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PROBING OPTICAL AND RADIO-LOUD AGN FRACTIONS : A COMPARATIVE ANALYSIS BETWEEN BCGs AND NON-BCGs SAMPLES at z < 0.1

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Abstract

Brightest cluster galaxies (BCGs) are the most massive and luminous galaxies located near the center of relaxed, virialized, and undisturbed galaxy clusters in the local Universe ([1, 2]. According to several observational studies ([3], [4]), these objects experience a special formation process differing from general galaxy evolution. Current theoretical models (e.g., [5, 6]) predict that dry mergers are the dominant mechanisms responsible for their mass assembly at $z < 1$. These objects are often observed to host a supermassive black hole (SMBH) in their center ([7]). The process of matter accretion into these SMBHs may release a large amount of energy, resulting in Active Galactic Nuclei (AGN). There are two primary modes in which SMBH accretion can occur: the so-called 'quasar mode' and the 'radio mode'. The quasar mode involves a high accretion rate of the SMBH via an optically-thick and geometrically-thin disk, with most of the energy being released in the form of radiation. In a radio mode scenario, the SMBH accretion of hotter gas occurs at a low rate in an optically-thin and geometrically-thick disk configuration, releasing energy in the form of relativistic particles, i.e. radio jets. The latter is typically observed in BCGs.

The evolutionary processes of BCGs are still not fully understood, and there are no specific studies comparing the frequency of different types of AGN in BCGs with respect to other types of galaxies (e.g., [8]).

The main scientific question driving the project of my thesis is to understand whether the different evolution of BCGs, along with their "special" environment, affects the accretion of SMBHs in their centers compared to other types of galaxies in the local universe, at $z < 0.1$. To address this question, I analyzed a sample of BCGs derived from the combination of the Sloan Digital Sky Survey Data Release 7 (SDSS DR7; described in [9]) and the C4 BCGs catalogue produced by [10]. For this BCG sample at z=0.02-0.1, I use the fluxes of optical lines ($H\alpha$, [OIII], $H\beta$, [NII], and [SII]

doublets) obtained by the MPA-JHU team using methods described in [11] to obtain a census of optical AGN through the NII and SII BPT diagnostic diagrams. Additionally, by cross-matching the previous catalogs with a collection derived from NVSS and FIRST radio surveys, as presented in [12], I identify the BCGs exhibiting radio loud emission, implying the presence of radio jets.

Following this classification, I finally estimate the fraction of BCGs classified as Optical and Radio Loud AGN. Subsequently, I derive the same fractions for the non-BCG selected galaxies according to the cross-match with the C4 catalogue ([10].

The analyses reveal that BCGs exhibit a higher fraction of optical AGN $\sim$ 50% compared to the non-BCG sample, which shows a percentage of $\sim$ 21%, consistent with results found by [13]. Simultaneously, the analysis of Radio Loud emissions indicates that BCGs are more inclined to host Radio Loud Activity, with a fraction of $\sim$ 12%. This fraction is found to be 20 times higher than the $\sim$ 0.6% observed in the non-BCG sample of selected galaxies.

In conclusion, these results strongly support the idea that BCGs are more likely to exhibit typical ionization due to AGN activity and radio emission. This implies that their privileged position supports frequent accretion of SMBHs in both accretion modes. Previous studies, such as [14–16], have already shown a prevalence of radio AGN among the BCG population in the local Universe. On the other hand, the larger fraction of BCGs selected as optical AGN compared to normal galaxies is intriguing. Future studies will aim to test the results obtained with this sample and understand if this higher fraction is specifically driven by differences in properties between BCGs and non-BCGs, such as mass, star formation rate, metallicity, and kinematics.

Contents

Chapter 1

Introduction

1.1 The Active Galactic Nuclei

Active galaxies constitute a distinctive class characterized by an intensely energetic source at their center, known as an Active Galactic Nucleus (AGN). Since the first observation of an active galaxy in the early 1900s, numerous studies have been conducted on this intriguing category of galaxies. To this day, efforts persist in unraveling the nature and role of active galaxies within the broader context of galactic formation and evolution.

Research in this field has demonstrated that the intense radiation must emanate from a compact region, with a spatial dimension not exceeding 100 parsecs. This estimation was derived from the temporal variability observed in some of these sources [17]. Additionally, it has been noted that AGNs exhibit luminosity variations of over 50% within timescales ranging from days to years. Such fluctuations can only be explained if a substantial portion of the emission region is randomly connected. These observations strongly imply that the central component of AGNs is likely a Supermassive Black Hole (SMBH), namely a rapidly accreting black hole.

AGN emissions span the entire electromagnetic spectrum, with variations in the different components depending on the classification of the observed nuclei. Despite these differences in emissions, a General Model known as the "Unified model" can still be defined, which applies to each classification of AGNs. [18]

In addition to the previously mentioned supermassive black hole (SMBH) at the center, there is an accreting disk located in close proximity, serving as a primary source of UV radiation. The central region, excluding the disk, is the main contributor to X-rays, while gas clouds orbiting near the BH give rise to Broad Emission Lines, forming what is known as the Broad Line Region (BLR). In the outer regions, situated both above and below the accreting disk, the primary contributor to Narrow Emission Lines, thus defining the Narrow Line Region (NLR), is the presence of diffuse gas. Additionally, surrounding the disk, there's a toroidal-shaped volume composed of a mixture of gas and dust, leading to the partial absorption of central radiation.

The final torus-shaped volume is indeed one of the main reasons for explaining the extreme variety observed in active galaxies and the different modes in which SMBH growth occurs. From a historical perspective, AGNs are divided into two main categories: Type 1 and Type 2, with the addition of Blazars. According to the 'Unified Model,' the main difference between these categories is merely apparent, arising from nothing more than variations in the observer's line of sight and the presence of the obscuring torus.

- **Type I:** The emission lines exhibit a broad component, typically in the range of $\sim 10^3$-$10^4, \text{km s}^{-1}$, along with a narrow component. In this configuration, the observer is situated at a small angle relative to the torus axis, allowing the radiation from circumnuclear regions to remain unobscured along the line of sight

- **Type II:** Emission lines exhibit only a narrow component, typically not exceeding $1200, \text{km s}^{-1}$. In this scenario, the line of sight intersects the obscuring matter of the torus.

- **Blazars:**

1.2 The Brightest Cluster Galaxies

The Hierarchical model stands as a cornerstone in our understanding of cosmic structure formation, delineating the principal pathways through which galaxies burgeon in both stellar luminosity and mass. At its core, this model elucidates how galaxies amass their content by drawing in and assimilating matter from their surroundings.

One of the most extreme examples in this context involves the study of Brightest Cluster Galaxies (BCGs), a unique class of galaxies, often situated at the center and typically standing out as the most luminous and massive objects within the entire cluster.(e.g. [19]).

Considering their environment, observational studies, such as [4], have indicated that the evolution of Brightest Cluster Galaxies (BCGs) differs from the normal galactic path. The prevailing model for cosmic structure formation (i.e. the Cold Dark Matter Model) suggests that the mass assembly of BCGs is primarily influenced by dry mergers [5, 6].

At low redshift, these objects exhibit a small dispersion in their aperture luminosities and, indeed, have been frequently chosen as standard candles for cosmological tests throughout the literature, also because of the shared properties with the cluster itself.

Mainly found to be Elliptical galaxies, BCGs seems to not be drawn from the same luminosity function as normal elliptic objects outside the cluster environment, and in general has been proven to differ also from generic Bright galaxies. (i.e. [20])

Due to their distinct evolutionary histories, the primary mechanism driving the mass growth of galaxies is associated with cooling flows within lower mass halos at high redshifts. However, at low redshifts, this phenomenon diminishes, primarily due to increased Active Galactic Nuclei (AGN) activity accreting mass into their typically hosted SMBH [7].

As presented before regarding AGN feedback, also BCGs are interested by both of the Quasi Stellar Object modes, resulting in both in the form of Optical AGN, and Radio Loud Emission such as Radio Jets(e.g. [16]).

These relativistic jets of radio emission is also recognized as one of the main explanation of the so called "Cooling flow problem". The unique relaxed and virialized environment defining the cluster often has cooling timescales much shorter than Hubble time, that following to the absence of a heating source would lead to the presence of a cooling flow.

However observational studies found that temperature of cluster cores fails to fall below $\sim 30\%$ at large radii resulting in an amount of cooling gas corresponding only to the $\sim 10\%$ expected from the existent cooling flow model. [21]

1.3 The Aim of this thesis

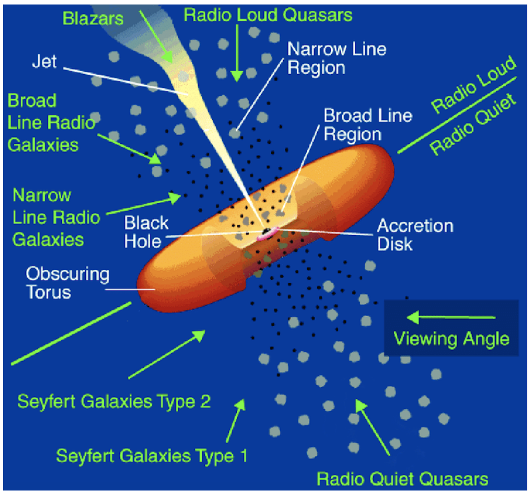

Figure 1.1: Fig 2 : Unified AGN model as proposed in [18]

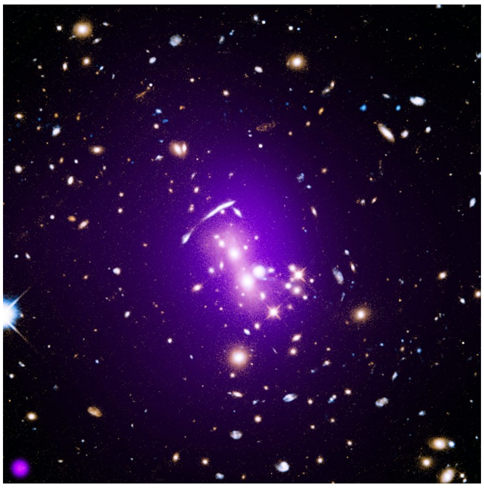

Figure 1.2: This image of galaxy cluster SPT-CLJ0310-464 X-rays from Chandra are shown along with optical data from Hubble

Chapter 2

Methods

2.1 Data Description

A description of the Data Samples Utilized, and its peculiarities, starting from The SDSS DR7 description, and following the work provided by the MPA-JHU team.

2.2 Data Analysis

How we analyzed the data, where do we defined the fractions calculated ?

2.2.1 Optical analysis

Describe each population of the BPT diagram and its peculiarities, before starting the description of how we collected and processed the data to finally create BPT diagrams . Finally there's the need to explain how we interpreted the diagrams to finally calculate the fractions (in this case you need to explain which algorithm has been chosen and why)

2.2.2 Radio Analysis

I certainly need to focus on how i have chosen the range of identification, to recognize which element of sdss was effectively recognized as a Radioloud.

Following to this it is necessary to explain how we selected the elements in which define the fractions, by selecting elements of SDSS nearby the location in which best et al finds mostly its radio-emitting elements!

Chapter 3

Results

A complete description of the results produced !!

3.1 The Prevalence of AGN activity in BCGs

Describe how the evidence of the data analysis we conducted leads to the description of BCGs in a confrontation to non-BCGs, and in how different is still from a pure optical view the response of the AGN feedback.

Present absolutely the Table with all of the percentage (and the counting) values of the populations of both BPT NII and BPT SII diagnostics and introduce a confrontation with also the results found in Vitale et AL and others.

3.2 The Radio activity of BCGs

Explain the evidences found in the analysis and possible ways to improve results obtained.

There's certainly also the need to add a discussion on how it is possible that we ignore some of the BCGs in the counting, issue that should be resolved by choosing a more complete source of data regarding Radio Emitters galaxies.

Conclusions

The final chapter of the thesis is a summary of the work done. Therefore, in its first part it resembles much the introduction, adding to it the actual result of the work, its future evolution and prospects, in the view of the writer.

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