Barred Galaxies
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A Survey of Orbits in 2D N-body Bars

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Abstract. A barred galaxy is mainly built of billions of stars moving on different orbits. Understanding of the orbital structure is essential for the interpretation of observations. The orbital structure can be investigated using analytical models and N-body simulations. This paper presents a method to classify orbits found in N-body simulations, i.e. orbits in a time-dependent potential. I present some results about mass loss and mass gain of bars and the influence of a bulge.

1. Time Dependent Potentials

The potential of a real galaxy can change for a number of reasons such as e.g. the passage of a companion or redistribution of mass. Therefore it is important to study the effects of a time-dependent potential on the periodic orbits. One opportunity to study evolving potentials is represented by N-body simulations. To understand the shapes of the orbits found in N-body simulations, it is necessary to first study the behavior of orbits in analytical potentials. A number of analytical potentials, resembling those of barred galaxies, have been constructed and used for integration of orbits. Some of these have been described by Contopoulos & Grosbøl (1989). A thorough discussion of the bar characteristics necessary to be considered, when constructing a model of a barred galaxy, can be found in Teuben & Sanders (1985).

2. An Orbit Classification Code

Orbits from an N-body simulation can be highly irregular, and due to the variety of shapes a survey can be hard to make. Figure 1 shows examples of orbits straight from N-body simulations; more examples can be found in Sundin et al. (1993). Some kind of classification scheme is essential if we are to obtain a general knowledge about the construction of the bar. I have therefore developed a computer code capable of distinguishing between some of the most common and important classes of orbits. These classes are orbits confined to either the bar or the disk, orbits around L_4 or L_5, and transitions between these classes. The input to the code is a file containing the positions and velocities, for 4000 randomly chosen particles, at each passage of the bar major or minor axis. The program is trained to recognize certain patterns, characteristic for each class. For example, an orbit around L_5 should have all axis passages on the extension of the bar minor axis and never cross the bar major axis, and an orbit confined to

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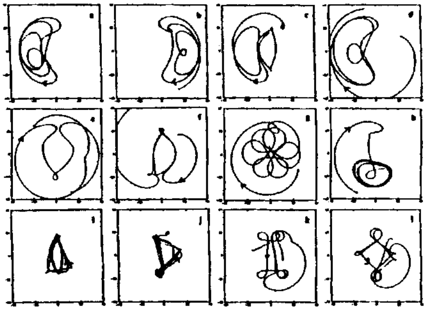

Figure 1. Some examples of orbits found in N-body simulations.

the bar should have consecutive passages of bar minor, major, minor etc., axes, always inside the bar. There are a large number of details to be considered, such as loops, so I continuously test the code and keep a class for uncertainties. The output from the code can be presented in several ways but, to put it shortly, we obtain the percentages of orbits belonging to each of the classes at all time-steps during the simulation.

3. Results

3.1. Mass Loss and Mass Gain of the Bar

The classification code can be used to study transfer of mass between the bar and the disk. So far, I have studied the influence of a perturber on the mass loss or mass gain of the bar. There exists a correlation between mass loss/gain and the pattern speed of the bar. Further information regarding this can be found in Sundin et al. (1993). Whether the bar will gain or lose mass depends on a combination of the mass of the perturber and the angle between the perturber and the bar major axis at the pericenter passage.

3.2. The Influence of a Bulge

The presence of a bulge will induce mass loss from the bar. This is due to the destruction of some of the x_1 orbits. The mass loss is approximately 2-4% during three rotation periods of the bar, for a bulge with a radius of half the bar major axis and a bulge mass between 0% and 14% of the total mass of the galaxy. A higher bulge mass leads to more mass loss, and finally no bar can form. A bulge with a high mass will also give the bar a higher initial pattern speed. In all cases, the bar will slow down as can be seen in Figure 2. The trend looks quite clear with a higher bulge mass leading to a higher initial pattern speed, and all bars slowing down. I would like to raise a word of caution though when comparing pattern speeds. Bars will form on different time-scales depending on e.g. the bulge model and it is hard to define an exact time as the bar formation in N-body simulations. Hence it might not be correct to compare the pattern speeds of two bars at the same time-step in different simulations since one of the bars could have had a longer time to slow down. To be able to compare pattern

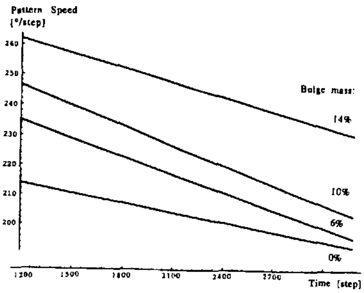

Figure 2. Linear fits of the pattern speed of the bar w.r.t. time.

speeds, I find it quite necessary to plot the pattern speed for several rotation periods starting early in the simulation. To separate between different slowing down rates, it can be useful to plot the time-derivative of the pattern speed. I have some work in progress in this area indicating that the slowing down rate decreases with time.

References

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Discussion

G. Contopoulos: Can you say why you don't find any figure-eight shaped orbits such as for instance Richard Miller found?

M. Sundin: The pattern speeds of these bars are high enough to prevent an ILR, thus no such orbits can be present.

P. Teuben: How does the classification program work?

M. Sundin: The program is trained to recognize certain shapes.

J. Hunter: Can you explain why your 6% bulge case seems to have a constant or a triple valued pattern speed for a significant length of time when the other cases do not?

M. Sundin: It was an effect of a bad fit, in Figure 2 I present some linear fits to the same data.

G. Contopoulos: Many of the orbits that you have shown seem rather regular or at least not strongly chaotic. Can you distinguish between almost regular orbits and strongly chaotic orbits?

M. Sundin: It could probably be done if the time-dependence of the potential is small.