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Simulations of Vertical Asymmetries in the Galatic Disk Induced by Interaction with a Satellite

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Abstract. Vertical asymmetries are common features in the disks of spiral galaxies and a typical type is the S-shaped warp. One possible explanation for this morphology is the interaction with a satellite galaxy. In this study, we performed a set of N-body simulations with the Gadget-2 code to investigate the correlation between the interaction with a dwarf galaxy and the amplitude of the perturbation induced in the host galaxy, considering different masses and orbit radii for the satellite. We find that the amplitude and the duration of the warp depend on the mass of the satellite.

Resumo. Assimetrias verticais são estruturas comuns no disco das galáxias espirais e um tipo característico é a warp em forma de S. Uma explicação possível para esta morfologia é a interação com uma galáxia satélite. Neste estudo, executamos um conjunto de simulações de N-corpos com o código Gadget-2 para investigar a correlação entre a interação com uma galáxia anã e a amplitude da perturbação induzida na galáxia principal, considerando diferentes massas e raios de órbita para o satélite. Verificamos que a amplitude e a duração da warp dependem da massa do satélite.

Keywords. Galaxies: interactions – Galaxies: kinematics and dynamics – Galaxies: structure

1. Introduction

The disks of spiral galaxies can exhibit vertical asymmetries. One of the most common types of asymmetry are S-shaped (or integral-shaped) warps, in which the disk has one side bent upwards and the other downwards. Possible explanations for this morphology include the interaction with a satellite galaxy (e.g. Semczuk et al (2020)).

The study of warps can bring important information about the formation and evolution of galaxies (Poggio et al (2019)). Since numerical simulations are important tools for this type of investigation, we aim to investigate the correlation between the interaction with a dwarf galaxy and the amplitude of the perturbation induced in the host galaxy, using N-body simulations.

2. Methods

To run the simulations, we used the Gadget-2 code (Springel (2005)). The initial conditions are composed of a Milky Way-like galaxy and a satellite dwarf galaxy, created with the Galstep code (Ruggiero (2017)).

For the host galaxy, we set the following values: number of particles $N_{\text{disk}} = 10^5$ e $N_{\text{halo}} = 10^6$ and mass $M_{\text{disk}} = 5 \times 10^{10}$ $M_\odot$ e $M_{\text{halo}} = 100 \times 10^{10}$ $M_\odot$. For the dwarf galaxy, the number of particles established was $N = 10^3$. We considered different masses (10^9 $M_\odot$ (M1), 5×10^9 $M_\odot$ (M2), 10^{10} $M_\odot$ (M3)) and orbital radii (12 kpc (R1), 20 kpc (R2), 30 kpc (R3)) for the satellite, resulting in a total of nine simulations.

Only in the case of the host galaxy the halo was represented by an analytical potential, because the large number of particles would require a significant amount of computational effort. Because the halo remains approximately spherical throughout the simulation, its particles can be replaced by an analytical profile representing the interaction between them. We used Hernquist's halo density profile (equation 1) and potential (equation 2) (Hernquist (1990)).

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

$$\phi(r) = -\frac{GM}{(r+a)} \tag{2}$$

where $a = 47$ kpc is the scale length.

In order to investigate the correlation between the interaction with the satellite and the amplitude of warp in the disk, we analyzed variations in the mean height and mean velocity in the z-axis. We also graphed the mean velocity and the mean height versus the angle theta. From this, it was possible to plot the maximum amplitude of warp A_{max} versus time for all the simulations: since the largest height differences are at the edges of the disk, we considered the circular sectors in the ring $20 <$ radius < 35 kpc to take an average of the maximum heights (the part of the disk that is tilted upwards) and the minimum heights, in modulus (the part of the disk that is tilted downwards). This average was defined as the A_{max}.

3. Results

Figures 1 and 2 show that, as time goes on, the largest differences in heights become more concentrated at the edges, characterizing the S-shape of the warp. These figures are related to the interaction with a satellite with mass 5×10^9 $M_\odot$ and orbital radius 20 kpc.

Figures 3 and 4 indicate the clear difference between the warps induced by the more and less massive satellites, at $t = 6$ Gyr. Finally, Figure 5 shows the evolution of the maximum amplitude with the passage of time, for 10 Gyr.

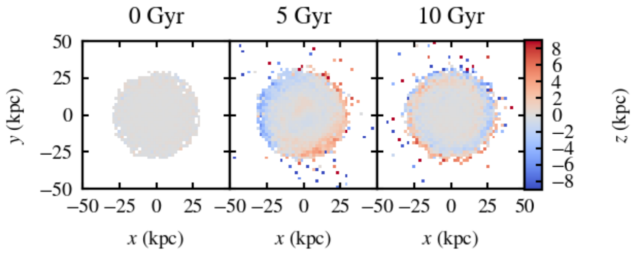

FIGURE 1. Mean height maps of the disk at different times.

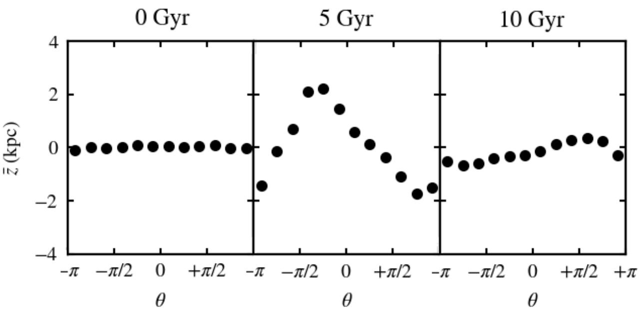

FIGURE 2. Z mean height versus the angle theta at different times.

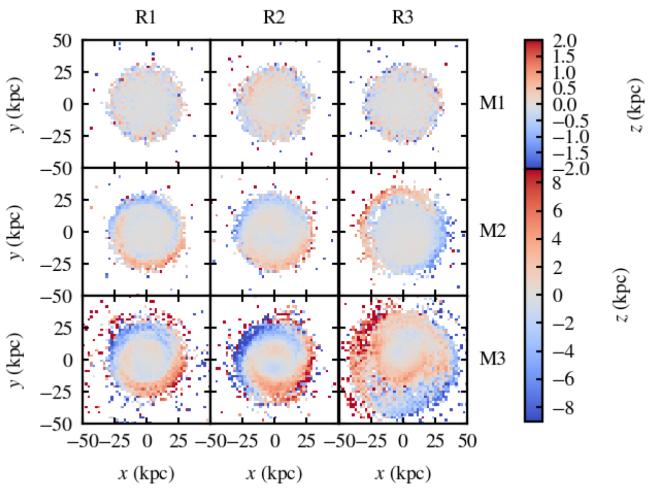

FIGURE 3. Mean height maps of the disk at $t = 6$ Gyr for all the simulations. Notice the different ranges in the first row.

4. Conclusion

In this study we investigated one of the possible causes of warp formation in galactic disks: the close passage of a satellite. We analyzed how the mean vertical heights and vertical velocities change after multiple satellite crossings. Also, we investigated how the maximum amplitude of the warp progresses over time in the simulations.

The amplitude of the vertical distortion in the host disk seems to strongly depend on the mass of the satellite, as shown in Figures 3, 4 and 5. A satellite galaxy with mass $10^9\ M_\odot$ does not disturb the disk noticeably, regardless of the radius of the orbit. However, more massive satellites ($5 \times 10^9\ M_\odot$ and $10^{10}\ M_\odot$) can produce warps that tend to be long-lived, with a lifetime of a few Gyr. This suggests that currently detected warps may have been caused by a disturbance that occurred about 6 Gyr ago, in agreement with recent simulations (e.g. Laporte et al (2018)).

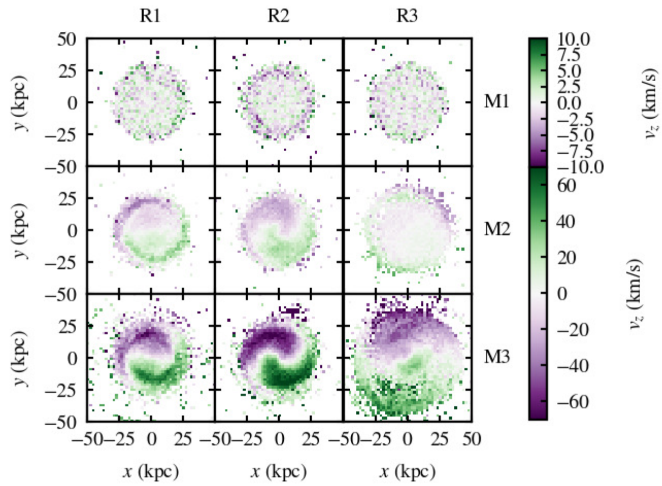

FIGURE 4. Mean velocity maps of the disk at $t = 6$ Gyr for all the simulations. Notice the different ranges in the first row.

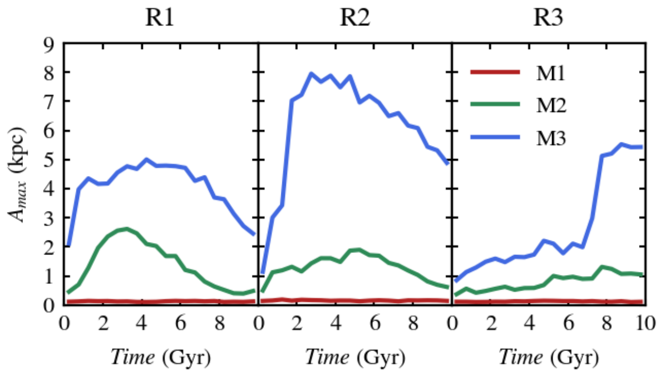

FIGURE 5. Time evolution of the warp amplitude for all the simulations.

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