Simulations of the formation of thick discs in galaxies
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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2009

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Villalobos Cofre, A. A. (2009). Simulations of the formation of thick discs in galaxies. s.n.

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Download date: 13-02-2020
Every time we are outdoors and we look around it is amazing how little attention we pay to the sky, even though it is practically half of what surrounds us. Normally when we look at it we are interested mostly in the present or the (near) future, in terms of just the atmospheric conditions. However we should remember that the sky and the deep space beyond hold also a whole lot of information about our past as well as about the origins and history of the Universe we live in.

Astronomy is the science that studies the light that reaches us from every corner of the Universe, looking for answers to fundamental and broad questions such as, How and when was the Universe born? How did galaxies, stars and planets form? Where did the elements we are made of come from? What is the origin of life on the Earth?

Figure 5.3: Milky Way rising (Credit: J. P. Stanley, http://www.flickr.com/photos/jpstanley).
Galaxies are made of billions of stars, as well as gas and dust, and in general they can be classified according to their shapes into: spirals (flattened discs), ellipticals (round or elongated) or irregulars (those that are neither spirals nor ellipticals, and whose morphologies often appear disturbed). Our Milky Way belongs to the first type. Based on different properties of stars, the structure of our Galaxy can be divided into several components (Fig. 5.4). From inside out these components are: the bulge, at the centre of the galaxy; the disc, which contains most of the stars of the Galaxy; and the more extended stellar halo that surrounds both the bulge and the disc. Furthermore, the disc of the Milky Way can be subdivided into a bright thin disc (where our Sun is located) of relatively younger stars, and a fainter thick disc of mostly older stars.

Among all the components of the Milky Way the thick disc is particularly interesting
since it contains some of the oldest stars in the Galaxy. This fact suggests that the process by which the thick disc was formed could be closely related to how the whole Galaxy was assembled. However, it is currently not well understood how the Galactic thick disc came into existence. Components similar to the thick disc of the Milky Way are not rare in the Universe since they have been observed in many other galaxies. Thus, investigations on the formation process of thick discs could lead to a better understanding of the formation of galaxies in general and in particular that of our Milky Way.

By means of numerical simulations, this Thesis explores the scenario in which a thick disc is formed when a thin disc of a galaxy is thickened after a collision with a smaller but relatively massive satellite galaxy. In this model the final thick disc is composed by stars from both the – now thickened – initial disc and the satellite which is disrupted after the encounter. A key characteristic of this scenario is that the final thick disc presents significant rotation about its centre, similar to that of the initial (progenitor) thin disc.

The main goals of this Thesis are to characterise in detail the aforementioned formation scenario of thick discs and to make for this model robust predictions that could be confronted to both current and future observations in the Milky Way and in other galaxies. Some of the most important questions addressed in this study are:

1. What is the final distribution of the stars from the disrupted satellite? What is its dependence on the initial configuration of the encounter?
2. Are there traces of the initial thin disc galaxy after the collision?
3. What general structural and kinematical observations of galaxies can be explained by this formation scenario?
4. What kind of evidence of this scenario is imprinted in the positions and velocities of thick disc stars located in small spatial volumes resembling the “Solar neighbourhood”?
5. What happens to a thick disc when a new thin disc is slowly grown? What are the most relevant aspects of the growth affecting this evolution?
6. Are the global and local observables and diagnostics previously identified in the simulated thick discs still valid after the slow growth of a new thin disc?
7. If the thick disc of the Milky Way was formed according to this scenario, what would have been the general properties of its progenitor disc (before the collision)? What should have been the orbital parameters of the infalling satellite favoured by this model?

In Chapter 2 I present an in-depth description and the analysis of a number of numerical experiments simulating a collision between a galaxy with a thin disc and a smaller satellite that result in the formation of a stable thick disc. In these simulations I explore several characteristics of the progenitors as well as of the collision itself that are likely to have an impact on the characteristics of the final thick discs. In particular, I explore how different structural properties of both the disc galaxy and the satellite, different mass-ratios between these systems, as well as how different morphologies and orbital parameters for the satellite influence the properties of the remnant object. I also study the orbital decay of the satellites and their mass loss as well as its dependence on the initial orbital parameters. I explore the final spatial distribution of stars from both the thickened disc and the satellite to establish...
which characteristics may possibly be uniquely attributed to this formation scenario. Finally, I analyse in detail both structural and kinematical properties of the simulated thick discs.

In Chapter 3 I re-analyse the simulations of Chapter 2 from a different perspective. This time the focus is on studying specific properties related to the final phase-space structure (positions and velocities) of thick disc stars when they are located within small volumes. The aim is to find robust indicators of the “origin-by-collision” of thick discs, which could be directly retrieved from observations of nearby stars in this Galactic component. I study the non-axisymmetries found in the final spatial distribution of the thick discs, their relation with the initial orbital parameters of the satellite and also their effect on the velocities of stars. I also determine the different distribution of stars from both the progenitor disc and the satellite in velocity space with special emphasis on the predicted distributions of heliocentric (radial) line-of-sight velocities.

In Chapter 4 I extend the evolution of the simulated thick discs of Chapter 2 to include the growth of a more massive and thin new disc, eventually embedded within each thick disc. I explore the impact of various properties of the new thin disc and of its growth on the morphology and kinematics of the thick discs. I also probe the robustness of the most important results obtained in Chapters 2 and 3 to the growth of the new disc.