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The host galaxy/AGN connection in nearby galaxies.

A new view of the origin of the radio-quiet/radio-loud AGN dichotomy?

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Abstract. With the aim of exploring the classical issue of the AGN/host galaxy connection in the new framework offered by the recent developments in our understanding of the properties of nearby galaxies, we started a systematic study of a sample of early-type galaxies. By using archival HST and Chandra observations to i) study the optical brightness profiles and ii) isolate the nuclear emission in the optical and X-ray bands, we found a suggestive link between the properties of the active nucleus and of the host galaxy. Galaxies with a shallow cusp in their brightness profile (core galaxies) are associated to radio-loud nuclei, while radio-quiet AGN are only hosted by galaxies with steep cusps (power-law galaxies). It appears that the radio-loud/radio-quiet dichotomy is univocally related to the core/power-law dichotomy in the host's profiles. Since the brightness profile is determined by the galaxy's evolution, through its merger history, our results suggest that the same process sets the AGN flavour. This provides us with a novel tool to explore the co-evolution of galaxies and supermassive black holes, and it opens a new path to understand the origin of the radio-loud/radio-quiet AGN dichotomy.

Key words. galaxies: active, galaxies: bulges, galaxies: nuclei, galaxies: elliptical and lenticular, cD, galaxies: nuclei, galaxies: structure

1. Introduction

The recent developments in our understanding of the nuclear regions of nearby galaxies provide us with a new framework in which to explore the classical issue of the connection between host galaxies and AGN.

First of all, it is becoming increasingly clear that most (if not all) galaxies host a supermassive black hole (SMBH) in their centers (Kormendy & Richstone 1995). The tight relationships between the SMBH mass and the stellar velocity dispersion (Ferrarese & Merritt 2000; Gebhardt et al. 2000) indicate that they follow a common evolutionary path. As recently demonstrated by Heckman et al. (2004)

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the synchronous growth of SMBH and galaxies is at work even now, in the nearby Universe.

In the last decade a new picture of the properties of nearby galaxies also emerged. Nearly all galaxies have singular starlight distributions with surface brightness diverging as $\Sigma(r) \sim r^{-\gamma}$, with $\gamma > 0$ (Lauer et al. 1995) and the distribution of cusp slopes is bimodal (Gebhardt et al. 1996; Faber et al. 1997). In some cases, the projected profile breaks to a shallow inner cusp with $\gamma < 0.3$ and these form the class of "core galaxies". In other objects $\gamma > 0.5$ down to the HST resolution limit; these systems are classified as "power-law" galaxies. Only a small number of "intermediate" galaxies have been identified (Ravindranath et al. 2001) with $0.3 < \gamma < 0.5$,. The central structure correlates with other galaxy properties, showing that luminous early-type galaxies preferentially have cores, whereas most fainter spheroids have power-law profiles. Moreover, cores are slowly rotating and have boxy isophotes, while power laws rotate rapidly and are disky (Faber et al. 1997). This scheme fits nicely with the revision of the Hubble sequence proposed by Kormendy & Bender (1996).

But despite this fundamental breakthrough in our understanding of the SMBH/galaxy system, we still lack a clear picture of the relationship between AGN and host galaxies. For example, while radio-quiet AGN are preferentially found in spiral galaxies, early type galaxies host both radio-loud (RL) and radio-quiet (RQ) AGN. Similarly, RL AGN are generally associated with the most massive SMBH as there is a median shift between the RQ and RL distribution, but both distributions are broad and overlap considerably (Dunlop et al. 2003).

2. The AGN/host galaxy coevolution: results from Chandra and HST archival data

With the aim of exploring the classical issue of the AGN/host galaxy connection in the new framework offered by these recent developments, we started a systematic study of nearby early-type galaxies. Early type galaxies appear to be the critical group of objects, in which the two classes defined on the basis of their brightness profiles (core and power-law galaxies) coexist and hosting both radio-quiet and radio-loud AGN. Since a characteristic feature common to all AGN is the presence of radio emission we selected a sample for which radio observations, combining high resolution, high frequency and sensitivity were available, in order to optimally isolate the genuine AGN emission.

Wrobel (1991) presented 5 GHz VLA radio-images of a complete sample of nearby early-type galaxies with a flux limit of $\sim$ 1 mJy, reaching levels of radio luminosity as low as 10^{19} W Hz^{-1}. The sample was extracted from the CfA redshift survey (Huchra et al. 1983) with the following criteria: (1) B $\leq$ 14, (2) Hubble type T$\leq$-1, (3) $\delta \geq 0$, (4) recession velocity < 3000 km/s leading to a total of 216 galaxies. This sample yielded 67 radio detections, enabling us to construct an initial distance and radio-flux limited sample of AGN candidates.

We studied the link between the properties of these low luminosity AGN and the surface brightness profiles (SBP) of their hosts. In the HST archive we found images for 48 of the 67 radio detected galaxies. For 37 galaxies the SBP can be satisfactorily fitted with a Nuker law (Lauer et al. 1995): 20 are classified as core galaxies, 14 as power-law galaxies, 3 as intermediate.

We used Chandra archival data (available for 24 out of 37 objects) to isolate nuclear power-law X-ray components and HST data to detect and measure the optical cores. In Fig. 1 we compare the nuclear X-ray (in the 2-10 keV band) and optical luminosity with the radio core power (at 5 GHz). Power-law and core galaxies cover different regions of the L_X vs L_r plane, with no overlap between the two groups. Power-law galaxies show a deficit in L_r at a given X-ray luminosity (or an excess in the X-ray, at a given L_r) with respect to core galaxies by a factor of $\sim$ 100. The only "intermediate" galaxy lies in the power-laws region. The comparison between optical and radio luminosity shows a completely independent and constistent picture.

The origin of the nuclear emission in core galaxies can be understood by comparing these

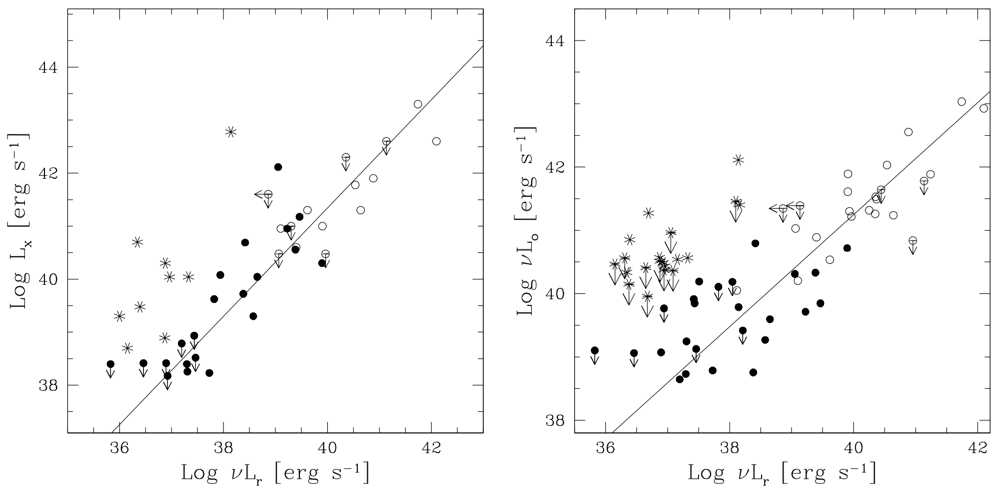

Fig. 1. Left panel: radio (at 5 GHz) vs X-ray (2-10 keV) nuclear luminosity for core galaxies (filled circles), power-law galaxies (stars) and for the low luminosity FR I radio-galaxies (empty circles). Core galaxies extend the behaviour of FR I and define a correlation (solid line) between L_X and L_R. Power-law galaxies show an excess of X-ray emission at a given radio luminosity by an average factor of ~ 100. Right panel: same as left panel but comparing optical and radio nuclear luminosities.

objects with low luminosity radio-galaxies (LLRG). Chiaberge et al. (1999) and Capetti et al. (2002) showed that in these sources the luminosity of the optical nuclear sources is strongly correlated with the radio-core luminosity, suggestive of a common non-thermal "jet" origin. The same result is found, with an even smaller dispersion (0.3 dex), by comparing the radio and X-ray luminosities (see Fig. 1). Core-galaxies extend the behaviour of LLRG to even lower luminosities supporting the interpretation that they represent the scale-down, low luminosity analogues of RL AGN. Indeed, their nuclei have large radio-loudness parameters with a median value of log R = 3.6. The same result is found estimating the radio-loudness parameter recently introduced by (Terashima & Wilson 2003) which takes into account the ratio between radio and X-ray luminosities, i.e. Log R_X = Log($\nu L_r/L_X$) ~ -0.5 / -1.5.

For the power-law (and intermediate) galaxies, we were able to isolate an X-ray nucleus (i.e. a power-law emission tail) in all objects and an optical core in most galaxies. They all have radio-loudness parameters similar to those measured in Seyfert galaxies and LINERs (Ho & Peng 2001) of comparable nuclear luminosities. Indeed, with only one exception, they all are spectroscopically classified in the literature as LINER or Seyfert galaxies. We then conclude that they are associated with genuine low luminosity active nuclei, representing the local manifestation of radio-quiet AGN.

3. Conclusions

The available data thus suggest that the brightness profiles dichotomy in early-type galaxies corresponds univocally to the dichotomy in the AGN flavour. Core galaxies are only associated with RL nuclei, while RQ nuclei are found only in power-law galaxies. If confirmed, it would open a new path to understand the origin of the radio-loud/radio-quiet AGN dichotomy and provide a further tool to explore the co-evolution of galaxies and the black holes they host at their centers.

A possible interpretation of this result relies on the different formation process of core and power-law galaxies. For example, it has been suggested that a core galaxy is the result of (at least) one major merger and that the core formation is related to the dynamical effects of the binary black holes (Milosavljević et al. 2002). Conversely, power-law galaxies partly preserve their original disky appearance, suggestive of a series of minor mergers (Faber et al. 1997). Thus, the SBP results from the formation history of the galaxy, via mergers. Apparently, the same process determines also the characteristic of the active nucleus. In the merger process, the SMBH associated to each galaxy rapidly sinks toward the center of the forming object. Thus, the resulting nuclear configuration after the merger (described by e.g. the total mass, mass ratio or separation of the SMBHs) is directly related to the evolution of the host. For example, among the different viable interpretations, Wilson & Colbert (1995) suggested that a radio-loud source can form only after the coalescence of two SMBH of similar (large) mass, forming a highly spinning nuclear object, from which the energy necessary to launch a relativistic jet can be extracted.

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