospheric extinction and galactic extinction using $E(B - V) = A(B)/4$ and then $A(V) = 3.1E(B - V)$. Subsequently we obtained the internal extinction coefficient and the fluxes were finally corrected with this quantity.

In Fig. 2 the blue (a) and red (b) parts of the spectrum of *he1320-2724* are shown.

In some cases it is possible to outline the contribution of the underlying galaxy, as can be seen in Fig. [down], in which some absorption features of the Balmer series (most probably produced by young A stars) are clearly present in the spectrum of knot IV (Fig. 3a [up]).

Fig. 3. [up] $H\alpha$ contour map of *he1155-0953*. [down] Knot IV of *he1155-0953*: Balmer absorption features of the underlying galaxy.

We derived the electronic densities from the [SII] doublet, the temperatures from the ratio between the nebular and auroral lines of [OIII], and then the abundances of oxygen relative to hydrogen using the formulas derived by Pagel *et al.* (1992) from the models of Stašinska (1990).

For those spectra in which the [OIII] λ 4363 line was not detected, we calculated some models using the photoionization code CLOUDY (Ferland 1991), in the attempt to reproduce the observed spectrum and giving to the flux of the λ 4363 the value obtained measuring the noise at its position. For these objects calculations are in progress, but the first models seem to give densities slightly higher than those found in the other objects and metal abundances of the order of one tenth of the solar value.

In Table 2 we present derived metal abundances for the first group of objects, those with the [OIII] λ 4363 line clearly visible in their spectra. For comparison, purposes we remember that the solar value is $12 + \log(O/H) = 8.92$ (corresponding to $Z = 0.02$).

Table 2. Measured electron densities, [OIII] temperatures and metallicities.

Object	n_e (cm^{-3})	$T_e(\text{OIII})$ ($^{\circ}\text{K}$)	$12 + \log(\text{O}/\text{H})$	Z^a
he1153-1609	298	25000	7.58	$9.9\text{e-}4$
he1155-1311	114	15400	7.88	$2.0\text{e-}3$
he1233-1047(I)	315	10000	8.49	$8.1\text{e-}3$
he1247-1115	161	12000	8.15	$3.8\text{e-}3$
he1256-1458	106	9000	8.50	$8.3\text{e-}3$
he1320-2724	90	12500	8.23	$4.5\text{e-}3$
he1328-2511	25	13500	8.12	$3.5\text{e-}3$

$$^a \log Z = 1.42 + \log(\text{O}/\text{H})$$

4. The presence of broad lines

The spectra of some objects of the sample show evidence of a broadening of the emission features. In Fig. [left] is represented the $H\beta$ (broadened) profile (solid line), superimposed to the gaussian profile derived from $H\alpha$. The FWHM of the gaussian is roughly coincident with that of the instrumental profile, so the effect seems to be real. Analogous effects are reported by Izotov *et al.* (1996).

Fig. 4. [left] $H\beta$ broadened profile (solid line) superimposed to $H\alpha$ gaussian profile (dashed line) for *he1328-2511*; [right] Diagnostic diagram adapted from Baldwin *et al.* (1981). Some BCGs of our sample show anomalous emission line ratios.

BCGs are sites of enhanced star formation, in bursting episodes which last $\sim 10^7$ years. During these bursts, $10^2 - 10^5$ O stars can be formed (Kunth & Sargent 1983). Due to the presence of these massive and short-living stars, the dynamic of interstellar medium (ISM) of BCGs is strongly influenced by processes such as intense stellar winds and supernova explosions. These mechanisms would transfer mechanical energy in the ISM, giving rise to bubbles of hot material and, in some cases, to shocks.

In literature are reported about 40 BCGs with evidence of broad emission features characteristic of WR stars. But WR emission lines are not observed in galaxies with oxygen abundances equal to or lower than 1/10 solar, in

agreement with predictions of evolutionary models of massive stars (Maeder 1990); this can account for the lack of emission features such as $\text{HeII}\lambda 4686$ in our spectra.

Several shock models appeared in the last few years to explain anomalous line ratios observed in some LINERS and in Seyfert's NLRs (see, f.e., Taylor et al. 1992; Dopita & Sutherland 1995). Phenomena like shocks seem to be the natural explanation for the shape of observed emission line profiles and for the "temperature problem" which arises from the very high ratios of the forbidden oxygen lines relative to $\text{H}\beta$ (Morse et al. 1996). In addition $[\text{OII}]\lambda 4363/\text{H}\beta$ ratios up to 14 are observed in our galaxies. These ratios are too high to be explained by simple photoionization.

Diagnostic diagrams (from Baldwin et al. 1981), such as this in Fig. 4[right], give some insight that ionization mechanisms other than photoionization by thermal sources could be present inside some BCGs.

5. Short summary

Enhanced star formation is the principal explanation for BCGs properties. In fact, the spectra of our objects mostly resemble those of HII regions, with line ratios consistent with excitation by thermal sources. Metallicities are around 1/10 of the solar value. So these objects are good candidates for the determination of the primordial helium content.

Some objects show line ratios non completely compatible with those expected by "pure" HII regions: this fact, combined with the presence of broadened emission features make clear that mechanisms, such as shocks generated in the turbulent ISM of these small galaxies, should be partly responsible of the observed line ratios.

References

- Baldwin, J. A., Phillips, M. M., Terlevich, R. 1981, *Pub. Ast. Soc. Pac.* 93,5.
 Campbell, A. 1992, *Astrophys. J.* 401, 157.
 Campbell, A., Terlevich, R., Melnick, J. 1986, *Mon. Not. R. Astron. Soc.* 223, 811.
 Dopita, M. A. 1995, *Astrophys. J.* 455, 468.
 Ferland, G. J. 1991, *Hazy: a brief introduction to CLOUDY 80.6*, OSU Astronomy Department - Internal Report 91-01.
 Izotov, Y. I., Thunau, T. X., Lipovetski, V. A. 1994, *Astrophys. J.* 435, 647.
 Izotov, Y. I., Dyak, A. B., Chaffee, F. H., Foltz, C. B., Kniazev, A. Y., Lipovetski, V. A. 1996, *Astrophys. J.* 458, 524.
 Kunth, D., Sargent, W. L. W. 1983, *Astrophys. J.* 273, 81.
 Maeder, A. 1990, *Astron. Astrophys. Suppl. Ser.* 84, 139.
 Morse, J. A., Raymond, J. C., Wilson, A. S. 1996, *Pub. Ast. Soc. Pac.* 108, 426.
 Pagel, B. E. J., Simonson, E. A., Terlevich, R. J., Edmunds, M. G. 1992, *Mon. Not. R. Astron. Soc.* 255, 325.
 Sargent, W. L. W., Searle, L. 1978, *Astrophys. J.* 162, L155.
 Stašinska, G. 1990, *Astron. Astrophys. Suppl. Ser.* 83, 501.
 Taylor, D., Dyson, J. E., Axon, D. J. 1992, *Mon. Not. R. Astron. Soc.* 255, 351.

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