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GALAXY EVOLUTION AND THE AGN CONNECTION

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RESUMEN

Hemos estudiado el entorno circungaláctico de las galaxias Seyfert, las galaxias IRAS brillantes y los LINERs. Encontramos que tanto las galaxias IRAS brillantes como los objetos tipo 2, tienen un exceso de galaxias compañeras cercanas, con respecto a galaxias de tipo 1 y galaxias no activas. Nuestros resultados no apoyan el llamado "esquema unificado" y sugieren mas bien un esquema evolutivo.

ABSTRACT

We have studies the circumgalactic environment of Seyfert galaxies, bright IRAS galaxies and LINERs. We found that both bright IRAS galaxies and type 2 objects have an excess of companion galaxies with respect to type 1 and to ordinary field galaxies. Our results do not support the so called "unified scheme", and rather suggest an evolutionary scheme.

Key Words: **SUBJECT HEADINGS: GALAXIES:ACTIVE – GALAXIES:STARBURST – GALXIES: ENVIRONMENT – GALAXIES:STATISTICS**

1. INTRODUCTION

One of the most interesting issues in the study of Active Galactic Nuclei (AGN) is the supply of material to feed the black hole. A black hole in an AGN can consume between 1 and 100 $M_\odot$ per year. Where does all this material come from? It is taken to the nucleus from the outer parts of the galaxy by the action of a non-axisymetrical potential, this potential can be provided by an interaction with another galaxy. So the question naturally arises: Are AGN more frequently found in interaction than "normal" galaxies?. To answer this question we have studied the circumgalactic environment of AGN and bright IRAS galaxies.

2. SEYFERT GALAXIES

In the 1980s, it was found that a relatively large fraction of Seyfert galaxies (Dahari 1984, 1985) had close companions, although claims that this excess was due to selection effects were never dismissed (Fuentes-Williams & Stocke 1988). More recent work revealed significant differences between Seyfert 1 and Seyfert 2 galaxies (Laurikainen et al. 1994), or at leat marginal differences (De Robertis, Yee & Hayhoe 1998). In both cases, an excess of companions was found for Seyfert 2 (Sy2) but not for Seyfert 1 (Sy1) galaxies with respect to nonactive galaxies. However, Rafanelli, Violato & Baruffolo (1995) also found no significant difference between Sy1 and Sy2 galaxies. We were left in an uncomfortable situation: the three most recent and comprehensive works provided inconsistent results, probably because these data are in such a way that the inherent complexity (and definition ambiguity) of the problem was starting to affect statistical inferences. The discrepancy was accounted for in Laurikainen & Salo (1995) and Dultzin-Hacyan et al. (1999a). In Dultzin-Hacyan et al. (1999b) the authors for the first time used complete and correctly defined samples, as well as other important methodological improvements, that lead to the confirmation of the result that it is only Sy2 galaxies that have excess companions.

The samples of Seyfert galaxies were compiled from the catalog by Lipovetsky, Neizvestny & Neizvestnaya (1988). This catalog was compiled on the basis of the Second Byurakan Survey, which is a survey based solely on the UV excess method. The sample consists of 72 Sy1 and 60 Sy2 galaxies. Both samples are volume limited, and the $V/V_{\rm max}$ test assures uniformity –and thus completeness (Schmidt 1976)– to a level of 92%. The redshifts are limited to $0.007 \le z \le 0.035$ (Sy1) and to $0.007 \le z \le 0.020$ (Sy2), and galaxies were selected with high galactc latitudes in order to avoid extinction and to avoid confusion due to galactic stars. In past work, this had not been properly taken into account. Including low galactic latitude fields produces a bias toward a lower fraction of companions, since detection is more difficult because of confusion and absorption. In Dultzin-Hacyan et al. (1999b) galaxies were selected exclusively with $b \ge 40°$. Also, rich clusters were avoided.

For the control samples the above criteria were also imposed. One important methodological improvement is the definition of control samples of non-active galaxies that match the Seyfert galaxies in *all* respects except that they are not Seyfert galaxies.

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In order to achieve this, *two control samples were defined*, one for each type of Seyfert galaxy, because both the Hubble type and redshift distributions of the two types of galaxies differ. The control samples were obtained from a list of more than 10,000 objects from the CfA catalog (Huchra, Davis & Latham 1983). For each control sample the Hubble-type distributions were first matched by artificially trimming the samples, then the redshift distributions were matched. Absolute magnitudes were *not* matched since this would introduce a bias because the Seyfert galaxies host a very luminous nucleus, instead, diameters distribution were matched. The control samples are complete in volume to a confidence level up to 97%. Although the above mentioned similarities were long ago known to be required for a proper comparison (Osterbrock 1993), in previous works, matching the distributions was impossible to achieve while maintaining the same densities, owing to the selection of small control samples from nearby galaxies. The search for a possible excess of companions within 100 kpc is inconsistent with the choice of the control sample galaxies in the vicinity of the Seyfert galaxies (Rafanelli et al. 1995; Salvato & Rafanelli 1997).

The procedure for estimating the foreground/background galaxy contamination is as crucial in this type of statistical work as is the correct definition of control samples. The fraction of Seyfert galaxies with "physical" companions (proximate in space) is the fraction of companions obseved within the given search radius, diminished by the fraction of galaxies with an optical companion. The probability of finding an optical companion within a given search radius was derived from the Poisson distributions. The use of the Lick counts given by Shane and Wirtanen (1967) to estimate the projection effects can introduce an important bias (as in Rafanelli et al. 1995 and Salvato & Rafanelli 1997; see also Laurikainen et al. 1994). One of the main improvements in the work by Dultzin-Hacyan et al. (1999a,b) was the determination of the number density, ρ, that goes into the formula for the predicted number of background galaxies within each area. The determination was made directly from the Digitized Sky Survey (DSS) plates using the Faint Object Classification and Analysis System (FOCAS; Jarvis & Tyson 1981) to count galaxies in regions of 1 deg^2 surrounding each galaxy. The background densities between samples are statistically equal according to a Mann-Whitney's U-test.

In order to look for companions, more than 500 DSS plates were analyzed using FOCAS. The correct use of this automated detection package requires a fine tuning of several parameters which shall be discussed elsewhere. This procedure reduces to a minimum the *subjective* bias present in all previous works, which were done counting galaxies from the POSS prints "by eye". The search for companions was done in circular areas around each galaxy, with radii equal to three times the diameter of the galaxy. The final result obtained is a confirmation of the first result obtained by Petrosian (1982): *it is only Sy2 galaxies that have excess companions, but not Sy1 galaxies.* The excess factor for Sy2 with respect to their control sample is 1.8. Our result is relevant to a confidence level of 99.5% according to a chi-square-test. Other statistical tests were also applied.

The difference in environment of Sy1 and Sy2 pose a challenge to the so called "unified scheme" for Seyfert galaxies, according to which *all* Sy2s are obscured Sy1s and the difference is solely due to orientation. A "minimalist" interpretation would require us to see Sy2 galaxies as obscured Sy1 galaxies *due to interaction*: strong interaction with a comparably sized companion enhances overall star formation and drives molecular gas toward the center of the galaxy, which may in turn obscure the active nucleus' broad line region (BLR). If an "obscuring torus scenario" applies, and if sources are observed at random orientation, then almost all interacting Sy2 galaxies should be obscured Sy1 galaxies. This interpretation allows for an observational verification: spectropolarimetry of an interacting Sy2 galaxy should reveal a "hidden" BLR in the majority of cases. An alternative scheme was proposed be Dultzin-Hacyan (1995): radiation due to accretion onto a black hole decreases, while the relative contribution of a circumnuclear starburst radiation increases from Seyfert nuclei type 1 to type 2. Statistical studies of the multifrequency emission of Seyfert galaxies (Mas-Hesse et al. 1995; Dultzin-Hacyan & Ruano 1996) independently support this scheme. It is also strongly supported by direct observations showing that Sy2 galaxies have more circumnuclear star-forming regions than Sy1 galaxies do, both in the optical (González-Delgado & Pérez 1993) and in the IR (Maiolino & Rieke 1995; Maiolino et al. 1997). Both alternatives are actually complementary since it is the interaction that drives the needed obscuring and/or star-forming material to the nucleus. But an "orientation only" difference between Seyfert types is not sustainable.

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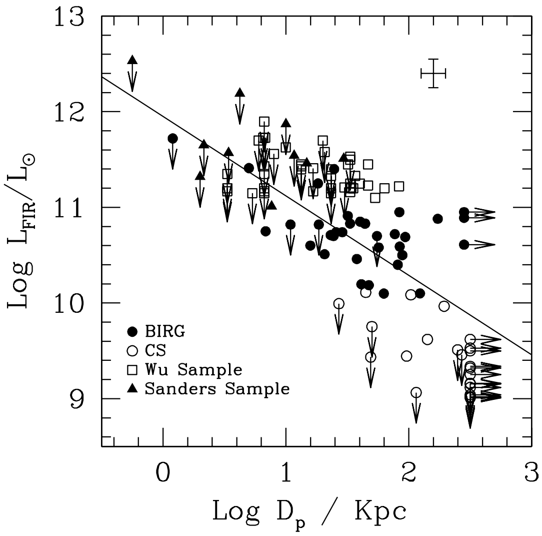

Fig. 1. Far Infrared Luminosity $L_{\rm FIR}$ vs. projected separation D_p from Wu, Zou & Deng (1988), Sanders, Surace & Ishida (1999) BIRG and CS galaxies with bright companion. 107 objects in total

3. BRIGHT IRAS GALAXIES

We have studied systematically for the first time (Krongold, Dultzin-Hacyan & Marziani 2002) the circumgalactic environment of bright IRAS (BIRAS) galaxies. The sample (87 objects) was compiled from the BIRAS Galaxy Survey by Soifer et al. (1989) for the Northern Hemisphere, and by Sanders et al. (1995) for the Southern one. The same methodology as described above for both sample and control sample was employed, except that the second generation DSS was used. From a search of nearby companions within 250 Kpc, we find that the circumgalactic environment of BIRAS is richer than that of galaxies of the optically selected control sample in terms of large companions and similar to that of Sy2 galaxies. We also found a correlation over a wide far IR luminosity range ($10^9 L_{\odot} \leq L_{\rm FIR} \leq 10^{12.5} L_{\odot}$), see Fig. 1. The correlation between projected separation and $L_{\rm FIR}$ confirms a very tight relationship between star formation rate and the strength of gravitational perturbations.

The timescale for the emergence of a type 1 active nucleus is $> 10^8$ (and even $> 10^9$ according to Hunt and Malkan 1999), a result supported by simulations. On the other hand, the time for a merger to evolve or for a bound companion to fly away is 10^8 yrs. The results obtained in this work give support to a scheme that several authors have considered (e.g. Hickson, Kindl & Auman (1989), and references therein; Sanders et al. (1988)). The scheme is an evolutionary sequence for AGN driven by interaction: $Interaction \longrightarrow Starburst \longrightarrow Seyfert2 \longrightarrow Seyfert1$. The same conclusion was reached by Hunt and Malkan (1999) from morphological considerations. This evolutionary sequence is supported by a number of evidences: Sy1 often occur in evolved mergers (Rafanelli et al. 1993), Sy2 with hidden BLR are similar to Sy1 in their IR properties, while Sy2 without a hidden BLR are similar to Starbursts (Gu, Dultzin- Hacyan, de Diego 2001). Finally, Oliva et al. (1995) found that both the L_H/M ratios and the $Br\gamma$ equivalent withs in Sy2 are consistent with the presence of starbursts which are older than those in HII galaxies. A large fraction of the near infrared ($< 2\ \mu$m) continuum in Sy1 also appears to be stellar but associated with even older starburst activity or normal red giants in the galaxy bulge. These results therefore provide additional support for evolutionary models in which Seyfert activity is related to the presence of a black hole which is formed/ fueled by the remnants of a pre-cursor starburst.

4. LINERS

We studied the environment of a sample of 193 Low Ionization Nuclear Emission Regions (LINERs), taken from the Multifrequency Catalog of LINERs (Carrillo et al. 1999). The LINERs are devided into three types: LINERs types 1 and 2 (L1 and L2 respectively), and transition liners (TL).

L1 have broad Balmer lines and are defined by the line ratios (Heckman 1980): [OII] > [OIII] and [OI] > 0.33 [OIII]. These types of objects can be explained as low luminosity AGN; they have compact radio, X-ray and UV sources and a power law spectrum. *We found no excess companions for this type of galaxies.*

L2 os "pure" LINERs also follow Heckman's definition, but do not have a BLR. Some are low luminosity AGN, but others are better explained by shocks and/or hot massive stars. *L2 have a similar excess of companions as Sy2 and BIRAS galaxies.*

TL follow only one of Heckman's criteria, and have properties intermediate between L2 and HII regions. They can be explained by shocks/and or hot massive stars. Only in one out of five do we find a compact radio source. *TL have similar excess of companions as L2, Sy2 and BIRAS*

We can propose for LINERs a similar evolutionary sequence as for Seyfert galaxies: $Interaction \longrightarrow TL \longrightarrow L_2 \longrightarrow L_1$.

5. CONCLUSIONS

Our study of the circumgalactic environment of Seyfert galaxies, BIRAS and LINERs, does not support the so called unified scheme for Seyfert galaxies, that claims that the only difference between types 1 and 2 is the viewing angle. Instead our study suggests an evolutionary scheme:

$$Interaction \longrightarrow Starburst \longrightarrow Sy2 \longrightarrow Sy1$$

$$Interaction \longrightarrow TL \longrightarrow L2 \longrightarrow L1$$

These evolutionary sequences can be regarded as the low AGN power extension of the proposed sequence $Interaction \longrightarrow ULIRG \longrightarrow QUASAR$.

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