Galaxy Evolution and Feedback across Different Environments
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Effects of supernovae feedback and black hole outflows in the evolution of Dwarf Spheroidal Galaxies

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Abstract. The gas evolution of a typical Dwarf Spheroidal Galaxy is investigated by means of 3D hydrodynamic simulations, taking into account the feedback of type II and Ia supernovae, the outflow of an Intermediate Massive Black Hole (IMBH) and a static cored dark matter potential. When the IMBH's outflow is simulated in an homogeneous medium a jet structure is created and a small fraction of the gas is pushed away from the galaxy. No jet structure can be seen, however, when the medium is disturbed by supernovae, but gas is still pushed away. In this case, the main driver of the gas removal are the supernovae. The interplay between the stellar feedback and the IMBH's outflow should be taken into account.

Keywords. hydrodynamics, ISM: jets and outflows, galaxies: dwarf, evolution, Local Group

1. Introduction

A common feature to local Dwarf Spheroidal Galaxies is the absence of neutral gas, that could be removed by ram pressure or tidal stripping. Hydrodynamic simulations, however, suggest that galactic winds are very efficient in expelling the gas out of the galaxy (Caproni *et al.* 2015, 2017). A physical process, not yet considered, is the outflow from a central black hole in these galaxies.

2. Code setup

The effects of an IMBH's outflow and the stellar feedback in the internal dynamics of a classical dSph galaxy are analyzed by means of 3D hydrodynamic simulations. The initial setup is the same as described in Caproni *et al.* (2017). The galaxy is simulated for 1 Gyr inside a computacional cube of 40^3 to 200^3 cells, twice as large as Ursa Minor's tidal radius (950 pc). An initial gas mass of 2.94×10^8 $M_\odot$ is in hydrostatic equilibrium with a dark matter halo mass of 1.51×10^9 $M_\odot$. An outflow is created by inserting a density in the central cell with a velocity in the z axis at t = 0 yr. The energy of the SNe is injected in the medium following the procedure of Caproni *et al.* (2017).

3. Results

3.1. *Stellar feedback*

Two scenarios were considered: one with SNe II only and other only with SNe Ia. Initially, SNe II occur at the center, creating a shock wave that pushes the gas to outer regions. The shocks mix the gas on the galaxy, creating "bubbles" of hot gas and high density that carry material out of the system. The mass fraction inside a spherical region

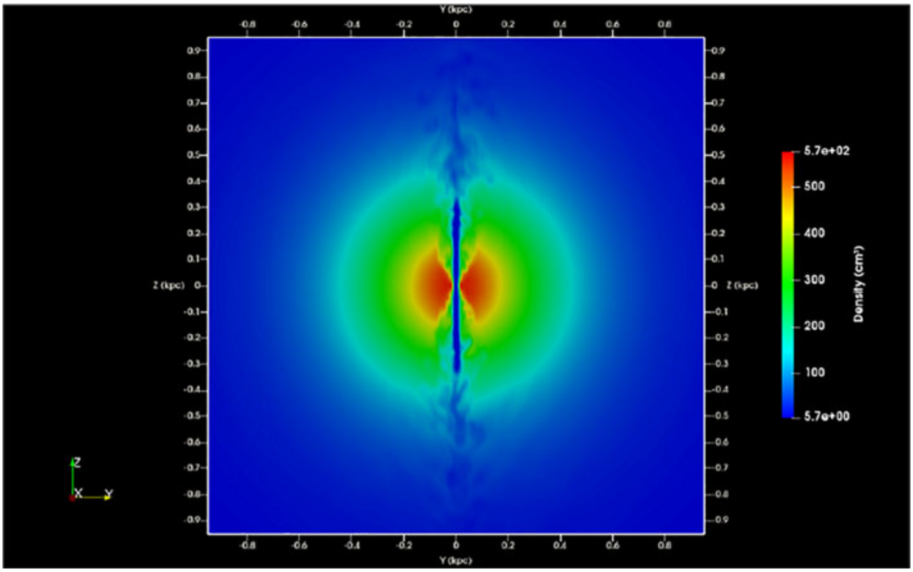

Figure 1. Density profile cut in the yz plane for the simulation with an IMBH's outflow with $\rho = 0.027$ cm^{-3}, v = 1000 km/s, $t_0 = 0$ yr.

of 300 pc radius drops slow to 85% of the inital value, but increases later to ~90%, remaining constant until the end of the simulation. Inside 950 pc radius, there is a very small decrease (~1%). In the second scenario, interactions among the SNe Ia remnants do not create a distinguished shock wave and gas is easier removed from the galaxy. The mass fraction starts decreasing fast at ~150 Myr, reaching ~80%; then the gas loss becomes slower reaching ~78% in outer regions. Compared to the SNe II case, SNe Ia removes more gas in outer than in inner regions and the decrease in the gas mass begins later and is slower.

3.2. *BH outflow*

Outflows with different initial density and the same initial velocity (1000 km.s^{-1}) are tested first in a medium where the density varies only radially. In the case $\rho = 0.008$ cm^{-3} the outflow does not have energy to break into the ISM, but gas is pushed away from the tidal radius. When the initial density is $\rho = 0.027$ cm^{-3}, the outflow creates a jet feature (Figure 1), pushing the gas and leaving behind a stream of very low density. When the medium is disturbed by SNe there is no jet feature. The shock waves created by the SNe give rise to regions of pressure and velocity much higher than the ones created by the outflow, making its propagation more difficult. Even though, the outflow pushes away gas from the galaxy. The fraction of initial mass left inside different radii is lower when the outflow's initial density is higher. In the case with an outflow beginning 30 Myr after the simulation is started, SNe lower the density of the central region , the outflow can develop easier, and the gas loss is higher in outer regions (950 pc).

4. Conclusions

SNe Ia are more efficient in removing gas, whereas SNe II affect only the central region. The BH's outflow effects depend on the conditions of the medium. These two types of feedback should be considered togheter in future studies, due to their strong interplay.

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