Probing Outer Disk Stellar Populations

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1 Introduction

The radial surface brightness profiles can exhibit three distinct forms. Type I profiles can be fitted with one exponential fitting function (de Vaucouleurs 1958). Type II profiles contain a down-bending exponential after the break (Freeman 1970; van der Kruit 1979). Profiles with up-bending outer exponential are the Type III (Erwin et al. 2005) profiles. However different these galaxies are regarding their radial surface brightness profiles, they do not differ morphologically. (See Online Material of Pohlen & Trujillo 2006, hereafter PT06.)

The presence of stars in the outer regions of a galaxy disk is not well explained by current star-formation theories (Kennicutt 1987; Elmegreen & Parravano, 1994; Schaye, 2004) which predict no stars should be forming (i.e. at regions where the gas density dropped below 10 $M_{\odot} pc^{-2}$). These stars are very often located beyond a well-defined feature of the radial surface brightness profile: the break, beyond which the disk is already very faint. In order to investigate how the star formation progresses in the different parts of the disks, we have chosen to study the color and stellar mass ditribution of a large sample of disk galaxies. This resulted in efficiently having gained some clues on the stellar mass buildup process.

2 The Data and Analysis Techniques

Our data are the 85 SDSS g' and r' band surface brightness profiles published in PT06. The galaxies were selected to be a representative, volume limited ($R_{max} \sim 46$ Mpc) sample of face-on to intermediate-inclined late-type disk galaxies brighter than $M_B = -18.4$ mag. In that sense, they range from fainter to brighter surface brightness, from lower to higher mass, and also from smaller to larger size. The surface brightness profiles are classified as 9 Type I, 39 Type II and 21 Type III, i.e., exponential, truncated and antitruncated profiles, respectively (see PT06 and Erwin et al. 2008 for more details).

2.1 Color to Stellar Surface Mass Density Conversion

It is straightforward to link the stellar mass density (Σ) profile with the surface brightness profile at a given wavelength (μ_λ) if we know the mass-to-light (M/L)

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ratio, using the expression below.

$$log_{10}\Sigma = log_{10}(M/L)_\lambda - 0.4(\mu_\lambda - m_{abs,\odot,\lambda}) + 8.629, \quad (1)$$

where $m_{abs,\odot,\lambda}$ is the absolute magnitude of the Sun at wavelength λ, and Σ is measured in $M_\odot pc^{-2}$. To evaluate the above expression, we need to obtain the (M/L) ratio at each radius. Following the prescription of Bell et al. (2003), we have calculated the (M/L) ratio as a function of color.

In this work we assume a Kroupa IMF (Kroupa 2001), which according to Bell et al. (2003) implies a deduction of 0.15 dex from the (M/L) using the following expression:

$$log_{10}(M/L)_\lambda = (a_\lambda + b_\lambda \times color) - 0.15, \quad (2)$$

where for $(g' - r')$ color, $a_\lambda = -0.306$ and $b_\lambda = 1.097$ is applied to determine the r'-band M/L.

3 Results

We have explored the averaged radial surface brightness profiles for the Type I, Type II and Type III galaxies, see, Figure 1. The increase towards the center over the inwards extrapolated (inner) disk starting typically at around $0.2R/R_b$ is due to the presence of bulges. In the outer regions the characteristic break features, truncations and antitruncations, are clearly seen in the mean profiles of Type II and III galaxies, respectively.

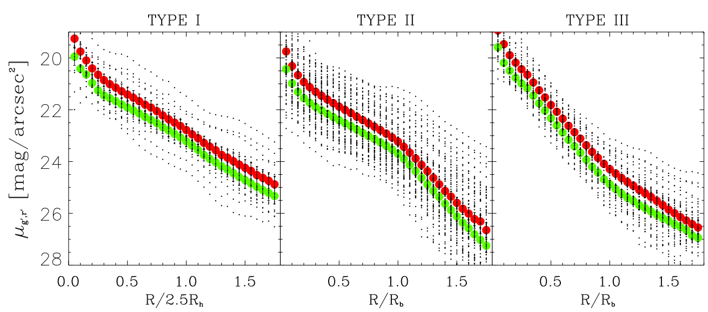

Fig. 1 - **Averaged surface brightness profiles** of #9 Type I, #39 Type II, and #21 Type III galaxy profiles in SDSS r' (red) and g' (green) bands. In order to have a direct comparison between galaxies of a given type, we use a normalized radius for the profiles. The normalization factor is their respective break radii (or 2.5 scale-lengths in case of Type I galaxies, because the breaks normally occur at 2.5 scale-lengths in Type II objects).

The radial color profiles (Figure 2) show that each galaxy type has its own characteristic color gradient. The color of Type I galaxies, after reaching an asymptotic value of $(g' - r') \sim 0.46$ mag in the outer regions ($\sim 2R_h$), stays within the error bars unchanged beyond. Type II galaxies show a minimum [at $(g' - r') =$

0.47 ± 0.02 mag] in their color profile at the break radius with the profile getting redder beyond. This is in qualitative agreement with stellar migration scenarios proposed by Roškar et al. 2008. The color of Type III galaxies, after the initial bluing, gets redder toward the break radius to a mean value of $(g' - r') = 0.57 \pm 0.02$ mag.

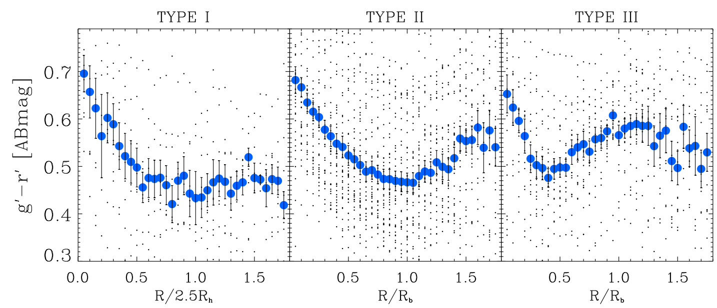

Fig. 2 - **Color profiles**: Type II galaxies after an inside-out bluing have a minimum $(g' - r') \sim 0.47 \pm 0.02$ mag in their color at the break, this is followed by a reddening outwards. Type III galaxies have a plateau region around the break with a value of $(g' - r') \sim 0.57 \pm 0.02$ mag. The large scatter in color is due to the difference between the absolute magnitude of the galaxies. (See Fig. 4.)

Using the color to calculate the stellar surface mass density profiles (as it explained in Sec. 2.1) reveals a surprising result, see, Figure 3. The breaks, well established in the light profiles of the Type II galaxies, are almost gone, and the mass profiles resemble now those of the pure exponential Type I galaxies. This result suggests that the origin of the break in Type II galaxies are most likely to be a radial change in stellar population, rather than being caused by an actual drop in the distribution of mass. The antitruncated galaxies on the other hand preserve their shape to some extent in the stellar surface mass density profiles.

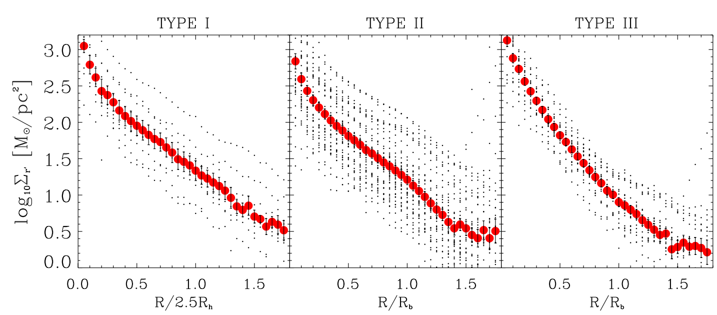

Fig. 3 - **Stellar surface mass density profiles**: The significance of break disappears in case of Type II galaxies, the profile resembles the Type I profile. This suggests that the break is due to stellar population changes and not caused by a drop in the distribution of stellar mass.

We find that the stellar surface mass density at the break for truncated (Type II) galaxies is $13.6 \pm 1.6\, M_{\odot} pc^{-2}$ and $9.9 \pm 1.3\, M_{\odot} pc^{-2}$ for the antitruncated (Type III) ones, see, Figure 4. We estimate that $\sim$ 15% of the total stellar mass in case of Type II galaxies and $\sim$ 9% in case of Type III galaxies are to be found beyond the measured break radii.

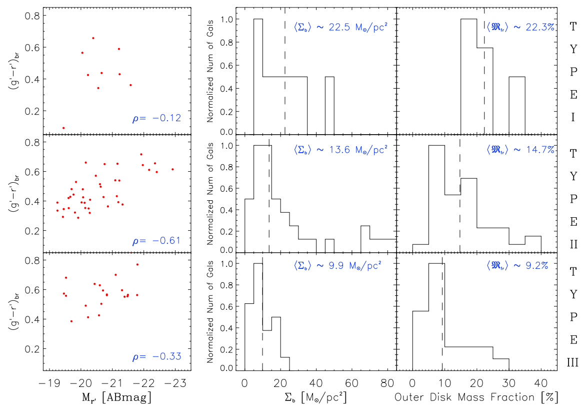

Fig. 4 - SDSS r' - band absolute magnitude and break color correlations. The correlation coefficient yielded by Spearman's correlation analysis is the highest for Type II galaxies, for Type I and Type III galaxies we lack the sufficient number of galaxies.)

Stellar surface mass density profiles of Type II galaxies suggest that the origin of the break is more likely to be a radial change in the stellar population than a drop in the stellar mass distribution. More about this research can be found in Bakos et al. 2008.

References

1. Bakos, J., Trujillo, I., Pohlen, M., 2008, ApJ, 683, L103
2. Bell, E.F., McIntosh, D.H., Katz, N., Weinberg, M.D., 2003, ApJS, 149, 289
3. de Vaucouleurs, G. 1958, ApJ, 128, 465
4. Elmegreen, B. G. & Parravano, A., 1994, ApJ, 435, L121
5. Erwin, P., Beckman, J. E., & Pohlen, M., 2005, ApJ, 626, L81
6. Erwin, P., Pohlen, M., & Beckman, J. E., 2008, AJ, 135, 20
7. Freeman, K. C. 1970, ApJ, 160, 811
8. Kennicutt, R. C., 1989, ApJ, 344, 685
9. Kroupa, P., 2001, MNRAS, 322, 231
10. Pohlen, M., & Trujillo, I., 2006, A&A, 454, 759
11. Roškar, R., Debattista, V. P., Stinson, G. S., Quinn, T. R., Kaufmann, T., Wadsley J., 2008, ApJ, 675, L65
12. Schaye, J., 2004, ApJ, 609, 667
13. van der Kruit, P. C., 1979, A&AS, 38, 15
14. van der Kruit, P. C., 1987, A&A, 173, 59