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The influence of local environment on the emergence of AGN activity in galaxies

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Abstract

We have carried out a spectroscopic study to determine the frequency and nature of the nuclear activity found in compact groups. With this aim we chose two samples, one selected from the Hickson Compact Groups Catalogue and another one from the Updated Zwicky Catalogue of Compact Groups. With the analysis of 1056 galaxies we found that more than 71% present some kind of emission, most of them, being low luminosity AGN ($L_{H\alpha} = 10^{39}$ erg s^{-1}). From these we only detect broad components in 16 which means a remarkable deficiency of broad line AGNs as compared to narrow line AGNs, despite the high frequency of active galaxies encountered in general in these groups.

1 Introduction

From the observational point of view it is recognized that gravitational interactions between galaxies play a fundamental role in the formation and evolution of galaxies, through mass assembly, morphological transformations, star formation or AGN activity. Within the frame of relation between galaxy interaction and nuclear starburst/AGN activity, the tidal torques produced during galaxy encounters are expected to result in an efficient mechanism to transport material to the very center. Theoretical simulations of interacting galaxies [4] suggest that, apart from a central burst of star formation, the inflow of gas towards the nucleus could have a positive feedback on a black hole, boosting AGN activity. However, it is still not clear the physical conditions of the host galaxies and the galaxy environments under which AGN may be favoured over star formation.

Compact Groups (GCs) of galaxies constitute ideal systems to analyze the influence of local environment on the morphological and dynamical evolution of galaxies. They consist of small physically bound aggregates of 3–8 galaxies with very high galaxy densities (comparable to rich clusters cores), with low velocity dispersions, that maximize the chance of non-disruptive galaxy encounters, and located in low galaxy density environments.

To explore the connection between AGN activity and environment in the nearby universe we have carried out a spectroscopic survey of two well defined samples of CGs: the Hickson Compact Groups [7] (HCGs) and the Updated Zwicky Catalogue of Compact Groups [5] (UZC-CGs). The main objective of our study is to determine the frequency and nature of the nuclear activity in the galaxy-members of the two compact group catalogues.

2 Sample data and nuclear classification

From the Hickson Catalogue we have selected a complete sample of 64 compact groups, with 280 member-galaxies, from the original concordant redshift catalogue (92 HCGs) by applying two additional constraints for completeness: a redshift z below 0.045 and having a surface mean brightness < 24.4 mag/arcsec^2.

For them we obtained new intermediate resolution optical spectroscopy for 200 members in the range from 3600 to 7000 Å using four telescopes: the 2.5 m NOT telescope in the Roque de los Muchachos Observatory (La Palma, Spain), the 2.2 m telescope in the Centro Astronómico Hipano-Alemán at Calar Alto Observatory (CAHA, Almería, Spain), the 2.12 m telescope in San Pedro Mártir Observatory (Baja California, Mexico) and the 1.5 m telescope at the Sierra Nevada Observatory (Granada, Spain). For all these new observed galaxies, we have subtracted from the spectra the underlying stellar contribution using observations of non-emission galaxy templates observed at the same time and the same setup. For 55 galaxies of the sample, we took the emission line fluxes obtained by [2, 3]. Spectra for 11 galaxies have been obtained from the ESO and 6dF Archives and for 4 galaxies more, we have collected the emission line ratios from the literature. A full description of this selected sample, the observations and data reduction can be found in [13, 12].

The UZC-CG catalogue consist of 291 compact groups, containing a total of 986 galaxies. It was obtained by [5] from the 3D galaxy UZC catalogue and applying an automatic neighbor search algorithm. We have searched for spectroscopic information for all the member galaxies of the whole UZC-CG catalogue in three database public archives: Z-Machine Archive, FAST Spectrograph Archive and the Sloan Digital Sky Survey – Data Release 7. Inspection of these three archives provide us spectra for a total of 900 member-galaxies. We collected 640 spectra from Z-Machine, 446 from SDSS-DR7 and 216 from FAST Spectrograph. From the comparison of spectra available for the same galaxy in more than one archive we found different detection rate of emission line galaxies in the 3 databases. SDSS and FAST spectra have similar efficiency in revealing emission lines while Z-Machine, with a lower spectroscopic sensitivity, loose about 20% of emission line galaxies. Thus when spectra were available, for the same galaxy, in more than one archive we choose SDSS-DR7 as first option, FAST as second and kept Z-Machine spectra only for galaxies without available spectrum in the two other archives.

To carry out our detailed analysis on the level and type of nuclear activity in this catalogue, we have selected what we named the UZC-CGs Complete Sample. It comprises the 234 UZC-CGs having spectra available for all its members (786 galaxies), 423 spectra come from SDSS-DR7, 226 from Z-Machine, 129 from FAST Archive and the remaining 8 from Archive Data and literature. It is a large sub-sample (80 %) of the whole UZC-CG catalogue of which it has the same fraction of emission line galaxies (74 %), and number of triplets (76 %). Moreover there is no difference neither in absolute magnitude distribution nor in morphology. Because the Z-Machine spectra have too low S/N ratios to measure broad components, we restrict our analysis to the 552 spectra found in the SDSS and FAST databases. Spectra from the SDSS survey were template subtracted using [6] eigenspectra and their PCA method. No correction was done for the galaxies in the FAST sample, due to the non availability of suitable spectra to use as templates.

To do the nuclear classification we have measured the emission lines fluxes of all the narrow emission lines galaxies using the task SPLOT in IRAF. Our classification method parallels the one used by [11]. Points located above the theoretical maximum sequence are classified as pure AGN. Points located below the empirical sequence which delimits star formation are classified as Star Forming Nucleus (SFN). TO galaxies fall between these two lines. In the case of pure AGNs, we also distinguish between Sy2 and LINERs using the classical upper limit $\log([\mathrm{OIII}]5007\text{Å}/\mathrm{H}\beta) < 0.4$ for LINER. Both CG samples are rich in galaxies having only [NII]6583Å and Hα. This phenomenon can be explained by the presence of a dominant intermediate age stellar population [2]. These galaxies were classified as SFNs when $\log([\mathrm{NII}]/\mathrm{H}\alpha) \leq -0.4$, as Low Luminosity AGNs (LLAGNs) when $\log([\mathrm{NII}]/\mathrm{H}\alpha) > -0.1$ and as TOs otherwise.

The identification of broad components was done by fitting a multi-component Gaussian on the emission lines. A χ^2 criterion, as described in [6], was applied to choose the fourth component parameters, establishing in this way its presence and characteristics.

The results of the nuclear classification for the emission line galaxies in our two samples are presented in Table 1. For each sample (column 1) we give the total number of emission line galaxies (column 2), the number of SFNs and TOs (columns 3 and 4), the number of Sy2, LINERs and LLAGNs (columns 5 to 7), which put together constitute the total NLAGN population in each sample. The number of BLAGNs is indicated in column 8, while columns 9 and 10 report the fraction of BLAGNs over NLAGNs and Sy1 over Sy2. We consider Sy1 all BLAGNs regardless they are type 1.8 or 1.9.

Table 1: Nuclear classification for the AGN galaxies

Sample	Emissions	SFN	TO	NLAGN			BLAGN	$\frac{\mathrm{BLAGN}}{\mathrm{NLAGN}}$	$\frac{\mathrm{Sy1}}{\mathrm{Sy2}}$
				Sy2	LINER	LLAGN		%	%
HCG	169	54	39	24	35	17	2	2.7	8.3
UZC-CG	420	143	58	81	46	78	14	6.8	17.3
HFS97	353	124	75	46	80	-	28	22	61
H05	42435	8700	7626	2424	650	-	1317	43	54
SRR06	57952	6061	-	1104	-	-	725	-	66

3 AGN population

The fraction of BLAGNs over NLAGNs in our two CG samples is extremely low: 2.7 % for the HCGs and 6.8 % for the UZC-CGs as well as the fraction of Sy1/Sy2: 8.3 % in the HCG and 17.3 % in the UZC-CG.

In Table 1 we also include the classification for other three comparison samples. [6] (H05) found in the nearby ($z < 0.33$) sample of SDSS, AGN galaxies covering four orders of luminosity and a BLAGN/NLAGN and Sy1/Sy2 ratio of 43 % and 54,% respectively. [16] also using SDSS spectra but without performing template subtraction found a higher Sy1/Sy2 ratio (66 %). Finally the fraction BLAGN/NLAGN in the [8] sample (HFS97) is 22 % and the ratio Sy1/Sy2 is 61 %. Assuming BLAGNs are slightly favored at higher luminosity (which is the normal expectation, based on the bulge size – black hole mass relation), the ratios encountered in the HFS97 sample are comparable to those found in H05. There is consequently a clear excess of NLAGNs compared to BLAGNs in CGs. This also appears as an extremely large difference in the number of Sy1 as compared to Sy2 galaxies. This excess is quite intriguing considering that there is no deficit of AGNs as a whole in CGs: 46 % AGNs in the HCG, 51 % in the UZC-CG compared to 44 % in the HFS97 sample.

Except for some galaxies in Virgo, all the galaxies in the HFS97 sample are located in low density environments (either loose groups or isolated). For comparison sake we have re-analyze the HFS97 sample using our classification criteria. The BLAGNs were classified as such by [9], based on the detection of a broad Hα component. To be consistent with our definition, all these galaxies were classified as Sy1. The remaining objects were classified using criteria explained in Sect. 2. Note that this only change slightly the results obtained by these authors.

4 Biases and detection limits

We can rule out any difference in observation, reduction or analysis method. In the UZC-CG sample we use 423 SDSS spectra that have been processed in the same way as the H05 sample since they derive from the same telescope, reduction and analysis methods. But BLAGN/NLAGN ratio in this UZC-CG sample is 4 % really much lower than the 43 % found for the H05 sample with the same data.

We also can exclude the difference in spectral resolution as the effect of our low BLAGN/NLAGN ratio. [9] used high resolution (2.5 Å) spectra but they have also perform tests with two others low resolution set-ups (5 Å and 10 Å, comparable to our own observations) obtaining similar results. The S/N continuum levels of the different surveys have been also studied. We found that they are all comparable.

We also checked if a higher galaxy contamination (the amount of galaxy light falling into the aperture) could explain a different BLAGN/NLAGN ratio, HFS97 with a median of 0.5 kpc and H05 with 7 kpc would found very different result which is not the case. This is the result of a very accurate template subtraction that accounts for the differences as explained in Sect 2. Regarding the BLAGN distribution in redshift we observed that nearby galaxies are not more likely BLAGNs than remote ones.

To test if our low number of Sy1 is due to a difference in morphologies, we have divided our two samples and the HFS97 one (when morphology is available) in three morphology bins: early-type galaxies (E-S0), early-type spirals (S0a-Sbc), and late-type spirals (Sc and later). For homogeneity, all the morphologies have been taken from the same source: the Hyperleda database. We have calculated the ratios of BLAGN/NLAGN and Sy1/Sy2 for each sample in each morphological bin. There are no BLAGNs in late-type spirals in any of the samples. In the HFS97 sample, the ratio BLAGN/NLAGN is marginally higher in the E-S0 bin, while the ratio Sy1/Sy2 is significantly higher, which indicates a definitive increase in BLAGNs in early-type galaxies (also as expected). In the two CG samples we can almost see an inverse trend: the ratios BLAGN/NLAGN and Sy1/Sy2 are both larger in the S0a-Sbc bin. It is well-known that there is a higher number of early-type galaxies in CGs than in other environments. Following the HFS97 trend, this should have produced more BLAGNs in CGs instead of less. This confirms that there is a clear excess of NLAGNs in CGs, regardless of the morphology.

We have also checked that there is no effect due to a lower sensitivity in our samples. Unfortunately Hα is only available in HFS97 sample where the median Hα luminosity of the NLAGNs is $\log(L_{\mathrm{H}\alpha}) = 38.72$. We obtain comparable values: 38.98 for the HCG and 38.80 for the UZC-CG. Lower sensitivity in our samples would have translated into higher values which is not the case.

The next step is to give a detection limit to each of our samples as explained in [9]. Different simulations were performed adding to each set-up spectra a grid of synthetic spectra with broad Gaussian components of various widths and amplitudes centered on Hα. We then applied our template and extraction analysis to deduce the following limits. For the CAHA and OSN spectra, broad components equivalent to 15 % or higher of the total blended flux in Hα+[NII] were recovered. Using medians of AGN blended flux and redshift this transforms into a detection limit in Hα broad luminosity of 3.5×10^{38} ergs s^{-1}. We find slightly higher fraction (20 %) for the NOT and SPM spectra, equivalent to a detection limit in luminosity of 4.0×10^{38} ergs s^{-1}. Only three BLAGNs in the HFS97 sample have a luminosity lower than these limits.

Based on the above analysis we can thus assure that the lack of BLAGNs encountered in our samples is not explained by any bias or differences with the comparison samples.

5 Discussion and conclusion

To ensure that those BLAGN do not have Broad Line Region (BLR) we would need spectropolarimetry observations. Since this data are not available we have tried to check this possibility in an indirect way. In [1] it is concluded through spectropolarimetry observations, that almost all AGNs without BLR, presented a bolometric to Eddington luminosity ratio lower than 0.043. If this is also applies to our AGNs, the BLR extinction hypothesis would become more reliable. We calculated the bolometric luminosity using the [OIII] luminosity ($L_{\mathrm{bol}} \sim 3500 L_{[\mathrm{OIII}]}$) and the Eddington luminosity using $L_{\mathrm{Edd}} = 1.26 \times 10^{38}\, M_{\mathrm{BH}}/\mathrm{M}_{\odot}$. We obtained form the Hyperleda database the necessary stellar velocity dispersions needed to derive the black hole masses. All HCG AGNs having the necessary information to calculate the bolometric and Eddington luminosity show a ratio lower than the [1] limit. In the case of UZC-CG AGNs, all but two are also below the limit indicating that most NLAGNs in our samples do not have BLR. Using the black hole mass we could also estimate the size of the BLR, if any, and the FWHM of the broad line component. If such broad component is above our detection limit and we do not detect it, it means that probably it does not exist. Using the expression for LLAGNs we obtain that NLAGNs in HCGs should have a broad component from 1114 to 2818 $\mathrm{km\,s^{-1}}$ and those of UZC-CG 1280 to 2704 $\mathrm{km\,s^{-1}}$. In both samples the range is above our limit detection. So, if they really exist we should have detected them.

According to recent results obtained by reverberation mapping, the size of the BLR in AGNs is also correlated to the optical luminosity at 5100 Å [10]. The luminosity at 5100 Å in our samples range from 40.7 to 43.1 in $\log(\lambda L_\lambda(5100\,\text{Å}))$ (in units of erg $\mathrm{s^{-1}}$); comparing with data of [15] our values lie in the lower luminosity part of their distribution, where very few broad line objects have been observed.

The fact that the average luminosity of the AGNs in CGs is low is another argument in favor of the dissolution hypothesis for the BLR. According to [14] low accretion rates rather than smaller mass black holes can explain the absence of BLRs in low luminosity AGNs which in fact is fully compatible with our observations.

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