SPECTROPHOTOMETRIC INVESTIGATIONS OF BLUE COMPACT DWARF GALAXIES: MARKARIAN 35

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ABSTRACT

We present results from a detailed spectrophotometric analysis of the blue compact dwarf galaxy Mrk 35 (Haro 3), based on deep optical (BVRI) and near-IR (JHK) imaging, Hα narrow-band observations and long-slit spectroscopy. The optical emission of the galaxy is dominated by a central young starburst, with a bar-like shape, while an underlying component of stars, with elliptical isophotes and red colors, extends more than 4 kpc from the galaxy center. High resolution Hα and color maps allow us to identify the star-forming regions, to spatially discriminate them from the older stars, and to recognize several dust patches. We derive colors and Hα parameters for all the identified star-forming knots. Observables derived for each knot are corrected for the contribution of the underlying older stellar population, the contribution by emission lines, and from interstellar extinction, and compared with evolutionary synthesis models. We find that the contributions of these three factors are by no means negligible and that they significantly vary across the galaxy. Therefore, careful quantification and subtraction of emission lines, galaxy host contribution, and interstellar reddening at every galaxy position, are essential to derive the properties of the young stars in BCDs. We find that we can reproduce the colors of all the knots with an instantaneous burst of star formation and the Salpeter initial mass function with an upper mass limit of $100 \, M_\odot$. In all cases the knots are just a few Myr old. The underlying population of stars has colors consistent with being several Gyr old.

Subject headings: galaxies: dwarf – galaxies: evolution – galaxies: individual (Mrk 35) – galaxies: starburst – galaxies: stellar content

1. INTRODUCTION

Blue Compact Dwarf (BCD) galaxies are narrow emission-line dwarfs that are undergoing violent bursts of star-formation (Sargent & Searle 1970). They are compact and low-luminosity objects (starburst diameter ≤ 1 kpc; $M_B \geq -18$ mag), often with low-metal content ($Z/50 \leq Z \leq Z/2$) and high star-forming (SF) rates, able to exhaust their gas on a time scale much shorter than the age of the Universe. Initially it was hypothesized that BCDs were truly young galaxies, forming their first generation of stars (Sargent & Searle 1970; Lequeux & Viallefond 1980; Kunth & Sargent 1986; Kunth, Marrogorrado, & Vigroux 1988), but the subsequent detection of an extended, redder stellar host in the vast majority of them has shown that most BCDs are old systems (Loose & Thuan 1986; Telles 1995; Papaderos et al. 1996a; Cairós 2000a; Cairós et al. 2001a, 2001b; Cairós et al. 2002a, 2002b). Although so far
the SF in BCDs has been commonly described as a bursting scenario—short intense episodes of SF separated by long inactivity periods (Thuan 1991; Mas-Hesse & Kunth 1999)—, there is increasing evidence that BCDs could rather have a gasping star formation, with long episodes of activity, separated by short quiescent intervals if any (Legrand 2000; Legrand et al. 2000; Recchi & Hensler 2005).

The evolutionary status of BCDs and their star formation history, as well as the mechanisms that trigger the recurrent star formation episodes, are still open questions, and, although much work has been done in the last years in this topic, no conclusive results have been achieved.

A fundamental step to approach such questions is a detailed analysis of individual nearby objects, using high quality data. In fact, most of the work done so far has focused on statistical analyses of BCD samples, and only recently a few studies have been devoted to examining in detail the characteristics of individual objects. [Papaderos et al. (1998, 1999) carried out a spectrophotometric analysis of SBS 0335-052 and Tololo 65, two BCDs belonging to the i0 class (extremely compact and low-metallicity objects with no evidence for a substantial underlying stellar component; see Loose & Thuan 1986 for the classification scheme); Noeske et al. (2000) studied the i,IC galaxies Mrk 59 and Mrk 71 ("Cometary BCDs", galaxies with star formation concentrated on one side); Tololo 1214-277 and SBS 0940+544 (also classified as i,IC) were studied by Frick et al. (2001) and Guseva et al. (2001), respectively. Despite the fact that nE (objects with a single central starburst superposed on a regular redder outer envelope) and iE (objects with a complex inner structure consisting of many SF knots atop a regular redder outer envelope) BCDs are the most common, there are very few studies of similar quality for galaxies belonging to these groups, the most notable one being the comprehensive analysis of the properties of the nE Mrk 86 carried out by Gil de Paz et al. (2000) and Gil de Paz, Zamorano, & Gallego (2000).

This prompted us to start an extensive observational project, whose aim is the thorough analysis of a sample of nearby BCD galaxies selected among those already studied by our group (C01a and C01b). In a first paper (C02) we introduced the method used to discriminate and analyze the stellar populations in BCDs, and presented the results for the iE galaxy Mrk 370. Here we apply the same method to Mrk 35, a BCD also belonging to the iE morphological class. Mrk 35 has an absolute magnitude $M_B = -17.75$ (C01b), and is located at a distance of 15.6 Mpc$^1$. According to the morphology and distribution of its SF knots, Mrk 35 belongs to the Type III (Chain/Aligned starburst) group, as introduced in C01b. The basic data of Mrk 35 are shown in Table 1.

Deep optical surface photometry, in the optical and in the NIR, was presented in C01ab and in C03. The galaxy displays the typical surface brightness profile (SBP) of BCD galaxies: at high and intermediate intensity levels the profile is dominated by the starburst component, which has quite a complex shape, whereas in the outer parts the SBP traces the luminosity structure of the old stellar population. Mrk 35 is included in the Mazarella & Boroson (1993) sample of Markarian galaxies with multiple nuclei. The presence of Wolf-Rayet stars (Steel et al. 1996; Huang et al. 1999) indicates that the galaxy underwent a starburst episode within the last 3-6 Myr. The cause of this star-formation episode is unclear. Whereas Steel et al. (1996) conclude that the star-formation is likely auto-induced, Sánchez-Portal et al. (2000) claim that Mrk 35 shows clear signatures of a merger episode. A recent paper by Johnson et al. (2004) studies the central starburst by means of near infrared and radio observations, and concludes that the hypothesis of a small scale interaction can not be ruled out.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Long-slit spectra

Long-slit spectra of Mrk 35 were obtained in February 2002 at the Observatorio del Roque de Los Muchachos (ORM) on the island of La Palma, using the 4.2m William Herschel Telescope (WHT). Observations were made with the blue arm of the ISIS double beam spectrograph, which was equipped with a 300 groove mm$^{-1}$ grating and a CCD array of $2100 \times 4200$ $13.5\mu m$ pixels, a combination which gives a linear dispersion of $0.86 \AA$ per pixel, and a spectral range of 3600 to 6920 $\AA$. A slit 4 arcmin long and $1''2$ wide was used. The positions of the slit we used is shown in Fig. 1 over-plotted on a continuum-subtracted Hα map.

The exact positions of the slit were derived from a di-
Spectrophotometric observations of Mrk 35

3. Results

3.1. Spectroscopic Analysis

Spectra of Mrk 35 were taken in two almost parallel positions (PA: 42° and 38°), as shown in Fig. 1, which pass through the five brightest SF knots of the galaxy. The spatial distribution of the intensity of the brightest emission lines (Hβ, Hβ, [O III]) has been used as a base for defining the regions from where one-dimensional spectra of each region were extracted. The different spatial regions we defined are shown in Fig. 1: the spatial length of the slit in Position 1 (S1) was divided into three subregions, while Position 2 (S2) was split into two subregions.

Figs. 2 and 3 display the integrated spectra of the different spatial regions, together with the spectrum integrated over the whole slit length for S1 and S2. We summarize below the main characteristics of the spectra.

- **Ap1** includes knot b1, a markedly red SF region \((B - V = 0.64; V - I = 0.53)\) located very close to the optical center of the galaxy (see the Hα map in Fig. 1). Absorption wings underneath the Balmer emission lines are clearly visible in Hβ, Hγ, and Hδ; other absorption features such as Ca II λ3933, the Mg I b triplet λλ5167, 5173, 5184 and Fe I λλ335 are also visible, which indicates the presence of an evolved population of stars (> 10 Myr).

- **Ap2** contains knot b2, the optical center of the galaxy, which also is a rather red knot \((B - V = 0.63; V - I = 0.70)\); see Fig. 1: interestingly, this source is a strong emitter in the broad-band frames — in the NIR it is, indeed, the emission peak — but is not an Hα peak. This implies that b2 is substantially more evolved. The Ca II λ3933, the Mg I b triplet and Fe I λλ335 absorption features are visible.

- **Ap3** is the sum of the Ap1 and Ap2.

- **Ap4** corresponds to knot c, a SF region located in the galaxy “tail-like” feature. It shows a flat spectrum, with prominent emission lines and no absorption features, which is characteristic of a dominant OB population.

- **Ap5** corresponds to knot A, the brightest SF region of the galaxy. It shows a flat spectrum characterized by strong nebular emission lines, and no visible absorption features. The Wolf-Rayet bump is
clearly discernible, as already reported by [Steel et al. (1996) and Huang et al. (1999)].

- Ap6 corresponds to knot d, also detached from the main body of the galaxy. It too has a flat spectrum, without absorption features.

3.1.1. Reddening Corrected Line Fluxes

Fluxes and equivalent widths of the emission lines were measured using the Gaussian profile fitting option in the iraf task Splot (a direct integration of the flux for each line gave virtually identical results).

It is known that these measurements are an underestimate of the real flux of the Balmer lines, because of the underlying absorption component. To correct for the underlying stellar absorption, some authors (McCall, Rybicky & Shields 1985; Skillman & Kennicutt 1993) adopt a constant equivalent width (1.5 − 2 Å) for all of the hydrogen absorption lines. However, the actual value of the absorption line equivalent width is uncertain, as it depends on the age of the star formation burst (Díaz 1988; Cananzi, Augarde, & Lequeux 1993; Olofsson 1995), and on the contribution of the underlying population of older stars.

The correction from underlying stellar absorption was done in two different ways, as explained below.

For the Balmer lines showing clear absorption wings, we fitted simultaneously an absorption and an emission component, using the deblending option in Splot.

In the other cases, we proceeded as follows. We first adopt an initial estimate for the absorption equivalent width, $W_{\text{abs}}$, correct the measured fluxes, and determine the extinction coefficient at $\lambda = 4861$ Å, $C(H\beta)$, through a least-square fit to the Balmer decrement given by the equation:

$$ \frac{F(\lambda)}{F(H\beta)} = \frac{I(\lambda)}{I(H\beta)} \times 10^{C(H\beta) \times f(\lambda)} $$

(1)

where $\frac{F(\lambda)}{F(H\beta)}$ is the line flux corrected for absorption and normalized to H\beta; $\frac{I(\lambda)}{I(H\beta)}$ is the theoretical value for case B recombination, from Brocklehurst (1971), and $f(\lambda)$ is the reddening curve normalized to H\beta which we took from Whitford (1958).

We then vary the value of $W_{\text{abs}}$, until we find the one that provides the best match (e.g. the minimum scatter in the above relation) between the corrected and the theoretical line ratios. This is done separately for each knot.

Reddening-corrected intensity ratios and equivalent widths for the different spatial regions, in the two observed positions, are listed in Tables 3 and 4.

3.1.2. Physical Conditions and Chemical Abundances

Table 5 lists the most relevant line ratios, the physical parameters and oxygen abundances derived for each aperture.

The excitation ratio [O III]/H\beta is > 2 in all the knots, and it is highest in knot a, the brightest star-forming region, where it reaches $\approx 3.6$. [N II]/H\alpha drops where [O III]/H\beta increases, as expected in regions of recent star-formation.

[O I] $\lambda$6300 is detected in all the apertures, but the fluxes measured are quite small. Photoionization by stars is the dominant mechanism. Although the presence of shocks cannot be completely ruled out, the small values of [S II]/H\alpha and [N II]/H\alpha indicate that shocks do not play a significant role. As expected, in the classical diagrams [N II]/H\alpha vs [O III]/H\beta, [S II]/H\alpha vs [O III]/H\beta and [O I]/H\alpha vs [O III]/H\beta, all the star-forming knots are located within the locus of H II regions. The electron density of the ionized gas was determined from the [S II] $\lambda$6717/$\lambda$6731 ratio. We used the task TEMDEN, based on the FIVEL program (Shaw & Dufour 1995), which is included in the IRAF package NEBULAR. For knot a we found a considerably high density (170 cm$^{-3}$), in good agreement with the value reported in Izotov & Thuan (2004). Knots b, c and d have lower gas densities ($\leq 100$ cm$^{-3}$), characteristic of massive H II regions.

A precise determination of the ionized gas temperature ($T_e$) requires an accurate measurement of the flux of [O III] $\lambda$4363; though we detected this line in five out of the six apertures, the uncertainties in the flux measurements — due to the weakness of the line as well as to the strong absorption wings of the nearby H\gamma line — make the derived values unreliable. Only in Ap5 and S2 the uncertainties in the flux measurements are less than 25%, and we could compute $T_e$ from the line flux ratio [O III] $\lambda$4363/($\lambda$4959 + $\lambda$5007).
### TABLE 3

| Line (Å) | Ion | Ap1 | Ap2 | Ap3 |
|----------|-----|-----|-----|-----|
| 3727     | [O II] | 2.058 ± 0.043 | 92.86 ± 12.74 | 2.404 ± 0.050 | 78.47 ± 8.53 | 2.230 ± 0.024 | 72.00 ± 2.20 |
| 3798     | H10 | 0.046 ± 0.037 | 1.14 ± 0.95 | ... | ... | ... | ... |
| 3835     | H9 | 0.059 ± 0.018 | 1.80 ± 0.72 | 0.044 ± 0.012 | 1.08 ± 0.35 | 0.048 ± 0.010 | 1.05 ± 0.30 |
| 3869     | [Ne III] | 0.243 ± 0.012 | 5.38 ± 0.38 | 0.216 ± 0.012 | 3.93 ± 0.27 | 0.227 ± 0.005 | 4.32 ± 0.12 |
| 3889     | He I + H8 | 0.169 ± 0.010 | 5.58 ± 0.52 | 0.152 ± 0.011 | 4.19 ± 0.42 | 0.160 ± 0.007 | 4.62 ± 0.28 |
| 3968     | Ne III + H7 | 0.141 ± 0.008 | 4.21 ± 0.31 | 0.128 ± 0.008 | 3.20 ± 0.25 | 0.131 ± 0.005 | 3.44 ± 0.17 |
| 4025     | He I | 0.031 ± 0.018 | 0.67 ± 0.41 | ... | ... | ... | ... |
| 4069     | S II | 0.025 ± 0.011 | 0.55 ± 0.25 | ... | ... | ... | ... |
| 4101     | Hδ | 0.266 ± 0.010 | 5.97 ± 0.22 | 0.297 ± 0.011 | 5.94 ± 0.23 | 0.265 ± 0.006 | 5.17 ± 0.13 |
| 4340     | Hγ | 0.465 ± 0.005 | 14.10 ± 0.22 | 0.484 ± 0.008 | 11.98 ± 0.21 | 0.468 ± 0.005 | 12.38 ± 0.16 |
| 4363     | [O III] | 0.039 ± 0.011 | 1.15 ± 0.35 | 0.032 ± 0.012 | 0.75 ± 0.31 | 0.028 ± 0.007 | 0.68 ± 0.18 |
| 4471     | He I | 0.064 ± 0.006 | 1.77 ± 0.20 | ... | ... | ... | ... |
| 4861     | Hβ | 1.000 ± 0.005 | 34.32 ± 0.15 | 1.000 ± 0.005 | 29.56 ± 0.17 | 1.000 ± 0.004 | 31.47 ± 0.12 |
| 4959     | [O III] | 1.025 ± 0.005 | 35.08 ± 0.22 | 0.894 ± 0.005 | 25.66 ± 0.15 | 0.936 ± 0.004 | 28.16 ± 0.14 |
| 5007     | [O III] | 3.021 ± 0.012 | 103.10 ± 0.61 | 2.540 ± 0.011 | 74.90 ± 0.31 | 2.708 ± 0.008 | 81.65 ± 0.24 |
| 5200     | [N I] | 0.020 ± 0.004 | 0.88 ± 0.17 | 0.023 ± 0.003 | 0.78 ± 0.12 | 0.022 ± 0.003 | 0.78 ± 0.10 |
| 5876     | He I | 0.127 ± 0.003 | 6.19 ± 0.22 | 0.118 ± 0.003 | 4.63 ± 0.14 | 0.123 ± 0.002 | 5.23 ± 0.11 |
| 6000     | O I | 0.046 ± 0.004 | 2.65 ± 0.26 | 0.061 ± 0.004 | 2.85 ± 0.20 | 0.054 ± 0.002 | 2.66 ± 0.11 |
| 6212     | S III | 0.016 ± 0.003 | 0.91 ± 0.20 | ... | ... | 0.014 ± 0.002 | 0.68 ± 0.13 |
| 6363     | O I | 0.013 ± 0.002 | 0.75 ± 0.14 | 0.021 ± 0.004 | 1.00 ± 0.20 | 0.016 ± 0.002 | 0.78 ± 0.09 |
| 6548     | [N II] | 0.092 ± 0.003 | 5.37 ± 0.28 | 0.110 ± 0.003 | 5.26 ± 0.18 | 0.101 ± 0.002 | 5.21 ± 0.13 |
| 6563     | Hα | 2.856 ± 0.017 | 165.40 ± 1.96 | 2.874 ± 0.038 | 140.40 ± 1.16 | 2.862 ± 0.012 | 146.80 ± 0.85 |
| 6584     | [N II] | 0.202 ± 0.003 | 17.30 ± 0.34 | 0.325 ± 0.005 | 15.78 ± 0.26 | 0.308 ± 0.003 | 16.19 ± 0.20 |
| 6678     | He I | 0.032 ± 0.005 | 2.05 ± 0.36 | 0.037 ± 0.005 | 1.88 ± 0.27 | 0.032 ± 0.003 | 1.75 ± 0.14 |
| 6717     | [S II] | 0.264 ± 0.004 | 16.91 ± 0.37 | 0.341 ± 0.006 | 17.20 ± 0.32 | 0.303 ± 0.002 | 16.48 ± 0.18 |
| 6731     | [S II] | 0.208 ± 0.004 | 12.94 ± 0.34 | 0.261 ± 0.005 | 13.33 ± 0.30 | 0.234 ± 0.002 | 12.73 ± 0.14 |

| Ion | C(Hβ) | W(Hα)abs(Å) | W(Hβ)abs(Å) | W(Hγ)abs(Å) | W(Hδ)abs(Å) | F(Hβ) |
|-----|-------|--------------|--------------|--------------|--------------|-------|
|     | 0.050 ± 0.005 | 0.064 ± 0.016 | 0.067 ± 0.004 | 6.0 | 0.0 | 5.5 |
|     | 3.8 | 4.2 | 3.5 | 4.2 | 3.5 | 4.5 |
|     | 25.2 ± 0.4 | 27.1 ± 1.1 | 55.6 ± 0.6 | 27.1 ± 1.1 | 55.6 ± 0.6 | 27.1 ± 1.1 |

**Note.** — Reddening-corrected line intensities, normalized to Hβ = 1, for the measured apertures from the long slit spectrum in position 1. Balmer lines are corrected from underlying stellar absorption. The reddening coefficient, C(Hβ), the value of the absorption correction in the Balmer lines, W(abs), and the corrected Hβ flux, F(Hβ) (×10⁻¹⁵ ergs cm⁻² s⁻¹), are also listed. [O II] data for Ap4 and S1 are affected by "ghost emission" from knot i and are omitted (see text in § 3.1.2 for details).
Fig. 1.— a) top-left: Contour plot of the continuum subtracted Hα image of Mrk 35. The two slit positions are plotted, and the different subregions we selected from the spectra are marked in bold line. b) top-right: Contour plot of the continuum subtracted Hα image of Mrk 35 with labels identifying the individual star-forming knots. c) bottom-left: B-band contours overlaid on the Hα gray-scale map. d) bottom-right: K-band map. Knot B2 is the optical center of the galaxy, but is not a Hα peak. Image orientation is north up and east left. Axis units are arcseconds.
Fig. 2.— Spectra of the different subregions defined in slit position S1, and its total integrated spectrum S1. The label indicates which knot each subregion includes. The inset is an enlargement of the spectrum around the Hδ line, to enhance the visibility of its absorption wings.
Fig. 3.— Spectra of the different regions defined in slit position S2, and the total integrated spectrum S2. The inset shows the blue Wolf-Rayet bump.
An alternative method to estimate $T_e$ is provided by the empirical relation proposed by Pilyugin (2001), which relies on the flux of [O II] $\lambda$3727.

The [O II] $\lambda$3727 fluxes we measured in knots C and D are abnormally high when compared to their H$\beta$ fluxes and give unrealistic values for $T_e$. This problem was found to be caused by strong contamination of the [O II] line in knots C and D by "ghost [O II] emission", originating from knots B1 and A. This ghost, whose amplitude is about one fourth that of the parent [O II] line, is visible in all the spectra of the other objects observed in the same run. Oddly enough, no ghost is produced by any other emission lines. In the regions between or outside the knots where the gas emission is fainter, we averaged the spectrum by 3 to 5 pixels in the spatial direction to increase the signal-to-noise ratio. At each spatial position, we averaged together the velocity values of the measured emission lines (after rejecting outliers), and took their scatter as an estimate of the associated uncertainty. A zero point offset on the velocity axis was applied to correct for small shifts in the wavelength scale, derived by measuring the position of a few bright sky-lines.

The velocity profiles in the two slit positions are very similar (Figures 4 and 5). There seems to be an over-density of gas in the inner parts of the galaxy, and a seemingly counter-rotating component, with a size of about 100 km s$^{-1}$, superposed. This decoupled region is located southwest of the continuum and H$\alpha$, is superposed. This decoupled region is located southwest of the continuum and H$\alpha$.

### 3.1.3. Gaseous Kinematics

The kinematics of the gas was determined by fitting a Gaussian to the strongest emission lines (H$\alpha$, H$\beta$, [O III] $\lambda$4959 and [O III] $\lambda$5007). In the regions between or outside the knots where the gas emission is fainter, we averaged the spectrum by 3 to 5 pixels in the spatial direction to increase the signal-to-noise ratio. At each spatial position, we averaged together the velocity values of the measured emission lines (after rejecting outliers), and took their scatter as an estimate of the associated uncertainty. A zero point offset on the velocity axis was applied to correct for small shifts in the wavelength scale, derived by measuring the position of a few bright sky-lines.

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### 3.1.4. Emission Line Contribution to the Broad-Band filters
TABLE 5
PHYSICAL PARAMETERS AND OXYGEN ABUNDANCES FOR THE APERTURES MEASURED IN MRK 35.

|       | Ap1 (knot b1) | Ap2 (knot b2) | Ap3 (knots b1+b2) | Ap4 (knot c) | S1 (knot A) | Ap5 (knot d) | Ap6 (knot b) | S2 |
|-------|---------------|---------------|-------------------|--------------|------------|-------------|-------------|----|
| log([O III]/Hβ) | 0.48          | 0.40          | 0.43              | 0.38         | 0.41       | 0.56        | 0.42        | 0.54|
| log([N II]/Hα)  | −0.99         | −0.95         | −0.96             | −0.95        | −0.96      | −1.12       | −0.98       | −1.10|
| log([S II]/Hα)  | −0.78         | −0.68         | −0.73             | −0.65        | −0.70      | −0.90       | −0.69       | −0.88|
| log([O I]/Hα)   | −1.79         | −1.67         | −1.72             | −1.57        | −1.69      | −1.89       | −1.64       | −1.87|
| Ne (cm⁻³)       | 150           | 110           | 120               | <100         | 100        | 170         | <100        | 170 |
| Te (K)          | 8700          | 8800          | 8700              | ...          | ...        | 10250       | ...         | 10770|
| 12 + log(O/H)   | 8.46          | 8.43          | 8.45              | ...          | ...        | 9200        | ...         | ... |
| 12 + log(O/H)   | 8.40          | 8.43          | 8.41              | 8.43         | 8.42       | 8.31        | 8.42        | 8.32|
| 12 + log(O/H)   | 8.43          | 8.36          | 8.35              | 8.36         | 8.35       | 8.26        | 8.36        | 8.27|

Note. — Line 6: Te derived from the [O III] λ4363/(λ4959 + λ5007) ratio; line 7: Te derived from Pilyugin (2001); line 8: abundance derived from Pilyugin (2001); line 9: abundance derived from Denicolò et al. (2002); line 10: abundance derived from Pettini & Pagel (2004).

Fig. 4.— Velocity profile for Position 1. The Hα flux profile (in 10⁻¹⁷ ergs cm⁻² s⁻¹ arcsec⁻² units) is also plotted to help relate kinematical and morphological features. Coordinate R = 0 was set at the center of the peak of the continuum emission, b2.

In objects with significant gas emission, such as BCDs, emission lines can contribute significantly to the flux through a broad-band filter, and thus affect broad-band colors; the exact amount of such contribution in a given band depends on the intensity of the emission lines and on their location under the filter transmission curve. Most of the evolutionary synthesis models (e.g. STARBURST99) do not take into account the emission line contribution to the broad-band filters, and therefore it is essential that this contribution be measured and subtracted out before computing the broad-band colors of the knots.

To do this we proceeded as follows. At each spatial position, and for each filter, we computed the integral of the curve obtained by multiplying the number of photons emitted per unit wavelength interval in the observed spectrum by the filter transmission curve. The same calculation was repeated on the continuum, modeled by fit-
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Fig. 5.—Velocity profile for Position 2. Coordinate $R = 0$ was set at the center of knot $a$.

Fitting a polynomial to the spectrum (we found that orders of about 20 gave the best results), using an iterative sigma-clipping algorithm that rejects all datapoints more than about 1 sigma off the fit.

This was straightforward for the B and V filters, as their cutoff values fall inside the wavelength range of our spectra. As for R, whose transmission curve extends to longer wavelengths than our spectra (which terminate at $\lambda \simeq 6920$), we computed $R'$ magnitudes, which we define as the magnitude for a $R'$ filter whose transmission curve is equal to that of the standard R filter up to $\lambda \simeq 6920$, and zero afterward.

Along position 2, the emission line contribution is larger (with a peak of $\simeq 0.70$ in V in knot $a$) and shows greater variations.

Unfortunately as we do not have NIR spectra, we could not extend this analysis to the NIR domain.

3.2. Photometric analysis

3.2.1. Morphological view of Mrk 35

The B-band contour map and the Hα map of Mrk 35 are displayed in Fig. 1. The starburst knots are aligned along the NE–SW direction, forming a bar-like structure, while the brightest knots ($A$, $B1$ and $B2$) form a "heart-shaped" structure in the central part of the galaxy. $B2$ is the center of the outer isophotes, while knot $A$ is the brightest SF region in the galaxy; the peaks of $A$ and $B2$ are separated by a distance of $3.9''$ (about 300 pc); in HST frames (Johnson et al. 2004) both knots are resolved into a number of smaller SF regions, many of them probably Super Star Clusters (SSCs). The optical frames suggest the presence of a dust lane (crossing the galaxy between knot $A$ and knot $B$, and extending out to the west), which is more clearly visible in the high resolution HST/WFPC F606W image by Malkan et al. (1998). The dust lane is more prominent in the $U$ and $B$ frames, and fade away moving toward redder wavelengths; it displays a redder color than the LSB component.
Fig. 6.— Magnitudes and colors differences between the observed spectrum and the interpolated continuum for Position 1. The discontinuities in the $B$ and $B - V$ plots correspond to the region affected by the "[O II] ghost", as described in §3.1.2.
Fig. 7.— Magnitudes and colors differences between the observed spectrum and the interpolated continuum for Position 2.
A tail-like feature extends in the SW direction, and connects with knots c and d, located \( \approx 20'' \) (1.5 kpc) from the center. The total length of the SF bar-like structure is \( \approx 70'' \) (5.3 kpc); the equivalent radius of the isophote at 27 \( B \)-mag arcsec\(^{-2} \) is 56'' (4.2 kpc).

The isophotes twist going from the inner regions, dominated by the starburst, to the outskirts of the galaxy, where they trace the shape of the underlying host, and have constant ellipticity for radii \( \geq 30'' \). The major axis of the outer isophotes has a position angle of 90 degrees, and forms an angle of 42 degrees with the central chain of knots. Sánchez-Portal et al. (2000) reported a P.A. of \( \approx 45 \) degrees for the outer isophotes, while Steel et al. (1996) set the major axis of the outer isophotes at P.A. \( \approx 58 \) degrees. In both cases the photometry was not deep enough to reach the low surface brightness (LSB) galaxy host, and what is claimed to be the “outer parts” is actually a region where the starburst emission is still significant. This discrepancy stresses once more the need for deep, high-quality data to correctly characterize the host galaxy in BCDs.

The morphology of the galaxy in the broad-band optical frames basically coincides with that in the infrared, though in the optical the inner isophotes are more distorted, likely due to dust. The spatial position of the five stronger sources coincide in all the broad-band frames. Knots B1 and B2 are the intensity peaks in the NIR, but they are not strong emitter in the blue band; and while \( \alpha \) is the intensity peak in the bluer bands (\( U, B, V \)), it is a weak source in the NIR. This fact indicates a highly inhomogeneous dust distribution and/or age differences among the knots.

Fig. 4 is the gray-scale \( H\alpha \) map of Mrk 35; \( B \)-band contours are over-plotted. The \( H\alpha \) emission is located in the central regions of the galaxy, elongated in the NE-SW direction, but slightly off-center to the NW. The underlying stellar host extends out much farther than the starburst region. The peaks of knots \( \alpha, c \) and \( d \) in the continuum (broad-band frames) are also peaks in \( H\alpha \), whereas knot B2, which is a strong emitter in the blue continuum, do not correspond to any of the \( H\alpha \) local maxima. The \( H\alpha \) map reveals intriguing features. Besides the eight relatively large SF regions labeled in Fig. 4, we found a number of smaller condensations around the main body of the galaxy: three knots, together with knot e form a "chain-like" structure extending in a north-east direction; two other knots are located about 10'' north of knots c and d; two small condensations are found south of knot d\(^3\). All these knots are continuum emitters, so they are stellar clusters. Faint, diffuse extensions emerge in the form of plumes and arcs from the main body of the galaxy; in particular, a remarkable arc-like structure with a diameter about 1 kpc, departs (apparently from knot \( \alpha \)) towards the West.

### 3.2.2. Color maps

High resolution and deep multi-wavelength broad-band observations, from the blue to the NIR, complemented by narrow band imaging, are powerful tools to study the stellar content of such complex systems as BCDs: i) the narrow-band frames allow us to identify the regions of the galaxies where active star-formation is taking place and, at the same time, the areas free of gas emission; ii) in the color maps we can discriminate the different stellar populations and see what regions are affected by gas contamination (for instance in \( B - V \) or \( B - R \) maps) or by dust lanes and patches (optical–NIR color maps).

![Fig. 8.— \( B - V \) color map of Mrk 35; isocontours for the continuum subtracted \( H\alpha \) frame are overlaid. North is up and east to the left; axis units are arcseconds.](image.png)

Fig. 8 displays the \( B - V \) map of Mrk 35; we clearly distinguish the starburst, elongated in the north-east south-west direction and placed atop the underlying extended and red elliptical host. The color distribution of the starburst region is neither blue nor homogeneous, as red patches appears along the chain. This is due to the emission line contamination: the strong [\( \text{O III} \)] \( \lambda 4959 \), 5007 lines account for a large fraction of the flux through the \( V \) filter, whereas the contribution of the emission lines in the \( B \) filter is significantly smaller, producing a substantial reddening of the \( B - V \) color (see Figs. 6 and 7). We have over-plotted the \( H\alpha \) emission on the color map; notice that the reddest patches inside the starburst coincide with the stronger gas emitters (namely, \( \alpha, c \) and \( d \)). This result highlights, once again, the need of taking into account the contribution of the gas emission and internal extinction, when interpreting the broad-band colors in starbursts.

Figs. 9 and 10 display the \( B - R \) and \( V - K \) color maps of Mrk 35. Because of the large difference in the interstellar extinction coefficient between blue and infrared bands, these maps are useful to recognize and trace dust lanes and patches. Unfortunately, the \( K \) frame is not as deep as the optical, and so we can build reliable color maps only for the central regions of the galaxy. A red band, crossing the galaxy in the north-south direction, between knots \( \alpha \) and B, is visible: this is possibly a dust lane. The inner regions in these maps are unlike the broad-band or the \( H\alpha \) knot distribution, as they display...
3.2.3. The Low Surface Brightness Stellar Component

Surface photometry of Mrk 35 in the optical and in the NIR was presented in C01b, C03 and Caon et al. (2005). In these works, the 1-D luminosity profile of the LSB component was modeled by a Sérsic law (Sérsic 1968). Here, we carry out a two-dimensional modeling of the surface brightness distribution of the LSB component following the method described in Amorín et al. (2007). The two main advantages of this novel approach are: the possibility of masking out the starburst region by following exactly its shape, rather than setting an inner radial limit to the 1-D profile fit; and the fact that we can then subtract out the best fit model from the galaxy image to recover the starburst.

The fit is done on the outer parts of the galaxy after masking out the central starburst and other disturbances such as small knots, foreground and background objects, etc. We used both Hα images and color maps to measure the size of the central starburst region. We start with a first mask, and run the program. Discrepant points are flagged out and the fit is re-done. The process is iterated until the fit converges, within a preset tolerance, to a solution that does not depend on the exact values of the input parameters.

The resulting two-dimensional Sérsic parameters of Mrk 35 in the optical and in the NIR bands are shown in Table 6. The model built in this way is finally subtracted from the original galaxy frame to recover the young starburst.

![Fig. 9. — B – R color map of Mrk 35. North is up and east to the left; axis units are arcseconds.](image)

![Fig. 10. — V – K color map of Mrk 35. North is up and east to the left; axis units are arcseconds.](image)

a patchy pattern, which probably results from the mixture of gas and dust.

| Band | $R_{\text{mask}}$ | $n$ | $R_e$ | $\mu_e$ | $m_{\text{LSB}}$ | $h/a$ | P.A. | $c$ |
|------|------------------|-----|-------|--------|------------------|-------|------|----|
| B    | 20.80            | 0.98| 15.04 | 22.33  | 14.11            | 0.72  | 74.0 | -0.02|
| V    | 19.45            | 1.01| 14.72 | 21.58  | 13.41            | 0.71  | 77.3 | 0.03 |
| R    | 19.45            | 0.97| 14.94 | 21.28  | 13.11            | 0.70  | 77.7 | -0.01|
| I    | 14.50            | 0.83| 15.33 | 20.80  | 12.63            | 0.71  | 74.9 | 0.01 |
| J    | 12.80            | 1.12| 16.70 | 20.52  | 11.65            | 0.70  | 58.1 | 0.18 |
| H    | 14.02            | 1.01| 19.99 | 20.00  | 11.19            | 0.67  | 63.2 | 0.15 |
| K    | 12.80            | 0.88| 20.50 | 19.70  | 10.89            | 0.70  | 60.6 | 0.03 |

Note. — Column (1): filter; col. (2): equivalent radius of the mask covering the central starburst region (arcsec); col. (3): Sérsic shape index $n$; cols (4) and (5): effective radius (arcsec) and surface brightness (mag arcsec$^{-2}$); col. (6): total magnitude of the LSB component derived from the fit (mag); col. (7): axis ratio; col. (8): position angle; col. (9): diskiness (negative)/boxiness (positive) parameter.

The spectroscopic analysis allows us to compute $F_{\text{LSB}}$ by means of the Sérsic modeling, as explained in the previous section, and thus derive

$$F_{\text{tot}} = F_{\text{LSB}} + F_{\text{young}} + F_{\text{emlines}}$$

(2)

The photometric analysis allows us to compute $F_{\text{LSB}}$ by modeling the spectral continuum as described in Sect 3.1.4 and thus derive

$$F_{\text{young}} + F_{\text{emlines}} = F_{\text{tot}} - F_{\text{LSB}}$$

(3)

The flux received from any given point in the galaxy is the sum of three components: the low surface brightness host, the continuum flux from the young stellar component and the flux in emission lines:

$$F_{\text{tot}} = F_{\text{LSB}} + F_{\text{young}} + F_{\text{emlines}}$$

(2)

Therefore, by combining photometry and spectroscopy we are able to derive separately each of these three components in filters $B$, $V$, and $R$ (the latter if we agree that the difference between the $R'$ and the $R$ band is not significant for our purposes.)
We illustrate how we proceed by taking knot A, whose diameter is about 6". In A the underlying stellar component, as described by the Sérsic model, accounts for ≃ 10% of the total flux in B and in V, and 5% in R. In the spectral aperture 6" wide centered on this knot, the continuum (that is, \( F_{\text{LSB}} + F_{\text{young}} \)) accounts for 75% of the flux in B, the emission lines 25%. In V we have 55% and 45% respectively; in R' 60% and 40%.

Combining the above data, under the simplifying assumption that the spectral data are constant within the whole A area, it is straightforward to derive that the young stellar component, \( F_{\text{young}} \), accounts for 65% of the total flux in B.

The same procedure can be applied to the other knots. The results are summarized in Table 7.

### 3.2.5. Photometry of the starburst

In order to identify the individual SF knots we used the FOCAS package and applied it to the continuum-subtracted H\(_\alpha\) images. FOCAS looks for local maxima and minima in the counts of the pixels in the image; we adopted the criteria that, for a knot to be detected, its area must be larger than 38 pixels (corresponding to an equivalent diameter of ≃ 1\" or 100 pc), to ensure that the diameter of the knot is larger than the point spread function; also the counts of each of its pixels must be higher than 2.5 times the standard deviation of the sky background. Using these criteria eight knots were identified (see Fig. 1).

The total H\(_\alpha\) flux of the galaxy is 1.09 × 10\(^{-12}\) ergs cm\(^{-2}\) s\(^{-1}\) (after setting a threshold of 3.8 × 10\(^{-18}\) ergs cm\(^{-2}\) s\(^{-1}\), 2.5 times the standard deviation of the sky background). With a diameter of 0.64 kpc and a total flux of 5.57 × 10\(^{-13}\) ergs cm\(^{-2}\) s\(^{-1}\), A is the brightest H\(_\alpha\) knot, emitting half of the total H\(_\alpha\) flux of the galaxy.

Next, we computed the broad-band magnitudes of the starburst knots identified in the H\(_\alpha\) frame, after convolving the broad-band images to match the PSF of the image with the worst seeing. Results of the photometry are presented in Tables 8 and 9. Table 8 displays the H\(_\alpha\) flux, luminosity and equivalent width of the knots. The central knot B2, not detected by FOCAS, is also included (fluxes are computed within a circular aperture 1\"/5 in radius). The data have been corrected from interstellar extinction and [N II] contribution using our spectroscopic information.

Table 9 lists the broad-band colors of the knots corrected for Galactic extinction and from [N II] emission. The equivalent widths are shown before and after the correction from the contribution of the LSB component to the continuum. H\(_\alpha\) fluxes are in 10\(^{-15}\) ergs cm\(^{-2}\) s\(^{-1}\) units; H\(_\alpha\) luminosities in erg sec\(^{-1}\) units. W(H\(_\alpha\)) is in Å.

#### 3.3. Disentangling the Stellar Populations

##### 3.3.1. The Starburst

In order to constrain the properties of the SF knots identified in Mrk 35, we adopted the Starburst99 evolutionary synthesis models (Leitherer et al. 1999), which produce a comprehensive set of observables of galaxies with active star formation. We use models with \( z = 0.004 \) and \( z = 0.008 \), which bracket the metallicity derived from the emission line fluxes (which is a reasonable approximation to the metallicity of a young population), and look for the scenario that best reproduces the collection of observables available for every knot: \( W(H\alpha) \), the optical and NIR colors, as well as \( W(H\beta) \) for those knots with spectroscopic information.

In all cases, we can reproduce the H\(_\alpha\) equivalent width with an instantaneous burst of star formation and the Salpeter IMF with an upper mass limit of 100 \( M_\odot \). Knot A, C and D are the youngest; their observables are consistent with ages of about 5 Myr. The central knots, B1 and B2, are slightly older, with ages of about 7 Myr.

In Fig. 1 our results are compared with the models. The equivalent width of the H\(_\alpha\) line is plotted versus \( B - V \). All the knots have H\(_\alpha\) equivalent widths in good agreement with model predictions, with ages rang-
Spectrophotometric observations of Mrk 35

Table 9

| Knot | Area | B  | B − V | V − R | V − I | J − H | H − K |
|------|------|----|-------|-------|-------|-------|-------|
|      |      |    |       |       |       |       |       |
| A    | 25.7 | 15.43 | 0.66 | 0.01 | 0.15 | 0.92 | 0.41 | 0.49 |
| B1   | 4.6  | 17.21 | 0.64 | 0.12 | 0.53 | 1.31 | 0.42 | 0.46 |
| C    | 8.4  | 18.61 | 0.61 | 0.09 | 0.35 | 0.98 | 0.50 | 0.31 |
| D    | 5.4  | 19.30 | 0.67 | 0.07 | 0.30 | 1.00 | 0.49 | 0.43 |
| E    | 2.4  | 22.33 | 0.67 | 0.26 | 0.78 | 0.42 | 0.46 | 0.49 |
| F    | 4.9  | 19.38 | 0.49 | 0.20 | 0.54 | 1.27 | 0.38 | 0.42 |
| G    | 2.7  | 19.09 | 0.50 | 0.23 | 0.62 | 1.33 | 0.47 | 0.35 |
| H    | 5.6  | 18.61 | 0.49 | 0.25 | 0.63 | 0.95 | 0.49 | 0.39 |
| B2   | 7.1  | 16.89 | 0.63 | 0.14 | 0.70 | 1.43 | 0.49 | 0.42 |

Note. — Upper rows: broad-band photometry for the star-forming regions detected in Mrk 35. Aperture photometry (within a radius = 1.5′′) for knot B2 is also included. Integrated total magnitudes have been corrected for Galactic extinction. Bottom rows: Magnitudes and colors of the young component, obtained by subtracting the low surface brightness host in every filter, and the contribution of emission lines in B and in B − V and V − R colors. Magnitudes and colors have also been corrected for both Galactic and interstellar extinction.

This is not surprising. Although the data have been corrected for the contribution of emission lines (Section 3.1.4), the contribution of the LSB host (Section 3.2.3) and for interstellar extinction, the various assumptions and simplifications we made to be able to work out such effects (for instance, that C(Hβ) and the emission line contribution do not vary spatially within a same knot) result in significant uncertainties on the final values. Also, in Mrk 35, the presence of a substantial amount of dust can also play an important role.

Fig. 12 displays the NIR color-color diagram of the SF regions. All the observed knots lie off the region of the models. We must keep in mind that NIR colors have not been corrected from gas line emission, and that SB99 includes only the contribution of the nebular continuum. However such a large disagreement is difficult to explain only in terms of emission lines. These excesses in the IR colors, already observed in starburst galaxies, could be a signature of the presence of hot dust (Vanzi 2002; Vanzi & Sauvage 2004; Johnson et al. 2004; Cresci et al. 2005).

3.3.2. The Low Surface Brightness Stellar Component

To constrain the evolutionary status of the host galaxy in Mrk 35 we can only use the information derived from its colors. Although some absorption features are detected in the spectra, they cannot be measured with sufficient accuracy.

The colors of the underlying galaxy host (derived from the Sérsic models) are tabulated in Table 10. They are not corrected from internal extinction, because the coefficients we derived, based on the gas emission lines, may not apply to the regions outside the area occupied by the starburst.

We use the spectral energy distribution (SED) derived from the Sérsic model to estimate the age of the underlying old stellar component. We employ models derived from the GALEV code (Bicker et al. 2004; Weilbacher et al. 2004; Leitherer et al. 1999). The numbers along the tracks mark the age in Myr.
as described by Anders et al. (2004). Our model grid consists of single metallicity models with $Z = 0.004$ and $Z = 0.008$ and we use single stellar population (SSP) as well as models with exponentially decreasing star formation rate with a characteristic timescale $1 < \tau < 12$ Gyr. As an alternative we also include chemically consistent models similar to those of Bicker et al. (2004), which are divided into different star formation histories to represent all galaxy types observed at the present day and use exponential timescales from $\tau = 1$ Gyr to constant star formation rate.

To look for the best agreement between the measured colors and the models we then derive an error weighted $\chi^2$ value of the observed magnitudes of every time-step of each model. Several models give a good fit; all those with half solar metallicity give a better fit than those with $Z = 0.004$. It is, however, difficult to obtain a good estimate of the dominant age of the stellar populations. Despite the wide wavelength range covered, the possible solutions are degenerate regarding age and star formation history (see Fig. 13). While the best matching single metallicity model is the SSP with $Z = 0.008$ at an age of 1.1 Gyr, other models with longer star formation timescales and only slightly worse $\chi^2$ values match at ages of 2.5 to 7.9 Gyr. Some of the chemically consistent models also give very good fits, the Sb-galaxy modeled after Bicker et al. (2004) provides the best overall match at an age of 8.7 Gyr.

We cannot help concluding that further observations, and especially data on spectral indices in the outer part of the LSB component, are necessary to determine the true dominant age of the underlying stars in the galaxy.

4. DISCUSSION

This work is the second of a series of papers devoted to a thorough spectrophotometric analysis of a sample of nearby BCDs. As we concluded in our previous work (C02, focused on the iE BCD Mrk 370), this kind of analysis, although scarce in the literature because of its difficulty, is essential to disentangle the stellar populations in systems as complex as BCDs and to put strong constraints on their SF histories and evolutionary status.

Here, by combining a wide set of photometric and spectroscopic data we disentangled the two stellar populations in the iE BCD Mrk 35: the starburst, which forms a bar-like structure extending in the northeast-southwest direction, and the underlying population of substantially older stars. The current star-formation not only takes place in the central knots (A and B), as pointed out by Johnson et al. (2004) — who worked with frames that covered only the innermost regions —, but also in the two knots placed at the end of the "tail-like" feature (C and D), as their Hα emission reveals.

The brightest knot, A, accounts for half of the Hα emission of the galaxy: the age we derived for it is about 5 Myr, consistent with the ages found in previous works (Johnson et al. 2004; Steel et al. 1996), and with the detection of WR stars (Steel et al. 1996; Huang et al. 1999). Knots C and D show almost identical ages, which rules out the hypothesis that the star formation is propagating along the "tail-like" feature. Knots B1 and B2 have slightly larger ages, about 7 Myr, but the age difference with the brighter knots ($\sim 2$ Myr) is probably too small to be consistent with a scenario of self-propagating

\begin{table}[h]
\centering
\caption{Colors of the LSB stellar component derived by fitting a S\`{e}rsic model.}
\begin{tabular}{ccccccc}
\hline
\hline
$B - V$ & $V - R$ & $V - I$ & $V - J$ & $J - H$ & $H - K$ \\
\hline
0.70 & 0.30 & 0.78 & 1.76 & 0.46 & 0.30 \\
\hline
\end{tabular}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig12.pdf}
\caption{\textit{J} - \textit{H} vs \textit{H} - \textit{K} color-color diagram. Solid points represent the knots parameters after applying the corrections from reddening and older stars. We also plot the tracks of two instantaneous bursts of $z = 0.004$ (solid line) and $z = 0.008$ (dashed line), both aged from 1 to 30 Myr, and with an IMF with $\alpha = 2.35$ and $M_{\text{low}} = 100M_\odot$ (Leitherer et al. 1999). The numbers along the tracks mark the age in Myr.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig13.pdf}
\caption{The \textit{B} to \textit{K} spectral energy distribution of the observed LSB component and three typical models. The y-axis shows the color relative to \textit{V}, the x-axis the wavelength. The observations are shown as crosses, where the x-error gives the approximate width of the filters and the y-axis the uncertainty of the S\`{e}rsic fit in each filter. Three selected models are shown: 1) an SSP with $Z = 0.008$ at an age of 1.1 Gyr; 2) a model with characteristic star-formation timescale $\tau = 1$ Gyr with $Z = 0.008$ at an age of 2.6 Gyr; 3) a chemically consistent model of an Sb galaxy ($\tau = 6.6$ Gyr) at an age of 8.7 Gyr.}
\end{figure}

et al. 2004; all of them use a Salpeter initial mass function and Padova isochrones and other input parameters
star-formation.

The high resolution frames combined with spatially resolved long-slit spectroscopy allowed us to carry out an exhaustive analysis of the starburst population. In order to characterize the current starburst episode, a considerable effort has been made to disentangle the young stars from the ionized gas emission, from dust and from older stars. Using deep broad-band frames we modeled the LSB host and subtracted it from the total emission; the spectra allowed us to estimate the contribution of emission lines, and to derive the extinction coefficient, in the different spatial regions along the two slit positions (see Table 7).

After applying these corrections, we derived colors, physical parameters and oxygen abundances for the SF knots, and investigated how they vary from one spatial location to another.

A very important aspect, often ignored in previous analyses, is the estimation of the contribution of emission lines to the total amount of flux measured using standard broad-band filters. In this case, using our spectra we calculated the amount of flux due to emission lines in the B, V, and R bands, along both slit positions. We found that this contribution is by no means negligible, and even more importantly, it shows spatial variations, not only from one knot to another, but even within the same knot. For instance, the contribution of emission lines in knot A (along the slit position 2), is as large as 0.7 mag: such a huge amount of flux can make the B − V starburst colors similar or even redder than those of the host (see the B − V color map in Fig. 8). Therefore, for a proper subtraction of the emission lines contribution a two-dimensional mapping of the line emission is required.

Several recent works have questioned the previous belief that BCDs have no or little dust (Hunt et al. 2001, Cairós et al. 2003; Vanzi & Sauvage 2004; Cabanac et al. 2005). Mrk 35 shows evidence of dust in its central regions. In the optical frames dust is visible as a lane between the central knots, A and B, extending to the west (as already pointed out by C03 and Johnson et al. 2004). Our color maps also suggest the existence of a more extended dust distribution: red patches are in fact visible at the north of knot A, and the pronounced "red" border, crossing the galaxy parallel to the central like-bar starburst, may also be due to dust which blocks light from the part of the galaxy behind.

One intriguing aspect is that, although we found evidence for the presence of dust, the derived reddening values in all the apertures are considerably small. From the Balmer decrement, we obtain AV = 0.17 in knot A and AV = 0.11 − 0.13 in knots B1 and B2 (in good agreement with the values reported in Steel et al. 1996, Johnson et al. 2004) however, working in NIR and radio wavelengths, found considerably higher extinction value for knot A, AV = 8. These discrepancies in the extinction measured at different wavelengths have been also found in other SF dwarfs (VV 114, Yun et al. 1994; He2-10, Kobulnicky et al. 1995): in a dusty environment, in which the dust is mixed with the emitting sources, there is a trend of increasing extinction from the optical to the IR. Therefore, the lower extinction values derived from our optical spectroscopy are most probably the result of a inhomogeneous dust distribution.

Indeed, the actual amount of dust (and its distribution) is currently a hot topic in BCD galaxy research. By studying the properties of the dust in these nearby dwarfs we can learn about the dust formation in primordial environments. Moreover, it is becoming more and more clear that an important fraction of the SF activity in these galaxies lies buried in dust and has not visible counterparts (Thuan et al. 1999; Kobulnicky & Johnson 1999, Hunt et al. 2001, Vacca et al. 2002; Johnson et al. 2003; Vanzi & Sauvage 2004). Integral Field spectroscopic observations, with which to build a spatial map of the extinction coefficient, together with high-resolution MIR observations to map the dust distribution and measure its emission, would provide important advances in the field.

The galaxy morphology — two major knots in the inner regions of the galaxy and the "tail-like" features — suggests that an interaction (and/or) merger could have played a main role in the galaxy shaping and evolution. Steel et al. (1996) rejected the merger hypothesis on the basis on the velocity of the central knots (almost identical) and the regularity of the outer isophotes, and favored the hypothesis of intrinsic self-induced star-formation. Nevertheless, only small age gradients have been detected across the galaxy, even with the deeper and better spatial resolution data in Johnson et al. (2004) and in this work. Although we cannot discard that some propagation is operating in Mrk 35, it does not seems to be the dominant mechanism. On the other hand, Johnson et al. (2004) favored a merger event as the one igniting the star-formation in Mrk 35: they argued that the regularity of the outer isophotes does not exclude a small-scale interaction, and the fact that A and B had similar redshifts also does not exclude that they were once separated systems. They compared Mrk 35 with the iE, BCD He 2-10, a very well studied object (Kobulnicky et al. 1995; Johnson et al. 2000; Cabanac et al. 2005), which has significant similarities with Mrk 35, and appears to be interacting with a massive cloud of gas that is falling into the main body of the galaxy (Kobulnicky et al. 1995; Johnson et al. 2000), and speculate that the nature of the star-forming trigger in Mrk 35 could be similar.

Our kinematical analysis seems to support the merger hypothesis. The apparently counter-rotating feature in the inner region of the velocity profiles could be the signature of a past merger or acquisition event. Integral field spectroscopy, which allows the derivation of the velocity field of the gas, is required to properly interpret the rotation pattern. Also, deep spectroscopic observations with large telescopes, which permit high signal-to-noise observations of absorption features and therefore to trace the kinematics of the stars, would be essential.

5. SUMMARY AND CONCLUSIONS

Optical and NIR broad-band images, Hα narrow-band frames and long-slit spectroscopic data for the iE BCD galaxy Mrk 35 have been analyzed in order to derive the properties of the different components of the galaxy, to constrain its evolutionary status and to investigate the possible mechanisms triggering the actual SF episode. From this study we highlight the following results:

- Two different stellar components are clearly distinguished in the galaxy: the actual starburst and an underlying older population. The current star for-
mation activity takes place in several knots, aligned along the NE-SW direction, in a bar-like structure; the brightest knots (A, B1 and B2) are arranged in a "heart-shaped" structure, in the central region of the galaxy, while knot C and D are located in the "tail-like" feature. An extended LSB component, with regular appearance and red colors, sits underneath the star-forming area.

- The brightest knot, A, is a powerful and young SF region, with Wolf-Rayet stars, and accounts for 50% of the total Hα luminosity of the galaxy.

- For each spatial region in the slit we derived reddening corrected intensity ratios, extinction values, physical parameters of the gas and oxygen abundances. Although we found evidences for the presence of dust, the extinction coefficient derived from the Balmer decrements are similar and small for all the regions ($A_V$ ranges from 0 to 0.17). The oxygen abundances do not show significant variations from knot to knot.

- The observed flux in the SF knots is the sum of, basically, three components: the light coming from the young stars, the contribution of emission lines and the emission from the low surface brightness underlying population of stars. We presented a methodology to disentangle and assess each of these components.

  - Using our spectroscopic information we first computed the contribution of emission lines to the $B$, $V$ and $R$ filters, along the two slit positions. We found that they can strongly affect the broad-band magnitudes and colors, as much as 0.7 mag in the $V$-band filter. This contribution also varies significantly from one knot to the next. Thus, only by a two-dimensional mapping of the gas emission (which can be done by means of Integral Field Spectroscopy) can we derive accurate photometric values of the young star colors.

  - We modeled the host galaxy with a Sérsic function, and subtracted it from the total emission to recover the colors of the young SF knots.

  - We compared the final observables with the predictions of evolutionary synthesis models, and found that we can reproduce the colors of the knots with an IB of star-formation and the Salpeter Initial Mass Function with an upper mass limit of 100 $M_\odot$. The ages of the knots are about 5 Myr, with B being slightly older. No significant age gradients have been found in the starburst region, which discards the propagated star formation scenario.

  - We found some evidence for the presence of dust in the central regions of the galaxy.

  - The kinematical analysis shows an overall rotation, with a peak-to-peak amplitude of $\sim 100$ km s$^{-1}$. However, the curve is irregular in the inner region, where there seems to be a counter-rotating component. This could support the idea that the galaxy has undergone or is undergoing an interaction or accretion process.

Based on observations with the WHT, operated by the Royal Greenwich Observatory, and with the Nordic Optical Telescope, operated jointly by Denmark, Finland, Iceland, Norway, and Sweden, both on the island of La Palma in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. We thank J. N. González-Pérez for his help in the initial stages of this project. We also thanks J. M. Vílchez, J. García-Rojas, A. R. López Sánchez and J. H. Huang for useful discussions. We are grateful to the unknown referee whose detailed review and many suggestions greatly helped us to improve this paper. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. L. M. Cairós acknowledges support from the Alexander von Humboldt foundation. This work has been partially funded by the spanish “Ministerio de Ciencia y Tecnología" (grants AYA2001-3939 and PB97-0158).

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