AUTOMATIC MORPHOLOGICAL CLASSIFICATION OF GALAXIES

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ABSTRACT. We study the performance and limitations of the morphological classification method based on luminosity concentration and mean surface brightness. In particular, the effects of the different colour bands and of a finite seeing are investigated.

1. Introduction

Whereas conventional morphological classification is based on one-by-one eye inspection of the images of galaxies, the need is evident for some computer-oriented method that uses quantitatively measurable parameters extracted from the galaxy images to give morphological classifications for the large numbers of galaxies detected in automated galaxy survey work, e.g., COSMOS and APM, and, in the near future, SDSS.

In the previous papers (Doi et al. 1992, 1993) we have proposed a simple method for morphological classification. The method is based on two simple parameters extracted from the equivalent surface brightness profile of a galaxy, the luminosity concentration index, and the mean surface brightness within a limiting surface brightness μ_l. The concentration index is defined as $C_{in} = L(\alpha r_l)/L(r_l)$, where $L(r)$ is the luminosity included within the equivalent radius r, r_l is the limiting equivalent radius corresponding to μ_l, and α is a parameter ($0 < \alpha < 1$). The mean surface brightness is defined as $SB = -2.5 \log[L(r_l)/(\pi r_l^2)] + \text{const}$. In this report we further this work by examining the effects of *different colour bands* and *finite seeing* on the diagram, in order to see its performance and limitation in classification of galaxies.

The plot of C_{in} as a function of SB contains information on the profile shape and is free from the scale of a galaxy *at the limit of zero seeing*. Model galaxies with $r^{1/4}$-law profile and those with exponential profile form two sequences which are clearly separated from each other in the diagram (Fig. 1). We take the parameters to be $\alpha = 0.3$ and $\mu_l = 25.5$, 24.5 and 24.0 mag arcsec^{-2} for B, V, and R bands, respectively. The location of a galaxy in the sequence is determined by the effective surface brightness; galaxies with higher surface brightnesses have larger values of C_{in}. A line of $C_{in} = aSB + b$ can be used to classify galaxies into early type ($r^{1/4}$-law dominant) and late type (exponential-law dominant) if a and b are chosen appropriately.

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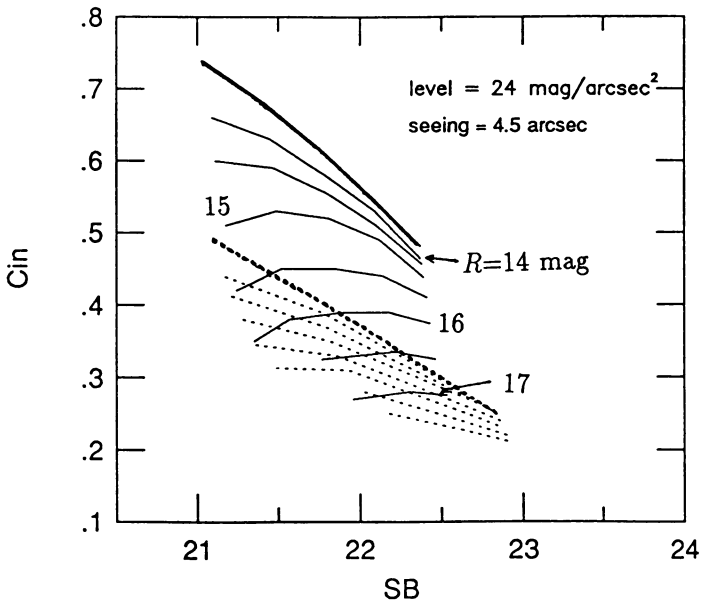

Figure 1. C_{in} - *SB* diagram for model galaxies having $r^{1/4}$-law profile (solid line) and exponential-law profile (broken line). At the limit of zero seeing (thick lines), the curves are independent of apparent magnitudes. In the case of 4".5 seeing (thin lines), the curves are shown for different apparent magnitudes from R = 14 mag to 17 mag at an interval of 0.5 mag.

We note two advantages of the C_{in} - *SB* diagram. First, it is based on simple parameters which can be derived routinely from usual surface photometry without any elaborate analysis. Second, both C_{in} and *SB* are distance independent as long as the seeing is negligible compared with the apparent size of a galaxy and $z \ll 1$. In particular, the second point suggests that the diagram is potentially effective for use in wide area surveys where galaxies at different distances are involved.

Furthermore, we expect that the plot in the C_{in} - *SB* diagram does not depend strongly on the colour band since the plot represents the global shape of the surface brightness profile. We confirm this expectation in this report using the *B* and *R* band data. On the other hand, the seeing effect could be critical to the power of this plot in classifying galaxy morphology. This is already noted in Doi et al. (1993). Here we present a systematic study to determine how a given value of seeing affects the diagram for galaxies with different apparent magnitudes.

2. Performance of C_{in} - *SB* Diagram

Doi et al. (1993) demonstrated that the C_{in} - *SB* diagram provides a useful method for morphological classification in the case of negligible seeing. Classification of 789 bright galaxies (V_T < 13 mag) in the 'Photometric Atlas of Northern Bright Galaxies' (Kodaira et al. 1990) with this method gave more than 85% coincidence with RSA classification in terms of early (E-S0/a)

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or late (Sa-Sm). The method was also successfully applied to the Coma cluster galaxies with $13 < B_{25.5} < 16$ mag using photographic data, where the images are significantly affected by the seeing.

A new observation was made for the Coma cluster with the Kiso Schmidt telescope using the mosaic CCD camera (Sekiguchi et al. 1993), which covered a central 3°.44 x 1°.66 region in the R band (0".75/pixel). This provides an opportunity to carry out a comparative analysis by combining the CCD data in the R band with those obtained in the photographic observation made previously in the B band (Doi 1993; Doi et al. 1993). The seeing was about 4".5 (FWHM) in both observations.

Figure 2 shows a comparison of C_{in} and SB between the B and R bands for 318 galaxies detected in both bands. The limiting magnitude of this sample is set by the B-band data as $B_{25.5} = 17.5$ mag. Tight correlations are seen in both parameters. This indicates that the morphological classification using the C_{in} - SB diagram is insensitive to colour bands.

Morphological types are available for only a very small fraction of the above galaxies. Instead of making one-by-one comparison for small number of galaxies, we show in Fig. 3 the C_{in} - SB diagram for the 318 galaxies using different symbols according to B-R colour. The colour systematically changes from upper left (red) to lower right (blue). The change is broadly consistent with the galaxy population expected from the model calculation (Fig. 1). This may be taken as evidence that the diagram measures galaxy morphology reasonably well.

How the 4".5 seeing affects the C_{in} - SB diagram is shown in Fig. 1, where the sequences of $r^{1/4}$-law galaxies and that of exponential-law galaxies are shown for several different apparent magnitudes. Because of the seeing, two sequences become degenerate at about $R = 16.5$ mag. Classification is feasible for galaxies brighter than this magnitude. The number of pixels per galaxy is 300±100 at $R = 16.5$ mag, which corresponds to the equivalent limiting diameter of $2r_l = 14 \pm 2$ arcsec. This translates to the relation that $\alpha(0.3) \times 2r_l \sim$ (seeing size), or $2r_l \sim 3$ x (seeing size). This may be regarded as the limit of useful classification using the C_{in} - SB diagram.

As seen in Fig. 1 the classification line should be a function of apparent magnitude, or possibly diameter, in the case of finite seeing. Figure 4 shows the sky distribution of galaxies brighter than $R = 16.5$ mag according to preliminary classification based on more or less subjectively defined classification lines as a function of apparent magnitude. It is noted that

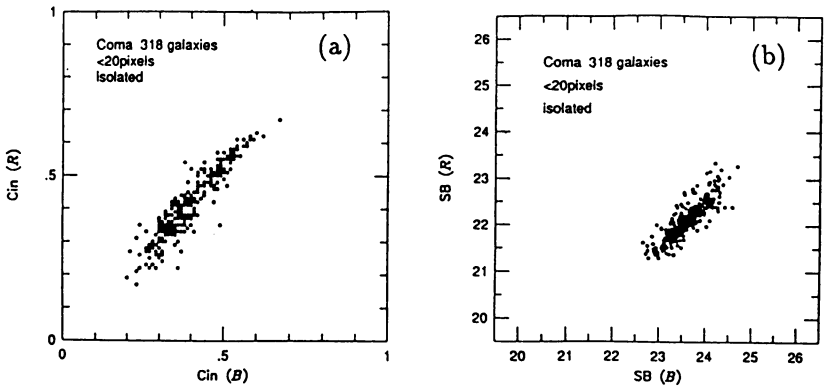

Figure 2. Comparison of C_{in} **(a)** and SB **(b)** between B and R bands.

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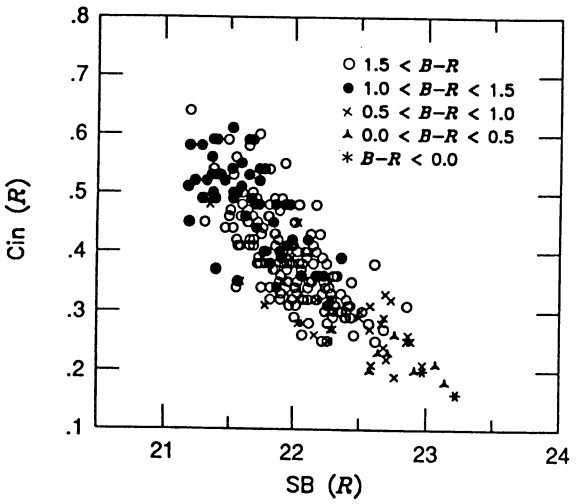

Figure 3. C_{in} - *SB* diagram for 318 galaxies detected in both *B* and *R* bands. Different symbols are used according to *B* - *R* colour.

dwarf ellipticals in the sample, if any, are classified as late type because of the exponential nature of their profiles (e.g. Ichikawa et al. 1986). We are presently investigating a method to define the classification line in an objective way.

3. Conclusion

The C_{in} - *SB* diagram is a useful tool for coarse (early vs. late) morphological classification of galaxies. It is insensitive to the difference of colour bands and is able to classify galaxies down to *R* ~16.5 mag with 4".5 seeing (FWHM). The limiting magnitude would be a few magnitudes fainter if the seeing is ~1" or better.

Acknowledgement

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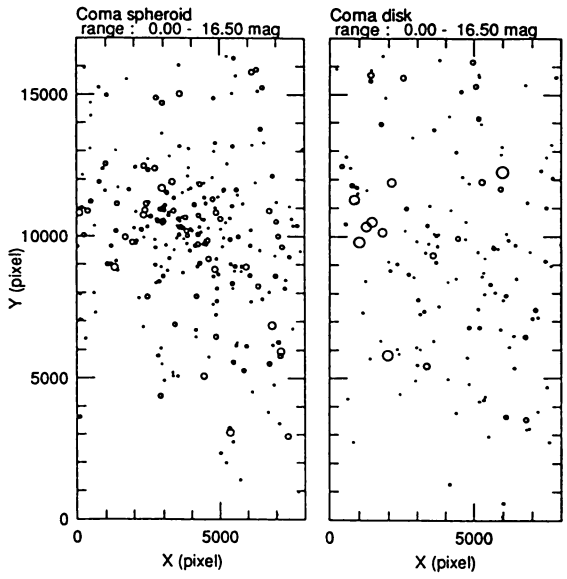

Figure 4. Sky distributions of 262 early-type galaxies (left panel) and 143 late-type galaxies (right panel) with $R < 16.5$ mag. The symbol size is proportional to the apparent magnitude.

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