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Circumgalactic gas medium influence on M31 and M33 interaction:

Morphology and star formation implications

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Abstract. Within the Local Group, there are two widely studied and notable galaxies due to their sizes and morphologies, the Andromeda Galaxy (M31) and the Triangulum Galaxy (M33). Through analyses of their specific dynamics and morphologies, as well as the presence of a possible gas bridge between them, it is presumed that there might be an interactive system between the two, with a pericentric passage having possibly already occurred. Around some galaxies there is a thin gaseous medium, known as circumgalactic medium, and recent constraints suggest that M31 could be surrounded by a circumgalactic medium, which could affect its evolution as well as its possible interaction with M33. Through a hydrodynamic *N*-body simulations with 10^6 particles resolution, each galaxy was modeled based on reference studies and observational data. By analysing the simulations results, morphological implications in the structures of both galaxies were noted. The gas disc of M33 showed significant changes, including warping and the formation of tidal tails. The morphology of M31 showed less pronounced deformations, which is consistent with the observational data. The star formation rate did not show a significant increase for the first two simulations, differing from what was expected based on references, although the third simulation showed a well pronounced peak close to the moment of pericentric passage.

Resumo. Dentro do Grupo Local, existem duas galáxias amplamente estudadas e notáveis por seus tamanhos e morfologias, a Galáxia de Andrômeda (M31) e a Galáxia do Triângulo (M33). Através de análises de suas dinâmicas e morfologias específicas, bem como a presença de uma possível ponte de gás entre ambas, presume-se que possa haver um sistema de interação entre si, tendo inclusive já ocorrido uma passagem pericêntrica. Ao redor de algumas galáxias há um meio gasoso de baixa densidade conhecido como meio circungaláctico, e estudos recentes sugerem que M31 pode estar rodeada por um meio circumgaláctico que poderia afetar sua evolução, bem como sua possível interação com M33. Utilizando simulações hidrodinâmicas de *N*-corpos com resolução de 10^6 partículas, cada uma das galáxias foi modelada a partir de estudos de referência e dados observacionais. Por meio das simulações, foi possível notar implicações morfológicas nas estruturas de ambas as galáxias. O disco gasoso de M33 mostrou alterações significativas, incluindo flambagem e formação de caudas de maré. A morfologia de M31 sofreu deformações menos expressivas, o que é condizente com os dados observacionais. A taxa de formação estelar não evidenciou aumento expressivo nas duas primeiras simulações, diferindo do esperado a partir das referências, mas a terceira simulação demonstrou um pico considerável de formação estelar condizente com os momentos acerca da passagem pericêntrica.

Keywords. Galaxies: Local Group – Galaxies: intergalactic medium – Methods: numerical

1. Introduction

Observations and analyses regarding the morphology of M33 indicated the presence of a distortion of approximately 8 kpc in its stellar disk. This distortion has an orientation consistent with the direction relative to the position of the M31 galaxy (Corbelli et al. 2014), which could be explained by past interaction between the two galaxies. Observational analyses also indicate the presence of gas bridges connecting both galaxies (Braun & Thilker 2004), and also based on simulation results (Bekki 2008), it is suggested that gas bridges are consistent with a model of interaction. Recent ultraviolet spectroscopy data analysis suggests M31 could be immersed in an extended circumgalactic medium (Lehner et al. 2015) which could be relevant during the interaction between M31 and M33. This work's aim is to evaluate the implications of the presence of M31's circumgalactic gas to the interaction between both galaxies, in terms of star formation and morphology.

2. Simulations

Based on recent observational constraints and previous numerical results, the interactive system was modelled and simulated via *N*-body hydrodinamical simulations (Springel et al. 2021). The first step was to model each galaxy individually, based on observational parameters and previous numerical results (Semczuk et al. 2018; Tepper-García et al. 2020). The rotation curve for both galaxies can be seen on Fig. 1

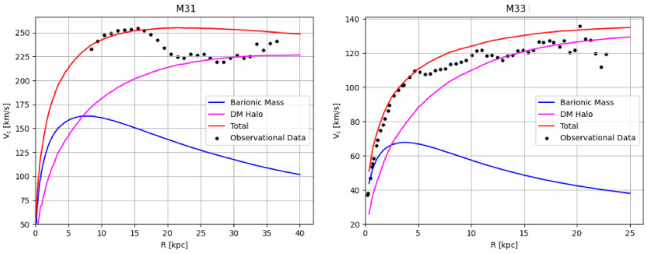

FIGURE 1. Rotation curves for M31 and M33 *N*-body models. Each model was compared to observational data (Corbelli et al. 2010, 2014).

The consulted initial conditions for relative distance and velocities were obtained via semi-analytic orbit integration of current observational parameters (Tepper-García et al. 2020). Our best simulation suggest the first pericentric passage of the interaction happened 0.95 Gyr ago, in which the distance between the two galactic centers were of approximately 48.7 kpc. The circumgalactic gas was added to M31's model in two differ-

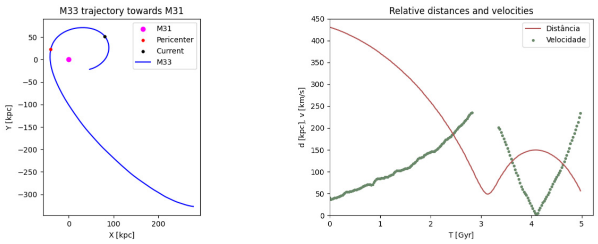

FIGURE 2. Relative distance between M33 and M31 on left figure, orbit of M33 towards M31 on left. Both images also highlight the moment of pericentric passage and moment of current distance between both galaxies.

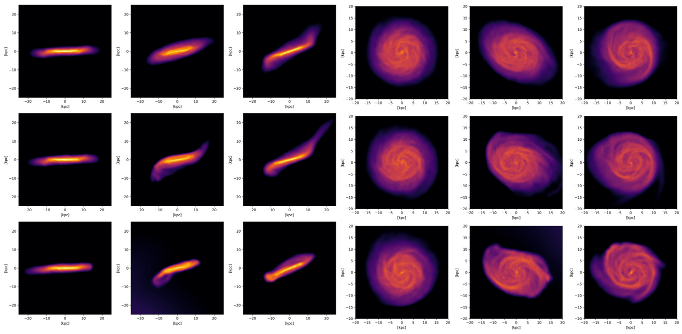

FIGURE 3. The left 3×3 mosaic shows the morphology of M33's gaseous disk, on an edge-on point of view, right 3×3 mosaic one shows the face-on. From left to right: 1 Gyr before pericentric passage, moment of pericentric passage, and present distance (roughly 1 Gyr after pericentric passage) . From top to bottom: No CGM, $3{\times}10^9$ $M_\odot$ CGM and $9{\times}10^9$ $M_\odot$ CGM .

ent masses: $3{\times}10^9$ $M_\odot$ and $9{\times}10^9$ $M_\odot$. All the simulations were made with the resolution of 10^6 particles.

3. Preliminary results

M33's gaseous disk has shown noticeable warping, which can be seen at Fig. 3 and is consistent with reference studies (Corbelli et al. 2014). On the $3{\times}10^9$ $M_\odot$ CGM simulation, a noticeable increase in M33's tidal tails has been shown, while on $9{\times}10^9$ $M_\odot$ CGM simulation, the tidal tail seems to be slightly less pronounced. The presence of CGM in the simulation has changed the morphology of M33's arms, as well as the eccentricity of M33's gaseous disk distorted morphology in the moment of pericentric passage.

M31's gaseous disk appears to have its dynamic drastically altered by the presence of CGM on its evolution. Studies regarding different methods for accomodation of circumgalactic disk on a galaxy simulation may be needed in future works. The gaseous disk of the galaxy has become shorter with the presence of the gaseous CGM, which can imply that the present evolutionary model would be unfit for data analysis about M31's morphology, specifically. Despite the presence of morphological warps and tidal wave formation on gaseous disk from both galaxies, the first two simulations show no significant increase in the system's star formation rate, while the $9{\times}10^9$ $M_\odot$ CGM simulation suffered two peaks in star formation rate, being one of them almost coincident with the pericenric passage. (Fig. 5).

The outcome of the simulations can be considered reasonably coherent with the expected, considering the estimated mass of M31's CGM to be of around $3\times10^9 M_\odot$ (Lehner et al. 2015) and no noticeable inconcistencies were found on the simulation of equal CGM value. Still, further research about the estimated size, mass and even metal distribution is still needed for understanding the implications of the presence of M33's CGM to the galaxy itself and its possible interactions.

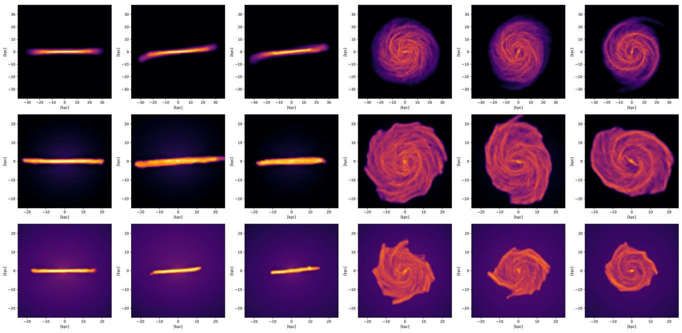

FIGURE 4. The left 3×3 mosaic shows the morphology of M31's gaseous disk, on an edge-on point of view, right 3×3 mosaic one shows the face-on point of view. From left to right: 1 Gyr before pericentric passage, moment of pericentric passage, and present distance (roughly 1 Gyr after pericentric passage) . From top to bottom: Evolution in abscence of CGM, presence of a $0.3{\times}10^{10}$ $M_\odot$ CGM and $0.9{\times}10^{10}$ $M_\odot$ CGM in the system.

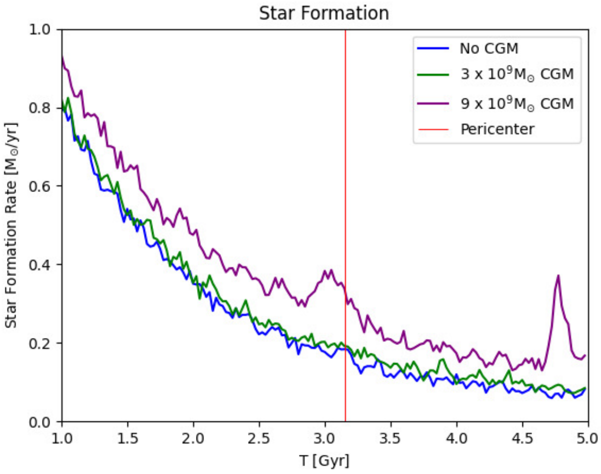

FIGURE 5. Star formation rate as a funcion of time for the entire system. Vertical red line highlights the moment of pericentric passage

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