Contribution of Spiral Arms to the Thick Disk along the Hubble Sequence

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The Formation and Evolution of Exponential Disks in Galaxies, October 5 - 9, 2014 Flagstaff, Arizona

Abstract

The first mechanism invoked to explain the existence of the thick disk in the Milky Way Galaxy, were the spiral arms. Up-to-date work summon several other possibilities that together seem to better explain this component of our galaxy, but the contribution of each one has not been straightforward to quantify.
In this work, we present a first comprehensive study of the effect of spiral arms in the formation of thick disks, as going from early to late type disk galaxies, in an attempt to characterize and quantify this specific mechanism in galactic potentials. To this purpose, we perform numerical simulations of test particles in a 3D spiral galaxy potential of normal spiral galaxies (from early to late types). **By varying the parameters of the arms we found that the vertical heating of the stellar disk is very important in some cases, and strongly depends on the galaxy morphology, pitch angle, arms mass and its pattern speed. The later is the galaxy type, the larger is the effect on the disk heating.** We applied this study to the specific example of the Milky Way Galaxy. From this we deduce that the effect of spiral arms of a MW potential, on the dynamical vertical heating of the disk is negligible, unlike later galactic potentials for disks.

Galaxy Model

We ran test particle simulations on a 3-D galactic potential that models normal spiral galaxies (Sa, Sb and Sc). The model includes an axisymmetric component (Bulge, Disk, Dark Matter Halo) (Allen & Santillán 1991), plus a detailed potential of spiral arms.

For the arms we use a bisymmetric self-gravitating potential, PERLAS model (Pichardo et al. 2003). This potential consists of individual inhmogeneous oblate spheroids superposed along a logarithmic spiral locus (Roberts 1979). This is a more realistic potential since it is based on a density distribution and considers the force exerted by the whole spiral structure, obtaining a more detailed shape for the gravitational potential, unlike a 2-D local arm such as the tight winding approximation (TWA).

The parameters used to model normal spiral galaxies (Sa, Sb and Sc) are presented in the next Table (Pérez-Villegas 2013).

Table: Parameters of the Galactic Models

Parameter		Value Sa	Value Sb	Value Sc	Reference
Axisymmetric Components					
M_B / M_D		0.9	0.4	0.2	1,2
M_D / M_H		0.07	0.09	0.1	2,3
Rot. Curve ($\mathrm{km\ s^{-1}}$)		320	250	170	4
M_D ($10^{10}M_\odot$)		12.8	12.14	5.10	3
M_B ($10^{10}M_\odot$)		11.6	4.45	1.02	M_B/M_D based
M_H ($10^{12}M_\odot$)		1.64	1.25	0.48	M_D/M_H based
Scale-lengths of the Axisymmetric Components (kpc)					
Bulge:	b_1	2.5	1.7	1.0	
Disk:	a_2	7.0	5.0	5.3178	
	b_2	1.5	1.0	0.25	
Halo:	a_3	18.0	16.0	12.0	
Spiral Arms					
locus			Logarithmic		5,9,10
arms number			2		6
pitch angle (°)		8-40	9-45	10-60	4,7
M_{sp}/M_D			1-5%		9
scale-length (kpc)		7	5	3	disk based
Ω_{sp} ($\mathrm{km\ s^{-1}\ kpc^{-1}}$)		-30	-25	-20	5,8
ILR position (kpc)		3.0	2.29	2.03	
CR position (kpc))		10.6	11.14	8.63	
inner limit (kpc)		3.0	2.29	2.03	∼ILR position based
outer limit (kpc)		10.6	11.14	8.63	∼CR position based

[1] Weinzirl et al. (2009). [2] Block et al. (2002). [3] Pizagno et al. (2005). 4 Ma et al. (2000). [5] Grosbøl & Patsis (1998). [6] Elmegreen & Elmegreen 2014. [7] Kennicutt (1981). [8] Gerhard 2011. [9] Pichardo et al. (2003). [10] Seigar

Initial Conditions

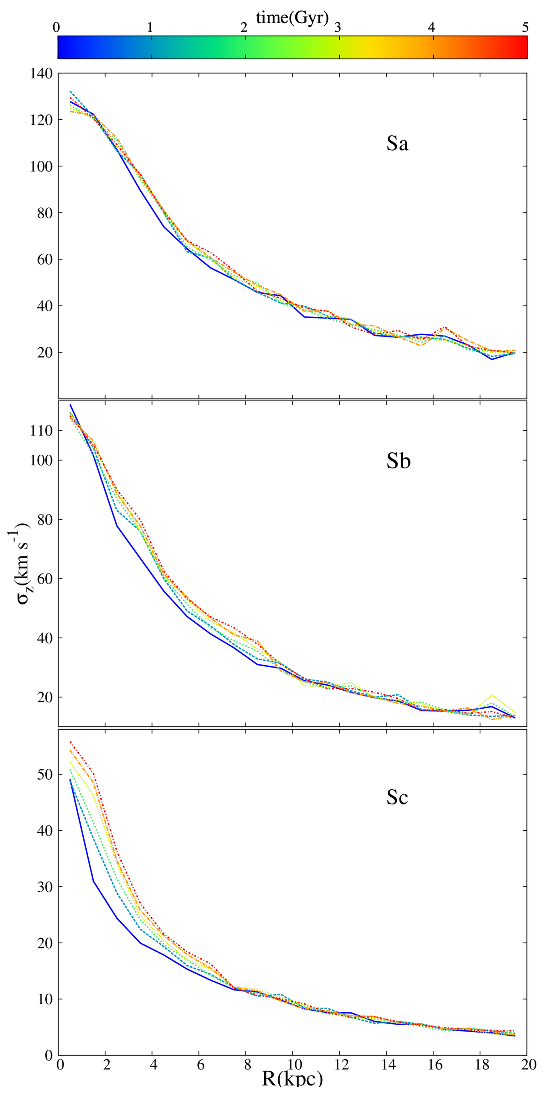
The initial stellar distribution follows the density profile of Miyamoto & Nagai (1975). This to avoid any transient effects induced by differences between the initial particle distribution and the imposed disk potential.

The particles are distributed in the velocity space by introducing a dispersion as a function of R in response to the background potential.

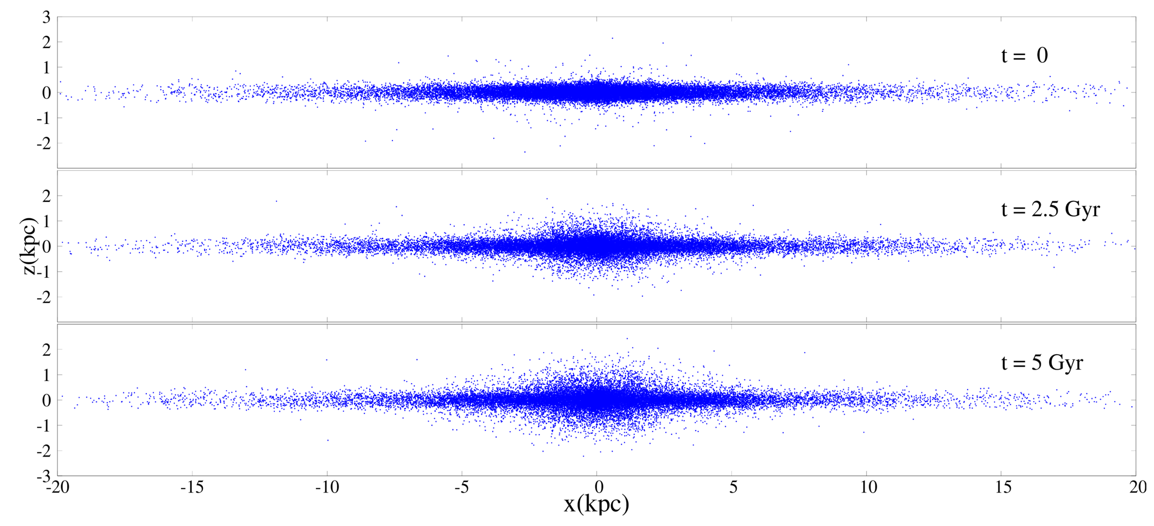
With this implementation the initial stellar disk has been proved stable under the axisymmetric components of the model.

Dependence on Morphology

Spiral galaxies come in a variety of morphologies and therefore spanning a wide range of values for the parameters that characterise the galaxy type. The plots show an increase in vertical dispersion due to the spiral arms. This increase is small for the Sa galaxy and grows with the morphological type, being bigger for the Sc galaxy.

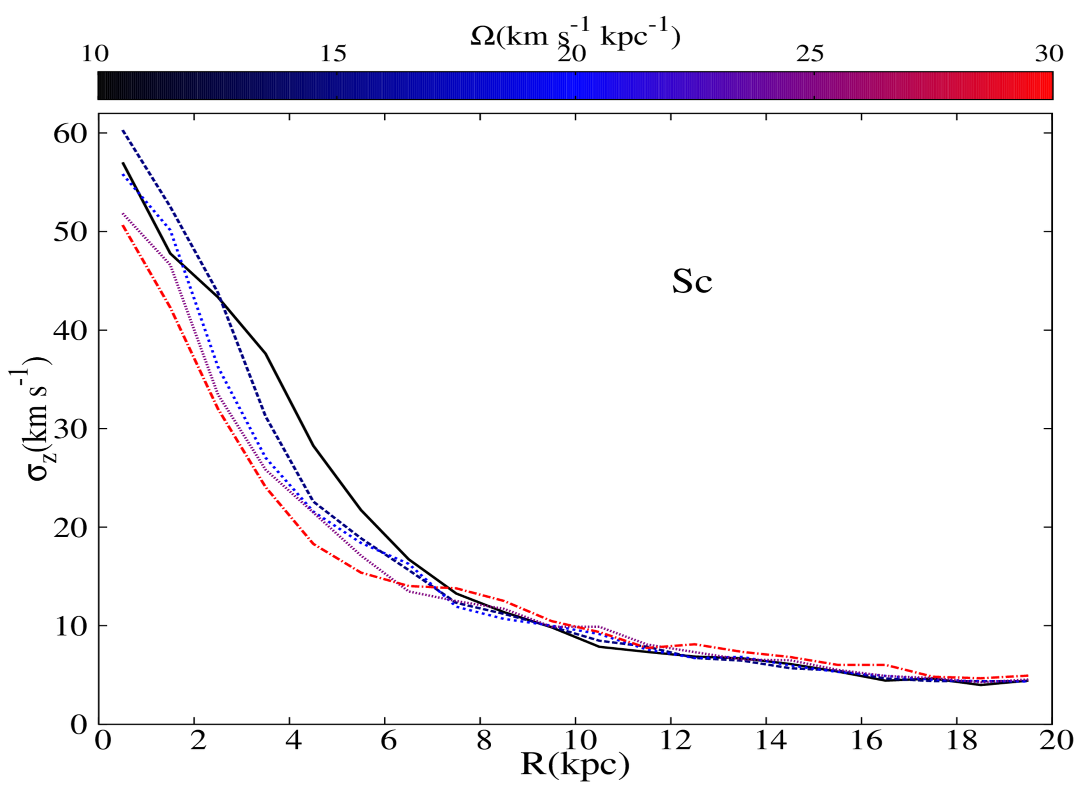


For a Sc galaxy we can see the heating directly on the spatial distribution of the stellar disk particles. In this $x - z$ projection of the stellar distribution we can see a thickening in the disk during the temporal evolution.

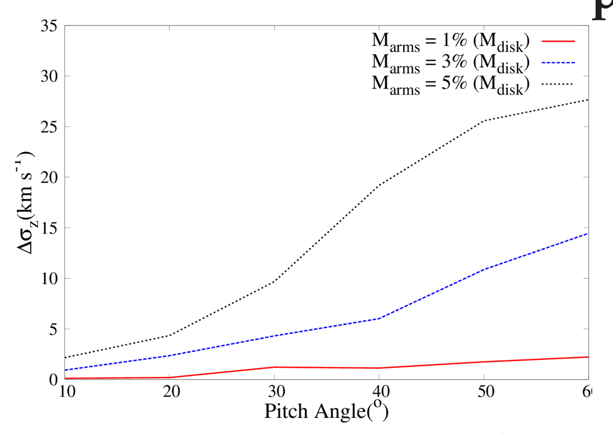


The Pattern Speed Ω

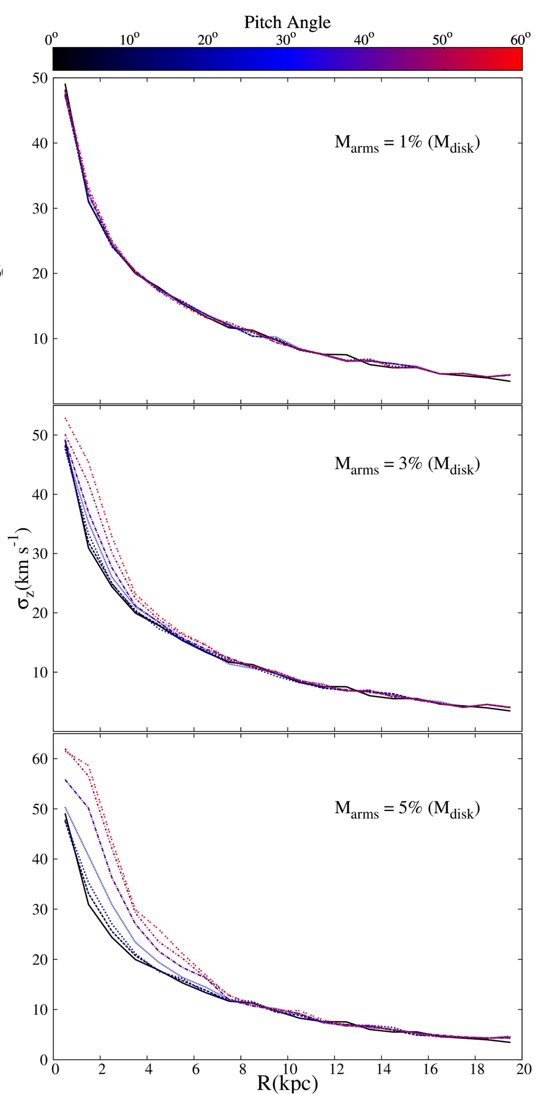
The vertical heating is greater for slow rotating arms and decrease for those that rotate faster. Small values of Ω allow the spiral arms to heat more efficiently the stellar disc, independently of galaxy type.



Arms Mass and Pitch Angle

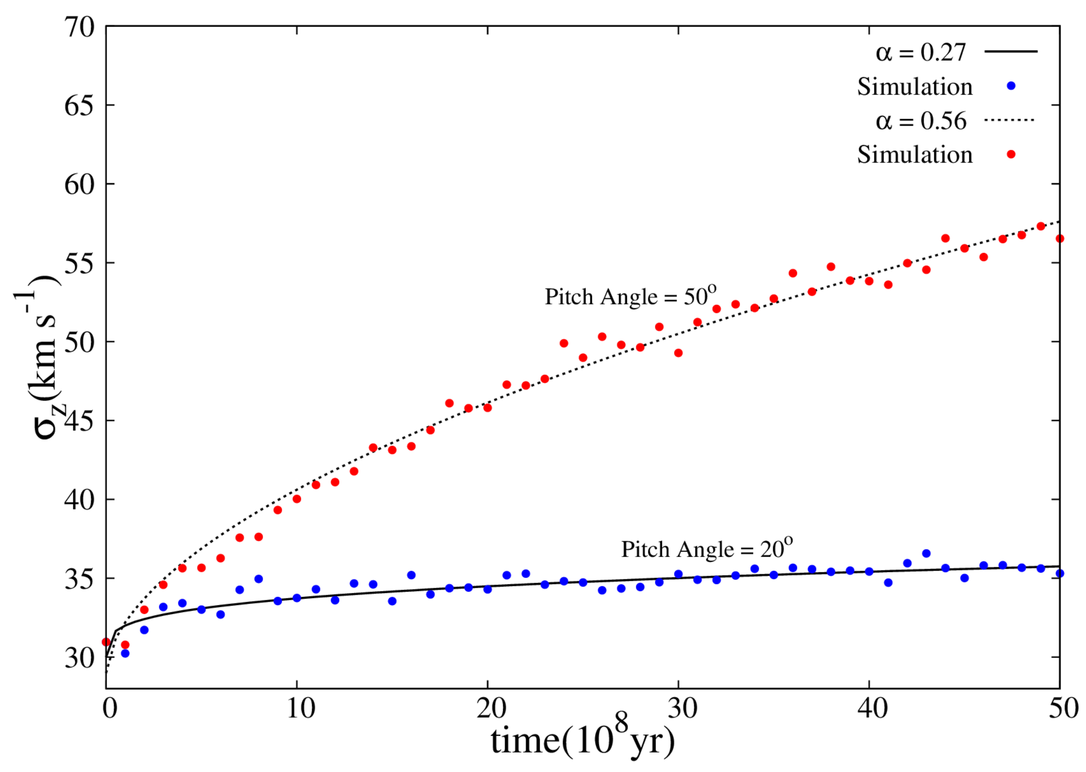


Massive arms and/or large pitch angles are responsible for the most prominent disc thickness found in our simulations. **By varying the parameters of the arms we found that the vertical heating of the stellar disk is very important in some cases, and strongly depends on the galaxy morphology, pitch angle, arms mass and its pattern speed.**



$\sigma_z \propto T$ relationship

- It is known that the age and velocity dispersion of stars are correlated. This has been established from observations in the solar neighbourhood (Holmberg 2009).
- The σ - t relation shows a smooth, general increase of the velocity dispersion with time and is best parametrized by a power law $\sigma_z \propto t^\alpha$ with $0.27 \leq \alpha \leq 0.56$.



The Milky Way

In the case of the Milky Way we found that:

- The galactic spiral arms by their own are incapable of induce any thickness in the disk, the increase in σ_z is negligible.
- If we add the galactic bar the vertical velocity dispersion increase considerably, mostly within the region covered by the bar. This means that for the Milky Way the bar is an important heating mechanisms of disk stars.