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Buckling instabilities in N-body simulations of barred galaxies

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Abstract. The formation of galactic bars is connected to the transfer of angular momentum from the stellar disc to the dark matter halo. This process is uneven during its secular evolution, bringing into evidence a particular phenomenon known as bar buckling. Among other effects, this period of instability is associated with an abrupt weakening and thickening of the disc bar, and the formation of a boxy/peanut structure in the galaxy center when observed edge-on. This work aims to explore some features of the stellar bar buckling, taking into account its effects on the dark matter halo bar. We analyze and compare three galaxies from N-body hydrodynamical simulations through a period of 10 Gyr. These galaxies differ in initial gas fraction and halo triaxiality, leading to different bar strengths. By decomposing mass distributions in Fourier series, we quantify the asymmetry for buckling in order to investigate the behaviour of the halo bar during the buckling episode. We find that the buckling of the stellar bar is mimmicked by the dark matter halo bar – which also develops a temporary vertical asymmetry, though in smaller scale – and its magnitude is proportional to the bar strength. The initial gas fraction weakens the buckling of the disc but not that of the inner halo.

Resumo. A formação de barras galácticas está ligada à transferência de momento angular do disco estelar para o halo de matéria escura. Este processo é inconstante durante a evolução secular, trazendo à tona um fenômeno particular conhecido como buckling da barra. Entre outros efeitos, este período de instabilidade está associado a um enfraquecimento abrupto e espessamento da barra do disco, aliados à formação de uma estrutura boxy/peanut no centro da galáxia quando observada de lado. Este trabalho tem como objetivo explorar algumas características do buckling da barra estelar, levando em conta os seus efeitos sobre a barra do halo de matéria escura. Analisamos e comparamos três galáxias de simulações hidrodinâmicas de N-corpos através de um período de 10 Gyr. Estas galáxias diferem na fração de gás inicial e na triaxialidade halo, resultando em diferentes forças da barra. Ao decompor as distribuições de massa em séries de Fourier, quantificamos a assimetria do buckling, a fim de investigar o comportamento da barra do halo durante este evento. Descobrimos que o buckling da barra estelar é reproduzido pela barra do halo de matéria escura – que também desenvolve uma assimetria vertical temporária, embora em menor escala – e sua magnitude é proporcional à força da barra. A fração inicial de gás enfraquece o buckling do disco, porém não o do halo interior.

Keywords. Galaxies: evolution – Galaxies: kinematics and dynamics – Galaxies: halos – Dark matter – Methods: numerical

1. Introduction

Barred galaxies are structures with a bar-shaped central region, comprising up to two-thirds of all spiral galaxies (e.g. Masters, et al. 2011). These bars, which evolve under the total gravitational potential of the host galaxies, are highly influenced by the presence of dark matter. Moreover, it has been shown that an elongated structure in the mass distribution of dark matter develops concomitantly (e.g. Colín, Valenzuela & Klypin 2006; Athanassoula 2005; Berentzen & Shlosman 2006; Petersen, Weinberg & Katz 2016), which is called the halo bar.

Stellar bars usually undergo a period of dynamical instabilities, known as buckling (Martinez-Valpuesta & Shlosman 2004). Seeking to understand the nature of this process, Łokas (2019) found that the vertical orbital instabilities are the most plausible explanation for the occurence of buckling. Recently, Collier, Shlosman & Heller (2018) found that the temporary weakening of the stellar bar (which is correlated with the buckling) is mimicked by the halo bar and Marostica & Machado (2018) recovered these results in simulations with different initial conditions. We here wish to broaden the study of the buckling instability with special attention to the halo bar.

2. Methods

We use N-body hydrodynamic simulations from Athanassoula, Machado & Rodionov (2013), run using `Gadget-2` (Springel 2005), which includes star formation and feedback. In order to explore galaxies with different initial conditions, these simula-

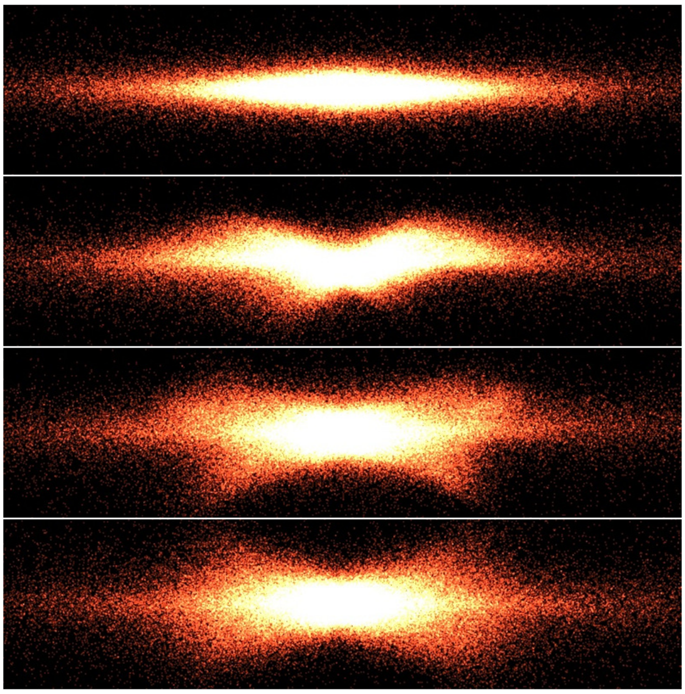

Figure 1. Vertical disk particles distribution of Galaxy 1 at t = 0.0, 3.8, 6.5 and 10.0 Gyr, respectively. This side-on view displays the whole disc (40×10 kpc) as it goes through the initial bending and ensuing formation of a peanut shape in its core.

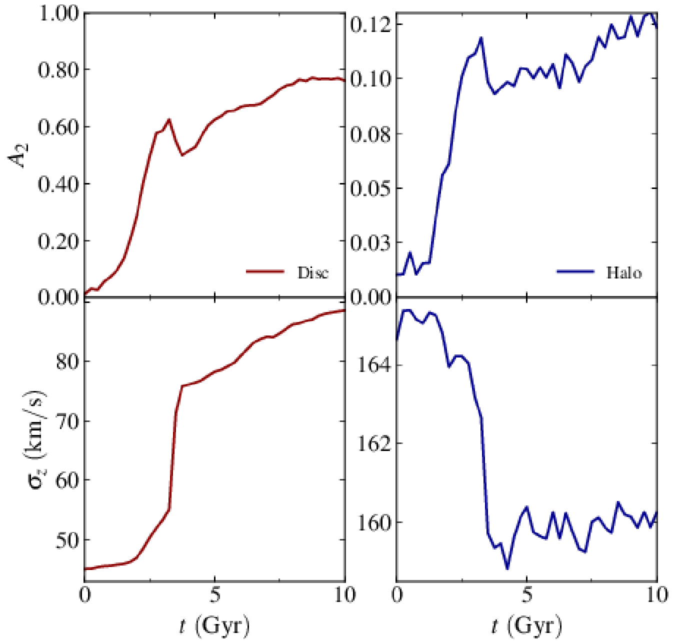

Figure 2. As an example, we plot the bar strength in the upper panels of both the stellar bar (to the left) and the halo bar (to the right) of Galaxy 1 as a function of time (notice the different scales: the halo bar is much weaker). In the lower panels, we plot the velocity dispersion of disk and halo particles along the z axis as a function of time. The velocity dispersions display sudden changes in its derivatives at the exact moment the bar strengths decrease.

tions comprise 10^6 dark matter particles in haloes with different initial axis ratios and also discs with different initial gas fractions. In order to highlight the effects of buckling, we have chosen galaxies with strong bars. Galaxy 1 is gasless and its halo initially spherical, whereas Galaxy 2 is gasless and its halo initially triaxial (b/a=0.8 and c/a=0.6). The dark matter halo of Galaxy 3 is initially spherical, and its initial gas fraction is 20% with respect to the total mass of disk particles.

In order to measure the bar strength and detect the buckling time, we decomposed the mass distribution of the disc and the halo using the relative amplitude of the m=2 mode of the Fourier series for time steps of 0.25 Gyr. We define the bar strength (A_2) as the maximum value of this amplitude. Buckling instabillities occur mainly along the z axis (Łokas 2019), so we measured the velocity dispersion and the average vertical position of the particles along this direction.

3. Results

Here we summarize the preliminary results of this ongoing work. Fig. 2 compares the bar strength with the velocity dispersion of both the disc and the halo as functions of time. We find an increase in the velocity dispersion of particles from the stellar disc, whereas the velocity dispersion of dark matter particles decreases in all galaxies at the moment of buckling. This effect is unusual and will be inspected further in forthcoming works.

Fig. 3 shows the average z position of particles along the x axis at the exact moment of buckling for both the disc bar and the halo bar. The halo mean distribution of particles along the x axis replicates that of the disc . The wings represent a quantification of the bending of the bars, which is approximately symmetrical sideways for both the disc and the halo. The presence of gas strongly interferes in the the vertical disposition of disk particles, albeit our quantification does not show the same strong effect over halo particles.

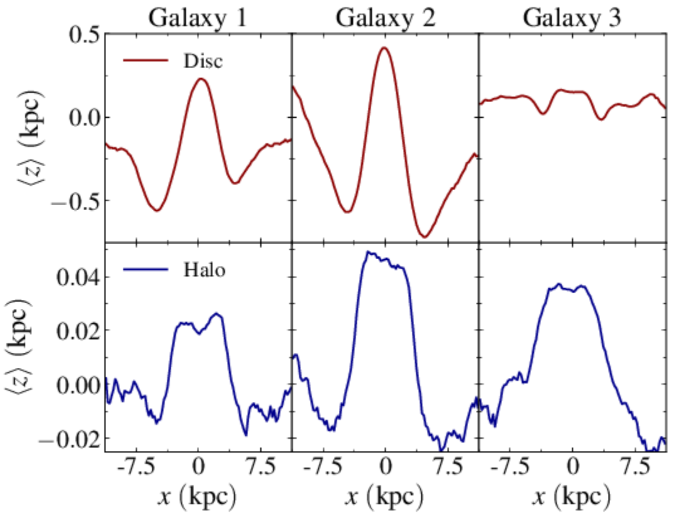

Figure 3. Average z position of particles along the x axis at the exact moment of buckling for both the disc bar (upper panel) and the halo bar (lower panel). The bar angle of each galaxy was obtained through the mass distribution decomposition in Fourier series, in order to rotate the whole structure and create this edge-on and side-on view. Columns represent galaxies 1, 2 and 3, respectively (notice the different scales: the halo bar z averages are much smaller).

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