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The environment of Sy1, Sy2 & bright IRAS galaxies: the AGN/starburst connection

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Abstract. We present a 3-dimensional study of the local ($\leq$ 100 h^{-1} kpc) environment of Sy1, Sy2 and Bright IRAS Galaxies. For this purpose we use three galaxy samples (Sy1, Sy2, BIRG) located at high galactic latitudes as well as three control sample of non-active galaxies having the same morphological, redshift and diameter size distributions as the corresponding Seyfert or BIRG sample. Using the CfA2 and SSRS galaxy catalogues as well as our own spectroscopic observations, we find that the fraction of BIRGs with a close neighbour is significantly higher than that of their control sample. We also find that Sy2 galaxies demonstrate the same behaviour with BIRG galaxies but not with Sy1s which do not show any excess of companions with respect to their control sample galaxies. An additional analysis of the relation between FIR colours and activity type of the BIRGs shows a significant difference between the colours of strongly-interacting and non-interacting starbursts and a resemblance between the colours of non-interacting starbursts and Sy2s. Our results support an evolutionary scenario leading from Starbursting to a Sy2 and finally to an un-obscured Sy1 galaxy, where close interactions play the role of the triggering mechanism.

Key words. Galaxy: AGN – Galaxy: Starbursts – Galaxy: Seyferts

1. Introduction

Despite the numerous studies conducted over the last decade investigating the relation among interacting galaxies, starbursting and nuclear activity (eg. Hernandez-Toledo et al. 2001; Ho 2005, González et al. 2008), the correlation between these physical processes remain uncertain. However, there is evidence that AGN galaxies host a post-starburst stellar population (eg. González Delgado 2001, Kaviraj 2008, Muller Sanchez 2008) while Kauffmann et al. (2003) showed that the fraction of post-starburst stars increases with AGN emission. Proving such a relation would simultaneously solve the problem of the AGN triggering mechanism. Interactions would be the main cause of such activities, being starbursting and/or the feeding of a central black hole. Indeed some studies seem to conclude that there is an evolutionary sequence from starburst to type 2 and then to type 1 AGN galaxies (e.g. Oliva et al. 1999, Storchi-Bergmann et al. 2001, Krongold et al. 2002, Chatzichristou 2002). In addition, Kim, Ho and Im (2005) using the [OII] emission line as a SFR indicator, reach the conclusion that type 2 are the precursors of type 1 quasars supporting the previous claims. Finally, a study by Ya-Wen Tang et al. (2008) tracing interactions by HI imaging, showed that 94% of their Seyfert sample exhibit HI disturbances in contrast with their inactive counterpart (15%). The above results raise doubts about the simplest version of the unification scheme of AGNs.

2. Observations & samples

The Bright IRAS sample consists of 87 objects with redshifts between 0.008 and 0.018 and was compiled from the BIRG survey by Soifer et al. (1989) for the northern hemisphere and by Sanders et al. (1995) for the southern. More details about the sample selection are given in Koulouridis et al. (2006b). We also use the control sample, compiled by Krongold et al. (2002) in such a way as to reproduce the main characteristics, other than the infrared emission, of the Bright IRAS sample.

The samples of the two type of Seyfert galaxies were compiled from the catalogue of Lipovetsky, Neizvestny & Neizvestnaya (1988). They consist of 72 Sy1 galaxies with redshifts between 0.007 and 0.036 and 69 Sy2 galaxies with redshifts between 0.004 and 0.020. The samples are volume limited as indicated from the V/V_{max} test and complete to a level of 92%. The sample selection details are described in Dultzin-Hacyan et al. 1999 (hereafter DH99) and Koulouridis et al. (2006a). We also use the two control samples, compiled by DH99 in such a way as to reproduce the main characteristics, other than the nuclear activity, of the AGN samples. The use of control samples is very important in order to be able to attribute the nuclear/starbursting activity to possible environmental effects and not to sample biases or possible host galaxy differences.

The redshift distribution of Seyfert galaxies peaks at a slightly higher redshift than that of BIRG galaxies imposing the Seyfert magnitudes to be relatively closer to the limit of the CfA2 and SSRS catalogues. Therefore we may be missing neighbours of a similar magnitude difference between them and the central BIRG or Seyfert galaxy. Note however that such a difference will not influence the comparison between the BIRG or Seyfert galaxies and their respective control sample galaxies (since both have the same redshift distribution).

In order to cover a larger magnitude difference between Seyferts/BIRGs and their neighbours than that imposed by the CFA2/SSRS magnitude limit ($m_B \sim 15.5$) we obtained our own spectroscopic observations of fainter neighbours around three subsamples consisting of 22 Sy1, 22 Sy2 and 24 BIRG galaxies (selected randomly from our samples). Around each galaxy we have obtained spectra of all galaxies within a projected radius of 100 h^{-1} kpc and a magnitude limit of $m_B \sim 18.5$.

Optical spectroscopy was carried out using the Faint Object Spectrograph and Camera (LFOSC) mounted on the 2.1m Guillermo Haro telescope in Cananea, operated by the National Institute of Astrophysics, Optics and Electronics (INAOE) of Mexico. A setup covering the spectral range 4200 – 9000Å with a dispersion of 8.2 Å/pix was adopted. The effective instrumental spectral resolution was about 15 Å. The data reduction was done using the IRAF packages.

3. Analysis and results

We identify the nearest neighbour of each Seyfert, Bright IRAS and control galaxy in our samples with the aim of estimating the fraction of galaxies that have a close neighbour. To define the neighbourhood search we use two parameters, the projected linear distance (D) and the radial velocity separation (δu) between the central galaxy and the neighbouring galaxies found in the CfA2 and SSRS catalogues or in our own spectroscopic observations. We search for neighbours with $\delta u \leq 600$ km/s, which is roughly the mean galaxy pairwise velocity of the CfA2 and SSRS galaxies or about twice the mean pairwise galaxy velocity when clusters of galaxies are excluded. We then define the fraction of active and non-active galaxies that have their nearest neighbour, within the selected δu separation, as a function of increasing D.

3.1. Neighbours analysis

In Fig. 1 we plot the fraction of Bright IRAS, Seyfert and control galaxies that have a close companion, as a function of the projected distance (D) of the first companion. We present results for $\delta u \leq 200$ km/s (left panel) and $\delta u \leq 600$ km/s (right panel).

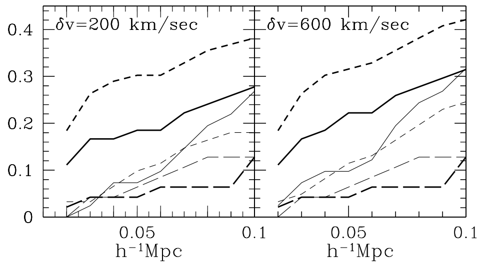

Fig. 1. Fraction of BIRGs (thick short dashed line), Sy2s (thick line), Sy1s (thick long dashed line) and their respective control sample galaxies (thin lines) which have their nearest neighbour within the indicated redshift separation, as a function of projected distance. Uncertainties are ~ ±0.05 in fraction.

It is evident that the Sy1 galaxies and their control sample show a consistent fraction of objects having a close neighbour (within the errors). On the other hand, there is a significantly higher fraction of Sy2 galaxies having a near neighbour, especially within $D \leq 75$ h^{-1} kpc, with respect to both their control sample and the Sy1 galaxies. This confirms previous results based on a two dimensional analysis (DH99). Adding the BIRG sample, which includes mostly starburst and Sy2 galaxies, we can clearly see that an even higher fraction of BIRGs tend to have a close companion within $D \lesssim 75$ h^{-1} kpc.

In order to investigate whether fainter neighbours, than those found in the relatively shallow CFA2 and SSRS catalogues, exist around our BIRGs, we have analysed our spectroscopic survey of all neighbours with $m_B \lesssim 18.5$ and $D \leq 75$ h^{-1} kpc for a subsample of 22 Sy1, 22 Sy2 and 24 BIRG galaxies. We find that the percentage of both Sy1 and Sy2 galaxies that have a close neighbour increases correspondingly by about 100% when we descent from $m_B \lesssim 15.5$ to $m_B \lesssim 18.5$, while the percentage of BIRGs rises only by ~45% reaching the equivalent Sy2 levels.

3.2. FIR colour analysis

In these section we investigate whether there is relation between the strength of the interaction of BIRGs with their closest neighbour and their FIR characteristics. The strength of any interaction could be parameterised as a function of the distance between the BIRG and its first neighbour. We divided the interactions in our sample into three categories based on the proximity of the first neighbour. We consider strong interactions when $D \leq 30$ h^{-1} kpc, weak interactions when $30 \leq D \leq 100$ h^{-1} kpc and no interaction when $D > 100$ h^{-1} kpc.

In Fig. 2 we present the colour - colour diagram of $\alpha(60, 25)$ versus $\alpha(25, 12)$, where $\alpha(\lambda_1, \lambda_2)$ is the spectral index defined as $\alpha(\lambda_1, \lambda_2) = log(S_{\lambda_1}/S_{\lambda_2})/(\lambda_2/\lambda_1)$ with S_{λ_1} the flux in Jy at wavelength λ_1. We can clearly see the differences between the FIR characteristics among different types of galaxies and different interaction strengths.

It is evident that the FIR characteristics of starburst galaxies in our BIRG sample differ significantly depending on the strength of the interaction. The majority of highly interacting starburst have $\alpha(60, 25)$ spectral indices greater than -2, while all, except one, non-interacting starbursts have less. We also find that normal galaxies and Liners are at the lower end of this sequence. However, Sy2 galaxies, interacting or not, seem to lay in the same area with non-interacting starburst galaxies, delineated by two dashed lines.

The FIR colour analysis of our sample strengthens our previous results. It clearly shows that the starburst activity is higher when interactions are stronger and ceases when the interacting neighbouring galaxy moves away. While the starburst activity weakens (if we

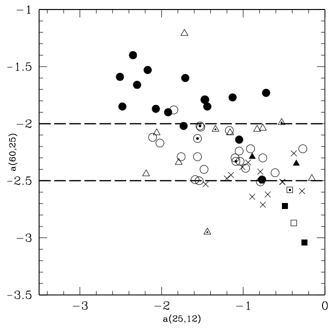

Fig. 2. FIR colour-colour diagram: $\alpha(60, 25)$ versus $\alpha(25, 12)$: Starbursts are represented by circles, Sy2s by triangles, Liners by squares and normal galaxies by crosses. Highly interacting galaxies are represented by filled shapes, weakly interacting by open dotted shapes and non-interacting by open shapes.

link position on the plot with time) Sy2 nuclei appear, giving further evidence on the causal bridging between these objects.

4. Discussion & conclusions

Our results can be accommodated in a simple evolutionary scenario, starting with an interaction, and ending in a Sy1. First, close interactions would drive molecular clouds towards the central area, creating a circum-nuclear starburst. Then, material could fall even further into the innermost regions of the galaxy, feeding the black hole, and giving birth to an AGN which at first cannot be observed due to obscuration. At this stage only a starburst would be observed. As starburst activity relaxes and obscuration decreases, a Sy2 nucleus would be revealed (still obscured by the molecular clouds from all viewing angles). As a final stage, a Sy1 would appear. In this case, the molecular clouds, initially in a spheroidal distribution, could flatten and form a “torus” (as in the unification scheme for Seyferts). As more material is accreted, it is possible that the AGN strengthens driving away most of the obscuring clouds, and leaving a “naked” Sy1 nucleus.

In order to better understand the role of interactions in driving starburst and nuclear activity, we are in the process of completing a study of AGN and starburst manifestations in the nearest neighbours of the active galaxies in our samples. Preliminary results show that more than 70% of the close companions of both type of Seyfert galaxies show some kind of activity. Most companions are HII galaxies and only a few are Seyferts. Furthermore, the fraction O[III]/Hb is significantly higher in all Sy2 companions indicating a higher ionisation. The correlation between high ionisation and galaxy interactions is relatively well established for HII galaxies (eg. Woods, Geller & Barton 2007), although Alonso et al. (2007) presents such a connection also for AGNs.

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