Formation of inner rings in 3D potentials of barred galaxies

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Abstract. In a 3D analytic potential we find the families of periodic orbits that support the formation of inner rings. These are families at high energies, between the inner radial ultraharmonic 4:1 (iUHR) resonance and corotation, influenced by the 4:1, 6:1 and 8:1 resonances. The inner rings they support are mainly ovals and polygons with 'corners' on the bar minor axis, on its sides, which correspond to morphologies often seen in real galaxies like NGC 6782 and IC 4290. We also investigate the conditions under which less probable shapes of rings may be supported by orbits at the region. Such rings include pentagonal features (NGC 3367) and hexagons with cusps on the major axis of the bar and two sides parallel to it (NGC 7020).

Inner rings are a feature often observed in barred galaxies (see e.g. Buta 1995). Most inner rings are oval, sometimes with a somewhat lemon shape because of density enhancements on the bar major axis (e.g. NGC 6782). Another usually observed ring morphology is the one of IC 4290 which has an oval ring with characteristic breaks or corners. In this case, the oval is not smooth and forms, or gives the impression of having, angles. As exceptional cases of inner rings we mention the ring of NGC 3367, which has an almost pentagonal geometry, and the ring seen in the deprojected image of NGC 7020 (Buta 1990), which has an hexagonal shape, with cusps on the major axis of the bar and two sides parallel to it.

In order to calculate stable periodic orbits which support a 3D ring, we use the fiducial case of the 3D bar potential described in detail in Skokos et al.(2002). The potential consists of a Miyamoto disc, a Plummer sphere bulge and a Ferrers bar. The families of periodic orbits that support the above mentioned ring morphologies belong to the so called $f-$ and $s-$group orbits (Patsis, Skokos, & Athanassoula 2003). Both families are located in the upper part of a type–2 gap (Contopoulos & Grosbøl 1989) of the x1 characteristic at the 4:1 resonance. The 'mother' planar 2D $f-$family and its 2D and 3D bifurcations are influenced by the 4:1, 5:1 and 6:1 resonances, while the orbits of the $s-$group are influenced by the 6:1, 7:1 and 8:1 resonances. Using weighted profiles of stable periodic orbits of the f and s groups of families, Patsis et al. (2003) were able to explain the shapes of the most frequently observed inner rings, as well as the rarity of

ring–types like the ones of NGC 3367 and NGC 7020. The main results of our study are:

1. In 3D Ferrers bars, inner rings are due to orbits belonging to families in the upper part of the type-2 gap at the inner radial 4:1 resonance. They are grouped in two orbital trees, which have as mother-families the planar f and s orbits. For building the rings one cannot invoke orbits from the x1 tree or other families. The orbits that make the rings belong in their vast majority to three-dimensional families of periodic orbits.

2. The prevailing types of inner rings are variations of oval shapes and are determined by the way the f and s families are introduced in the system, i.e. by the tangent bifurcation mechanism (see Contopoulos 2002, pg. 102 for a definition). The orbits on the stable branch of their characteristic, together with their stable 3D bifurcations, support ovals with a more or less strong lemon shape, or oval-polygonal rings with 'corners' along the minor axis of the bar. These types of inner rings represent frequently observed morphologies.

3. Pentagonal rings are rare, because the families building them have small stable parts and usually come in symmetric pairs. Thus, in order for these rings to appear, the symmetry must be broken and only one of the two branches be populated, due to some particular formation scenario.

4. If orbits are trapped around stable s periodic orbits at the energy minimum of the s characteristic, then an NGC 7020 morphology can be reproduced. Although such a morphology is in principle possible, it should be rare, because it would necessitate that considerable amount of material be on regular orbits trapped around periodic orbits in a very narrow energy interval. Indeed the hexagonal orbits with cusps on the major axis are on the unstable branch of the tangent bifurcation.

References

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