Boletim da Sociedade Astronômica Brasileira, **31**, no. 1, 137-138

Relation between the outflow of a central black hole and the interstellar medium of dwarf spheroidal galaxies

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Abstract. Dwarf Spheroidal Galaxies (dSph) are structurally simple systems, but with a complex evolution not yet fully understood. A striking feature of these objects is the complete absence of neutral gas. Different physical mechanisms, both internal (stellar feedback) and external (ram pressure, tidal stripping), have already been proposed as being responsible for the removal of the gaseous content of dSph. A physical process, however, not yet explored in the dSph galaxies is the outflow due to an intermediate-mass black hole (IMBH) in the center of these galaxies. Recent observational evidence indicates the presence of black holes of intermediate masses (M $\sim 10^4 - 10^6 M_\odot$) at or near their center. In this work, using a 3D hydrodynamic simulation code adjusted for a typical Dwarf Spheroidal Galaxy, the interplay between the outflow of the IMBH and the interstellar medium of the galaxy in its central region (up to 300 pc) was studied, both in an homogeneous medium and in one disturbed by supernova explosions. By adopting a ratio of baryonic matter-dark matter derived from cosmic background radiation and a static and cored dark matter potential, the gas distribution in the central region of the galaxy is allowed to evolve over 300 Myr taking into account the outflow of the black hole.

Resumo. As galáxias anãs esferoidais (dSph) são sistemas estruturalmente simples, mas com uma evolução complexa ainda não totalmente compreendida. Uma característica marcante desses objetos é a completa ausência de gás neutro. Diferentes mecanismos físicos, internos (*feedback* estelar) e externos (pressão de arrasto, força de maré), já foram propostos como responsáveis pela remoção do conteúdo gasoso das dSph. Um processo físico, no entanto, ainda não explorado nas galáxias dSph é o *outflow* devido a um buraco negro de massa intermediária (IMBH) no centro dessas galáxias. Evidências observacionais recentes indicam a presença de buracos negros de massas intermediárias (M $\sim 10^4 - 10^6 M_\odot$) no ou próximo ao centro de dSphs. Neste trabalho, usando um código tridimensional de simulação hidrodinâmica ajustado para uma típica esférica anã esferoidal, estudou-se a interação entre o *outflow* do IMBH e o meio interestelar da galáxia em sua região central (até 300 pc), tanto em um meio homogêneo quanto em um perturbado por explosões de supernovas. Ao adotar uma proporção de matéria bariônica — matéria escura derivada da radiação cósmica de fundo e um potencial de matéria escura estático e nucleado, a distribuição de gás na região central da galáxia foi evoluída por mais de 300 milhões de anos levando em conta o *outflow* do buraco negro.

Keywords. Galaxies: dwarf – Galaxies: evolution – Hydrodynamics

1. Introduction

The Dwarf Spheroidal Galaxies of the Local Group (LG) are relatively simple objects, but with complex evolution, characterized by different star formation histories, different stellar populations and different chemical enrichment. They exhibit no visible structure (nucleus, spiral arms, bulge, bars), are characterized by low total masses (10^6 - 10^8 $M_\odot$), small radius (∼ 1 kpc), are poorly enriched and contain mostly old stellar populations, with stars with ages larger than 10 Gyr (Mateo 98, Tolstoy, Hill & Tosi 2009). Several recent studies indicate that the evolution of these galaxies is much more complex than their properties suggest. A common feature to all these galaxies is the complete absence of neutral gas (Grcevich & Putman 2009), yet not satisfactorily explained. There is not a consensus regarding which physical processes are responsible for the removal of the gas in dSph galaxies. Several works argue in favor of external processes such as ram pressure and tidal stripping. On the other hand, hydrodynamic simulations demonstrated that galactic winds triggered by SNe are very efficient in expelling the gas out of the galaxy, but not able, alone, to remove it completely (Ruiz et al 2013, Caproni et al. 2015, 2017). A remaining internal physical process, not yet taken into account, is the effect of an outflow from a central black hole in these galaxies. Both the radiation emitted by matter falling into the black hole and the jet of particles of the nucleus of active galaxies can remove the gas from the central region of the galaxy generating a galactic wind, as observational evidence suggests in larger galaxies (Tombesi et al. 2015). Recent observational studies suggest that also dwarf galaxies could harbor central black holes of intermediate mass - 10^4 - 10^6 $M_\odot$ (Moran et al. 2004, Lora et al. 2009). The effects of a IMBH on the internal dynamics of these galaxies, however, have not yet been studied neither from the theoretical nor the observational point of view.

In this work, we for the first time: examine the effects of the outflow from the IMBH in the galaxy and its interaction with the ISM in an homogeneous medium and in a medium disturbed by SNe explosions; and analyze the interplay between the IMBH outflow and the SNe feedback.

2. Results

The effects of an IMBH outflow in the internal dynamics of a classical dSph galaxy started to be analyzed by means of a hydrodynamic code already used in previous works of the group (Caproni et al. 2015, 2017). The initial setup of the code is the same as the one used in Caproni et al. (2017) for the dSph galaxy Ursa Minor. Starting from this point, an outflow was created by inserting a density in the central cell with a velocity in the z axis at $t = 0$ yr. It was simulated the central region (300 pc) of the galaxy, for 300 Myr, inside a computational cube with 120 cells in each side.

Starting from a hydrostatic equilibrium between the dark matter potential and the interstellar gas (Figure 1), the outflow was created and its propagation analyzed. In the case of a perturbed medium, the SNe rate adopted was the one from the

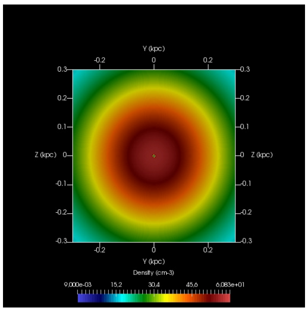

Figure 1. Cut in the yz plane in t = 0 yr, for the density profile.

chemical evolution models of Lanfranchi & Matteucci (2010), following the prescriptions described in Caproni et al. (2017).

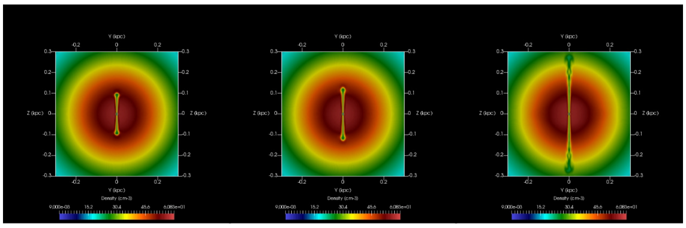

Figure 2. Cut in the yz plane for the density of the gas at t = 16 Myr (left), 20 Myr (center), and 80 Myr (right), for an homogeneous medium.

From the hydrostatic equilibrium in t = 0 yr, the propagation of the outflow was analyzed in an homogeneous ISM, free from perturbations. It was inserted in the central cell a density of $\rho = 3\times10^{-3}$ particles.cm^{-3} with a velocity of v = 1000 km/s in z axis, both directions. In this scenario, the outflow moves freely in a straight line, with symmetry in both directions (left panel, Figure 2). In the line of the propagation appears a high density region that pushes the ISM gas, leaving behind a stream of very low density compared to the surroundings (center panel, Figure 2). After a few million years, the outflow leaves the simulated region without disturbing the medium of the galaxy (right panel, Figure 2).

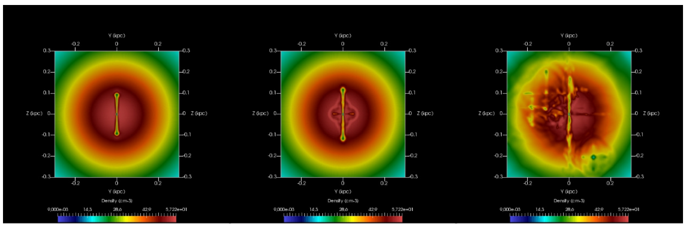

Figure 3. Cut in the yz plane for the density of the gas at t = 16 Myr (left), 20 Myr (center), and 80 Myr (right), for a disturbed medium.

In the case of a disturbed medium, besides the outflow, it was taken into account the energy of SNe that is released in the ISM. The values of the main parameters (v and ρ) of the outflow are the same as in the homogeneous case. In these conditions, there is a substantial change in the propagation of the outflow: the symmetry is lost, the velocity is lower, and it is even halted eventually (Figure 3). The energy injected in the medium by SNe is responsible for these differences. The shock waves created by the SNe give rise to regions of pressure and velocity much higher than the ones created by the outflow, disrupting its propagation in some points.

Differences in the ISM changes the propagation velocity of the outflow. In a homogeneous medium the velocities are higher (~ 50 km/s compared to 10 km/s) and the same in both directions, whereas in the heterogeneous medium the velocities change regularly, are lower, reaching sometimes zero (Figure 4).

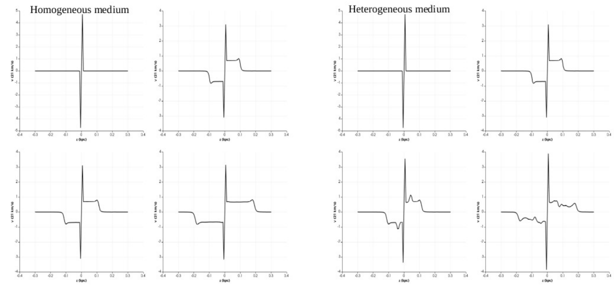

Figure 4. Velocity (in 20 km/s) of the outflow in z axis in t = 0 yr (up left), 8 Myr (up right), 10 Myr (bottom left) and 40 Myr (bottom down), for the case of an homogeneous medium (left panel) and a disturbed medium (right panel).

3. Conclusions

It has been found that an outflow with density of 3 $\times10^{-3}$ particles.cm^{-3} with an initial velocity of 1000 km/s propagates both in a homogeneous medium as in a medium disturbed by SNe. In the latter case, however, the propagation is more difficult; the jet symmetry is lost, its propagation speed is smaller (~ 5 times), and the outflow can even be interrupted in a few moments. These changes are caused by the displacement of gas due to supernova explosions, which inject large amounts of energy into the medium in small regions.

Acknowledgements. This work has made use of the Sistema de Computação Petaflópica do SINAPAD - Laboratório Nacional de Computação Científica (LNCC). The authors thank the Brazilian agency CNPq (grant 304928/2015-1) and FAPESP (grants 2014/11156-4, 2017/25651-5 and 2017/25799-2).

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