Boletim da Sociedade Astronômica Brasileira, **32**, no. 1, 171-172

Effects of supernovae types II and Ia in the gas dynamics of dwarf spheroidal galaxies

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Abstract. Local Group Dwarf Spheroidal Galaxies are totally devoided of gas. The physical mechanism that consumed or removed the gas, however, is still unknown: galactic winds triggered by supernovae or external physical processes such as ram pressure or tidal stripping could remove a large fraction of the gas from these galaxies. In this work, the effects of supernovae feedback on the dynamics of the gaseous content of a classical Dwarf Spheroidal Galaxy are investigated by means of a 3D hydrodynamic simulation code. Adopting a ratio of baryonic matter-dark matter derived from cosmic background radiation and a static and cored dark matter potential, the gas distribution inside the tidal radius of the galaxy is allowed to evolve over 1 billion years, taking into account the feedback of SNe II and SNe Ia, with different prescriptions for their spatial and temporal distribution.

Resumo. Galáxias Esferoidais Anãs do Grupo Local são completamente desprovidas de gás. O mecanismo físico que consumiu ou removeu o gás galáctico, entretanto, não é ainda conhecido: ventos galácticos deflagrados por supernovas ou processos físicos externos como pressão de arrasto ou força de maré podem remover um grande fração do gás dessas galáxias. Neste trabalho, os efeitos do *feedback* das supernovas na dinâmica do conteúdo gasoso de uma Galáxia Esferoidal Anã clássica são investigados através do uso de um código 3D de simulação hidrodinâmica. Adotando o valor da razão entre matéria bariônica e matéria escura dos dados da radiação cósmica de fundo e um potencial de matéria escura estático e nucleado, a distribuição do gás dentro do raio de maré da galáxia evolue por 1 bilhão de anos, levando em conta o *feedback* das supernovas do tipo II e Ia, com diferente prescrições para a sua distribuição espacial e temporal.

Keywords. Galaxies: dwarf – Galaxies: evolution –Hydrodynamics

1. Introduction

The first observations of the Dwarf Spheroidal Galaxies - dSph (Shapley 1938, Wilson 1955) suggested that they could be simple systems, very similar to globular clusters, without complex structures. As more detailed observations emerged, the scenario changed. It is now known that these galaxies are characterized by different stellar populations, chemical enrichment not yet fully explained, complex star formations, exhibit a large amount of dark matter, and total absence of gas (Tolstoy, Hill & Tosi 2009, Grcevich & Putman 2009). The lack of gas is not yet explained, turning critical the studies of the mechanisms that could be responsible for the removal of the gaseous content of dSphs. Previous simulations suggested that galactic winds triggered by SNe are not able to remove all the gas from the dSph medium. This would be possible only for systems with masses lower than 10^{5-6} $M_\odot$ (Fragile et al. 2003). However, these conclusions depend on the star formation history adopted (Ruiz et al. 2013): an intense stellar formation can give rise to an efficient galactic wind, whereas a low SNe rate is not sufficient for the removal of the interstellar gas from the galaxy. In this work we will investigate the interaction between the energy released by SNe of types II and Ia with the ISM of a dSph galaxy adopting different prescriptions for their spatial distribution and analyze the hydrodynamic evolution of the galactic gas in those conditions. The amount of gas lost will be also quantified.

2. Results

The analysis of the interaction between the energy released by SNe with the ISM of a dSph galaxy was performed by means of a 3D hydrodynamic code already fitted to the Ursa Minor galaxy (Caproni et al. 2015, 2017). Different scenarios were adopted with SNe II occurring in a specific position and time, distributed over a specific time and space, distributed randomly in space, and SNe Ia distributed randomly in space. The dynamics of the gas in the galaxy was simulated for 1 Gyr, using a computational box twice as large as the tidal radius (950 pc), divided in 40^3 to 200^3 cells. Initially (t = 0 yr), the interstellar gas is in hydrostatic equilibrium with the gravitational potential. The density distribuiton and the pressure profiles of the gas are almost homogeneous (vary only with the radius) at the beginning of the simulation whereas the temperature is contant all over the galaxy. Starting from this point, the energy of each SNe is injected in the galaxy according to different scenarios.

2.1. 100 and 1000 supernovae in the central point at t = 0 yr

In this case, a spherical shock wave is created (left panels Figure 1) and propagates toward outer regions. At the same time is formed a thin region of high pressure and temperature, pushing a fraction of the gas outwards. After a few Myr, the gas falls back and the density in the central region increases again. The gas fraction that is lost varies with the radius and in each case: 4% and 15% at 300 pc and 2% and 7% at 950 pc for 100 and 1000 SNe, respectively.

2.2. 1000 SNe II distributed in time and space

We adopted the SNe rate of Lanfranchi & Matteucci (2007) and the position where each SN occurs is random, weighted by the density. The SNe start at the center, creating a shock wave that pushes the gas to outer regions. New SNe create regions of high density in different points (Figure 2) destroying the spherical shock wave and mixing the gas on the galaxy. “Bubbles” of hot gas are created carrying material out of the system. A fraction

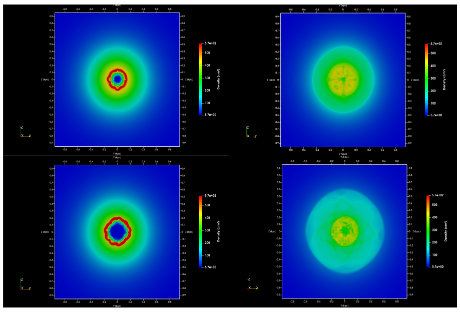

Figure 1. Cut in the yz plane for the density of the gas at t = 5 Myr (left) and 40 Myr (right) for 100 (top) and 1000 SNe (bottom).

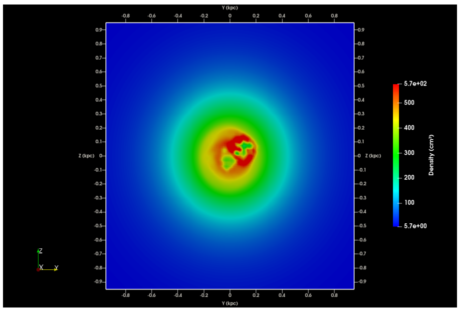

Figure 2. Cut in the yz plane for the density of the gas at t = 50 Myr with SNe II.

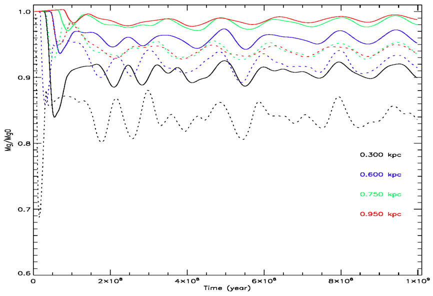

Figure 3. Mass fraction of the inital gas at different radii for 1000 SNe spreaded in space (solid line) and central (dashed line).

of the gas is slowly pushed away, but the density in the central region increases again after a few Myr. The mass fraction drops slower to 85% at 300 pc (solid lines in Figure 3) but increases later, remaining constant at ~ 90%. At 950 pc it is almost constant, with a very small decrease (~ 1%). When the SNe are distributed over time and space the gas loss is less efficient and faster at all regions compared to central SNe (dashed lines in Figure 3) since their effect on the ISM is diluted.

2.3. SNe Ia

The adopted SNe Ia rate is the one from Lanfranchi & Matteucci (2007) and they can occur anywhere in the galaxy, including outer regions. Interactions among the SNe remnants do not create a distinguished shock wave (Figure 4). Outer SNe can remove the gas of the galaxy easier. The mass fraction starts decreasing fast at ~ 150 Myr (dashed line in Figure 5) reaching ~ 80%; then the gas loss becomes slower and reaches ~ 78% in outer regions. Contrary to previous cases, SNe Ia remove more gas in outer than in inner regions. The decrease begins later and slower compared to SNe II case (solid lines). SNe Ia are more efficient in removing the gas.

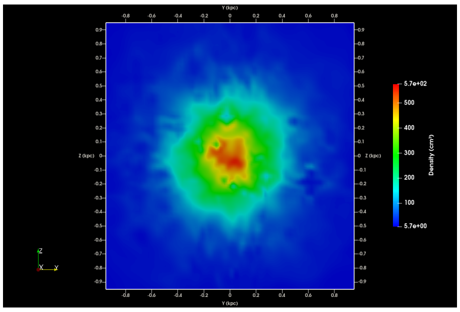

Figure 4. Cut in the yz plane for the density of the gas at t = 400 Myr with SNe Ia.

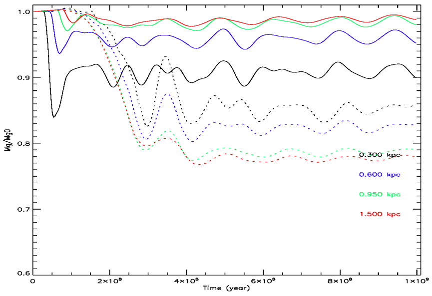

Figure 5. mass fraction of the inital gas at different radii for 1000 spread SNe II (solid line) and SNe Ia (dashed line).

3. Conclusion

We studied the effects of SNe in the dynamics of a dSph galaxy medium, in different scenarios. When only SNe II are taken into account, their effect is stronger when they explode at once in the center of the galaxy. In this case, a spherical shock wave is created and it propagates to outer regions of galaxy removing a fraction of the gas. The distribution of SNe II over time and space dilutes the effect. At the end of the simulation (1 Gyr) central SNe II remove ~ 6% of the gas at 950 pc, whereas SNe distributed over time and space remove only 1%. On the other hand SNe Ia, if equal in number, have a stronger effect in the ISM. The gas takes a longer time to leave the galaxy, but at the end of the simulation the fraction of gas loss is higher (~ 22% at 950 pc) compared to the case of SNe II.

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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