A morphological study of sigma-drop galaxies

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Summary. We study a sample of 20 galaxies with an observed central drop in the stellar velocity dispersion (σ-drop) matched with a control sample of galaxies without a σ-drop. We search for correlations between σ-drops and the properties, primarily morphological, of the inner zones and discs of their host galaxies. Both morphological parameters and luminosity profiles are used to classify the samples. We find a larger fraction of Hα rings and nuclear dust spirals in the σ-drop sample. We also find that the fraction of Seyfert galaxies in the σ-drop sample is bigger than that of LINERs and that the reverse is true for the control sample. Our findings indicate that a σ-drop is very probably due to inflow-induced star formation in a dynamically cool disc, or in a gas ring, shock focused by an inner Lindblad resonance above a certain critical density level. The same mechanism that feeds the nuclear ring or the nuclear disc may well be responsible for the higher rate of Seyfert galaxies among the σ-drop hosts.

1 Introduction

It is usually thought to be reasonable that the stars near the centre of a galaxy, close to the bottom of the potential well, ought to have the highest velocity dispersions. That means that a radial plot of velocity dispersion across a galaxy should peak on the nucleus. With the improvement in angular resolution of spectroscopic observations, detailed measurements on some nearby galaxies have shown an unexpected drop in the stellar velocity dispersion as the nucleus is approached, a phenomenon termed a dispersion drop or σ-drop ([3]; [4]). The rate of σ-drops in galaxy populations still in discussion, but some estimates currently reach 50% or even more in disc galaxies (E. Emsellem, private communication).

Different explanations have been proposed for this phenomenon, both using theoretical arguments and numerical simulations. For disc galaxies, the most reasonable scenario proposes that the stellar population in a σ-drop galaxy has been formed from a circumnuclear, rapidly rotating, dynamically cool, gaseous component. The stars acquire the dynamics of the gas from which they form, so their velocity dispersion is lower than that of the older stars. The resulting spectrum is dominated by the lower velocity dispersion of the younger stars because a young stellar population dominates an older population in luminosity (see, e.g., [13], also [1], [2]). This effect can be enhanced by the dissipation of energy of gas in a dense environment such as a cold disk, as shown in [6]. Simulations ([14]) have shown that a σ-drop can form in less than 500 Myr and that it can remain for more than 1 Gyr if the nuclear zone is continually fed with gas to maintain star formation.

2 Sample selection

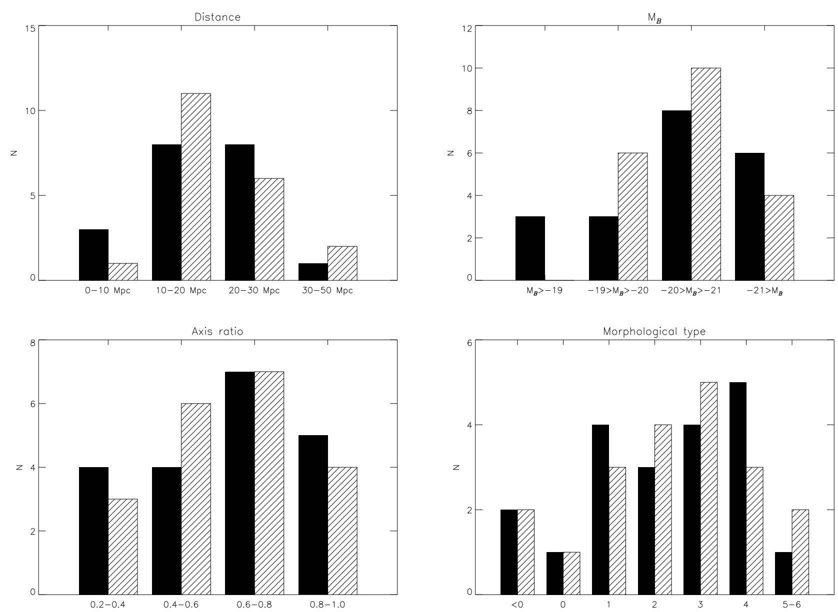

Fig. 1. Matching of the σ-drop and the control sample with respect to four parameters of the host galaxy: distance (top left), B absolute magnitude (top right), axis ratio d/D (bottom left), and morphological type (bottom right). The filled bars correspond to the σ-drop sample and the dashed bars denote the control sample.

Our σ-drop galaxy sample is a sub-sample of the selection of disc galaxies listed in [5] as showing spectroscopic evidence for the presence of a σ-drop. We choose those galaxies that were not classified as edge-on in the RC3 catalogue ([12]) and which had been imaged with the *Hubble Space Telescope* (*HST*). For all of these galaxies we retrieved WFPC2 or ACS red images from the

HST archive, and also Hα images taken with the WFPC2 or ACS cameras when they were available.

We then constructed a control sample that matches almost exactly the σ-drop sample in the statistical distribution across four parameters of the host galaxies. The four parameters are the distance, the absolute blue magnitude, the axis ratio and the morphological type. The matching appears in Fig. 1.

We used the downloaded images to derive continuum-subtracted Hα images and structure maps following a standard procedure (see [7] and [8] for a description of Hα subtraction and [11] for a description of structure maps).

3 Results

For this section we define $r_{\rm c}$, a measure of the radius which is directly related to the visible size of the galaxy, as 2 % of the radius of the galaxy (where the latter is half of D_{25} as taken from the RC3). We use the definition for $r_{\rm c}$ because it is similar to the effective radius of the bulge of a spiral galaxy ([9])—it thus provides an objective but simple and effective working definition of the central region.

3.1 Size of the σ-drop region

We find some hint that higher $r_{\sigma-{\rm drop}}/r_{\rm c}$ ratios are found in smaller galaxies and vice versa. This appears to indicate that $r_{\sigma-{\rm drop}}$ is not directly related to the size of the galaxy.

3.2 Bars

There is no significant difference in the bar distribution between the two samples.

3.3 Dust classification

We used the structure maps we constructed for our sample galaxies to study the central dust morphology across our samples. We used the classification criteria developed in [10] to the central area ($r_{\rm c}$) of each galaxy:

- *Grand design (GD)*: Two spiral arms with an 180° offset. At least one arm must be a dominant feature and must reach the unresolved centre of the galaxy.
- *Tightly wound (TW)*: A coherent spiral from the unresolved centre to $r_{\rm c}$, with a pitch angle smaller than 10°.
- *Loosely wound (LW)*: A coherent spiral from the unresolved centre to $r_{\rm c}$, with a pitch angle greater than 10°.

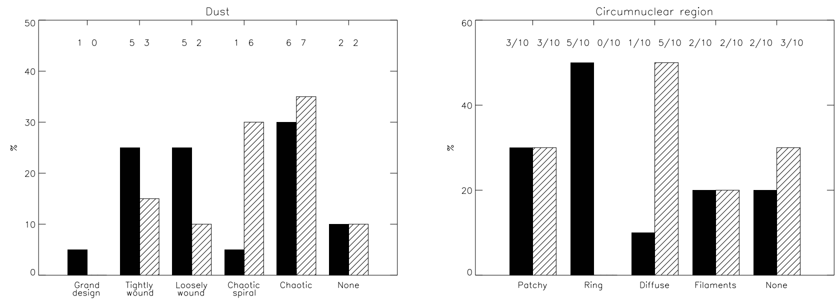

Fig. 2. Comparison of the dust distribution (*left*) and Hα in the two samples (*right*) between the two samples. In both panels filled bars correspond to the σ-drop sample and dashed bars denote the control sample. The numbers at the top of each bin refer to the number of galaxies in each bin.

- *Chaotic spiral (CS)*: Evidence of spiral arms not coherent over a wide radial range but with a unique sense of chirality.
- *Chaotic (C)*: No evidence of spiral structure.
- *No structure (N)*: No apparent dust.

The results of this classification can be seen in the left panel of Fig. 2. We find that eleven of the 20 σ-drop galaxies show clear dust spiral structure ($55\% \pm 11\%$), versus only five ($25\% \pm 10\%$) in the control sample.

3.4 Hα classification

We have produced Hα continuum-subtracted images for 10 galaxies in each sample. We classified the images separately for two radial regions, $r_{\rm c}$, as defined above, and the inner kpc. We find no morphological differences for the region inside $r_{\rm c}$. In the zone between $r_{\rm c}$ and the inner kpc radius, we used the following classification criteria:

- *Patchy*: Individual regions of Hα, similar to the H II regions found in the discs of galaxies.
- *Ring*: Hα emission organised in a well-defined ring of star formation of at least two hundred parsecs in radius. We are classifying only the inner kpc in radius and rings with bigger radii are not taken into account.
- *Diffuse*: Hα emission is present but cannot be ascribed to individual and well-defined H II regions.
- *Filaments*: Hα emission distributed in long filaments of H II regions.
- *None*: Less than 1% of the area of the inner kiloparsec region has any Hα emission.

The results of this classification can be seen in the right panel of Fig. 2. For the inner 1 kpc region we notice that star-forming activity is much higher in σ-drop galaxies than in control-sample galaxies. Patches and filaments are more obvious in σ-drop host galaxies than in the control sample galaxies and more extended (covering a larger surface area). Galaxies in the σ-drop sample often show strong starbursts with bright Hα rings and patches. Most of the control galaxies are devoid of strong Hα-emitting areas and have only weak diffuse emission. Another difference between the two subsamples is that the mean morphological type of the control sample is earlier than that of the σ-drop sample (mean Hubble morphological type 1.8 and 2.6, respectively). In [8], galaxies with no circumnuclear emission or diffuse emission tend to be from an earlier-type galaxy and patchy emission tends to be in later-type galaxies, which is coherent with what we have found in the two subsamples. Using the statistics of [8], corrected for the nuclear ring fractions reported there for each morphological type of the host galaxy, we find that four of our σ-drop galaxies and six control galaxies should have a circumnuclear ring even though the observed numbers are five and zero. It is thus safe to think that the higher proportion of circumnuclear star-forming rings in σ-drop galaxies is a true effect correlated with the σ-drop presence. Whether many, most, or even all circumnuclear rings are accompanied by σ-drops remains to be seen.

3.5 Nuclear activity

We find that the proportion of galaxies in the σ-drop sample that have a Seyfert nucleus is $65\% \pm 11\%$ while in the control sample it is $30\% \pm 10\%$. On the other hand, LINERs make up $25\% \pm 10\%$ of the σ-drop sample but $60\% \pm 11\%$ of the control sample. This points to a link between σ-drops and Seyferts, and links the other galaxies with a more reduced level of activity. This result has to be handled with care because in both samples we have a proportion of AGN of around 80%, which is far higher than the proportion of active galaxies that is found in a randomly taken sample. An explanation might be that *HST* tends to be employed to observe 'interesting' objects, which implies a higher fraction of AGN in the galaxies that have been observed with the space telescope.

3.6 Other parameters

We also searched for correlations between the presence of a σ-drop and gas emission in CO and H I as well as with luminosity profiles of the galaxies. We found no significant correlations.

4 Conclusions

Our main conclusion is that σ-drops are related to nuclear dust spirals, nuclear star-forming rings and Seyfert activity. We also find that the σ-drop radius is independent of the other tested parameters of the host galaxy. We note that LINERs are found more often in galaxies without σ-drops, and find that a bar is not necessary to cause a σ-drop in a galaxy.

The main theory for σ-drop formation points to cold gas accumulation and a posterior starburst in the inner parts of the galaxy (see e.g., simulations by [13]). This kind of gas concentration should ignite and start to create stars at a given density threshold. This threshold would probably be related only to local gas properties so the σ-drop size is independent of galactic large-scale parameters, as it has been borne out by our results. The big dispersion in σ-drop sizes is probably related to the different extents of the cool gas volume at the moment it reached the critical density or to a reduction of their size when they become old.

We suggest the following model for the creation and evolution of σ-drops. Gas is driven inwards by bars, and/or spiral arms, and/or minor mergers. The gas is collimated by ILRs in a ring-like area. When a given critical density threshold is reached the gas ignites and creates dynamically cold stars that dominate the spectrum and are detected as a σ-drop. Alternatively, if there is no ILR, gas can be focused in a cold nuclear disc. Part of the gas and dust escapes due to the dynamical friction from the ring (disc) and falls to the nucleus, as traced by the dusty spirals in our structure maps. This gas feeds energetic nuclear activity such a Seyfert. As σ-drops are long-lived (as shown by [14]) and last for more time than a starburst or the activity in an active nucleus, there is no one-to-one relationship between the σ-drop indicators and the σ-drop itself. Further modelling and observing is necessary to strengthen our conclusions.

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