Revista Mexicana de Astronomía y Astrofísica Serie de Conferencias, 60, 200-201, (2026)

OPEN ACCESS https://doi.org/10.22201/ia.14052059p.2026.60.177

Evolution of the orbital structure in self-consistent N-body simulations

Diego Valencia-Enríquez[1] **and Ivânio Puerari**[2]

[1]*Universidad Mariana, Calle 18 No. 34 - 104, 52001 Pasto, Colombia.*
[2]*Instituto Nacional de Astrofísica, Óptica y Electrónica, Calle Luis Enrique Erro 1, Santa María Tonantzintla, 72840 Puebla, México.*

Keywords: *galaxies: bulges, galaxies: structure, galaxies: evolution, methods: numerical*

Corresponding author: dvalencia@umariana.edu.co

We present a comprehensive analysis of the orbital dynamics in three N-body models, each consisting of a stellar disk embedded within a dark matter halo. As these models undergo evolution, bars naturally form within the galactic plane, exhibiting different buckling stages depending on the initial conditions. Subsequently, the bars take on varied shapes such as boxy, peanut, or elongated forms. We assess the orbital evolution by conducting frequency analyses on phase space coordinates for all disk particles at 1 Gyr intervals. Despite the short integration time and notable early-time bar evolution, histograms of the ω_z/ω_x ratio (the vertical frequency to the frequency along the bar major axis) for particles from the 2:1 family exhibit a consistent pattern, transitioning from a high to low ω_z/ω_x ratio as the bar evolves. After the initial Gyr, the disk-dominated model develops a boxy structure lasting for 1 Gyr before transitioning to a peanut shape, which persists until the end of the simulation. The intermediate model manifests a boxy structure after 2 Gyr, enduring for approximately 2 Gyr before evolving into a peanut shape. In contrast, the halo-dominated model develops the boxy structure much later, around 3 Gyr, and the peanut morphology is only incipient at the end of the simulation (7 Gyr).

We studied the orbital structure evolution for three N-body models from Valencia-Enríquez et al. (2019, 2023) using the dominant frequencies of the disk particles. The models differ on the values of the initial Spin parameter of the disc λ_d. We recalculated the simulations with high time resolution to get the frequencies of the orbits in the disk particles.

In order to analyze these frequencies, we take the bar frame of reference where the bar is in a horizontal position for all snapshots. We calculate the frequencies of the orbits from each disk particle using the phase space coordinates as a function of discrete time ($x(t)$, $y(t)$, $z(t)$, $v_x(t)$, $v_y(t)$, and $v_z(t)$ for Cartesian coordinates, and the azimuthal position $\theta(t)$ and the radial velocity $v_r(t)$, for cylindrical coordinates) in each Giga year of evolution. Therefore, we analyze the orbital frequency distribution of the bar structure in a disk galaxy as the bar potential evolves.

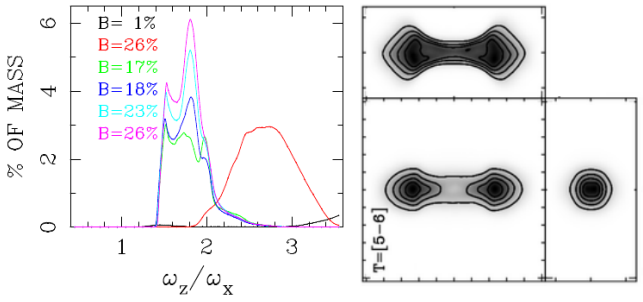

Figure 1. The left side shows histograms of orbital frequency for ω_z/ω_x ratio and the contribution to the bar orbits. The colors represent the time interval of one Giga-year of frequency analysis: black, red, green, blue, cyan, and purple lines are for 0-1, 1-2, 2-3, 3-4, 4-5, and 5-6 Giga-years, respectively. The right side of the figure represents the orbits assembly density profile (OADP) in edge-on (top panel), face-on (bottom left panel), and end-on (bottom right panel) views for Barred orbits from the disk dominate model for the last time interval.

We focused on bar-type orbits, which fill the $1.9 < \omega_R/\omega_x < 2.1$ interval, where we found that before the bar formation, the ratio ω_z/ω_x shows high values, see red line of Figure 1, during the bar formation, a phenomenon called "buckling" takes place and pushes orbits out of the galactic plane. In this process, the vertical frequencies move to lower values; see the rest of the lines, which represent the evolution of the frequency analysis. On the other hand, the "buckling" is responsible for the formation of the peanut and/or the X shape observed in edge-on-barred galaxies. This process is shown in the right side of Figure 1.

"XVII LARIM", Montevideo, Uruguay, November 27 - December 1, 2023.Volume Editors: Gonzalo Tancredi, Cecilia Mateu & Juan José Downes

References

Valencia-Enríquez, D., Puerari, I., & Chaves-Velasquez, L. 2023, MNRAS, 525, 3162, doi: 10.1093/mnras/stad2437

Valencia-Enríquez, D., Puerari, I., & Rodrigues, I. 2019, AJ, 157, 175, doi: 10.3847/1538-3881/ab100f

"XVII LARIM", Montevideo, Uruguay, November 27 - December 1, 2023.Volume Editors: Gonzalo Tancredi, Cecilia Mateu & Juan José Downes