The backbone of 3D bars

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Abstract

The backbone of 3D bars is the 'x1-tree'. This is a tree of families of periodic orbits consisting of the plain x1 orbits and its bifurcations.

1 3D bars

Orbital theory has often provided useful information on the structure of galactic bars. Thus it is now understood that a 2D bar is basically due to regular orbits trapped around the so called 'x1' periodic orbits (Contopoulos & Grosbøl 1989), which are elongated along the bar major axis. Such orbits do not extend beyond the corotation resonance, and in many cases no suitable elongated orbits can be found beyond the 4:1 resonance. This led orbital theory to predict that bars should end at or before corotation (Contopoulos 1980).

In a series of papers (Skokos et al. 2002a,b ; Patsis et al. 2002a,b) we investigate the orbital structure of 3D models representing barred galaxies. We use a fiducial case to describe all families of periodic orbits that may play a role in the morphology of three-dimensional bars. We show that, in a 3D bar, the backbone of the orbital structure is not just the x1 family, as in 2D models, but a tree of 2D and 3D families bifurcating from x1. Besides the main tree we have found also two other groups of families of lesser importance. The first builds a bubble of orbits around the 3:1 resonance, and the second is located beyond a gap of the x1-characteristic. We also find that 3D orbits alongated along the bar minor axis can be formed by bifurcations of the planar x2 family. They can support 3D bar-like structures along the minor axis of the main bar. Banana-like orbits around the stable Lagrangian points build a forest of 2D and 3D families as well. The importance of the 3D x1-tree families at the outer parts of the bar depends critically on whether they are introduced in the system before or after the local maximum of the x1 characteristic at the radial 4:1 resonance.

Furthermore we investigate the orbital structure in a class of 3D models for galactic bars. We consider different values of the pattern speed, of the strength of the bar and of the parameters of the central bulge of the galactic model. The morphology of the stable orbits in the bar region is associated with the degree of folding of the x1-characteristic. This folding is larger for lower values of the pattern speed. The elongation of rectangular-like orbits belonging to x1 and to x1-originated families depends mainly on the pattern speed. The detailed investigation of the trees of bifurcating families in the various models shows that major building blocks of 3D bars can be supplied by families initially introduced as unstable in the system. In models without radial and vertical 2:1 resonances we find, except for the x1 and x1-originated families, also families related to the z-axis orbits, which support the bar. Bifurcations of the x2 family can build a secondary 3D bar along the minor axis of the main bar. This is favoured in the slow rotating bar case.

2 Conclusions

- So far the x1 orbits were considered the backbone of bars. This, however, can only be the case for 2D bars, since the x1 can only populate the z=0 plane.

For 3D bars the backbone is the x1 together with the tree of its 3D bifurcating families. Trapping around these families will determine the thickness and the vertical shape of galaxies in and around the bar region.

- The (x, y) projections of the 3D families of the x1-tree retain in general their morphological similarity with their parent family at the same energy. This has important implications for the morphology of a galaxy since it introduces building blocks which have similar morphology as the x1 orbits, but have a considerable vertical extension.
- The way the 3D families of the x1 tree are introduced in the system depends on the location of the instability strip associated with the vertical resonance at which they are bifurcated.
- The radial 3:1 resonance region provides in the system several 2D and 3D stable families. Their role, however, is locally confined as in 2D models.
- 3D orbits elongated along the minor axis of the bar can be formed by bifurcations of the planar x2 family.
- At the even radial resonances we have gaps in the x1-characteristic, as in 2D models. Beyond these gaps we find isolated groups of families of 2D and 3D orbits.
- We have found several families of 3D banana-like orbits around $L_{4,5}$.
- Stable families found beyond corotation circulate material between the outer parts of the system and regions as far inwards as 1 kpc. This contributes to the mixing of the elements in a disc galaxy.
- In all models we examined, the extent of the orbits which are most appropriate to sustain 3D bars is confined inside the radial 4:1 resonance.
- The evolution of the characteristic of the basic family x1 depends heavily on the pattern speed. The slower the bar rotates, the most complicated the x1-characteristic curve becomes. In the slowest of our models the families x1, x2 and x3 share the same characteristic curve.
- The bars can be supported not only by x1-originated families but, depending on the model, by 3D orbits bifurcated from families related with the z-axis orbits. This has been encountered in the case of a model without radial or vertical 2:1 resonances.
- Slow pattern rotation favours the presence of 3D x2-type orbits along the minor axis of the main bar. These orbits can lead to a 3D inner bar.
- The most elongated 4:1 rectangular-like orbits have been encountered in the fast rotating bar model.
- In the x1-tree we encounter complex instability mainly in the family bifurcated from x1 at the vertical 2:1 resonance. However, complex instability is found in 3D banana-like orbits as well. In 3D Ferrers bars non-linear phenomena like collisions of bifurcations, inverse bifurcations and bubbles (Contopoulos 1986) are very common.

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