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BAR-HALO INTERACTIONS AND THEIR EFFECT ON THE BAR STRENGTH AND PATTERN SPEED

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RESUMEN

Las simulaciones de N cuerpos muestran que las barras se forman de manera natural en los discos galácticos. Esto sucede aun si los discos son submáximos, a causa de la contribución de las partículas resonantes del halo. El halo no es rígido, sino que responde a la barra, y parte de su masa está en resonancia con ella. Las partículas del disco atrapadas alrededor de las órbitas periódicas cerradas de la familia x_1, o alrededor de las órbitas 3D que se bifurcan a partir de ella, emiten momento angular, el cual se absorbe ya sea por las partículas en resonancia del disco exterior, o por las del halo. Como la barra es una perturbación de momento angular negativo, mientras más momento angular pierde, más intensa se vuelve. Así, las barras más intensas se encontrarán en los casos en los que que la cantidad de momento angular intercambiada haya sido mayor. Discuto las propiedades de los discos y halos que determinan la cantidad de momento angular intercambiada.

ABSTRACT

N-body simulations show that bars form naturally in galactic discs. This can happen even if the discs are sub-maximum, due to the contribution of the halo resonant particles. The halo is not rigid, but responds to the bar and some of its mass is in resonance with the bar. The disc particles trapped around the closed periodic orbits of the x_1 family, or around the 3D orbits that bifurcate from it, emit angular momentum, which is absorbed either by particles at resonance in the outer disc or by resonant halo particles. Since the bar is a negative angular momentum perturbation, the more angular momentum it loses, the stronger it will become. Thus the strongest bars will be found in cases where the amount of angular momentum exchanged has been largest. I discuss the disc and halo properties that determine the amount of angular momentum exchanged.

Key Words: **DARK MATTER — GALAXIES: EVOLUTION — GALAXIES: HALOS — GALAXIES: KINEMATICS AND DYNAMICS — METHODS: NUMERICAL**

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Already in the early seventies (Miller, Prendergast & Quirk 1970, Hohl 1971, etc) N-body simulations had shown that bars can grow spontaneously in galactic discs. 2D simulations, or 3D simulations with rigid haloes, or low resolution simulations argued convincingly that haloes can stabilise discs. Thus, ironically, stabilising discs against bar formation was one of the first arguments in favour of massive haloes in disc galaxies (e.g. Ostriker & Peebles 1973; Ostriker, Peebles & Yahil 1974).

Advances in computer technology have now made it possible to model properly disc systems embedded in live haloes. Such modelling has shown that there is considerable interaction between the disc and the halo and that this influences the evolution of the system. I will here briefly discuss the exchange of angular momentum between the disc and the halo and its effect on the bar growth and slowdown. The work presented here has been taken from five papers, of which three are published (Athanassoula & Misiriotis 2002, hereafter AM; Athanassoula 2002a, hereafter A02a; Athanassoula 2002b, hereafter A02b) and two will be submitted shortly (A03a, A03b). Since this is a vast subject I have restricted myself to initially spherical, non-rotating, isotropic haloes and neglected the gas component. Qualitatively similar results should be found for oblate, rotating, non-isotropic haloes, whose disc lies in their equatorial plane, although there could be important quantitative differences. A total of over 150 simulations were used for the work described here. The initial conditions and the numerical methods are described in AM and A02.

AM showed clearly that, contrary to previous belief, bars can grow in sub-maximum discs and that they can actually be stronger than bars which have grown in maximum discs. This is possible since the angular momentum that is emitted in the bar region is absorbed not only by the resonant particles in the outer disc (Lynden-Bell & Kalnajs 1972), but also by resonant particles in the halo component. The existence of such resonant particles in the halo, as well as their distribution amongst the various reso-

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nances, was shown by A02 with the help of spectral analysis. The more angular momentum the halo can absorb, the more angular momentum can be taken from the bar. Since the bar is a negative angular momentum perturbation, the more angular momentum is taken from it, the stronger it will grow. This explains how bars in sub-maximum discs can grow to be stronger than bars in maximum discs. Yet this relation is not always monotonic, since emitters and absorbers should be in equilibrium. It is thus of no use to have a halo that can absorb very large quantities of angular momentum if the bar is only capable of emitting a small amount. The balance between the two is followed in detail in (A03b).

Exchange of energy and angular momentum between the disc and the halo affects not only the bar strength, but also its pattern speed. Several studies have shown a decrease of the pattern speed with time (e.g. Tremaine & Weinberg 1984; Weinberg 1985; Hernquist & Weinberg 1992; Athanassoula 1996; Debattista & Sellwood 1998, 2000; Valenzuela, these proceedings), but there is no general agreement as to how strong this effect is. This does not necessarily mean that some of these estimates are wrong. As shown in A03a, important slowdown rates occur in cases where a considerable amount of angular momentum has been exchanged between the emitters and the absorbers, while small slowdown rates occur in cases with little exchange. Nevertheless, the relation between the pattern speed change and the angular momentum exchange is more complicated than the corresponding relation for the bar strength, since the bar inertia is involved in the former.

Everything else being equal, a large amount of angular momentum exchange means that there are abundant emitters as well as absorbers. To concentrate on the halo, this means that the halo must have sufficient mass in the resonant regions. Mass, however, is not the only factor determining this exchange, since it is the whole halo distribution function that comes into play. Indeed hotter material can absorb less angular momentum than cold material, as is quantitatively shown in A03a. Indeed, in that paper I show that it is possible to restrict both the length of the bar and its slowdown rate by changing either the mass of the halo in the resonant regions, or its responsiveness, via its distribution function. This effect can explain a number of the differences between results in the literature, since some simulations have bigger and/or more responsive haloes than others.

The disc responsiveness plays also a crucial role. Indeed by increasing the initial value of Q in the disc it is possible to stop the bar slowdown (A02b). Thus a cold disc can show a considerable bar slowdown, while a hot disc with an identical mass distribution, embedded in an identical halo, could have no bar slowdown. This effect can explain a number of the differences in the literature, since some simulations start off very cold, and others less so.

Finally numerical effects also can influence the energy and angular momentum exchange. For example, if the softening was chosen too small for the number of particles in the simulations, then noise will dominate and particles will not be able to stay on resonant orbits and emit/absorb angular momentum. Thus this numerical inadequacy will artificially stop the angular momentum exchange and limit the strength of bars and their slowdown rate.

To summarise I can say that the amount of angular momentum emitted by the inner disc and absorbed by the outer disc and halo determines both the strength and the slowdown rate of the bar. This amount exchanged is a function of the distribution functions of the halo and disc components, and not only of their mass. Thus the bar slowdown rate can not be used to set a limit to the halo-to-disc mass ratio, unless precise knowledge of the disc and halo distribution functions is available, which is certainly not the case for real galaxies.

REFERENCES

Athanassoula, E. 1996, in “Barred Galaxies”, ed. R. Buta, D. A. Crocker & B. G. Elmegreen, ASP conf. series 91, 309

Athanassoula, E. 2002a, ApJ, 569, L83

Athanassoula, E. 2002b, in “Galactic Discs : Kinematics, Dynamics and Perturbations”, ed. E. Athanassoula, A. Bosma & R. Mujica, ASP conf. series, 275, 141

Athanassoula, E. & Misiriotis, A. 2002, MNRAS, 330, 35

Debattista, V. & Sellwood, J. A. 1998, ApJ, 493, L5

Debattista, V. & Sellwood, J. A. 2000, ApJ, 543, 704

Hernquist, L. & Weinberg, M. D. 1992, ApJ, 400, 80

Hohl, F. 1971, ApJ, 168, 343

Lynden-Bell, D. & Kalnajs, A. 1972, MNRAS, 250, 161

Miller, R. H., Prendergast, K. H. & Quirk, W. J. 1970, ApJ, 161, 903

Ostriker, J. P. & Peebles, P. J. E. 1973, ApJ, 186, 467

Ostriker, J. P., Peebles, P. J. E. & Yahil, A. 1974, ApJ, 193, L1

Tremaine, S. & Weinberg, M. D. 1984, MNRAS, 209, 729

Weinberg, M. D. 1985, MNRAS, 213, 451

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