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Jellyfish galaxies crossing a discontinuous medium

E. A. Mello-Terencio & R. E. G. Machado

[1] Universidade Tecnológica Federal do Paraná, Paraná, Brasil, e-mail: elvisamandio@alunos.utfpr.edu.br, rubensmachado@utfpr.edu.br

Abstract. Jellyfish galaxies are characterized by their distinctive tails of gas stripped by ram pressure, a process directly influenced by the local density within a galaxy cluster. Sloshing spirals, commonly observed in galaxy clusters, create significant density and temperature discontinuities that may impact the evolution of a jellyfish galaxy crossing them. We aim to quantify how crossing discontinuities similar to those seen in sloshing spirals can alter jellyfish galaxy properties, such as gas content, star formation rate and color index. Using Arepo, a code designed for solving astrophysical hydrodynamical problems, we conducted a sequence of simulations. We set up a wind tunnel in a box with periodic boundaries, tailoring tunnel properties in order to simulate discontinuities. We began by defining two base environments with high and low gas density. From these, maintaining the center similar to the base high/low density environments, we used an analytical function in order to recreate discontinuities along the tunnel and produce different scenarios. An idealized galaxy was then placed at the tunnel's center, where wind was introduced by setting the tunnel gas to typical velocities in cluster-galaxy interactions. Preliminary results show that galaxies in the higher density environments experience greater gas stripping, initially increasing star formation rate and obtaining a bluer color index.

Resumo. Galáxias jellyfish são caracterizadas pelas suas caudas de gás retirado da galáxia por ram pressure, um processo diretamente influenciado pela densidade local em um aglomerado de galáxias. Espirais de sloshing, comunmente observadas em aglomerados de galáxias, criam descontinuidades significativas em densidade e temperatura que podem impactar a evolução de uma galáxia jellyfish que a cruza. Nós buscamos quantificar como o cruzamento de descontinuidaes simulares àquelas vistas em espirais de sloshing podem alterar propriedades de galáxias jellyfish, como conteúdo de gás, taxa de formação estelar e índice de cor. Usando Arepo, um código desenvolvido para resolver problemas hydrodinâmicos astrofísicos, nós conduzimos uma sequencia de simulações. Nós configuramos um túnel de vento em uma caixa com limites periódicos, configurando as propriedades do túnel para simular descontinuidades. Começamos definindo dois ambientes base com alta e baixa densidade. Disso, mantendo o centro similar aos ambientes de alta/baixa densidade, usamos uma função analítica para recriar descontinuidades ao longo do túnel e produzir cenários diferentes. Uma galáxia idealizada foi colocada no centro do túnel, onde vento foi introduzido ao dar ao gás do túnel velocidades típicas de interações entre aglomerados e galáxias. Resultados preliminares mostram que galáxias em ambientes com maior desidade experienciam mais perda de gás por ram pressure, inicialmente aumentando taxa de formação estelar e obtendo um maior índice de cor.

Keywords. Galaxies: clusters – Galaxies: clusters: intracluster medium – Galaxies: evolution

1. Introduction

Galaxy clusters are the biggest collapsed structures in the universe and commonly interact with each other. These interactions can give rise to cold fronts (Ascasibar & Markevitch 2006) due to sloshing, creating sloshing spirals (SS). It is also known that the immediate environment a galaxy interacts with can affect its evolution, being one of the main factors contributing to gas stripping (Gunn & Gott 1972).

Hydrodynamical simulations have been extensively employed to study extragalactic phenomena, specifically when galaxies interact with the intracluster medium (ICM), such as for measuring star formation and gas tripping rate (Kronberger et al 2008; Steinhauser et al 2012), analysing morphology (Tonnesen & Bryan 2009) and color index changes (Steinhauser, Schindler & Springel 2016), while making use of different numerical setups, such as wind-tunnels, to isolate important parameters (Tonnesen 2019).

With this study we aim to analyze how different galaxy properties can be affected by crossing a sloshing spiral. We used a wind-tunnel setup filled with an ICM profile that reproduces a trajectory a galaxy may take through a cluster, crossing discontinuities in temperature and density.

2. Simulation setup

We used the Arepo code for all simulations. Arepo is an astrophysical N-body simulation code that implements an adaptive moving mesh for hydrodynamical interactions (Weinberger, Springel, & Pakmor 2020).

In order to recreate the SS environment a galaxy may cross we set up a period simulation box of $100 \times 100 \times 200$ kpc, essentially creating a wind-tunnel into which a relaxed galaxy was inserted and simulations began.

2.1. Galaxy creation

The galaxy was created using the Python3 version of galstep[1] (Ruggiero & Lima Neto 2017) with parameters that generate a late-type galaxy roughly Milky Way like in size and mass. For the dark matter halo and the bulge Galstep follows a Hernquist (1990) density profile:

$$\rho(r) = \frac{M}{2\pi} \frac{a}{r(r+a)^3} \tag{1}$$

where M is the total mass and a is a scale length. We employed $M_\mathrm{h} = 10^{12}\,\mathrm{M}_\odot$, $M_\mathrm{b} = 2\times10^{10}\,\mathrm{M}_\odot$ and $a_\mathrm{h} = 47$ kpc, $a_\mathrm{b} = 1.5$ kpc,

[1] https://github.com/elvismello/galstep

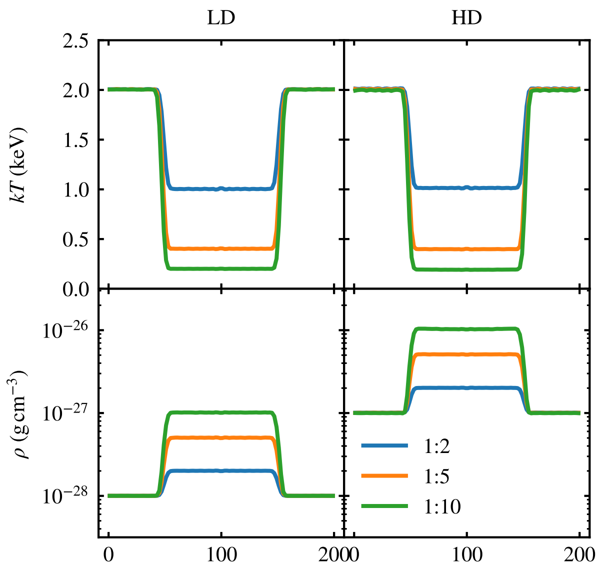

Figure 1. Measured simulation box profiles showcasing the analytical distribution with the eq. 3 for density and temperature at each transition.

respectively for the halo and the bulge. The stellar and gas disc components are defined with a double exponential profile:

$$\rho_\mathrm{d}(R, z) = \frac{M_\mathrm{d}}{4\pi R_\mathrm{d}^2 z_\mathrm{d}} \exp\left(-\frac{R}{R_\mathrm{d}}\right) \mathrm{sech}^2\left(\frac{z}{z_\mathrm{d}}\right), \qquad (2)$$

with M_d the disc total mass, R_d and z_d radial and vertical scale lengths. For our galaxy, we chose $M_\mathrm{star} = 5 \times 10^{10}\,\mathrm{M}_\odot$, $R_\mathrm{star} = 3.5$ kpc and $z_\mathrm{star} = 0.7$ kpc for the stellar disc and $M_\mathrm{gas} = 2 \times 10^{10}\,\mathrm{M}_\odot$, $R_\mathrm{gas} = 3.5$ kpc, $z_\mathrm{gas} = 0.035$ kpc for the gas disc.

This base galaxy is then relaxed for 1 Gyr before interacting with our wind tunnel, being used for all models considered.

2.2. Wind-tunnel creation

The wind-tunnels were generated with a profile for density and temperature transitions described by logistic functions along z:

$$f(z) = \frac{A}{1 + e^{-k(z - z_0)}} + B, \qquad (3)$$

with A the amplitude of the curve before and after both transitions, B the amplitude in between transitions, k its steepness and z_0 its position. Values for A and B for density and temperature along the tunnel are chosen such that they maintain constant pressure, which is required for stability, and are comparable to those observed in real SS. Examples for the considered tunnels are illustrated by Fig. 1.

For the actual simulations, two base environments were chosen, namely low density (LD1) and high density (HD1), with a constant density throughout the simulation box of 10^{-28} g cm^{-3} and 10^{-27} g cm^{-3}, respectively. For each of these we created 3 other tunnels, keeping B from eq. 2 at the base density and setting A to $2B$, $5B$ and $10B$ in order to cover different possible scenarios. This resulted in low density tunnels LD1, LD2, LD5 and LD10 and high density tunnels HD1, HD2, HD5 and HD10, where the number represents the amplitude of transition.

After setting density, temperature and pressure along the entire simulation box, a velocity of $v_z = -1000$ km s^{-1} was given to all gas cells, effectively simulating the typical wind a galaxy would experience from its reference system when interacting with the ICM.

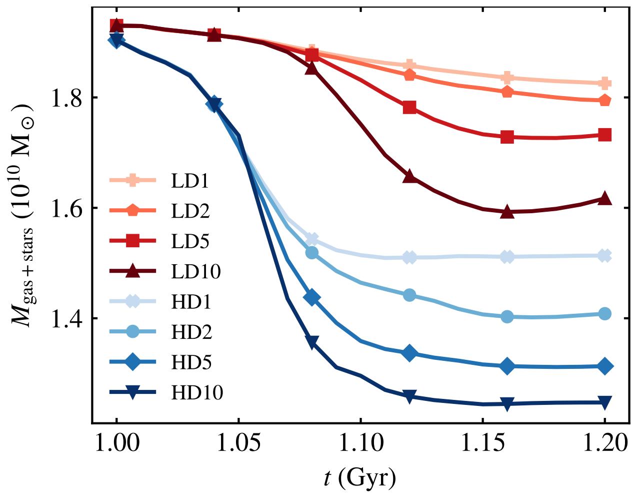

Figure 2. Mass measured on the galaxy disc for every model, considering only baryonic matter (gas and stars). Most gas is removed right after 1.05 Gyr, when the galaxy crosses the transition and starts experiencing the densest part of the wind tunnel, which increases ram pressure stripping.

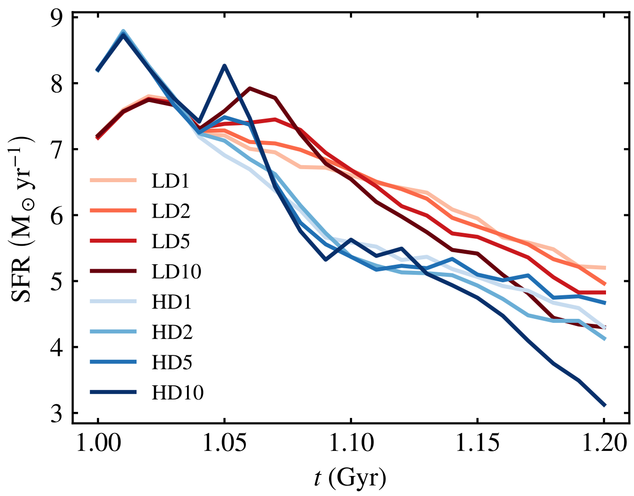

Figure 3. Star formation rate in the disc.

3. Preliminary results and analysis

Fig. (2) shows the measured mass on the galaxy disc over each different model for the wind tunnel. As should be expected, there is a direct corelation between the mass kept on the galaxy and the ICM density it encounters, where the denser the ICM, the more gas is stripped and less gas remains on the disc.

As for the star formation rate (SFR), Fig. 3, when the galaxy starts going through the transition on 1.05 Gyr it is quickly heightened, slowly decreasing thereafter in a rate directly proportional to the transition amplitude for the LD models. The HD models show no apparent order other than having their SFR greatly decreased while inside the densest part of the wind tunnel. In general, the most striking difference between simulations is that HD models show a decrease in SFR while inside the densest part of the wind tunnel.

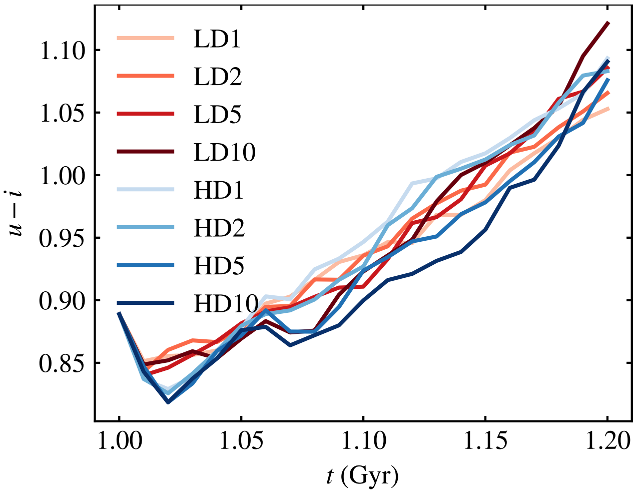

Figure 4. Integrated color index evolution simulated with FSPS for every model.

Color index was obtained using the FSPS code (Conroy, Gunn & White 2009; Conroy & Gunn 2010), that returns magnitudes for a given stellar population age and its metallicity. The resulting integrated color index from the galaxy over time, Fig. 4, shows at most 5 % difference between all models. However, for the models LD10, HD5 and HD10, the integrated color index becomes significantly bluer after crossing the discontinuity. This effect is rather short lived, only lasting longer for the HD10 simulation.

4. Sumary and conclusions

In this work, 8 models were created and analyzed in order to identify how a SS like structure may affect a galaxy that traverses it. These simulations span 2 base environments with 3 different amplitudes for an idealized SS, including 2 control cases with constant density and temperature. Mass evolution, SFR and galaxy integrated color were analyzed and compared between all simulations.

Preliminary results show that crossing the SS mainly affects the mass on a galaxy due to ram pressure stripping. Color index isn't significantly changed, showing only short lived differences between all models. Although SFR is also diminished initially for the HD models, it generally has similar values after the galaxy crosses the idealized SS.

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