THE $V_c - \sigma_0$ RELATION IN LOW SURFACE BRIGHTNESS GALAXIES: INCLUDING THE LIGHT CONCENTRATION

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Abstract
It has been found that there is a strong correlation between the circular velocity $V_c$ and the central stellar velocity dispersion $\sigma_0$ of galaxies. In this respect, low surface brightness galaxies (LSB) follow a different relation when compared to Elliptical and high surface brightness (HSB) galaxies. The intrinsic scatter of the $V_c - \sigma_0$ is partially due to the different concentration of the light distribution. In this work we measure the $C_{28}$ concentration parameter for a sample of 17 LSB finding that the $C_{28}$ parameter does not account for the different behavior in the $V_c - \sigma_0$ for this class of objects.

Introduction
It has been recently found that the circular velocity $V_c$ measured in the flat region of the rotation curve and the stellar central velocity dispersion $\sigma_0$ are related (Ferrarese, 2002). It has successively found that Low Surface Brightness (LSB) galaxies follow a different $V_c - \sigma_0$ relation compared with HSB (High Surface Brightness) and E (Elliptical) galaxies (Pizzella et al., 2005). It has been suggested (Courteau et al., 2007) that the light concentration of the luminous component, measured by the $C_{28}$ parameter, may account for this difference. Aim of this work is to measure the $C_{28}$ for a sample of LSB galaxies and see if their behaviour in the $V_c - \sigma_0 - C_{28}$ plane is different with respect to HSB galaxies.

Data reduction
We selected a sample of 17 LSBs whose circular velocity $V_c$ and central velocity dispersion of the stellar component $\sigma_0$ are known (Pizzella et al., 2008, Cardullo Laurea Thesis 2006). For all the sample galaxies we have broad band imaging. For each galaxy we derived the radial surface brightness profile. We first derived, by means of the IRAF task ellipse, the photometric center, position angle and ellipticity of the isophotes. For each pixel of the image we computed its deprojected distance to the center of the galaxy (that is the distance of the pixel to the center on the plane of the disk). We derived the mean surface brightness profile and the $\pm 1\sigma$ uncertainties. In this
process we automatically masked out the pixel affected by stars. In Fig. 1 you can see the radial surface brightness profile for ESO 514-10. We then extrapolated with a straight line the outer surface brightness profile, computed the total luminosity and, finally, the radii enclosing the 80% and 20% of the total galaxy light. A Monte Carlo simulation that allows some variation in the center, position angle and ellipticity of the isophotes has been used in order to derive the uncertainties in the $C_{28}$ parameter.

We compared our data points with the data points and the empirical fit

$$\log\left(\frac{V_c}{\sigma_0}\right) = 0.63 - 0.11C_{28}. \quad (1)$$

found by Courteau et al. (2007) (Fig. 2). The two distributions seem to follow a similar relation, although the limited number of points does not allow us to derive an independent linear regression for LSB alone. Pizzella et al.
Figure 2: log $V_c/\sigma_0$ ratio versus the concentration parameter $C_{28}$ for our data points (black) compared with the data points (red) and the fit (green line) found by Courteau et al. (2007).

(2005) found that in the log $V_c - \log \sigma_0$ plane LSB galaxies mostly lies below the relation defined by the HSB and E galaxies. This is shown in Fig. 3 where different morphological types of galaxies are shown. To better compare HSB and LSB galaxies, we perform a linear regression of HSB data points. We used the linear regression described by Akritas & Bershady (1996). The result of the linear fit is also shown in Fig. 3.

Results

Now that we have measured the $C_{28}$ parameter for LSB galaxies we used the empirical relation found by Courteau et al. (2007) and shown in Fig. 2 to derive their $V_{\sigma,C_{28}}$ from $\sigma_0$ and $C_{28}$. In Fig. 4 we plot our new LSB points together with the points derived by Courteau et al. (2007) for HSB galaxies. Applying a linear regression we found

$$\log V_{\sigma,C_{28}} = 0.672 + 0.707 \log V_c. \quad (2)$$

LSB galaxies still seem to follow a different relation, having, for a given $V_c$ a smaller value of $V_{\sigma,C_{28}}$. 

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Figure 3: log $V_c$ versus log $\sigma_0$ for the data points of the Courteau et al. (2007) sample and for our data points. Different colours indicates different morphological types as listed in the labels. LSB galaxies (green points) mostly lies below the relation derived by Pizzella et al. (2005). The red line indicates the linear regression of the HSB data only.

Let us remind that our aim is to test whether LSB and HSB share the same $V_c - \sigma_0 - C_{28}$ relation. The best way of doing it is to analyze the distribution of the scatter of the HSB and LSB measurements with respect to the linear regression defined by the HSB sample. For each data point we computed the scatter as done by Pizzella et al. (2005), that is computing the difference between the observed value and the linear regression and normalizing it by means of its observational uncertainties. The scatter distribution of HSB and LSB is then compared by means of a KS test. We performed this analysis both on the $V_c - \sigma_0$ and $V_c - \sigma_0 - C_{28}$ relations in order to understand how the two relations compare. The plot of the residuals is shown in Fig.5. The result of the KS test is that LSB and HSB have two distinct distributions both considering the $V_c - \sigma_0$ relation (and this is basically the result obtained by Pizzella et al. (2005) with a similar data set) and considering the $V_c - \sigma_0 - C_{28}$ relation.

Conclusions
Figure 4: $\log V_c$ versus $\log V_{c, C28}$ derived from $\sigma_0$ and from $C_{28}$ with the relation empirically found by Courteau et al. (2007). The red line indicates the linear regression of the HSB data points while the black line is the $V_c = V_{\sigma, C28}$ line.

The KS test indicates that the distribution of HSB and LSB are different at a 99.9% and 99.8% confidence level in the $V_c - \sigma_0$ and $V_c - V_{\sigma, C28}$ plane respectively. Our conclusion is therefore that, concerning LSB galaxies, the $C_{28}$ parameter does not account for the different behaviour in the $V_c - \sigma_0$ relation. Since $\sigma_0$ is related to the SMBH mass and $V_c$ is related to the dark matter halo mass, this result may indicate that either LSB galaxies follow a different $M_{SMBH} - \sigma_0$ relation with respect to HSB galaxies, or alternatively, that LSB galaxies have SMBH of smaller mass compared with HSB galaxies.

References

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Figure 5: **Left panel**: Histograms of the scatter from the linear regression for HSB and LSB in the $V_c - \sigma_0$ plane (Fig. 3). We can note that our LSB data points mostly lies only in the negative side of the distribution indicating that these galaxies follow a different relation. **Right panel**: As left panel in the $V_c - V_{\sigma,C28}$ plane. Again, LSB show a different distribution.

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