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Constraints on secular evolution in unbarred spiral galaxies: disentangling disk heating agents

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Abstract

The evolution of spiral galaxies is far from being completely understood, especially in terms of internal secular evolution. To address this problem, we combine the kinematics and stellar population parameters extracted from long slit spectra of major and minor axis of six galaxies in order to disentangle disk heating agents. Including arm class and molecular gas surface density measurements we conclude that spiral structure could be the major driver for radial heating mechanisms. However, scattering by giant molecular clouds cannot be ruled out as a three-dimensional agent.

1 Introduction

Galaxies continuously evolve together with the Universe itself. In the early Universe, the dominating processes were galactic mergers and hierarchical clustering [5, 21, 12]. These processes still continue, but they depend on rather dense environments. Since expansion continues, the number of mergers will decrease [21, 4] and other processes will start driving galactic evolution in a so-called secular way. Here we concentrate on internal secular evolution, focusing on the disk regions.

The stellar kinematics of galaxies are an important factor in their evolution. A key parameter connecting kinematical information is the velocity ellipsoid. This is the ratio of the vertical velocity dispersion σ_z over the radial velocity dispersion σ_R and can be used as a measure of the disk heating. Galaxy disks seen in edge-on observations show usually rather thin structures whose extent is vertically confined and dominated by the random motions of the stars within the disk. These random motions however are not necessarily intrinsic to the stars, but usually acquired during their lifetime [8]. Therefore, gravitational scattering between the stars in the disk potential will transfer the energy of the systematic rotation to the random motion during the stars' lifetime [10]. The gravitational perturbation leading to the increase in random velocities of the disk stars is due to so-called heating mechanisms or disk heating agents whose origin is still not clear. Among many distinct theories, there are two leading ones that can and will be tested in our study: the encounters with giant molecular clouds (GMCs) and the perturbation from irregular and transient spiral structure (e.g. [20, 11, 14]). There are still numerous other theories, e.g. thickening of disks through clustered star formation [13], scattering by dark halo objects or halo black holes [9], satellite accretion or minor mergers [23] where the energy dissipated in such a collision would significantly heat the original stellar population.

GMCs and spiral structure can also be compared with numerical studies, e.g. [11] or [18]. The idea is to evaluate the different influence of the two agents: while the scattering off GMCs acts as a three-dimensional agent causing the random motions to increase overall, transient spiral structure will act predominantly in the radial direction, thus produce an increase in σ_R rather than in σ_z.

The findings of the simulations are consistent with the above. Combining these two agents and varying their relative importance, [11] find that the heating of the disk measured in terms of the velocity ellipsoid decreases as spiral strength increases: σ_R is growing faster when the spirals have a stronger influence. Furthermore, [18] finds that transient spiral patterns cause the metallicity gradients to be reduced.

So far, several studies probed the velocity ellipsoid from both long slit and integral field observations, e.g. by [2] for elliptical and lenticular galaxies. We present long slit data to complement the kinematic analysis by [19] and [7] and provide estimates on the stellar populations. We try to recover full star formation histories (SFHs) and compute mass- and luminosity-weighted ages and metallicities. With these results we hope to furthermore be able to disentangle distinct disk heating agents. So far, a correlation between velocity ellipsoid and color was found by [7]; see left panel of Fig. 1. As color cannot simply stand for either age or metallicity, as shown in the right panel of Fig. 1, we aim to separate these two stellar population parameters.

2 Data and methods

The data for this work was taken from already performed observations by [19] and [7] comprising long slit observations of major and minor axes of the following galaxies spanning the Hubble sequence: NGC 2460 (Sa), NGC 2775 (Sa/Sb), NGC 1068 (Sb), NGC 4030 (Sbc), NGC 3810 (Sc), NGC 2280 (Scd). In particular, we want to stress that this sample is chosen to present only intermediate inclinations, e.g. $\approx 45°$.

We separated each spectrum into central, bulge and disk regions. The first contained the central velocity dispersion drop, usually indicating a kinematically decoupled component.

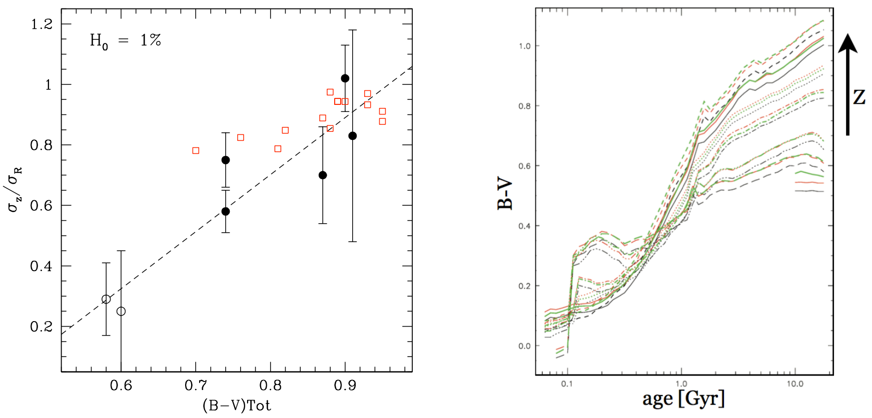

Figure 1: The linear relation between the velocity ellipsoid and color from [7] (*left*) and the relation between color and age from [22] (*right*).

The bulge and disk were separated using radial surface brightness profiles on the integrated spectra. After, we used the pPXF (penalized PiXel Fitting) code developed by [1], to extract the kinematics. With the Gas AND Absorption Line Fitting (GANDALF) package by [17] we performed the emission line removal. Finally, we computed the SFHs with Starlight [3] for all the individual regions of the cleaned galaxy spectra. We obtain full luminosity- and mass-weighted SFHs. Here we will use and present only the results for the disk regions and average the resulting mass-weighted ages and metallicities.

3 Preliminary results

In Fig. 2 we present the values of the velocity ellipsoid as a function of the overall averaged mass-weighted ages and metallicities for the disk regions, determined with Starlight. For neither, we can confirm a strong correlation. Although the probability of correlation is 80% for the metallicity relation, we can rather distinguish two groups: one for late-type galaxies and one for the early-types.

Separating the resulting SFHs into an old ($>$ 5 Gyr) and a young ($<$ 5 Gyr) population, see Fig. 3, the relation with age reveals an interesting twist: the old stellar population —for most of the galaxies the dominating one in mass— seems to be related to the kinematic parameter, while the young population seems to have no relation with the velocity ellipsoid.

This can be explained by the influence of the mass generating the potential on the dynamics of the galaxy. Therefore, this massive stellar population is the likely source of the heating and hence linked to the kinematics observed.

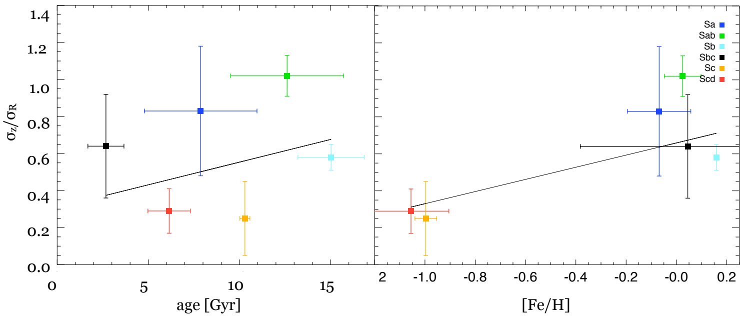

Figure 2: The velocity ellipsoid as a function of mass-weighted age (*left panel*) and metallicity (*right panel*) in the disk region.

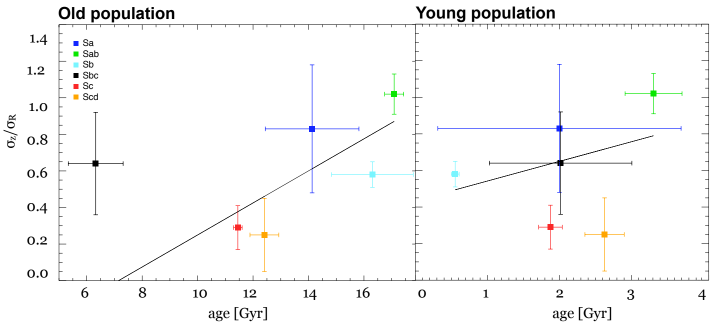

Figure 3: The velocity ellipsoid as a function of mass-weighted age. *Left panel*: for an old (> 5 Gyr) population. *Right panel*: for a young (< 5 Gyr) population.

3.1 Spiral structure as the radial heating agent

In some of the following figures, more than the six galaxies are shown. Those are previously determined values by [19] and [7]. Probing spiral structure as the radial heating agent, we expect an increase in σ_R and furthermore use spiral "arm class" as a proxy for spiral strength. Arm class is defined by [6] to describe the orderliness of spiral structure from flocculent (class F or 1) over multiple arm (class M) to grand design (class G or 12); the number classification was first and more refined and as the classifications were available for our galaxies, we used this refined scheme which can be seen in Fig. 4.

There is a correlation between σ_R and arm class in the expected direction: more irregular, flocculent systems provide stronger radial heating than regular spiral structure. Additionally, the lack of correlation between arm class and σ_z/σ_R (not shown) indicates that spiral structure has no effect on the shape of the velocity ellipsoid. From the stellar population parameters we also deduce a tentative relation between σ_R and age, reminiscent of the age-σ trend observed in the Milky Way [15]. These results are all consistent with the expected behavior of the radial heating agent, making spiral structure a strong candidate for the radial heating mechanism.

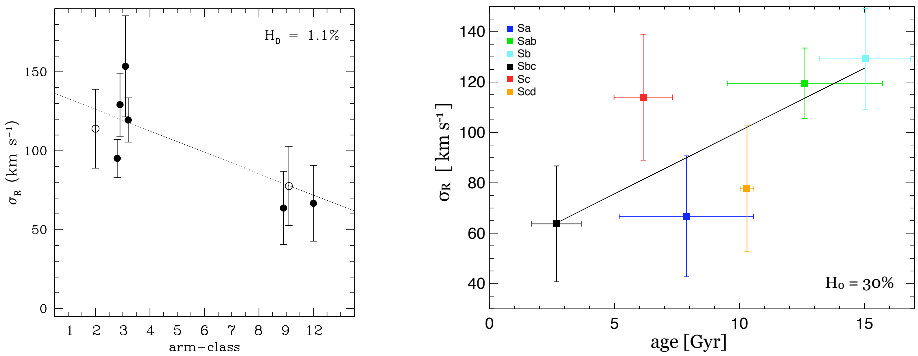

Figure 4: σ_R as a function of arm class from [7] (*left*) and mass-weighted age (*right*).

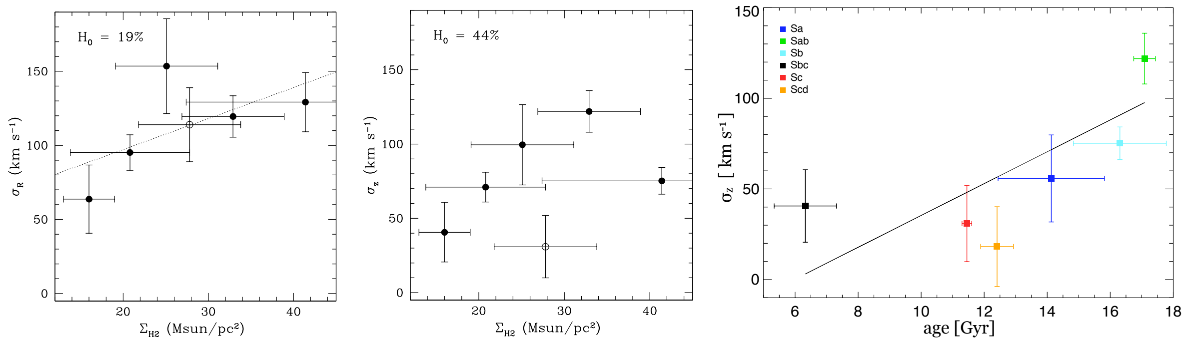

Figure 5: The velocity dispersions as a function of the H_2 gas surface density from [7] (*left* and *center*) and σ_z as a function of mass-weighted age.

3.2 Encounters with giant molecular clouds as the 3D agent

Scattering of stars through gravitational encounters with giant molecular clouds (GMCs) has been extensively studied theoretically as a possible three-dimensional heating affecting both σ_R and σ_z. We test this directly by comparing our kinematics with molecular gas surface density ΣH_2 measurements [24] over the same radial range in our sample galaxies and correlate ΣH_2 with each dispersion velocity and the velocity ellipsoid, shown in Fig. 5.

Both σ_z and σ_R are loosely correlated with ΣH_2. However, there is no correlation between gas surface density and σ_z/σ_R (not shown here). Inspecting the ages, we find a slightly stronger correlation with σ_R than with σ_z, both as functions of age. The relation with metallicity is tentative too, however it is strongly segregated into two agglomerations and therefore is difficult to pinpoint with this small sample of galaxies. We suspect GMCs to act more on σ_R than σ_z due to a preferential in-plane movement of the stars. Therefore the scattering would not be completely isotropic which is supported by [10] and our results showing a stronger correlation with σ_R. GMCs are therefore marginally consistent with being the three-dimensional heating agent, but more detailed gas data are required to determine whether GMCs or an alternative mechanism are responsible for this heating.

4 Conclusions

We conclude that spiral structure could be a major driver for radial heating mechanisms. We also show that older populations indeed show larger radial velocity dispersions as simulations predict. Scattering by giant molecular clouds seems to increase the disk heating overall, however seems to also have a larger impact on the radial velocity dispersion component due to anisotropic scattering. Nevertheless, it cannot be ruled out completely as a three-dimensional agent yet. It is thus critical, that we expand our sample in order to draw statistically more robust conclusions.

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