# $N$-BODY SIMULATIONS OF DISC GALAXIES CAN SHED LIGHT ON THE DARK-MATTER PROBLEM

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ABSTRACT

In this contribution, we discuss the enigmatic coupling between dark matter and spiral structure in disc galaxies, and emphasize the strong impact that recent advances in $N$-body modelling can have on the solution of the problem.

## 1. Introduction

Dark matter is not so invisible in disc galaxies. Indeed, it can influence their observable structure through the dynamical action of the halo (for a review of dark matter halos around galaxies see the comprehensive work by Salucci & Persic 1997).

The basic reason seems to be well understood: the mass and mass distribution of the halo, among other factors, affect the stability properties of the whole galaxy and, in turn, stability affects morphology. Roughly speaking, a galaxy with non-massive halo tends to be strongly unstable and to develop a barred spiral structure, whereas a galaxy with massive halo tends to be weakly unstable and to develop a normal spiral structure. (See, e.g., Binney & Tremaine 1987; Sciama 1993.)

On the other hand, the precise dynamical interplay between halo and disc is not yet clearly understood. Their masses and mass distributions give rise to a universal rotation curve (Persic et al. 1996; Salucci & Persic 1997). The related angular speed and epicyclic frequency enter the stability properties in two major ways: through the Toomre parameter, and through the corotation and Lindblad resonances. To complete the chain, all these factors together determine the spiral structure of the galaxy but, at the same time, not all the dynamical characteristics manifest themselves in the form of observables. (See, e.g., Bertin & Lin 1996.) Thus the link with the halo is indirect and difficult to discern.

Because of that, careful approaches progress slowly, but are becoming more and more predictive (cf. Block et al. 1994). Simpler approaches may look appealing, but ignore important aspects of the problem (cf. Athanassoula et al. 1987). One such aspect is the fundamental role that cold interstellar gas can play in the instability process. As a matter of fact, this component acts on the stability threshold and level of the disc, and thus changes the criterion for choosing realistic values of the Toomre parameter (Bertin & Romeo 1988).

Finally, we should not forget that there are two interesting alternatives to the classical scenario. The first is that dark matter in spiral galaxies is, in large part, cold gas (Pfenniger et al. 1994; Pfenniger & Combes 1994; Combes & Pfenniger 1997). The second is a modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis (e.g., Milgrom 1983, 1989; see also McGaugh & de Blok 1998a, b). The dark-matter problem still awaits solution.

## 2. Towards a Better Understanding of the Dark-Matter Problem

A better understanding of the dark-matter problem can only result from a closer interdisciplinary connection between theories, simulations and observations, as is in the spirit of this conference (Masiero, Persic & Salucci 1998). Let us emphasize the potentialities of simulations and, why not, also their weaknesses.

The importance of computer simulations in astrophysics is analogous to that of experiments in other branches of physics. They also serve as a welcome bridge between theories, often restricted to idealized situations, and observations, revealing instead the complexity of nature. Major present objectives are to construct physically consistent $N$-body models of disc galaxies and to simulate their dynamical evolution, especially in regimes of spiral structure in which a fruitful comparison between theories and simulations can be made (e.g., Pfenniger & Friedli 1991; Junqueira & Combes 1996; Zhang 1996, 1998a, b; Bottema & Gerritsen 1997; Fuchs & von Linden 1998). The construction of such models is indeed a difficult task which has not yet been fully accomplished, and which should eventually provide clues of vital importance to a number of open questions posed by both theories and observations.

$N$-body simulations of disc galaxies can shed light on the dark-matter problem, because in such experiments we can control the amount and distribution of dark matter and probe their dynamical effects. This research programme demands to optimize the fidelity of simulations, apart from their technical performance. The current fashion is to try and improve the models by including more realistic phenomena, often without checking the physical consistency of the basic model. Figures 1 and 2 illustrate one such example: the result of the simulation is an artifact of the code. In contrast, our involvement has been threefold:

- We have investigated how faithful simulations are [Romeo 1994 (Paper I)].
- We have devised a method for exploring the dynamical effects of softening*, which is a critical factor in simulations, and we have focused on two applications that reveal the dynamical differences between the most representative types of softened gravity [Romeo 1997 (Paper II)].

* Such an artifice removes the short-range singularity of the gravitational interaction, which is dynamically unimportant and computationally troublesome, whereas leaves its long-range behaviour unchanged.

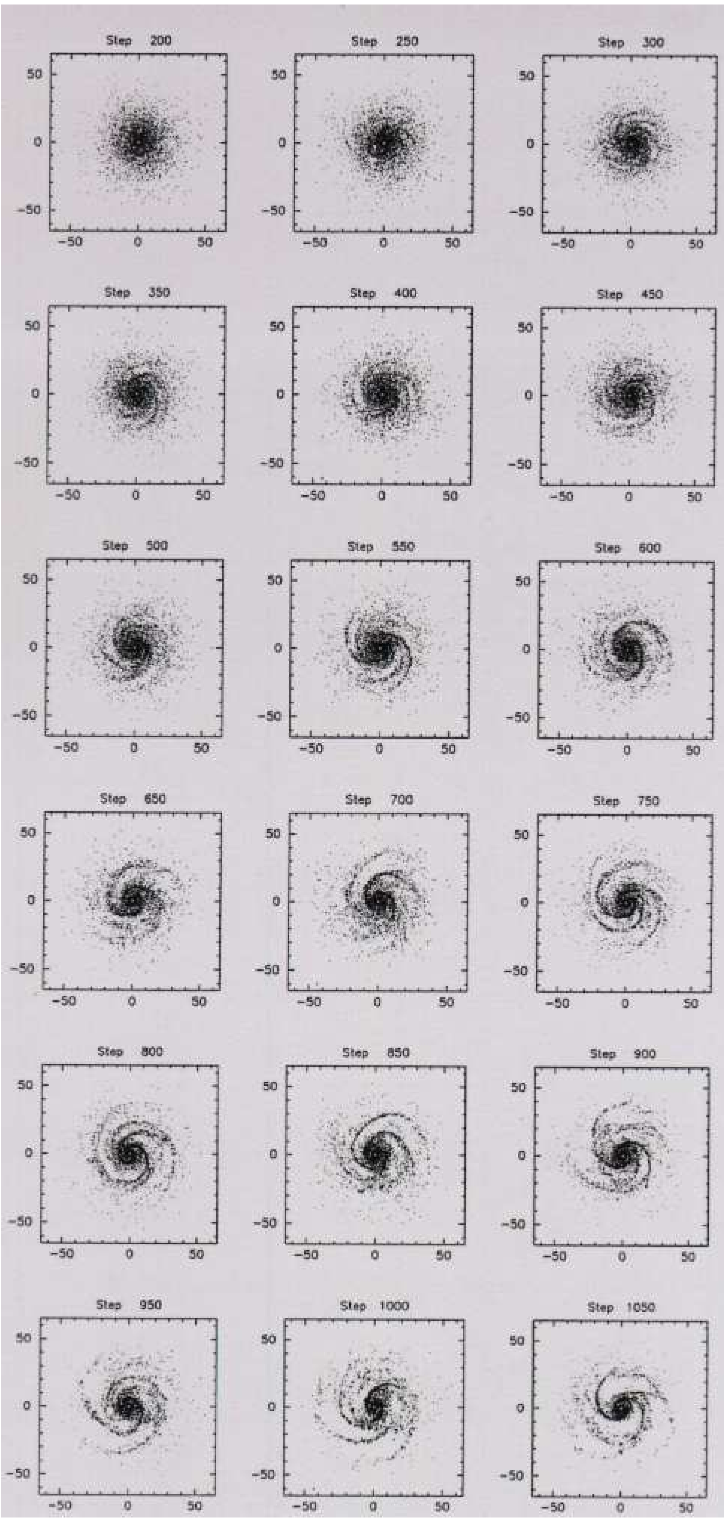


Fig. 1. $N$-body simulation of a disc galaxy with long-lived grand-design spiral structure. The dynamical model and computer code are equivalent to those of Thomasson et al. (1990) (see also Elmegreen & Thomasson 1993)

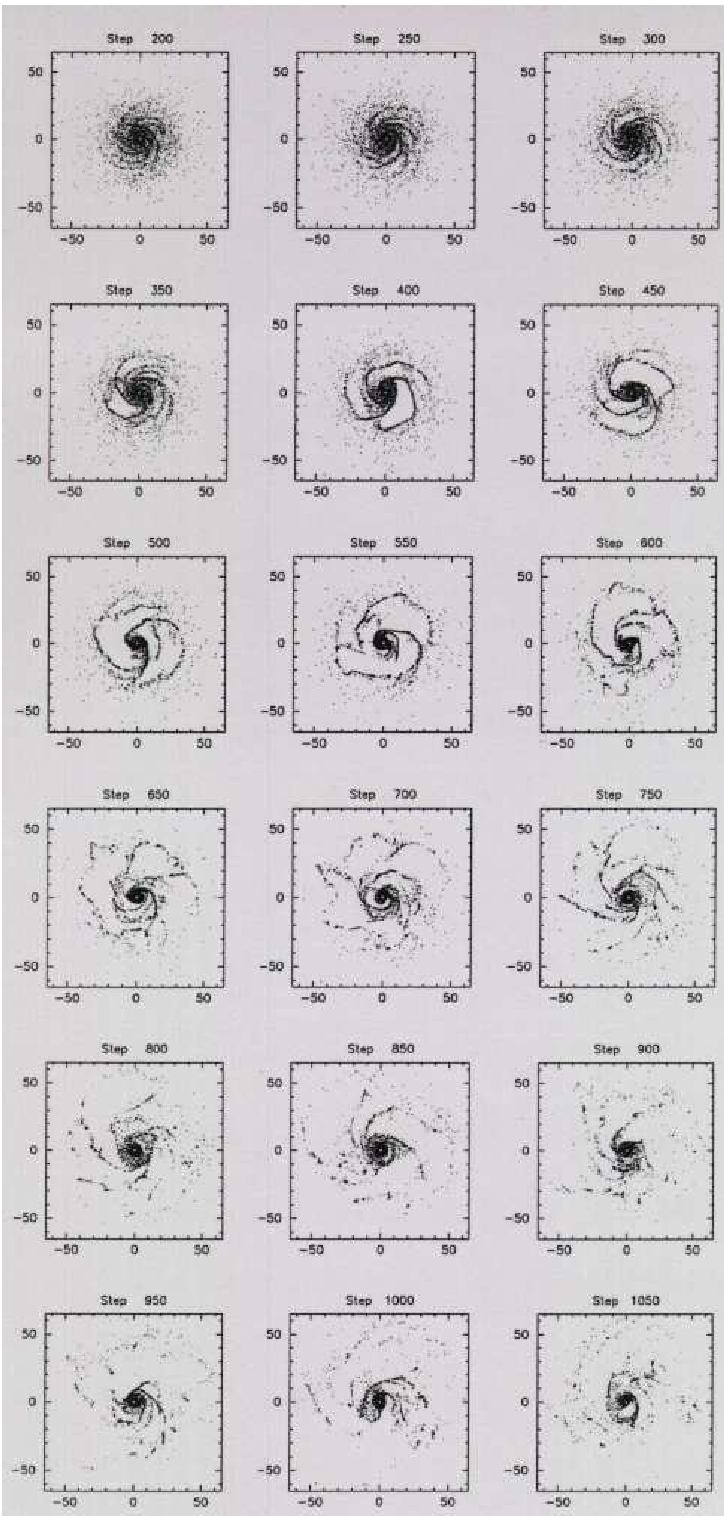


Fig. 2. This is what happens when we use the same model as in Fig. 1 and just halve the mesh size in the (particle-mesh) code: the spiral structure becomes flocculent and short-lived. The conclusions are clear (cf. Sect. 2)

- We have shown that our method can be applied in another, more fruitful, way: for developing new ideas about softening. Indeed, it opens a direct route to the discovery of optimal types of softened gravity for given dynamical requirements, and thus to the accomplishment of a physically consistent modelling of disc galaxies, even in the presence of a cold interstellar gaseous component and in situations that demand anisotropic resolution [Romeo 1998 (Paper III)].

Our three research works lay the foundations of the proposed plan.

## 3. Conclusions

At the present stage, it is premature to draw conclusions. We hope that the trilogy (Papers I-III) and these further reflections will strongly encourage $N$-body experimenters to apply our method for optimizing the fidelity of their simulations, and that the result will be a better understanding of the dark-matter problem.


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