# Optical & NIR surface Photometry of I Zw 18*

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**Abstract**

Using *HST* and ground-based optical and NIR data, we investigate whether the blue compact dwarf (BCD) galaxy I Zw 18 has an extended low-surface-brightness (LSB) older stellar population underlying the star-forming regions, as is the case in evolved iE/nE BCDs. Subtraction of narrow band H$\alpha$ and [O III] exposures from $R$ and $V$ images shows that the filamentary LSB envelope extending out to $\sim$2 kpc away from the starburst region, and hence the optical broad-band colors observed therein, are due mainly to ionized gas emission. Ionized gas accounts already at a galactocentric distance of 0.7 kpc for more than 80% of the $R$ band line-of-sight intensity and contributes more than 40% of the integrated $R$ band light of I Zw 18. The structural properties (such as the exponential scale length) of the *stellar* LSB component underlying the extended ionized gas emission place I Zw 18 among the most compact BCDs studied so far. Contrary to evolved nE/iE BCDs the stellar component in I Zw 18 shows no appreciable color gradients over a range of $\sim$8 mag in surface brightness.

In order to understand the dynamical formation and the evolutionary state of I Zw 18, it is important to investigate whether or not the star-formation activity in this system is taking place on top of an extended and evolved *stellar* low-surface-brightness (LSB) host. If the putative underlying older stellar population has photometric properties typical of evolved (a few Gyr old) iE/nE BCDs (cf. Loose & Thuan 1985), then its detection should be feasible with current instrumentation. The underlying LSB component of BCDs shows for $M_B \gtrsim$–16 mag a central surface brightness excess of $\gtrsim$1.5 mag and an exponential scale length reduced by a factor of $\sim$2 as compared to, e.g., dwarf irregulars (Papaderos et al. 1996; hereafter P96, Patterson & Thuan 1996, Salzer & Norton 1999), i.e. its mean surface brightness is significantly higher than in other dwarf galaxy types. Moreover, in such systems the emission of the evolved stellar host contributes on average about half of the $B$ band light within the 25 $B$ mag/$\square''$ isophote and dominates the radial intensity and color distribution for fainter surface brightness levels (P96).

In the following, we investigate the photometric properties and nature (stellar and/or gaseous) of the extended LSB envelope surrounding I Zw 18 (cf. Fig. 1a&c) using ground-based and *HST* data. We adopt a distance of 15 Mpc (Izotov et al. 2001) and a mean extinction $A_V$=0.16 mag for I Zw 18. This study is based on archival broad-band *HST* WFPC2 data in $B$ (F450W), $V$ (F555W) and $R$ (F702W) by Dufour et al. (1996). Narrow band [O III] (F502N) and H$\alpha$ (F658N) images were used to correct the broad band data for the contribution of ionized gas line emission. Furthermore, we include $B$ (90 min), $V$ (40 min), $R$ (70 min) and $I$ (60 min) ground-based data taken with the Calar Alto 1.23m/2.2m and Kitt Peak 2.1m telescopes. NIR exposures in $J$ (66

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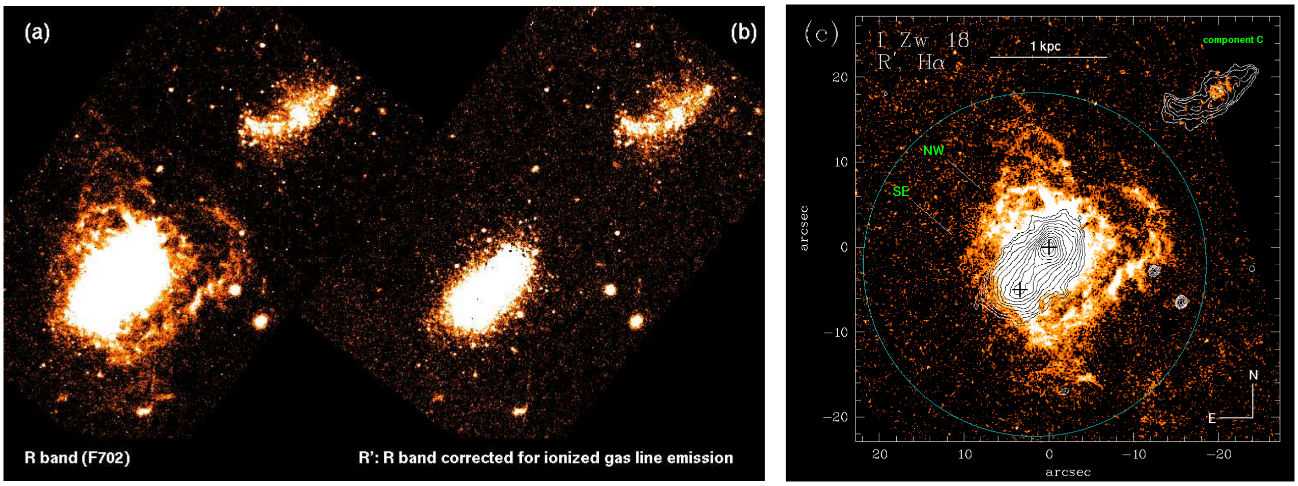


Figure 1: **(a)** *HST* WFPC2 exposure of I Zw 18 in the $R$ (F702W) band. **(b)** The same $R$ band exposure after scaling and subtraction of the H$\alpha$ (F658N) map (in the following referred to as $R'$). Both images are displayed in the same intensity range. **(c)** $R'$ contours overlaid with an H$\alpha$ map of the main body of I Zw 18. Contours correspond to surface brightness levels from 18.5 $R'$ mag/$\square''$ to 25 $R'$ mag/$\square''$ in steps of 0.5 mag. The SE and NW star-forming regions are indicated by crosses.

min), $H$ (36 min) and $K'$ (35 min) were acquired with the Omega 1k$\times$1k camera attached to the prime focus of the 3.5m telescope at Calar Alto.

The surface brightness profiles (SBPs) of the main body of I Zw 18, derived from ground-based $B$ and $R$ data (Fig. 2a), can be well fitted by an exponential law for radii $8'' \leq R^* \lesssim 16''$. A linear fit to the $B$ band profile yields for the LSB envelope a central surface brightness $\mu_0 = 22.3 \pm 0.1$ $B$ mag/$\square''$, an exponential scale length of $3\farcs45$ ($\sim$250 pc) and an apparent magnitude of $m_B$=17.7 mag ($\sim$24% of the total $B$ band emission).

The same result can be verified independently from *HST* data. As shown in Fig. 2b, *HST* WFPC2 data in $V$ (F555W) and $R$ (F702W) allow to trace the surface brightness distribution of the LSB host out to its Holmberg radius. The SBPs derived from the latter data are in the radial range $8'' \leq R^* \leq 14''$ practically indistinguishable from those inferred from ground-based images in $B$ and $R$. This lends further support to the conclusion of Papaderos (1998) and Kunth & Östlin (2000; hereafter KÖ2000) that the surface brightness distribution of the LSB envelope of I Zw 18, despite its patchiness, can be well approximated by an exponential fitting law.

The $B-R$ and $V-R$ colors of I Zw 18 (Fig. 2c) increase smoothly with galactocentric distance with a mean gradient of $\sim$0.05 mag/$''$ and level off at $B-R \approx$+0.55 mag and $V-R \approx$+0.47 mag for $R^* > 8''$. This $B-R$ color derived for the outlying regions of I Zw 18 is in good agreement with the value of $\sim$+0.6 mag obtained by Papaderos (1998) and KÖ2000. The $B-J$ color index was determined to be $\lesssim$+0.6 mag at the equivalent radius of $R^* = 9''$. Beyond that radius, corresponding to a surface brightness level of $\sim$25 mag/$\square''$ in the $J$ band, noise and source confusion do not allow a reliable determination of optical–NIR colors. We note that our data *do not show* the steep and systematic increase of the $B-J$ index (up to +1.7 mag at $R^* \approx 12''$) reported by KÖ2000.

Assuming that ionized gas emission is negligible in the outskirts of I Zw 18, then the relatively red $B-R$ or $V-R$ colors would imply that the extended LSB component of this system is made of an evolved stellar population, typical for iE/nE BCDs. Indeed, evolutionary synthesis models for the colors of this component would yield an age as high as $\sim$20 Gyr. However, the assumption that the LSB emission in I Zw 18 is primarily of stellar origin is not tenable when all the color

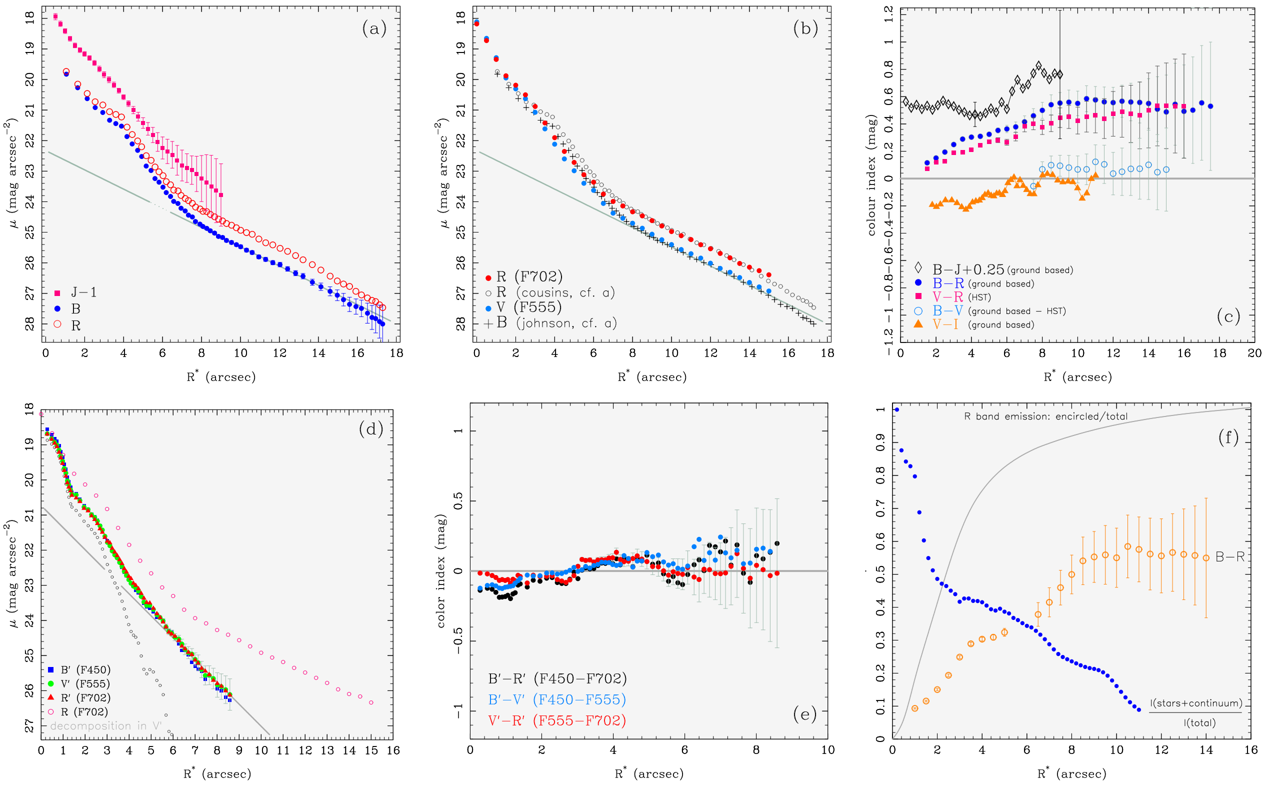


Figure 2: **(a)** Surface brightness profiles (SBPs) of I Zw 18's main body in $B$, $R$ and $J$ computed from ground-based data. The straight line shows a fit to the exponential regime of the $B$ band SBP for radii $\geq 9''$. **(b)** Comparison of the $B$ and $R$ SBPs shown in panel (a) with those obtained from archival *HST* WFPC2 data in $V$ (F555W) and $R$ (F702W). Note that for radii $>9''$ the $B$ band SBP matches closely the $V$ band profile. **(c)** $B-R$, $V-R$, $V-I$, $B-V$ and $B-J$ color indices computed from ground-based and *HST* data. **(d)** SBPs of I Zw 18 in $B$, $V$ and $R$ computed after correction for the contribution of ionized gas line emission (labelled $B'$, $V'$, $R'$). A linear fit to the $V'$ band SBP for $R^* \geq 6\overset{''}{.}5$ is shown by the solid line. The SBP in the $R$ band as computed before correction for the H$\alpha$ emission (cf. panel a) is included for comparison. **(e)** Color profiles of the main body of I Zw 18 derived from SBPs in $B'$, $V'$ and $R'$. **(f)** Fractional contribution of the stellar background and the gaseous continuum to the $R$ band line-of-sight intensity of the main body of I Zw 18 as a function of the equivalent radius $R^*$ (filled circles). For $R^* > 9\overset{''}{.}6$ ionized gas accounts for >80% of the $R$ band emission and hence determines the moderately red $B-R$ color (open symbols) observed all over the filamentary LSB envelope of the BCD.

distributions displayed in Fig. 2c are considered. The $B-V$ and $V-I$ indices remain blue (~0 mag) out to $R^* \approx 14''$, i.e. over a range of 8 mag in surface brightness. No model with only a stellar population and no gaseous emission can reproduce the colors observed in the outskirts of I Zw 18 (e.g. red $V-R$ and blue $V-I$ colors), irrespective of the age or metallicity of that stellar population.

The striking filamentary appearance of the LSB envelope of I Zw 18 (Fig. 1a,c), together with its observed colors both suggest a substantial contribution of ionized gas emission for radii $\gtrsim 4''$ (cf. eg. Izotov et al. 1997, Papaderos et al. 1998). Östlin et al. (1996) first presented an H$\alpha$ equivalent width ($EW$(H$\alpha$)) map of I Zw 18 from high resolution ground-based data and inferred an $EW$(H$\alpha$) as high as $\sim$ 1500 Å over an appreciable fraction of its main body. The significant contribution of ionized gas emission in the halo of I Zw 18 has also been discussed by Vílchez & Iglesias-Páramo (1998) and Izotov et al. (2001).

An upper limit to the isophotal size and scale length of the stellar component in I Zw 18 can be obtained by scaling and subtracting [O III] and H$\alpha$ maps from the $B$(F450W)[1], $V$(F555W) and $R$(F702W) images. The resulting images, referred to as $B'$, $V'$ and $R'$, account therefore mainly for the combined emission of the stellar background and the gaseous continuum in the main body of the BCD. Figure 1b illustrates the importance of this correction for ionized gas line emission to the study of the stellar content in I Zw 18: while subtraction of ionized gas emission has practically no effect on the morphology and photometric properties of component C where the H$\alpha$ line is very weak, it results in the virtual removal of the filamentary LSB envelope surrounding the main body.

The photometric properties of the compact (the effective radius is $\sim$150 pc) and relatively smooth residual emission can be derived from the $B'$, $V'$ and $R'$ surface brightness profiles (Fig. 2d). Linear fits for $R^* \geq 6.''5$ yield consistently a mean exponential scale length of 125$\pm$10 pc and a $V'$ band central surface brightness of 20.7$\pm$0.4 mag/$\square''$, placing I Zw 18 among the most compact BCDs studied so far. The narrow range of scale lengths in all these bands implies a nearly constant color throughout the main body of I Zw 18. The color profiles derived from $B'$, $V'$ and $R'$ data (Fig. 2e) are still contaminated by line and continuum emission from ionized gas, so their interpretation in terms of stellar population age is not straightforward. It is worth noting, however, that color profiles computed this way show – contrary to those displayed in panel c – a weak gradient and a small scatter of $\sim$0.2 mag around zero.

From profile integration, we obtain a lower limit for the contribution of gaseous emission to the integrated light of I Zw 18 of $\sim$20% and $\sim$40% in $V$ and $R$, respectively. The contribution of the H$\alpha$ emission line to the observed intensity as a function of the equivalent radius $R^*$ can be assessed from the $R$ and $R'$ SBPs (Fig. 2a and Fig. 2d). Figure 2f shows that for $R^* > 9.''6$ (0.7 kpc) the average contribution of the stellar background to the $R$ band line-of-sight intensity is less than 20%, implying that the colors observed in the LSB envelope of I Zw 18 (cf. Fig. 2c) result mainly from ionized gas emission.

For larger radii, the available data do not go deep enough to allow to put firm constraints on the surface density of the stellar background possibly underlying the ionized gas envelope of I Zw 18. An estimate can be obtained by extrapolating the exponential slope determined for the $B'$, $V'$, $R'$ SBPs (Fig. 2d). Within the $2\sigma$ bound in the profile fitting, we obtain upper limits of 21.6 $B$ mag/$\square''$ for the central surface brightness, and of 146 pc for the scale length of the underlying stellar component in I Zw 18. These values yield for the surface brightness of the stellar component a conservative upper limit of $\sim$30.5 $B'$ mag/$\square''$ at a galactocentric distance of 1.2 kpc ($16.''5$), i.e. only $\sim$7% of the observed $B$ band intensity.

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[1]Note that the transmission curve of the F450W filter includes the [O III]$\lambda$5007 emission line.