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A Multiwavelength Study of Dual AGN in the Nearby Universe

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Abstract

Hierarchical galaxy formation theories consider mergers as the primary mechanism for the growth of galaxies. During the merging process, when both supermassive black holes (SMBHs) are actively accreting the surrounding material and are closer than 10 kpc, the system can be considered a dual active galactic nucleus (AGN). In the nearby Universe, the observed fraction of dual AGN among optically selected AGNs is low, likely due to the obscuration during different merger stages. In this contribution, we discuss how we can start to identify and characterize this still hidden population with a combination of multi-wavelength observations. Furthermore, we present results from our group at the Pontificia Universidad Católica de Chile leading a multi-wavelength program of nearby confirmed dual AGN (nuclear separation <10 kpc). Specifically, we focus on our ongoing work obtaining optical Integral Field Unit (IFU, NFM-MUSE) spectroscopy and ALMA maps for several dual AGN at z<0.1. These high-resolution multi-wavelength studies allow us to understand the complex connection between black hole growth and galaxy evolution in this critical stage uncovering the complexity of inflow and outflow kinematics and morphologies.

1 Introduction

According to hierarchical galaxy formation theories, galaxy interactions and mergers are the main mechanisms for the growth of galaxies. Therefore, they have a crucial role in galaxy evolution and formation (e.g., [1]). Theoretical models and computational simulations (e.g., [2, 3, 4, 5]) have shown that these interactions/mergers provide a very efficient mechanism to drive gas from the outskirts to the nuclear regions fueling star formation bursts and supermassive black hole (SMBH) growth, triggering the so-called "quasar" (luminous active galactic nucleus, AGN) phase.

A natural consequence of this scenario is that dual AGN (systems in which the two nuclear SMBHs are growing simultaneously at nuclear separations <10 kpc) should be relatively

common (e.g., [6, 7, 8]). However, despite extensive searches (e.g., [9, 10]), the dual AGN fraction remains poorly constrained due to a range of biases that require a multi-wavelength approach. This is due to enhanced obscuration (e.g.,[11]), which reach a clear maximum at late merger stages [12, 13]. Hard X-rays (>10 keV) from Swift-BAT offer a near-complete census of AGN even in heavily-obscured systems [14]. This has led to many spectacular dual AGN discoveries, including UGC4211 at 230 pc (0.3") separation [15], the closest ever resolved with multiwavelength information (only a single closer binary SMBH 0402+379 at 7 pc, has been discovered with VLBI [16] but cannot be spatially resolved by any other facility).

2 Sample

We have carried out a comprehensive approach to build a sample of dual AGN candidates with high-spatial-resolution multiwavelength data (see Fig. 1). For that, we have searched the entire HST and Keck AO NIR archives for available observations of the Swift-BAT hard X-ray selected AGN to select the best candidates during several ALMA and ESO calls. Through the creation of this sample, we propose conducting the first systematic study of AGN within mergers covering a broad range of separations and luminosities (and hence black hole accretion rates). Covering a range of separations is essential for rigorously testing theoretical models in terms of SMBH mass, AGN activity, host gas content, morphology, and merger mass ratios. Here, specifically, we focus on our work obtaining high spatial resolution optical Integral Field Unit (IFU, NFM-MUSE) spectroscopy and Atacama Large Millimeter Array (ALMA) maps for several dual AGN at z<0.1. These high-resolution multi-wavelength studies allow us to understand the complex connection between black hole growth and galaxy evolution in this critical stage uncovering the complexity of inflow and outflow kinematics and morphologies.

2.1 ALMA continuum observations

Millimeter and submillimeter emission is largely unaffected by obscuration. Therefore, it has the potential to unveil previously missed dual AGN in hidden mergers at very small, <1 kpc, nuclear separations. Taking advantage of this potential, we have obtained high-resolution ALMA band 3 continuum data (∼100 GHz, angular resolution ∼0.05 ") for a sample of visually-selected post mergers aimed to find hidden dual AGN.

2.2 MUSE observations

The Adaptative-Optive (AO) Narrow Field Mode (NFM) MUSE optical IFU observations cover a wavelength range from 4800 to 9300Å over a field of view of 7.5"x7.5" with a spatial sampling of 0.025". Thus, it also has the potential to identify and resolve dual AGN, at very small nuclear separations (<1 kpc), in nearby galaxies. In addition, we have WFM MUSE observations that allow us to characterise the entire merger systems and their local environment.

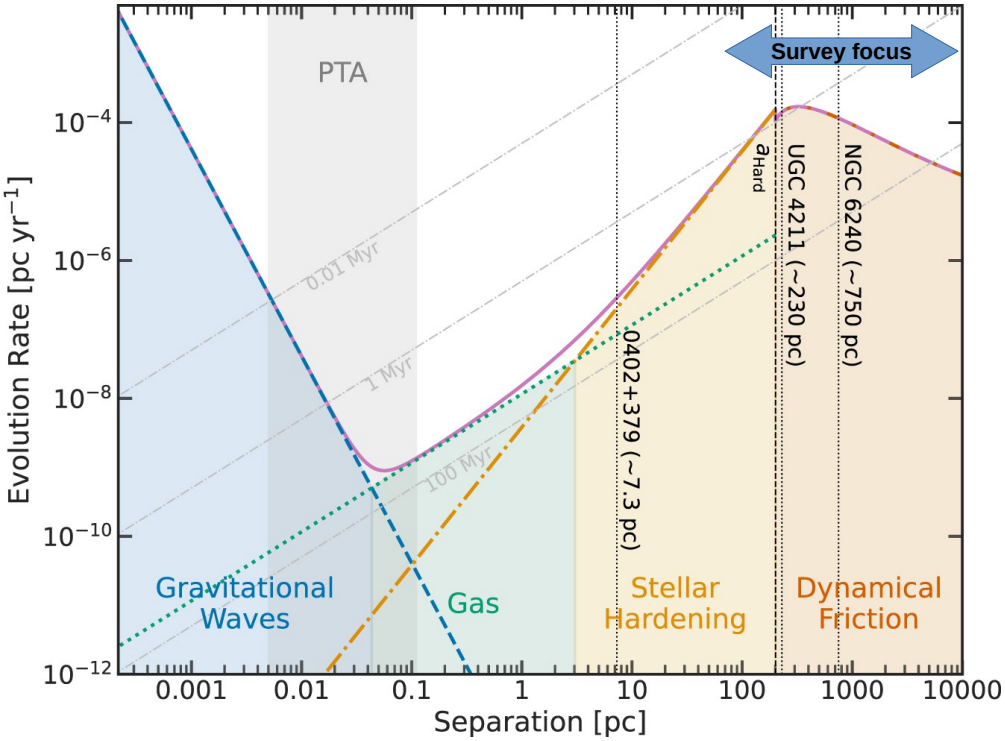

Figure 1: Adapted from [15]. Predicted evolution of the decay rate of a SMBH pair orbit as a function of the nuclear separation. The dynamical friction (orange region), stellar hardening (yellow region), gas dragging (green region), and gravitational wave emission (blue region) phases are individually presented. The blue double arrow show the on-going survey.

3 Current work and results

In this section, we focus in on-going projects, carried out with the presented dataset by our group at the Pontificia Universidad Católica de Chile.

- **Supermassive Black Hole Pairs at separations <1 kpc and their role in black hole growth:** Recently, a tight relation between the nuclear, <10 pc, mm (100-250 GHz) and hard X-ray (2-10 keV) emission in a large sample of hard X-ray selected AGN was found [17, 18]. By taking advantage of these observed correlations, well-established for isolated sources, we can first confirm or unveil the presence of dual AGN in a sample of local major galaxy mergers with archival ALMA observations. With these data, we can then measure their individual luminosities, and hence the associated SMBH accretion rates (Droguett et al in prep.).
- **Gas and Stellar Properties of the Nearby Merger LIRG II ZW 096 from High-resolution VLT/MUSE Optical IFU observations:** IIZW096 is a local luminous infrared galaxy undergoing a major merger, characterized by high infrared luminosity and complex structural interactions. This type of late-stage mergers enable to study feedback mechanisms and galaxy evolution processes. Additionally, questions about the number of systems involved in this merger and the nature of their interactions persist. We are carrying out an analysis using both WFM and NFM MUSE data to characterise the morphology, kinematics, and ionization states across the system (Riesco et al. in prep.).
- **Physical properties of Major Galaxy Mergers from Multiwavelength SED fitting:** Using multi-wavelength photometric data, we aim to construct the Spectral Energy Distribution (SED) from far-ultraviolet (FUV) to far-infrared (FIR) wavelengths for a sample of 70 nearby galaxies, all containing single or dual AGN (Tronocoso et al. in prep). This study aims to measure and characterize the physical properties as galaxies undergo merger process covering a large range of separations (0.3 to 29.6 kpc).
- **Dual AGN identification using NFM MUSE data:** Using our NFM data, we are carrying out a systematic work to: (1) test for the presence of AGN in both nuclei, measuring high-ionization emission line ratios in their vicinity (i.e., spatially-resolved BPT classification with [OIII]λ5007/Hβ vs [NII]/Hα); (2) study the spatially resolved kinematics of the stars and ionized gas to constrain nuclear dynamics and search for signs of nuclear outflows; (3) using nuclear velocity dispersion measurements and the MBH - σ relation, estimate the mass of each SMBH, a key parameter for both SMBH-galaxy co-evolution.

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