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Breaks and truncations: a unified picture for spiral galaxies

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Abstract. Departures from a simple exponential decay (usually called breaks or truncations) in the surface brightness distribution of galaxy disks are found in the vast majority of spirals. Understanding the origin of these breaks and how they evolve with time are key to address the mechanisms of galaxy growth. However, the community has encountered a significant discrepancy among the results obtained when the galaxies are observed face-on versus those cases where the projection is edge-on. In fact, truncations in edge-on disks are found at much larger radial distances than the breaks observed in face-on projections. In order to solve this puzzle, we have explored a large collection of edge-on late-type spiral galaxies using the SDSS and the S^4G (*Spitzer*) surveys. We observe that breaks and truncations are not the same phenomena: we find both features coexisting in our spiral galaxies. We propose a unified picture where breaks are likely caused by a threshold in the star formation activity whereas truncations are associated to a drop in the distribution of stars caused by the maximum angular momentum of the disk. Our scheme is capable of unifying all the previous observations into a simple picture.

Key words. galaxies: formation – galaxies: spiral – galaxies: structure – galaxies: photometry – galaxies: fundamental parameters

1. Introduction

The first photometric studies of spiral galaxies revealed how their radial surface brightness profiles seemed to decline following an exponential behaviour. (Patterson 1940; de Vaucouleurs 1958; Freeman 1970). However, for most of spiral galaxies, an exponential law with a unique scalelength parameter is not sufficient to describe the entire surface brightness profile when the measurements are extended beyond $\sim$ 10 kpc from the galactic center (van der Kruit & Searle 1981, 1982; Erwin et al. 2005). Depending on the shape of the surface brightness distribution, a classification for face-on galaxies has been developed by Erwin et al. (2005) and Pohlen & Trujillo (2006). It distinguishes three different types of profiles. Type I (TI) is the classical case, with a single exponential describing the entire profile; Type II (TII) profiles have a downbending brightness beyond the break. Type III (TIII) profiles are characterized by an upbending brightness beyond the break radius. Relative frequencies for each type are 10%, 60% and 30% (Pohlen & Trujillo 2006) in the case of late-type spirals.

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Two main mechanisms have been proposed to explain the most common TII profiles. On the one hand, a break can be caused by a threshold in the star formation in the galactic disk (Fall & Efstathiou 1980; Kennicutt 1989; Elmegreen & Parravano 1994; Schaye 2004). On the other hand, the maximum angular momentum of the proto-galactic cloud can also be related to the formation of a break as suggested by van der Kruit (1987, 1988).

A major problem in the understanding of these breaks in the surface brightness profiles appears when comparing observational results from face-on and edge-on spirals. While edge-on spirals show sharp truncations at around four or five times the exponential scalelength of the disk (van der Kruit & Searle 1981; Barteldrees & Dettmar 1994; Kregel et al. 2002), measurements of face-on spirals find softer breaks closer to the galactic center, typically around two or three exponential scalelengths (Erwin et al. 2005; Pohlen & Trujillo 2006; Erwin et al. 2008). In addition, edge-on results tend to support the angular momentum scenario meanwhile face-on studies point to the threshold in the star formation as the most plausible explanation for the break formation. Important questions remain then open: Are breaks and truncations the same phenomenon? Do they have a common physical origin? What causes the differences between edge-on and face-on observations?

2. Data

We selected a sample of edge-on galaxies present both in the Sloan Digital SDSS Data Release 7 (Abazajian et al. 2009) and in the *Spitzer* Survey of Stellar Structure in Galaxies (S^4G) (Sheth et al. 2010). The final sample contains 34 highly-inclined, late-type (Sc or later) and brighter than $M_B = -17$ spiral galaxies. The photometric quality of both surveys allow us to trace the radial surface brightness profiles typically down to $\sim$ 26 mag arcsec^{-2}. We used data from the five SDSS photometric bands $\{u', g', r', i', z'\}$ plus images from the *Spitzer* 3.6μm band, reduced by the S^4G group.

For each galaxy in the sample, we calculated its radial surface brightness profile along a 1.2 kpc width slit aligned with the major axis of the galaxy. To avoid any contamination coming from background objects, we first masked every object in the images apart from the target galaxy. Then the profiles were measured on these masked images. With the six surface brightness profiles (five from the SDSS and one from the S^4G survey), we also calculated the $(g'-r')$, $(r'-i')$ and $(r'-3.6\mu m)$ radial color profiles and the stellar surface mass density profile as explained in Bakos et al. (2008) following Bell et al. (2003).

3. Breaks and truncation

The galaxy NGC 4244 is a representative example of the overall behavior in our sample of galaxies. All the measurements obtained from this galaxy are shown in Fig. 1. A first break, at $\sim$ 8 kpc from the galactic center on average, is found in 80% of our galaxies. While this break appears clearly in all the surface brightness profiles, regardless of the photometric band, it is almost disappeared in the stellar surface mass density profile (upper right panel in Fig. 1). The smoothed break in the stellar surface mass density profile is observed in all the galaxies showing a TII profile. In addition to a first break, we find in 20 out of 34 galaxies in the sample a second change in the exponential behavior. This so called *truncation* in the radial surface brightness profile appears at larger distances (typically around 14 kpc) and it remains a clear feature even while observing the stellar surface mass density profile, as can be seen in the top-right panel of Fig. 1.

The differences between breaks and truncation appear also when comparing how the break and truncation radii correlate with the host galaxy properties. For example, in Fig. 2 is shown the correlation between the break and truncation radius (red squares and blue dots respectively) with the maximum rotational velocity of the galaxy. It is clear from the Spearman's rank correlation coefficients that the correlation for the break is weaker than the correlation for the truncation ($\rho_{\rm break} = 0.5$ vs $\rho_{\rm trunc} = 0.8$). The right vertical axis of Fig. 2 is just a transformation between the maximum rotational velocity of the galaxy and its specific

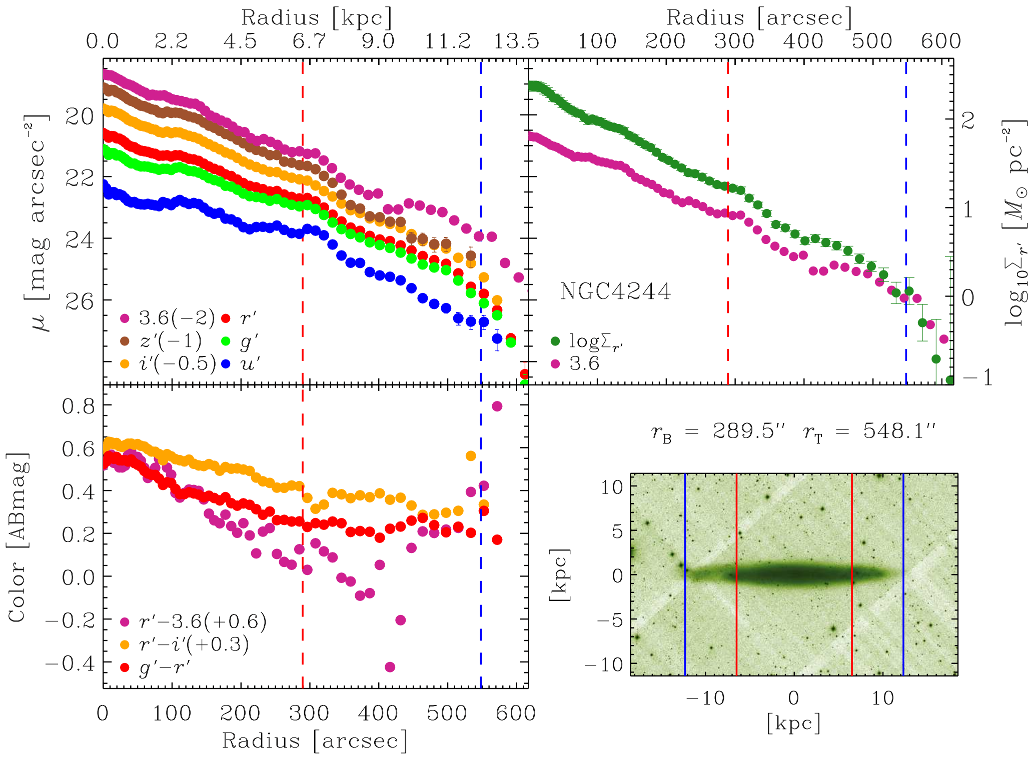

Fig. 1. Surface brightness, color and stellar surface mass density profiles of NGC 4244. The upper left panel shows six surface brightness profiles from the different photometric bands used in the current paper. Dashed vertical lines mark where a change in the exponential behavior happens. On the upper right panel are simultaneously plotted the stellar surface mass density profile and the 3.6μm surface brightness profile. The bottom left panel shows the three deeper color profiles from the available photometric bands. Lastly, the bottom right panel is occupied by a g'-band image of the galaxy. For this object the surface brightness distribution shows two clearly differentiated regions: one inner region before the red line and a second outer region after the blue line. The position of the two breaks is shown on the bottom right panel. The last characteristic radius is near to the visible edge of the galaxy and it is reflected as a drop in the stellar surface mass density profile. On the other hand, the first break is clearly within the galactic disk and does not seem to affect dramatically the behavior of the mass distribution.

angular momentum following the empirical expression proposed by Navarro & Steinmetz (2000).

The agreement between the properties of inner breaks found in our radial surface brightness profiles and previous observational results of face-on galaxies (see Erwin et al. 2005; Pohlen & Trujillo 2006), and also between our measurements of the outer truncations and the results coming from studies of edge-on galaxies (see van der Kruit & Searle 1981; Barteldrees & Dettmar 1994) lead us to propose the following scenario: ***breaks*** and ***truncations*** might be two different phenomena. Breaks, first detected in face-on galaxies, could be caused by a threshold in the star formation in the galactic disk meanwhile truncations, commonly observed in edge-on galaxies, are more likely related with the maximum angular momentum of the proto-galactic cloud.

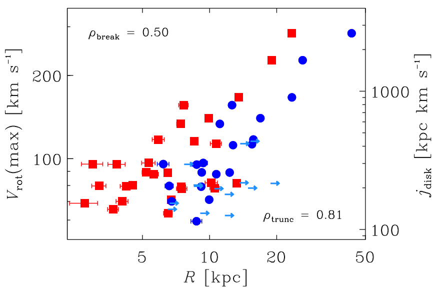

Fig. 2. Correlations between the positions of the inner breaks (red squares) and the radial position of the truncations (blue dots) versus the maximum rotational velocity and vs the specific angular momentum of the disk. Light blue arrows correspond to those galaxies where no truncation has been detected (so, they should be considered as a lower limit for the truncation radius). The Spearman's rank correlation coefficients for breaks (top left) and truncations (bottom right) are over-plotted.

4. Conclusions

Using SDSS and S^{4}G imaging, we have found the following important aspects regarding the behaviour of surface brightness profiles in edge-on late-type spirals:

1. The majority of our galaxies (82 ± 16%) show a TII surface brightness profile as those found in photometric studies of face-on galaxies, with the break occuring at a mean radial distance from the galactic center equal to 7.9 ± 0.9 kpc.
2. Truncations, previously described in edge-on galaxies as a quick drop in the surface brightness profile, have been found in 20 of the 34 galaxies in our sample. This drop, also observed in the stellar surface mass density profile, occurs at an average radial distance of 14 ± 2 kpc.
3. For many galaxies, breaks and truncations coexist as two differentiated features in the light distribution of the disks in spiral galaxies.
4. Strong correlations exist between the truncation radius and the maximum rotational velocity, and the specific angular momentum of the disk. These correlations are, however, less strong in the case of breaks.

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