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The influences of stellar ages on the length of galactic bars

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Abstract. Galactic bars are common structures found in galaxies of the local universe, and their study is a significant task in extragalactic astronomy. An effective approach to investigate their complex orbital dynamics involves *N*-body simulations, which allow for proposing mechanisms of bar formation and mapping their structure. These simulations offer advantages over observational approaches by minimizing attenuation effects in the galactic bulge region caused by stellar dust at certain wavelengths. Our objective is to assess how selecting different stellar populations affects measurements of the length and ellipticity of the galactic bar. We employed the *N*-body simulation code GADGET-4 for our numerical model, including modules for star formation and supernova feedback. Measurements of the bar were conducted by fitting concentric ellipses to the isocurves of the galaxy's mass distribution. Our analyses, upon selecting populations of old (age < 2.1 Gyr), intermediate (age < 1.6 Gyr), and young (age < 1.1 Gyr) stars, indicate that younger stars tend to contribute to an increase in both the length and ellipticity of the bar. The results show variations of up to 20% for certain star groups, suggesting that different stellar populations distinctly influence the properties of the galactic bar.

Resumo. As barras galácticas são estruturas comuns encontradas nas galáxias no universo local, e seu estudo é uma tarefa relevante para a astronomia extragaláctica. Uma abordagem eficaz para estudar sua dinâmica orbital complexa são as simulações de *N*-corpos permitindo propor mecanismos de surgimento da barra e mapear sua estrutura. Essas simulações são vantajosas em comparação com as abordagens observacionais por minimizarem os efeitos de atenuação na região do bojo galáctico causada por poeira estelar em determinados comprimentos de onda. Nosso objetivo é avaliar como a seleção de diferentes populações estelares afeta medidas do comprimento e elipticidade da barra galáctica. Utilizamos o software de *N*-corpos GADGET-4 para executar nosso modelo numérico, contendo módulos de formação estelar e feedback de supernova. As medições da barra foram feitas ajustando elipses concêntricas nas isocurvas da distribuição de massa da galáxia. Notamos, ao selecionar grupos de estrelas velhas (idade < 2.1 Gyr), intermediárias (idade < 1.6 Gyr) e jovens (idade < 1.1 Gyr), que estrelas mais jovens tendem a contribuir para um aumento no comprimento e na elipticidade da barra. Os resultados mostram variações de até 20% para certos grupos de estrelas, indicando que diferentes populações estelares influenciam distintamente as propriedades da barra galáctica.

Keywords. Galaxies: structure – Galaxies: stellar content – Methods: numerical

1. Introduction

The galactic bars are structures commonly found in the local universe (Hoyle et al. 2011) and are therefore essential components for understanding the evolution of a considerable fraction of known galaxies. However, their complex orbital structures make it very difficult to measure their properties, especially the bar length (Ghosh & Di Matteo 2023). Considering these difficulties, *N*-body simulations are a very common approach to help understand bar properties and their evolution.

The *N*-body simulations can be used to reproduce observational approaches, such as obtaining the bar properties through purely geometric information (ellipticity and position angle) (Méndez-Abreu et al. 2018), from its brightness (or mass) distribution. In *N*-body simulations, the possibility of selecting specific populations and avoiding biases such as the extinction of certain galactic components is particularly useful.

The temporal evolution of our numerical model is illustrated in Fig. 1, which contains optical mock images of the simulated galaxy, Illustrating with different colors the simulation of the stellar properties of each simulated star particle, such as age and metallicity. It can be seen that after a few giga years there are simultaneously different stellar populations distributed across the disk.

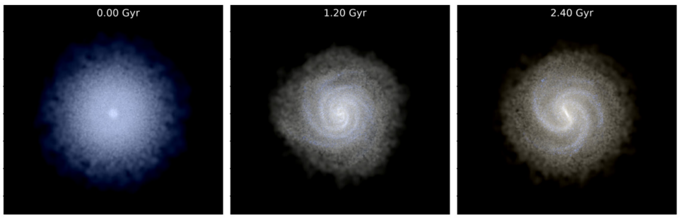

Figure 1. Optical mock images of the simulated galaxy. Each frame is 60 kpc wide. Rendered plot was maded with a modified of the star.render code from the python library pynbody.

2. Objective

Observational estimates of bar length often give priority to wavelengths that are resistant to extinction by galactic dust, such as the -i band, however, this filters can attenuate the presence of certain stellar populations, which can affect measures (Lange et al. 2015). With the different challenges of measuring the bar length in mind, we aim to estimate whether the selection of certain stellar populations of stars affects the bar length measurement.

3. Methods

Our barred galaxy model has exponential profile components such as the galactic disk and the gas disk simulated with N-bodies and a halo of the Hernquist profile (Hernquist 1990) type simulated as an analytical potential. The initial condition was generated with the software Galstep (Ruggiero & Lima Neto 2017) and the *N*-body code was GADGET-4 (Springel et al. 2021). The simulation was run until the galaxy had a bar suitable to be measured and a favorable star formation rate, which occurred at 2.6 Gyr.

To estimate the length of the bar, we developed an algorithm that fits concentric ellipses to the mass isocurves of the 2d histograms of the galaxy.

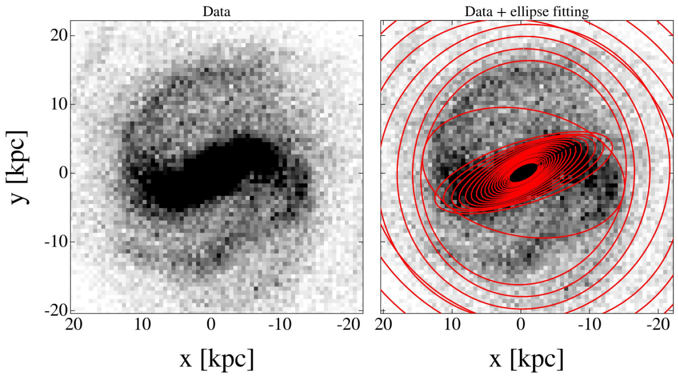

Figure 2. Ellipse fitted to the galaxy bar in the 2.6 Gyr snapshot.The image of the bar (left) and the ellipse fitting algorithm applied (right).

The criterion for defining the length of the bar is the abrupt variation in the position angle (PA) and the ellipticity of the fitted concentric ellipses (Michel-Dansac & Wozniak 2006). As can be seen in Fig. 3, the end of the plateau in the parameter graph indicates the end of the bar and the beginning of the galactic disk.

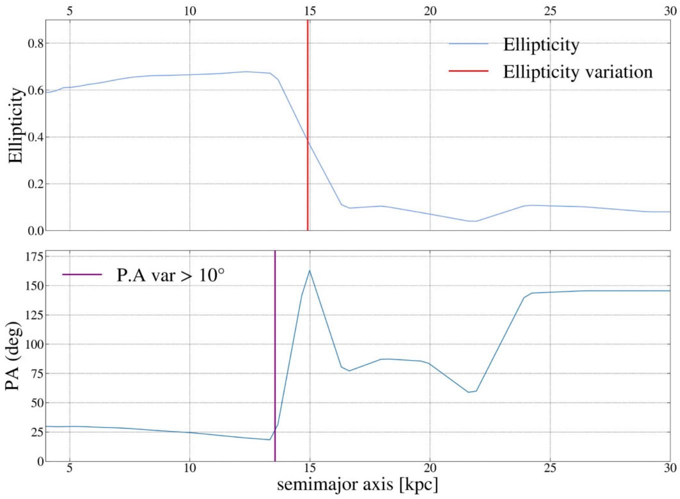

Figure 3. Ellipticity (e) and the position angle (PA) versus the radius of the galaxy derived from the semi-major axis obtained from the ellipse fitting.

To analyze different ages, we selected 3 stellar populations according to the formation time of the simulated stellar particles: old group (age < 2.1 Gyr) intermediate group (age < 1.6 Gyr) young group (age < 1.1 Gyr), excluding the disk from the initial condition.

4. Results and Conclusions

As can be seen in Fig. 4, groups of younger stars tend to contribute to an elongation and flattening of the bar. The values obtained for the bar length, ellipticity and position angle can be found in table 1. The position angle remained constant for the 3 groups analyzed.

Table 1. Measures from the algorithm for estimating the bar length by ellipse fitting.

Stellar Population	Max Bar Ellipticity	Bar Length (kpc)
Old (age < 2.1 Gyr)	0.71	13.06
Intermediate (age < 1.6 Gyr)	0.80	14.36
Young (age < 1.1 Gyr)	0.86	15.80

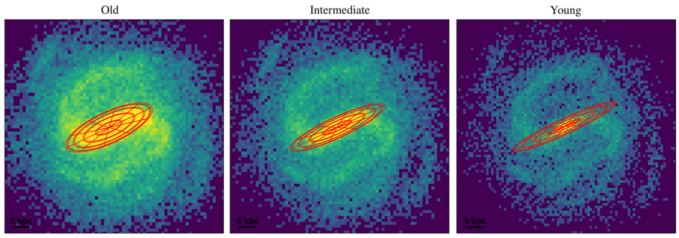

Figure 4. 2D mass histograms and ellipsoids of estimated bar length and ellipticity for three stellar populations.

Based on the ellipticity and length results obtained for the same snapshot when selecting the mass distribution of different stellar populations, we can propose:

- In our simulation context younger star populations tend to contribute to a lengthening and flattening of the bar. However, numerically they make a smaller contribution.
- The ellipticity variation of up to 20% suggests that using maximum ellipticity to define the end of the bar may not be the best approach. The position angle remains constant for all 3 groups.
- The three ellipsoids bar models from the same snapshot suggest that one of the challenges of measuring the length of the bar may arise from different populations of stars that make it up.

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