Model	Periodic orbits in the bar 000	Unstable invariant manifolds 000

Manifolds and orbits in a warped bar potential

Patricia Sánchez Martín Directors: J.J. Masdemont, M. Romero-Gomez

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Work in progress

Model and Potentials

• What is the goal?



Galaxy ESO 510-G13 photographed by Hubble telescope.



Work in progress

Equations of motion

• The Precessing Miyamoto-Nagai Ferrers galactic model:

$$\begin{cases} \dot{x}_1 = x_4 \\ \dot{x}_2 = x_5 \\ \dot{x}_3 = x_6 \\ \dot{x}_4 = 2\Omega\cos(\varepsilon)x_5 + \Omega^2\cos(\varepsilon)^2x_1 + \Omega^2\sin(\varepsilon)\cos(\varepsilon)x_3 + \phi_{x_1} \\ \dot{x}_5 = -2\Omega\cos(\varepsilon)x_4 - 2\Omega\sin(\varepsilon)x_6 + \Omega^2x_2 + \phi_{x_2} \\ \dot{x}_6 = 2\Omega\sin(\varepsilon)x_5 + \Omega^2\sin(\varepsilon)\cos(\varepsilon)x_1 + \Omega^2\sin(\varepsilon)^2x_3 + \phi_{x_3} \end{cases}$$

 ε the tilt angle, Ω the angular velocity of the bar and ϕ the potential ($\phi = \phi_{bar} + \phi_{disc}$).

 Model as in Pfenniger (1984): Ferrers bar + Miyamoto-Nagai disc

with parameters:

- A = 3, B = 1, a = 6, b = 1.5, c = 0.6 (kpc), n = 2.
- $GM_d \in [0.5, 0.9], GM_b \in [0.1, 0.4] (G(M_d + M_b) = 1).$
- $\Omega \in [0.05, 0.06] \text{ rad}/[u_t] = [24.44, 29.33] \text{ km/s/kpc}.$
- $\varepsilon \in [0, 0.2] \text{ rad} = [0, 5.73]^{\circ} \ (\varepsilon \ tilt \ angle).$

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- Onstable invariant manifolds
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Model	Periodic orbits in the bar ●○○	Unstable invariant manifolds 000	
arepsilon=0			
Periodic	orbits, L_3		

- Periodic orbits in central equilibrium point, L₃.
 - Stable periodic orbits give structure to the bar.
 - Parameters: $GM_b = 0.1$, $\Omega = 0.05471$.
 - Tilt angle $\underline{\varepsilon} = 0$:



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Model	Periodic orbits in the bar ○●○	Unstable invariant manifolds 000	Work in progress
arepsilon=0.1, 0.2			
Modify t	he tilt angle		

• Tilt angle $\varepsilon = 0.1$:



• Tilt angle $\varepsilon = 0.2$:



Model				
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Periodic orbits in the bar ○○●

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Work in progress

$\varepsilon = 0, 0.1, 0.2$

Comparison between $\varepsilon's$



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- Periodic orbits in the bar
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Model	Periodic orbits in the bar 000	Unstable invariant manifolds •00	
In L_1 and L_2			
Invarian	t manifolds		



Invariant manifolds. In the centre of the plot, a white solid line shows the Lyapunov orbit around L_1 . The two branches of the unstable invariant manifold are indicated by red lines, the two branches of the stable invariant manifold by green lines, and grey by the forbidden region surrounded by the zero velocity curves.

Model	Periodic orbits in the bar 000	Unstable invariant manifolds ○●○	
In L_1 and L_2			
Morpho	ology of a galaxy		

• Morphology given by the invariant manifolds when varying Ω , the bar mass, GM_b, and the inclination ε :



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Model	Periodic orbits in the bar	Unstable invariant manifolds	Work in progress
In L_1 and L_2			
Galaxy v	warps		



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Model
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- Periodic orbits in the bar
- Unstable invariant manifolds
- Work in progress



How stars feel this precession?

- Test-particle simulations:
 - Hot initial conditions simulating old disc population (K-giants).
 - Integrating i.c. in the precessing galactic model introducing the bar adiabatically.

Model	Periodic orbits in the bar 000	Unstable invariant manifolds 000	

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Model	Periodic orbits in the bar 000	Unstable invariant manifolds 000	

Por si acaso...



Untsable invariant manifolds and periodic orbits for $\varepsilon = 0.2$



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Model and Potentials

- Model: Ferrers bar + Miyamoto-Nagai disc.
- Potential: $\phi = \phi_{bar} + \phi_{disc}$.

$$\phi_{bar} = \pi \ G \ abc \frac{\rho_0}{n+1} \int_{\lambda}^{\infty} \frac{du}{\Delta(u)} (1-m^2(u))^{(n_h+1)}$$
$$\phi_{disc} = -\frac{GM_d}{\sqrt{R^2 + (A+\sqrt{B^2+z^2})^2}}$$

- Parameters:
 - A = 3, B = 1, n = 2, a = 6, b = 1.5, c = 0.6.
 - $GM_d \in [0.5, 0.9], GM_b \in [0.1, 0.4] (G(M_d + M_b) = 1).$
 - $\Omega \in [0.05, 0.06], \ \varepsilon \in [0, 0.2].$