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Effects of supernovae types II and Ia in the gas dynamics in Dwarf Spheroidal Galaxies

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Abstract. Local group dwarf spheroidal galaxies are known to have no detectable neutral gas, however the physical mechanism that consumed or removed their gas is still unknown. In this work, the effects of the feedback from supernovae of types Ia and II on the dynamics of the gaseous content of a classical dwarf spheroidal galaxy are investigated by means of a non-cosmological 3D hydrodynamic simulation code. Our results suggest that type Ia supernovae are more effective in expelling the gas out of the galaxy whereas type II supernova remove the gas from the central regions of the system. The spatial distribution of the supernovae is more important to the gas loss than the temporal distribution, but both should be taken into account in stellar feedback studies.

Resumo. Sabe-se que as galáxias esferoidais anãs do Grupo Local não possuem gás neutro detectável, no entanto o mecanismo físico que consumiu ou removeu seu gás ainda é desconhecido. Neste trabalho, os efeitos do feedback de supernovas dos tipos Ia e II sobre a dinâmica do conteúdo gasoso de uma galáxia esferoidal anã clássica são investigados por meio de um código tridimensional de simulação hidrodinâmica não cosmológica. Nossos resultados sugerem que as supernovas do tipo Ia são mais eficazes em expulsar o gás da galáxia, enquanto as supernovas do tipo II removem o gás das regiões centrais do sistema. A distribuição espacial das supernovas é mais importante para a perda de gás do que a distribuição temporal, mas ambas devem ser levadas em consideração em estudos de retroalimentação estelar.

Keywords. Galaxies: dwarf – Galaxies: evolution –Hydrodynamics

1. Introduction

When the classical dwarf spheroidal galaxies (dSph) were first detected (Shapley 1938) they were thought to be simple systems, very similar to globular clusters, without complex structures, with a single stellar population, and uniform chemical properties. As more detailed observations emerged, the scenario changed drastically. It is now known that these galaxies are characterized by different stellar populations, chemical enrichment not yet fully explained, complex star formation histories, and exhibit a large amount of dark matter (Tolstoy, Hill & Tosi 2009). Completing this scenario, all analyzed dSph share a common feature: the total absence of detectable neutral gas (Grcevich & Putman 2009). How the gas is removed from the galaxy or is consumed internally remains a critical point. In this work, the different roles played by different types of SNe (type II and Ia) in the internal dynamics and in the gas removal of a typical isolated dSph are investigated by means of non-cosmological, 3D hydrodynamic simulations of its gas using the computational code PLUTO. The galactic gas distribution is evolved for 1 Gyr taking into account both SNe II and SNe Ia, assuming an initial baryonic-to-dark-matter ratio derived from the cosmic microwave background radiation and a cored and static dark matter gravitational potential.

2. Results

The initial setup of the simulation is exactly the same one adopted for Ursa Minor dSph (used as a template for a classical dSph galaxy), described in details in Caproni et al. (2017) and Lanfranchi et al. (2021). The galaxy is simulated over 1 Gyr inside a computational cube with 3.6 kpc length, divided in 180 cells each side. All simulations in this work were performed in the Brazilian supercomputers Sdumont.

The total number of SNe and their distribution over time are taken from the results of chemical evolution models that reproduce several observed chemical properties of Ursa Minor (Lanfranchi & Matteucci 2010). An energy of 10^{51} erg is injected in the medium every time t_{snia} or t_{snii} is achieved. The location (computational cell) where the energy is injected in each case, however, follows different prescriptions. For SNe II the choice of the site for the injection of energy depends on the gas density of each computational cell whereas for SNe Ia the energy can be injected anywhere in the galaxy: the choice is completely random.

Two simulations were performed, each one with different fractions of SNe II and SNe Ia. In the simulation SN4505LM 45,000 SNe II and 5,000 SNe Ia are adopted whereas in simulation SN3020LM 30,000 SNe II and 20,000 SNe Ia are taken into account. The rates of SNe II and SNe Ia are the same as in the chemical evolution models of Lanfranchi & Matteucci 2010, but the SNe explosions are halted when the maximum number of each SN type is achieved.

2.1. SN4505LM

The effects on the gas dynamics and on the evolution of the gas content are concentrated in the central region of the galaxy and in the early galactic ages. The first SNe II start exploding around 15 Myr after the beginning of the simulation at the center of the galaxy creating a region of higher temperature (8,400 K) and lower density (33% lower than in the vicinity). As the galaxy evolves, the number of SNe Ia increases and their feedback at more external regions of the galaxy becomes increasingly important. After the feedback of both types of SNe ceases, the external regions of the galaxy (from around 600 pc to 950 pc) are totally heated with a mean temperature ~10,000 K, whereas in the center (within a 150 pc radius) the temperature starts to decrease reaching 7,500 K at 600 Myr.

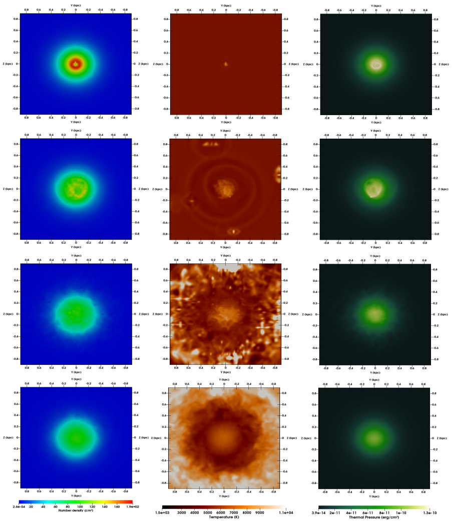

Figure 1. Cut in the x plane for the gas density (left), gas temperature (center), and thermal pressure (right) of the gas at t = 21 Myr (upper), 90 Myr (second panel), 300 Myr (third panel), and 900 Myr (bottom) for the simulation SN4505LM.

2.2. SN3020LM

A higher fraction of SNe Ia affects the medium over a longer timescale and at more external regions. As the evolution proceeds, regions of low density (33% and 22% lower than the surroundings), high temperature (8,800 and 6,800 K) and low pressure increase in size (from tens to hundred pc). New SNe explode diluting the region of high gas density and increasing the gas temperature at the center of galaxy. As the galaxy evolves more SNe explode heating the gas, that reaches peaks of 8,500 K at the tidal radius at 300 Myr and 15,000 K everywhere in the galaxy at 900 Myr. In the center, after SNe is halted, the temperature remains almost constant from 300 to 900 Myr with a value close to 7,500 K. The gas density at the center of the galaxy, on the other hand, decreases around 30% in the same time interval.

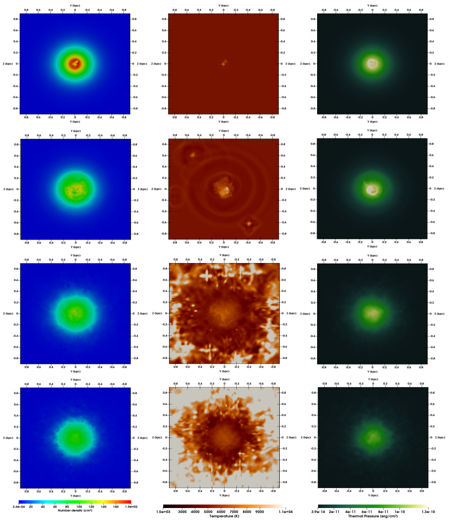

Figure 2. Cut in the x plane for the gas density (left), gas temperature (center), and thermal pressure (right) of the gas at t = 21 Myr (upper), 90 Myr (second panel), 300 Myr (third panel), and 9600 Myr (bottom) for the simulation SN3020LM.

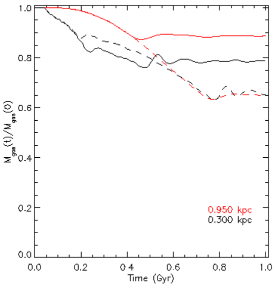

Figure 3. Mass fraction as a function of time inside two different galactic regions (300pc - black lines - and 950 pc - red lines) for the simulations SN4505LM (solid lines) and SN3020LM (dotted lines).

2.3. Mass fraction

The gas fraction that remains in the galaxy inside different radii (300 pc and 950 pc) as a function of time is computed by integrating numerically the mass density distribution obtained in the simulations. Inside 300 pc both SNe are important for gas loss: there is no difference in both cases up to ~180. After that, however, the initial decrease in the mass continues until ~400 Myr in the case S4505 due to the higher number of SNe II whereas in S3020 the higher fraction of SNe Ia removes more gas after 500 Myr. Inside 950 pc, SNe Ia are more important: after ~400 Myr gas loss stops in S4505 (SNe Ia ends), but continues decreasing in S3020 until ~760 Myr due to high number of SNe Ia.

3. Conclusion

Our results strongly suggest that the sites were the energy is inserted, if the SNe are clustered or not, and the temporal distribution of the SNe play a significant role in the gas dynamics and should be addressed with care when stellar feedback is investigated. SNe Ia favor the gas loss in the whole galaxy whereas clustered SNe II only favor the mass loss in central regions of the galaxy and in short timescales. After SNe II cease to explode, gravity pulls back the gas to the center of the galaxy and the fraction of the initial gas that is indeed lost is low. On the other hand, the continuous launch of energy by SNe Ia in the medium keeps the ISM at high temperatures and low densities for a long period, preventing the gas to fall back due to gravity. At the same time, when SNe Ia inject energy in the outskirts of the system, the gas is easier blown out from the tidal radius and does not fall back. When both types of SNe are considered, the case with a higher fraction of SNe Ia exhibits a higher gas loss and at the end of 1 Gyr and the remaining gas inside the galaxy (within a 950 pc radius) is lower: 65% compared to 90% in the simulation with 45,000 SNe II.

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