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Simulations of ram pressure stripping due to the circumgalactic medium

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Abstract. The circumgalactic medium (CGM) is a diffuse gas compared to the interstellar medium (ISM) with a volume considerably larger than the optical disk of galaxies. Recent constraints based on observational data from the eROSITA mission characterized the X-ray luminosity profile of the CGM gas in galaxies the size of Andromeda (M31) and the Milky Way, as well as in similar galaxies present in the Illustris TNG simulation. During a galactic interaction, the presence of a CGM may affect the morphology and star formation of a satellite galaxie due to the ram pressure effect between gaseous structures The goal of this work is to verify whether the presence of a CGM during a galactic interaction can affect the gas morphology of a satellite galaxy, as well as alter its star formation. To quantify these effects and their correlation with different orbital configurations and CGM masses, four hydrodynamic N-body simulations were performed with two orbital configurations (pericentric passages of 200 kpc and 50 kpc) and two CGM masses (4×10^{10}M⊙ and 36×10^{10}M⊙), comparable to plausible values according to observational data from the eROSITA mission and simulated data from Illustris TNG. Results indicate tail formation, representing a gas mass loss from the galaxy approximately three times greater in cases of denser CGM. Regarding the star formation rate, it remained minimally altered in the orbital configurations with a pericentric passage of 200 kpc, showing an increase in cases with a pericentric passage of 50 kpc, and specifically the highest value was found in the situation with denser CGM. The difference in the mass of stars formed at the end of 2 Gyr of evolution was approximately $0.35\times 10^{8}\mathrm{M}_{\odot}$ between the case with the largest pericentric passage and less dense CGM and the case with the smallest pericentric passage and denser CGM.

Resumo. O meio circumgaláctico (CGM) é um gás rarefeito comparado ao gás do meio intergaláctico (ISM) com volume consideravelmente maior que o disco óptico de galáxias. Pesquisas recentes baseadas em dados observacionais da missão eROSITA caracterizaram o perfil de luminosidade de raios X do gás do meio circumgaláctico (CGM) em galáxias do porte de Andrômeda (M31) e da Via Láctea, bem como em galáxias similares presentes na simulação TNG Illustris. Durante uma interação galáctica, é possível que a presença de um CGM afete a morfologia e formação estelar de galáxias satélites por conta do efeito de pressão de arraste entre os gases. O objetivo deste trabalho é verificar se a presença de um CGM durante uma interação galáctica pode afetar a morfologia do gás de uma galáxia satélite, bem como alterar sua formação estelar. Para quantificação dos efeitos e sua correlação com diferentes configurações de órbita e diferentes massas de CGM, utilizando simulações hidrodinâmicas de N-corpos, quatro simulações foram feitas com duas configurações orbitais (passagens pericêntricas de 200 kpc e 50 kpc) e duas massas de CGM ($4 \times 10^{10}\mathrm{M}_{\odot}$ e $36 \times 10^{10}\mathrm{M}_{\odot}$), comparáveis a valores plausíveis de acordo com os dados observacionais da missão eROSITA e dados simulados da TNG Illustris. Resultados indicam formação de cauda, representando perda de massa de gás da galáxia cerca de três vezes maior nos casos de CGM mais denso. Quanto à taxa de formação estelar, se manteve pouco alterada nas configurações de órbita com passagem pericêntrica de 200 kpc, apresentando um aumento nos casos de passagem pericêntrica de 50 kpc e especificamente o maior valor constatado na situação de CGM mais denso. A diferença de massa de estrelas formadas ao final de 2 Gyr de evolução foi de aproximadamente $0.35\times 10^{8}\mathrm{M}_{\odot}$ entre o caso de maior passagem pericêntrica com CGM menos denso e menor passagem pericêntrica com CGM mais denso.

Keywords. Galáxias: interações – Galáxias: formação estelar – Métodos: numéricos

1. Introduction

Constraints based on observational data from the eROSITA mission have quantified X-ray surface brightness profile ranges of the gas in the circumgalactic medium (CGM) in M31-like and Milky Way-like galaxies (Zhang et al. 2024). In similar galaxies from the IllustrisTNG simulation, the gas density and temperatures of the CGM also have been characterized (Ramesh et al. 2022). During a galactic interaction, it is possible that the presence of a CGM, may affect the morphology and star formation rate of satellite galaxies, due to ram pressure stripping.

2. Simulations

The interactions were modelled and simulated via N-body hydrodinamical simulations using Gadget-4 code (Springel et al. 2021). Two CGM were modelled ($4 \times 10^{10}\,\mathrm{M}_{\odot}$ and $36 \times 10^{10}\,\mathrm{M}_{\odot}$), based on observational parameters of X-ray brightness (Zhang et al. 2024). CGM density and temperature profiles were also compared to constraints from TNG Illustris (Ramesh et al. 2022), which can also be seen on Fig. 1.

The host galaxy was simulated by analytical Hernquist potential (Hernquist 1990) with comparable mass parameters to M31 ($191 \times 10^{10}\,\mathrm{M}_{\odot}$), and the satellite galaxy was made similar to M33 in terms of mass ($52.9 \times 10^{10}\,\mathrm{M}_{\odot}$). The two CGM were relaxed by 2 Gyr under host galaxy's analytical potential, and satellite galaxy was relaxed by 2 Gyr in isolation. After these steps, four simulations were performed with resolution of 10^{6} particles, each of them depicting a combination of CGM density and orbital configuration.

3. Results

As evidenced on Figs 2 and 3, the effect of ram pressure between the galactic gas from the satellite galaxy has happened in all four simulations. The galactic gas portion located up to 40 kpc above galactic thickness has been considered "tail", and galactic gas that has been pushed beyond 40 kpc as part of the "trail". Denser CGM simulations showed an increase of up to three times the tail

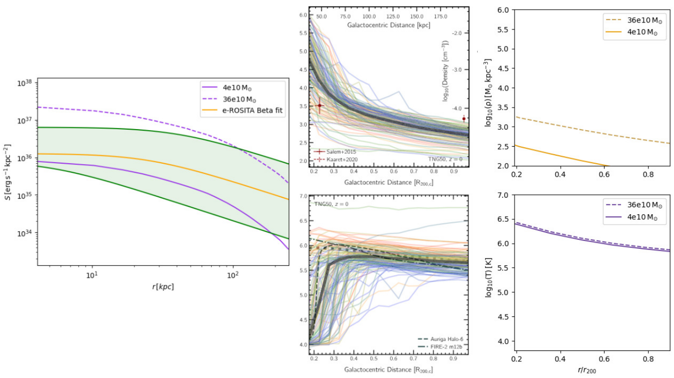

Figure 1. Left portion (single panel) shows X-ray surface brightness profile from 4 $\times 10^{10}$ $M_{\odot}$ and 36 $\times 10^{10}$ CGM, compared to observational confidence values and beta fit based on eROSITA constraints (Zhang et al. 2024). Right portion (2x2 mosaic) shows density and temperature profiles, in which left column refers to TNG Illustris CGM profiles (Ramesh et al. 2022) and right column refers to this work CGM.

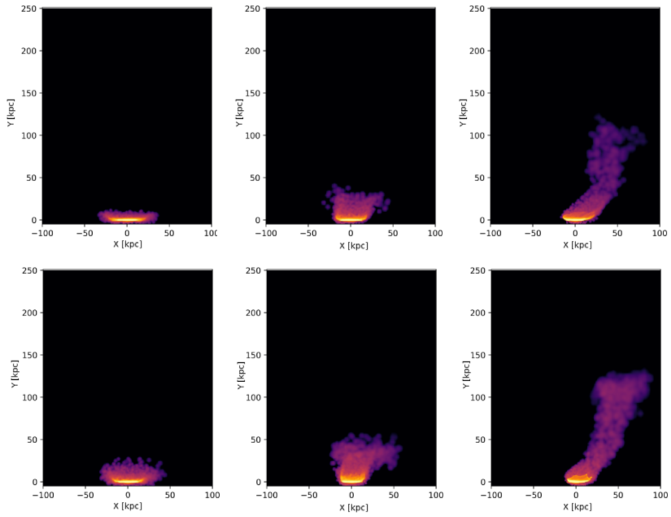

Figure 2. 50 kpc orbit simulation. 0.2 Gyr before pericentric passage (left), during pericentric passage (center) and 0.2 Gyr after (right). From top to bottom, 4 $\times 10^{10}$ $M_{\odot}$ and 36 $\times 10^{10}$ CGM mass.

and trail mass, in comparison to less denser CGM cases, which can be seen on Fig. 4. In terms of star formation, although the cases of denser CGM did showed an increase in star formation, the effect was much more pronounced in the simulations with 50 kpc of pericentric distance, and almost unnoticed in cases of pericentric distance of 200 lpc, as seen in Fig. 5. At the end of 2 Gyr of evolution, the increase in star formation led to an increase of approx. 0.35 $\times 10^{8}$ $M_{\odot}$. Results suggest that the CGM density and orbital configuration has implications on morphology and star formation of a satellite galaxy undergoing galactic interaction. The two simulations with denser CGM showed an increase of gas loss from the satellite galaxy (up to three times more mass), in comparison with less denser CGM cases. The two simulations with denser CGM also showed star formation rate increase (up to 0.4 $M_{\odot} yr^{-1}$ increase for star formation rate, resulting in roughly 0.35 $\times 10^{8}$ $M_{\odot}$ more cummulative mass from new stars), in comparison to less denser CGM ones, although orbital configuration difference appear to induce more significant change for star formation implications.

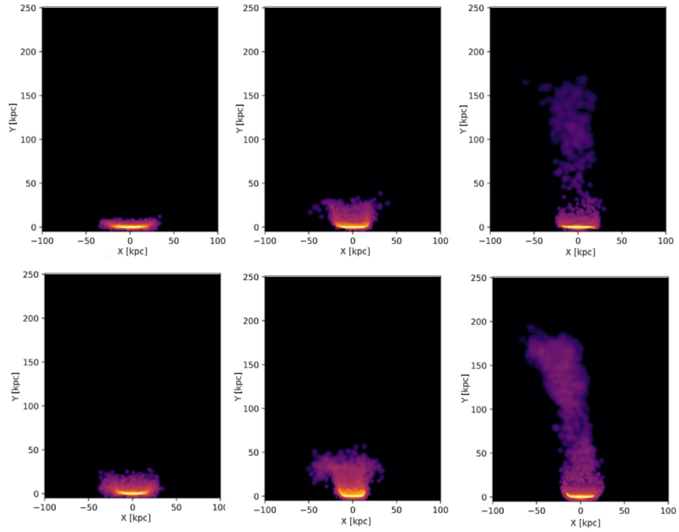

Figure 3. 200 kpc orbit simulation. 0.2 Gyr before pericentric passage (left), during pericentric passage (center) and 0.2 Gyr after (right). From top to bottom, 4 $\times 10^{10}$ $M_{\odot}$ and 36 $\times 10^{10}$ CGM mass.

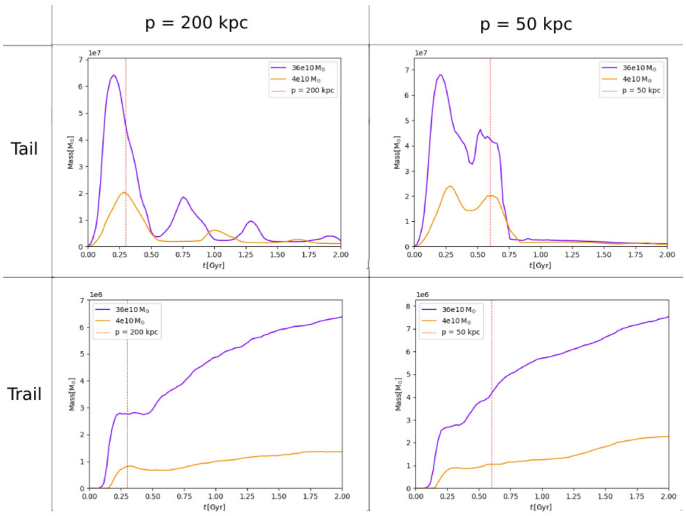

Figure 4. Tail and Trail formation mosaic. From left to right, 200 kpc and 50 kpc; from top to bottom, 4 $\times 10^{10}$ $M_{\odot}$ and 36 $\times 10^{10}$ CGM mass.

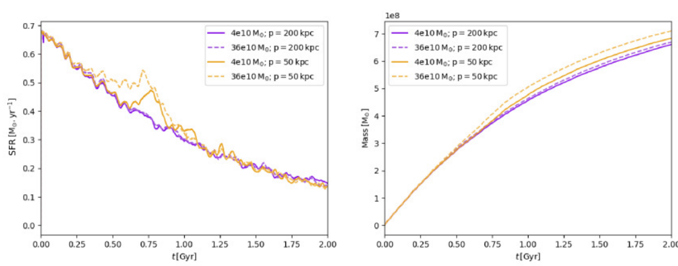

Figure 5. Star formation rate (left panel) and new stars mass (right panel).

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