Structure of Disk Galaxies: Environment Dependent?

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Abstract

This contribution gives a short overview of ongoing projects in Bochum concerning the influence of the environment on the formation and evolution of structures within disk galaxies. The first section deals with the formation of box- and peanut-shaped bulges, where a bar resonance phenomenon scenario is favoured. Based on deep optical images of edge-on galaxies, the second section discusses possible environmental influences for the observed deviations of the radial light profiles from the usual exponential model.

1 Box- and Peanut-Shaped Bulges

1.1 Background

In our statistical study on b/p bulges (Lütticke et al. 2000a) we carried out a visual classification on Digitized Sky Survey (DSS) images of bulge shapes for a statistically complete sample of 1343 galaxies drawn from the RC3 (de Vaucouleurs et al. 1991). Our analysis reveals that 45% of all bulges are b/p-shaped. Therefore these kind of structures are not as unusual as thought before, and common processes are needed to explain this high frequency. There are several approaches to explain the origin of these bulge shapes quoted in the literature. May et al. (1985) propose that external cylindrically symmetric tidal torques act on an initially non-rotating prolate triaxial spheroidal stable system so that it becomes box-shaped. Binney & Petrou (1985) propose an accretion scenario, where infalling satellite companions on a decaying orbit around the parent galaxy losing their stars so that the bulge appears box-peanut shaped. In a similar approach Whitmore & Bell (1988) explain b/p bulges by the accretion of a gas-rich companion, where the gas settles into a new oblique disk, and forms stars which spread out into a precession cone and hence appear in projection as an X-shaped structure. Another scenario is the origin of b/p bulges in bar resonances (e.g. Combes et al. 1990, Raha et al. 1991), by which disk stars are transported into higher orbits forming the b/p structure.

1.2 Environment Properties

By means of catalogued *cluster membership* (Tully 1988) we find that the number of b/p bulges within the Virgo and Ursa Major cluster is not significantly larger compared to the total fraction. Using the available *density parameters* from the Nearby Galaxy Catalog (Tully 1988): ρ [#gal/Mpc^3], and ESO Lauberts & Valentijn (1989): e.g. NGT [#gal/deg^2], we do not find any evidence for a correlation with the local galaxy density. Van den Bergh et al. (1996) provide an *interaction index* by a morphological sequence of interacting/merging galaxies. Thereby we classified our (type $=$ 1)-b/p bulges (cf. contribution by Aronica) in comparison to a control sample (non-b/p) and find that galaxies with b/p bulges show significantly more indication of interaction. The normalized interaction index is 0.9 ± 0.2 for galaxies with b/p bulges, whereas for the control sample it is only 0.2 ± 0.1. Analysing the Zaritsky et al. (1997) sample of isolated galaxies with

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and without *satellite systems* shows, that for the 9 b/p bulges and 7 non-b/p bulges in common, all b/p bulges and only two non-b/p have satellites. This means that 82% of galaxies with satellites have b/p bulges. Although hampered by small number statistics this is statistically significant. Searching the $5{*}D_{25}$-*environment* of peanut-shaped galaxies (30 galaxies) we find that according to NED[1] galaxies with b/p bulges have a mean number of 1.23 ± 0.31 companions, whereas we only find 0.55 ± 0.17 for the control sample. Similar results are found for possible (projected) satellites: 2.7 ± 0.3 for b/p and only 1.8 ± 0.3 for non-b/p. Taking together all these indications we conclude that b/p bulges are more influenced by satellites (their nearby environment) than by their global (cluster) environment.

Two possible mechanisms to trigger the formation of b/p bulges by satellites can be considered. The satellite accretion scenario is rather unlikely since the special impact conditions needed are inconsistent with the high observed frequency. Whereas the bar formation triggered by satellites and the subsequent formation of a b/p bulge by resonances is the currently favoured scenario for the formation of *normal* (cf. contribution by Vergani) b/p bulges. The evidence presented above is supported by several other strong indications for a bar, b/p bulge connection, such as the similarity in the frequency distribution of bars and b/p bulges versus morphological type (Lütticke et al. 2000a), direct NIR observations of bars in edge-on galaxies (Lütticke et al. 2000b), N-body simulation (Combes et al. 1990), as well as by observing the gas kinematics of b/p bulges (Bureau & Freeman 1999).

2 Disk Structure

2.1 Background

Fitting a three-dimensional one-component galactic disk model to surface photometric data of edge-on disk galaxies provides physical parameters such as scalelength h, scaleheight z_0, or central surface brightness μ_0 (Pohlen et al. 2000b). Our model is based on the empirically found exponential radial light distribution (de Vaucouleurs 1959; Freeman 1970), combined with a description for the vertical density distribution and a radial truncation according to van der Kruit & Searle (1981). The resulting luminosity density distribution $\hat{L}$ for our disk model is:

$$\hat{L}(R,z) = \hat{L}_0 \exp\left(-\frac{R}{h}\right)\, f_j(z,z_0)\ \mathrm{H}(R_{\mathrm{co}} - R) \qquad \left[\frac{\mathrm{L}_\odot}{\mathrm{pc}^3}\right]$$

By minimizing the difference between the observed 2D-image and an image of our 3D-disk model integrated along the line of sight we specify the inclination, the fitting function f_j for the z-distribution (exp, sech, sech^2) of the disk, and the best values for the structural parameters such as scalelength, scaleheight, central surface brightness, and the disk cut-off radius R_{co}. We did this for a sample of 31 galaxies (Pohlen et al. 2000b) and are now in the course of analysing our new deep images for a sample of ≈ 80 edge-on galaxies.

Whereas the exponential nature of the radial surface luminosity profiles is empirically well established, its physical origin is still unknown. A possible explanation comes from the viscous disk evolution scenarios where approximately exponential disks result if the viscous time-scale is comparable to the star-formation time scale (Zhang & Wyse 2000; Firmani et al. 1996; Lin & Pringle 1987). Prior to this Seiden et al. (1984) showed that if the stars just follow the initial gas distribution $\rho_{\mathrm{gas}} = 1/R$ they mimic an exponential decline. Similar to this the existence of truncations for disks of spiral galaxies is now widely accepted (Pohlen et al. 2000a and references therein) and confirmed by similar observations for the Milky Way, whereas its physical origin is also still a matter of discussion. Only few theoretical models can be found in the literature addressing a

[1]NASA Extragalactic Data base: http://nedwww.ipac.caltech.edu/index.html

physical description for the origin of cut-off radii. *Galaxy formation:* Van der Kruit (1987) proposes a hypothesis where galactic disks develop from collapsed rotating proto-galaxies. The dark matter settles into an isothermal sphere, and the first star-formation in the center builds up a bulge component. The remaining material settles in a flat disk under conservation of specific angular momentum j. Therefore the cut-off radius should be produced by pre-collapse gas with highest j. The deduced R_{co} of 4-5 h is in agreement with the observations of van der Kruit & Searle (1982). *Galaxy evolution:* Seiden et al. (1984) show that within their "*s*tochastic, *s*elf*p*ropagating *s*tar *f*ormation" (SSPSF) theory the radial dependence of the luminosity profile is $I(R) \propto 1/R$ in contrast to Freeman's $I(R) \propto \exp(-R/h)$. By plotting $I(R)$ logarithmically a feature like a cut-off appears, without introducing any additional free parameter. This would generally result in a R_{co} of $\approx 4\ h$. *Critical gas density for star-formation:* Kennicutt (1989) observes a radial SF limit and explains this by a dynamically critical gas density $\Sigma_{\rm c}$ for a thin, rotating, isothermal gas disk (Toomre disk). This would imply that the cut-off radius corresponds to the radial position were $\Sigma_{\rm gas}(R) = \Sigma_{\rm c}$. *Tidal interaction:* Tidal interactions between neighbouring galaxies may be the reason for sharp disk truncations in individual cases, as shown in numerical simulations (e.g. Noguchi & Ishibashi 1986).

2.2 Observed Structures

As already realized in our first approach (Pohlen et al. 2000b) disks do not always follow our one-component truncated galactic disk model. By means of our new sample (Pohlen 2001), selected by environment, we will classify the observed deviations and try to relate them to environmental influences. Here we summarize some preliminary results for the radial distribution (cf. Fig.1). Only few disks (e.g. ESO 436-034) behave model-like with a typical value for the distance independent ratio of cut-off radius versus radial scalelength of $R_{\rm co}/h \approx 3.4$. Several galaxies (e.g. NGC 3564, NGC 4179) do not show a truncation at all. This is typical for S0-galaxies which also follow the well known morphology-density relation. Few galaxies (e.g. UGC 3326) are very short, already truncated at $R_{\rm co}/h \approx 2.0$, which seems to be a typical feature of low surface brightness galaxies, which are in general slowly evolving systems, preferentially located in the field and not in clusters. Some galaxies (e.g. UGC 9977 which is a binary galaxy, and NGC 5775 clearly interacting) show a shallow inner profile followed by a very steep decline, which could be the typical feature for tidal truncations. Many disks (e.g. ESO 380-019, MCG -01-33-071) show some kind of two-slope profiles. This could be the effect of a 'smooth truncation' which is not as sharp as assumed in the model (cf. de Grijs et al. 2001). Currently there is no evidence relating this phenomenon to the environment.

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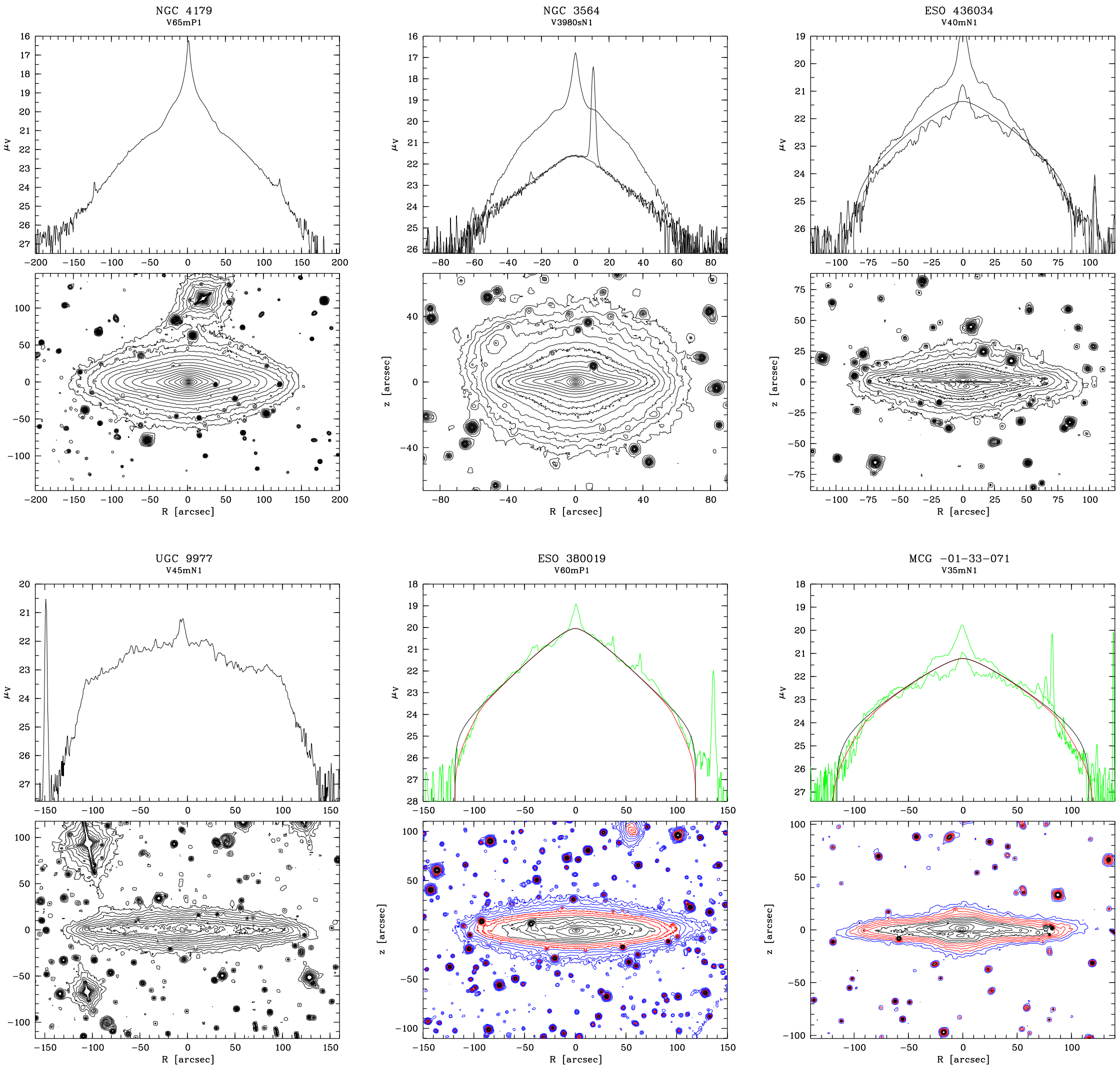

Figure 1: top panels: Radial (major axis or parallel) light profiles, partly overlayed by the best fitting model and/or a two slope model; lower panels: Contour plots

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