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The growth of a central black hole in dwarf spheroidal galaxies

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Abstract. Currently, it can be said that almost all large spiral and elliptical galaxies host supermassive black holes (M_{BH} ~ 10^9 $M_\odot$) in their centers, observational evidences are accumulating of dwarf galaxies with central black holes, though with lower masses (M_{BH} ~ $10^{(4-5)}$ $M_\odot$) - the so-called intermediate massive black holes (IMBH). One promising scenario to the formation of the supermassive black holes (SMBH) takes into account the growth, by merge or accretion, of these IBMHs in a small timescale (up to ~ 1 Gyr), but there isn't a consensus of how these objects grow and evolve. A particular suitable site to search for and investigate the growth of IMBHs are dwarf galaxies. By means of a non-cosmological, three-dimensional hydrodynamic code fitted to a classical dwarf spheroidal galaxy, the evolution and growth, by matter accretion, of a central black hole from a seed with a mass of ~ 600 $M_\odot$) up to the current day estimated masses (between 10^4 $M_\odot$ and 10^6 $M_\odot$) will be investigated. The effects of the black hole outflow in the interstellar medium of the galaxy will also be analyzed, including the occurrence or not of the AGN (Active Galactic Nuclei) phenomena in this type of galaxy, and the eventual gas loss.

Resumo. Da mesma maneira que quase todas as grandes galáxias espirais e elípticas hospedam buracos negros supermassivos (M_{BH} ~ 10^9 $M_\odot$) em seus centros, já estão sendo discutidas evidências observacionais de galáxias anãs com buracos negros centrais já estão sendo discutidas, embora com massas mais baixas (M_{BH} ~ $10^{(4-5)}$ $M_\odot$) – os chamados buracos negros de massa intermediária IMBH (Intermediate-mass Black Hole). Um cenário promissor para a formação dos buracos negros supermassivos SMBH (Supermassive Black Hole) leva em consideração o crescimento, por fusão ou acreção, desses IBMHs em uma pequena escala de tempo (até ~ 1 Gano), embora não haja um consenso de como esses objetos crescem e evoluem. Um local adequado para se investigar o crescimento de IMBHs são as galáxias anãs. Por meio de um código hidrodinâmico tridimensional não cosmológico ajustado a uma galáxia esferoidal anã clássica, serão investigados a evolução e o crescimento, por acreção de matéria, de um buraco negro central a partir de uma semente com massa de ~ 600 $M_\odot$) até massas atualmente estimadas (entre 10^4 $M_\odot$ e 10^6 $M_\odot$) serão investigados. Também serão analisados os efeitos do outflow do buraco negro no meio interestelar da galáxia, incluindo a ocorrência ou não dos fenômenos de AGN (Active Galactic Nuclei) neste tipo de galáxia, e a eventual perda de gás.

Keywords. Galaxies: active, dwarf, evolution, formation, black hole.

1. Introduction

It is a consensus that practically all large spiral and elliptical galaxies host in their centers a SMBH that, when active, gives rise to very powerful jets that can remove a large fraction of the interstellar gas of the galaxy (Rees 1984). There isn't however a definitive scenario for the formation and evolution of the SMBHs, but one of the possible paths invoke the existence of intermediate massive black holes (IMBH) with masses in the range (M_{BH} ~ $10^{(4-5)}$ $M_\odot$). The IMBHs would grow through accretion of matter or merger in a timescale of less than ~ 1 Gyr: quasars observed at very high redshifts (z>5.7) reveal the existence of black hole with masses larger than ~ 10^4 $M_\odot$ (Greene 2012, Bañados et al. 2021).

Direct observations of such IMBHs are, however, very difficult and only indirect evidence is available. A possible site that might host IMBHs are dwarf galaxies with AGN phenomena (Greene 2012, Manzano-King & Canalizo 2020). Studies based on the observed relation between the bulge mass and the black hole mass indicate that galaxies with masses in the range of the dwarfs should host black holes with masses around $10^{(4-6)}$ $M_\odot$ (Greene 2012). Moran et al. (2014) identified in local dwarf galaxies with low luminosities 28 AGNs, whose activity would be related to the presence of an IMBH with a mass in the range ($M_{BH} \leq 10^6$ $M_\odot$). Adopting a different approach, Manni et al. (2015) analyzed X-ray sources in the direction of the dSphs Draco, Leo I, Ursa Major II and Ursa Minor and found, in this last one, a central source connected to a compact object with a luminosity with a superior limit around 4.02×10^{33} ergs^{-1}. The correlation with a radio source near the galactic center suggested a black hole with a mass 2.56×10^6 $M_\odot$. By means of a N-body simulations, an inferior mass (2-4$\times 10^4$ $M_\odot$) was estimated by Lora et al. (2009) for the possible black hole in Ursa Minor, that would be located off-center.

An internal feedback, yet almost unexplored in dwarf galaxies, is the *outflow* from a central IMBH in the center of the galaxy. Through an analytical approach, Dashyan et al. (2017) argued that there is a critical halo mass for dwarf galaxies below which the feedback from a central black hole can remove gas from the galaxy and be more important than the stellar feedback. They suggested that AGN feedback can be an important driver of gas loss, more efficient than SNe. Results from 3D hydrodynamic simulations lead Lanfranchi et al. (2021) to opposite conclusions. They studied the effects of the *outflow* from an IMBH in the center of a classical dSph, using Ursa Minor as a template and argued that a minimal initial speed and a minimal initial density are required for the *outflow* to propagate, with the values depending on the conditions of the medium. In these simulations, however, the growth of the black hole is not taken into account and the density and the velocity of the *outflow* are constant during the whole period of its activity.

2. Main Goals

The aim of the project is to investigate the evolution and growth of a central black hole in a classical dwarf spheroidal galaxy by means of a non-cosmological, three-dimensional hydrodynamic code already fitted to the classical dwarf spheroidal galaxy Ursa Minor (Caproni et al. 2015, 2017, Lanfranchi et al. 2021). The analysis will start from a black hole (BH) seed with a mass of $\sim 600\ M_{\odot}$ that will accrete mass until it reaches the current day estimated value (between 10^4 and $10^6\ M_{\odot}$). The effetcs of the black hole outflow in the interstellar medium of the galaxy will also be analyzed, including the occurrence or not of the AGN phenomena in this type of galaxy, and its contribution to the gas loss.

3. Methodology

The growth of an intermediate massive black hole and the existence or not of the AGN phenomena in a classical dSph will be investigated numerically following the canonical set of equations given in Shapiro (2005) and Jolley & Kuncic (2008), and many others, and by means of 3D hydrodynamic simulations of the gas content of a typical classical dSph using Ursa Minor as a template.

The growth of the IMBH starts from an initial seed, with a mass of $\sim 600\ M_{\odot}$, as suggested by cosmological simulations (Madau & Rees 2001). The accretion of mass by the seed will then be considered during the whole phase of star formation, following the equations described in Shapiro (2005) and Jolley & Kuncic (2008). During the accretion process, the fraction of mass accreted in time, $\dot{M}$, transformed into energy L_{rad} with a radiative efficiency η_{rad}, and can be determined by the expression:

$$L_{rad} = \eta_{rad} \dot{M}_0 c^2$$

3.1. Observational Comparison Values

A survey by Birchall et al. (2020) to quantify AGN's in local dwarf galaxies used samples that observed dwarf galaxies in the X-ray luminosity range of 2.43×10^{36} erg s^{-1} and 5.35×10^{42} erg s^{-1}.

4. Results

The parameters numerically analyzed through the equations that refer to the *outflow*, have a direct connection with the mass and the growth of the black hole. One way to investigate the growth of the central IMBH in a dwarf spheroidal galaxy can be carried out through an inverse process, that is, to determine observationally consistent values for *outflow* parameters and to verify, from these, the potential for the growth of the black hole by radiation.

5. Perspectives - The Hydrodynamic Code

- Analyze the growth of the black hole from the parameters obtained.
- The 3D hydrodynamic simulations of the gas of a typical isolated dSph galaxy will be performed with the code PLUTO, with the following prescriptions.
- We assume an initial baryonic-to-dark-matter ratio inferred from the cosmic microwave background radiation and a cored and static dark matter gravitational potential.
- The galactic gas distribution is evolved for 3 Gyr taking into account the outflow of a central IMBH and SNe feedback.
- The initial setup of the simulation is exactly the same as one adopted for Ursa Minor dSph (used as a template for a classical dSph galaxy), described in detail in Caproni et al. (2015, 2017) and Lanfranchi et al. (2021).

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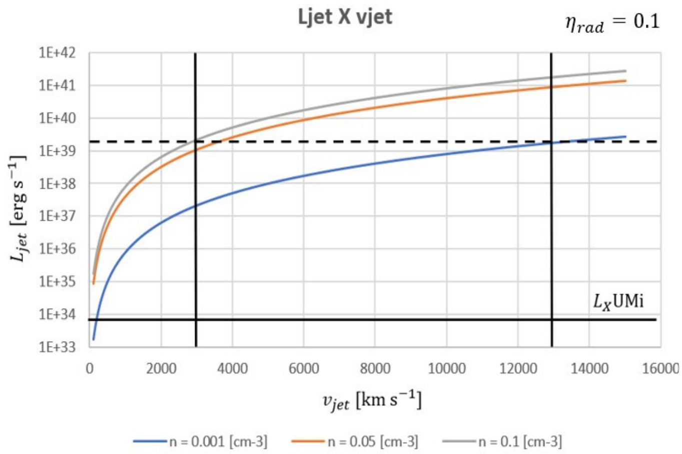

Figure 1. Representation of the theoretical curves of the *outflow* luminosity in relation to the initial velocity variation with the fixed densities represented in different colors in the graph. The solid horizontal line shows the luminosity value in X-ray for UMi and the dashed line shows the upper limit of luminosity, also in X-ray.

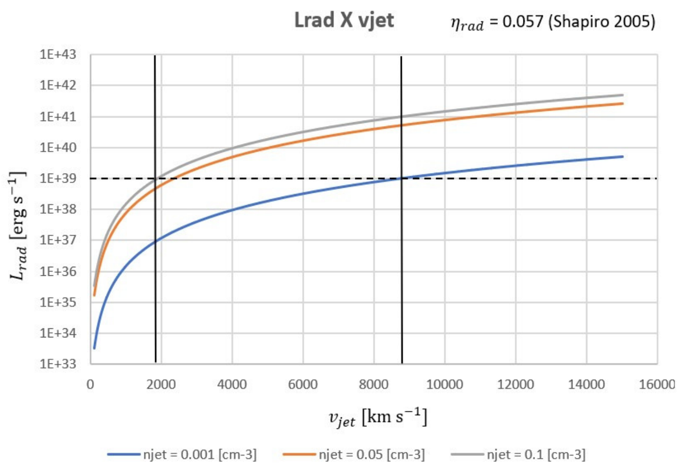

Figure 2. Representation of the theoretical curves of luminosity in relation to the speed variation fixed to radiative efficiency. The colors of the curves represent the different densities adopted during the accretion phase.

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