NEAR INFRARED PHOTOMETRY OF EARLY TYPE SPIRALS

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Abstract

Near infrared (NIR) structural parameters, colors, mass-to-light ratios of bulges and disks have been determined for 14 early type spiral galaxies, using two different numerical approaches (parametric and non parametric). Average properties of the sample concerning internal extinction, stellar content, surface brightness distributions, and dark halos are briefly discussed.

1 Introduction

Surface photometry - mostly in the optical, but recently also in the NIR - has been largely used to investigate the structure of spiral galaxies, in particular the properties of their major components, bulges and disks, in terms of morphology, stellar populations, opacity of the disks ([7],[11],[4], [5]). When coupled to kinematical data, such as rotation curves (RCs), photometry can also be used to infer the mass-to-light ratios (M/L's) of the components and the dark matter halo properties ([8],[9], [10]).

Studies of this kind start with the separation of the contributions from disk and bulge to the total amount of light in every point of the galaxy image. Previous work ([15],[2],[12]) has shown that such a task is far from simple. The decomposition of 1d brightness profiles is often unreliable, making a 2d analysis of the whole distribution compulsory; the effect of atmospheric seeing has to be taken into account; in the optical bands the extinction in the disk can be important; the shape of the distributions of bulges and disks is not known a priori; finally optical passbands are not good tracers of the stellar mass of disk galaxies.

These difficulties can be partly ameliorated by refining the schemes of data analysis and shifting to more appropriate wavelengths, namely to NIR bands, where extinction is lower (a factor $\sim$ 10 between V and K) and probably negligible, and where the bulk of the luminosity is contributed by the old population, comprising most of the stellar mass. We present here some preliminary results from a study on a sample of early-type spirals imaged in the NIR, aimed at the description of structure, colors and mass distribution of bulges and disks for this class of objects. The full analysis will be described in two forthcoming papers ([12], [13]). We note that among spiral galaxies early-type ones are the less dust rich, which makes more plausible the hypothesis of negligible internal extinction.

2 Data analysis

Our sample contains 14 early type spirals selected for having accurate observed RCs, both from optical emission lines and from the radio 21 cm emission line. We have obtained J (1.25 μm) and K (2.2 μm) images at the Tirgo telescope (CH) with the Arcetri Near Infrared Camera ARNICA. Data acquisition and reduction was accomplished following standard NIR procedures. Besides, r band brightness profiles for 10 of our galaxies have been published by [10].

2.1 The decomposition of surface brightness distributions

We have adopted a model galaxy consisting of two components: an ellipsoidal bulge and an infinitely thin disk. Both are assumed to be completely transparent. The decomposition of the surface brightness distributions has been performed following two distinct approaches, namely a parametric and a non-parametric one. In both cases we analyzed the *entire 2d distribution*, and took into account the effect of seeing.

2.1.1 The parametric decompositions. In this case the model bulge is described by a generalized exponential law ([16]). In intensity units:

$$I_b(x,y) = I_e \exp\left\{-\alpha\left[\left(\frac{1}{r_e}\sqrt{x^2+\frac{y^2}{(1-e_b)^2}}\right)^{1/n} - 1\right]\right\} ; \quad (1)$$

where the index n determines the shape of the profile; for $n = 1$ we obtain an exponential law, while $n = 4$ corresponds to the de Vaucouleurs profile. For the disk we adopt a simple exponential:

$$I_d(x,y) = I(0)\exp\left[-\frac{1}{r_d}\sqrt{x^2+\frac{y^2}{(1-\cos i)^2}}\right] . \quad (2)$$

The parameters of the distributions (scale lengths and surface brightnesses, plus inclination i and bulge ellipticity e_b) were determined by fitting the model to the brightness distribution simultaneously in J and K after convolution with a gaussian PSF. Scale lengths, i, and e_b were kept fixed in the two bands, yielding 8 parameters to be fitted for every galaxy. For the exponent index we considered four fixed values: $n = 1, 2, 3, 4$.

2.1.2 The non parametric decompositions. They are a generalization to the 2d case of a method proposed by Kent ([9]) which makes use of an iterative algorithm based on the difference in apparent ellipticities between bulge and disk. These two parameters must be determined a priori; for this purpose we fitted elliptical isophotes to each image, letting the ellipticity vary with radius. The ellipticity profile was then used to estimate the values at the galaxy center (where bulge dominates) and in the outer parts.

2.2 The fit to the rotation curves

The intrinsic surface brightness distributions of bulge and disk, together with their assumed geometry, were used to calculate the RC of each galaxy in the hypothesis of constant M/L for each component. Such ratios were determined as free parameters in a fit of the model RC to the observed one. When a constant or rising RC beyond the peak of the visible matter contribution suggested the presence of a dark halo, we added a third contribution to the mass distribution, for which we experimented two possibilities, namely a constant density halo and a pseudo-isothermal sphere. Conservatively, we always considered maximum bulge+disk solutions, i.e. we assigned to the stellar matter the highest mass compatible with the observed RC.
Figure 1 shows an example of both the surface brightness decomposition and the fit to the RC for NGC 2775 in the non parametric case.

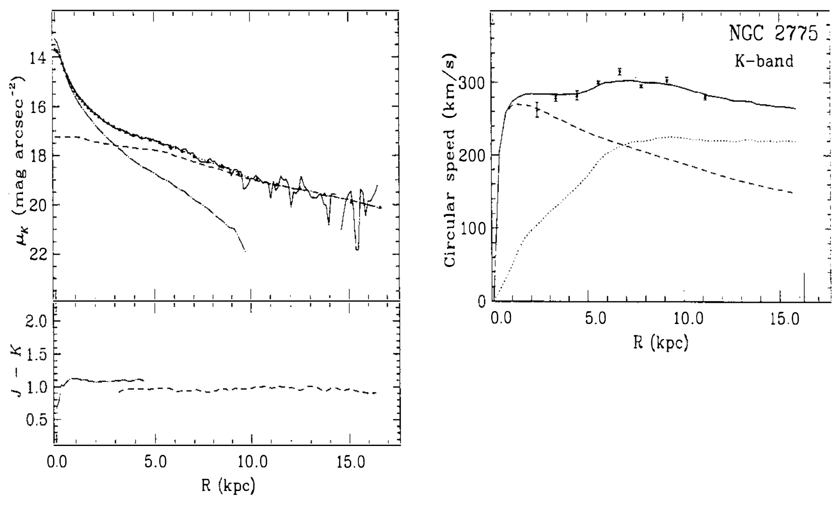

Figure 1. Left: Surface brightness decomposition for NGC 2775 (non parametric case, K band). The dots represent the major axis brightness profile extracted along elliptical contours; the continuous line is the cut along the major axis; the model galaxy is represented by the dot-dash line (bulge), the dashed line (disk) and the dotted line (sum of the two). In the lower panel we report the $J-K$ color profiles of bulge and disk. Right: the fit to the rotation curve for NGC 2775 (from the non parametric decomposition). The dots represent the observed curve. No halo has been introduced in this case.

3 Results

3.1 Structure

We summarize here the main results emerging from parametric decompositions.
The bulge exponent index yielding the best result from the point of view of the quality of the

fit in most cases is $n = 3$. This is in agreement with [1] who suggest that such an index depends on the morphological type, in the sense of lower n for bulges of late type galaxies. In any case, an exponential bulge ($n = 1$) seems definitely inadequate for early-type spirals.
As already noted by [4], we find a dispersion of the face-on disk central brightnesses $I(0)$'s significantly higher in the K band than the one measured at optical wavelengths (Freeman's law, [6]), and the value is comparable to the one we find for the bulge effective brightnesses (around 0.8 mag arcsec^{-2}).
The various parameters appear to be correlated. For instance, shorter scale lengths of bulges and disks correspond to higher values of the respective face-on surface brightnesses ([4] finds a similar correlation only for the disks). Moreover the scale lengths of the two components are bound by a nearly linear relationship, significant at 99% level if three discrepant points are removed, with a mean ratio of $r_e/r_d = 0.40 \pm 0.06$ (see figure 2). This value is definitely higher than the one found by [3], 0.13 ± 0.08, for a sample of late type spirals. The discrepancy is partly due to the different parametrization ([3] adopt an exponential law for the bulge); however, with $n = 1$ our sample yields a ratio $r_e/r_d = 0.23 \pm 0.03$, still higher than [3]'s value, implying a possible dependence of such correlation on morphological type, with r_e/r_d decreasing from early to late types.

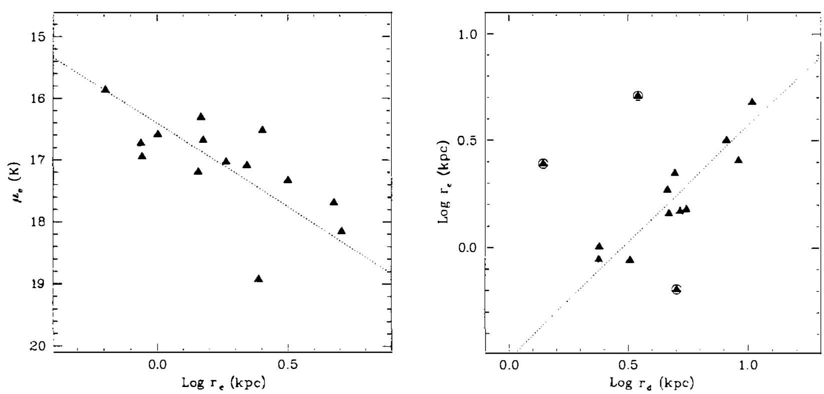

Figure 2. Left: bulge surface brightness vs. scale length. The dotted line is the best fit to the data. Right: r_e vs. r_d with the best fit obtained excluding the three encircled points.

3.2 Extinction

A few tests seem to confirm our hypothesis of low internal extinction. In particular we have checked the correlations with inclination of various parameters, the spread of surface brightnesses in different bands, the presence of color gradients, the variation of scale lengths with wavelength. Using standard extinction models for the disks we deduce an upper limit of about 3 for the central optical depth in the V band, $\tau_V(0)$.

3.3 Stellar populations

Observed colors and mass-to-light ratios can be compared to the predictions of stellar synthesis models, to try to constrain ages and metallicities of bulges and disks. Figure 3 reports the

average colors and M/L's for our sample, together with Worthey's single burst population models ([17]). The plots show that there is substantial agreement between models and data. On average the disk population seems to be *older* and *less metal rich* than the one of the bulge, the former beeing more than $\sim$ 10 Gyr old with $Z \simeq Z_\odot$, and the latter 5 $\sim$ 8 Gyr old with supersolar metallicity.
The claimed difference in age is mainly supported by the fact that bulge M/L's are lower, on average, than the ones of the disks. Such a difference could be reduced or eliminated assuming that the observed rotation velocity in the inner part of the galaxy, where the bulge dominates, is systematically underestimated. This is actually the case, as already noted by [10], for three galaxies of the sample which exhibit a particularly slowly rising inner RC; these three objects, however, were excluded from the statistics of bulge M/L's. On the other hand the presence of significant extinction in the central regions would lead to overestimate the ratios.
For what concerns the disks, their M/L's could be also overestimated (we note that we adopted maximum disk solutions), yielding a higher average disk age. Yet, comparing with the results from [14], this seems to be unlikely.

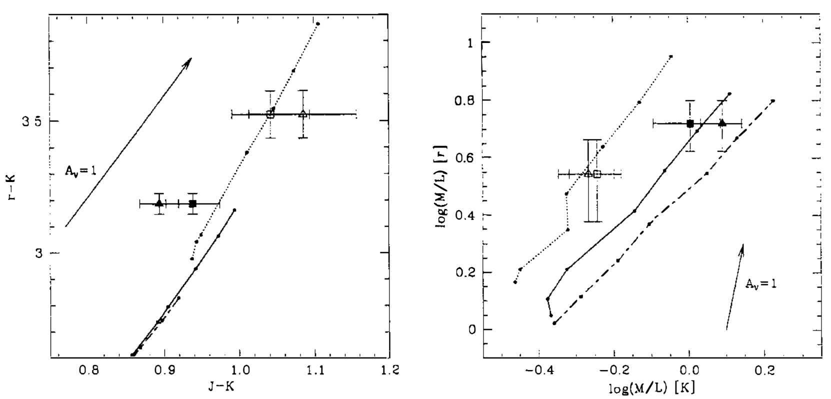

Figure 3. Left: Comparison of average colors to Worthey's models of stellar population synthesis. We plot three models with different metallicities: [Fe/H]=0.5 (dotted line), [Fe/H]=0.0 (solar metallicity, continuous line), [Fe/H]=-0.25 (dashed line). Age increases from bottom to top; marked points correspond to ages of 1.5, 2, 3, 5, 8, 12, 17 Gyr. Filled symbols represent average colors of disks with the relative uncertainties; the triangle is for the parametric results and the square for the non parametric ones. Empty symbols are the bulge values. Right: the same comparison for M/L's (r and K bands).

3.4 Dark halos

They were introduced in 6 galaxies out of 14, namely in all cases in which an extended observed rotation curve was available. The halo parameters (core radii and central densities) are in full agreement with typical values obtained from studies in the optical bands. Correlations between structural parameters, mass to light ratios and halo parameters are under investigation.

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