HST OBSERVATIONS OF THE BLUE COMPACT DWARF SBS 0335–052: A PROBABLE YOUNG GALAXY

Trinh X. Thuan
Astronomy Department, University of Virginia, Charlottesville VA 22903, USA; txt@virginia.edu

Yuri I. Izotov
Main Astronomical Observatory, Ukrainian Academy of Sciences, Goloseevo 252650, Kiev-22, Ukraine; izotov@mao.gluk.apc.org

and

Valentin A. Lipovetsky
Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhyz, Karachai-Circassia 357147, Russia; val@sao.stavropol.su

Received Accepted

Submitted to the Astrophysical Journal

\footnote{Based on observations obtained with the NASA/ESA Hubble Space Telescope through the Space Telescope Science Institute, which is operated by AURA,Inc. under NASA contract NAS5-26555}
We present HST WFPC2 V and I images and GHRS UV spectrophotometry of the spectral regions around Ly\(\alpha\) and OI \(\lambda 1302\) of the extremely metal-deficient (\(Z \sim Z_\odot/41\)) blue compact dwarf (BCD) galaxy SBS 0335–052. All the star formation in the BCD occurs in six super-star clusters (SSC) with ages \(\leq 3-4\) Myr. As there is no evident sign of tidal interaction, star formation in the BCD is probably triggered by stochastic cloud collisions in the HI envelope. Dust is clearly present and mixed spatially with the SSCs. There is a supershell of radius \(\sim 380\) pc, delineating a large supernova cavity. The instantaneous star formation rate is \(\sim 0.4\) \(M_\odot\) yr\(^{-1}\).

Strong narrow Ly\(\alpha\) emission is not observed. Rather there is low intensity broad (FWZI = 20 \(\AA\)) Ly\(\alpha\) emission superposed on even broader Ly\(\alpha\) absorption by the HI envelope. This broad low-intensity emission is caused by resonant scattering of Ly\(\alpha\) photons. The absence of strong Ly\(\alpha\) emission may be due partly to dust absorption, but mainly to multiple scattering which removes Ly\(\alpha\) photons from the small HST aperture. As the HI cloud is seen nearly edge-on, geometrical effects may play also a role as photons escape more easily in a direction perpendicular to the plane than along it.

The BCD appears to be a young galaxy, undergoing its very first burst of star formation. This conclusion is based on the following evidence: 1) the underlying extended low-surface-brightness component is very irregular and filamentary, suggesting that a significant part of the emission comes from ionized gas; 2) it has very blue colors \((-0.34 \leq (V-I)_0 \leq 0.16)\), consistent with gaseous emission colors; 3) the OI \(\lambda 1302\) line is not detected in absorption in the GHRS spectrum, setting an upper limit for \(N(O)/N(H)\) in the HI envelope of the BCD of more than 3000 times smaller than the value in Orion.

Subject headings: galaxies – young: interstellar matter – nebulae: HII regions
1. INTRODUCTION

The formation of galaxies is one of the most fundamental problems in astrophysics, and much effort has gone into the search for primeval galaxies (PG). A possible definition of a primeval galaxy is a young system undergoing its first major burst of star formation. It is now widely believed that the vast majority of galaxies underwent such a phase at redshifts $\sim 2$ or greater. In most galaxy formation scenarios, young galaxies are predicted to show strong Ly$\alpha$ emission, associated with the cooling of the primordial gas and the subsequent formation of a large number of massive ionizing stars (Partridge & Peebles 1967; Meier 1976; Baron & White 1987; Charlot & Fall 1993). Yet, despite intensive searches, the predicted widespread population of Ly$\alpha$ primeval galaxies has remained elusive (Pritchett 1994). The reasons for this non-detection are not yet clear.

Several objects have been put forward as possible PG candidates, ranging from high-redshift radio galaxies to Ly$\alpha$ emitters found around quasars and damped Ly$\alpha$ systems, mainly on the basis of very high luminosity and star formation activity (Fontana et al. 1996; Pettini, Lipman & Hunstead 1995; Yee et al. 1996). However, most of these candidate PGs already contain a substantial amount of heavy elements, implying previous star formation and metal-enrichment and hence not satisfying the above definition of PG. For example, the spectrum of the PG candidate discussed by Yee et al. (1996) shows a strong P-Cygni profile in CIV $\lambda$1550, indicating the presence of heavy elements since low-metallicity stars do not have strong winds and show no or weak P-Cygni profiles. Moreover, even if PG candidates at high-redshift are discovered, it is difficult to study them in detail because of their extreme faintness and very compact angular size. Here we take a different approach to the PG problem. Instead of searching for very high-redshift galaxies in the process of forming, we look for nearby galaxies undergoing their first burst of star formation, and hence satisfying the above definition of a PG. The best candidates for such a search are blue compact dwarf galaxies (BCD).

BCDs are extragalactic objects with $M_B \geq -18$ where intense star formation is presently occurring, as evidenced by their blue UBV colors, and their optical spectra which show strong narrow emission lines superposed on a stellar continuum which is rising toward the blue, similar to spectra of HII regions. Star formation in BCDs cannot be continuous but must proceed by bursts because of several observational constraints: 1) Gas is transformed into stars at the rate of approximately $1 M_\odot$yr$^{-1}$, so that the current burst cannot last more than about $10^8$ yr before depleting the gas supply; 2) Optical-infrared colors of BCDs give ages of about $10^7$ yr; and 3) Population synthesis of UV spectra of BCDs give invariably jumps in the stellar luminosity function, indicative of starbursts (see Thuan 1991 for a review).

Ever since their discovery, the question has arisen whether BCDs are truly young systems where star formation is occurring for the first time, or old galaxies with an old underlying stellar population on which the current starburst is superposed (Searle, Sargent & Bagnuolo 1973). Thuan (1983) carried out a near-infrared JHK survey of BCDs and concluded that all the objects in his sample possessed an old underlying stellar population of K and M giants. That result was not unambiguous as the JHK observations were centered on the star-forming regions and the near-infrared emission could be contaminated by light from young supergiant stars. The advent of CCD detectors allowed to look for the low-surface-brightness underlying
component directly. Loose & Thuan (1985) undertook a CCD imaging survey of a large BCD sample and found that nearly all galaxies (≥ 95%) in their sample show an underlying extended low-surface-brightness component, on which are superposed the high-surface-brightness star-forming regions. Subsequent CCD surveys of BCDs have confirmed this initial result (Kunth, Maurogordato & Vigroux 1988, Papaderos et al. 1996). Thus, most BCDs are not young galaxies. In Kunth et al. (1988)' sample, the BCD I Zw 18 does not show an underlying component. This BCD with a metallicity of only $Z_{\odot}/50$ is the most metal-deficient galaxy known (Searle & Sargent 1972). It has been discussed as a possible young galaxy, currently undergoing its first burst of star formation (Kunth & Sargent 1986). Hunter & Thronson (1995) obtained HST images of I Zw 18 and concluded that the colors of the underlying diffuse component are consistent with those from a sea of unresolved B or early A stars, with no evidence for stars older than $\sim 10^7$ yr.

For more than 20 years, I Zw 18 stood in a class by itself. The BCD metallicity distribution ranges from $\sim Z_{\odot}/3$ to $\sim Z_{\odot}/50$, peaking at $\sim Z_{\odot}/10$, and dropping off sharply for $Z \leq Z_{\odot}/10$ (Kunth & Sargent 1986). Intensive searches have been carried out to look for low-metallicity BCDs but they have met until recently with limited success. For example, the majority of the BCDs in the Salzer (1989) and Terlevich et al. (1991) surveys have metallicities larger than $Z_{\odot}/10$. Several years ago, a new BCD sample has been assembled by Izotov et al. (1992, 1993) from objective prism survey plates obtained with the 1m Schmidt telescope at the Byurakan Observatory of the Armenian Academy of Sciences during the Second Byurakan Survey (SBS, Markarian, Lipovetsky & Stepanian 1983). The most interesting feature of the SBS is its metallicity distribution (Izotov et al. 1992): it contains significantly more low-metallicity BCDs than previous surveys. It has uncovered about a dozen BCDs with $Z \leq Z_{\odot}/15$, more than doubling the number of such known low-metallicity BCDs and filling in the metallicity gap between I Zw 18 and previously known BCDs. This low-metallicity sample has been used to determine the primordial helium abundance (Izotov, Thuan & Lipovetsky 1994, 1996), heavy element abundances in metal-deficient environments (Thuan, Izotov & Lipovetsky 1995) and study the BCD large-scale spatial distribution (Pustilnik et al. 1995).

Here we focus our attention on the most metal-deficient BCD in the SBS sample, SBS 0335–052. Using the Hubble Space Telescope (HST), we have obtained optical imaging and UV spectroscopy for the galaxy. We discuss the HST observations and their data reduction in §2. We argue for the youth of SBS 0335–052 in §3. In §4 we show how other observational data also support the youth hypothesis, and discuss the Ly$\alpha$ problem in the BCD and its implications on Ly$\alpha$ searches of high-redshift primeval galaxies. We also compare the properties of SBS 0335–052 with those of other nearby young galaxy candidates. We summarize our conclusions in §5.

2. OBSERVATIONS AND DATA REDUCTION

The BCD SBS 0335–052 was discovered by Izotov et al. (1990) to have an extremely low metallicity. With $Z \sim Z_{\odot}/41$ (Melnick, Heydari-Malayeri & Leisy 1992), it is the second most-metal deficient BCD known, only behind I Zw 18. Its integral characteristics are summarized in Table 1. At the adopted distance of 54.3 Mpc, 1″ corresponds to a linear size of 263 pc. To

\[^{2}\text{We shall adopt throughout a Hubble constant of 75 km s\(^{-1}\)Mpc\(^{-1}\).}\]
understand better the nature of this extraordinary object, we have obtained images and high resolution UV spectra of SBS 0335–052 with the refurbished HST, in the course of a larger study of extremely metal-deficient BCDs. The superior angular resolution of HST is ideal for studying this extremely compact ($d_{25} \sim 12''$) object.

2.1. Imaging

We obtained images of SBS 0335–052 on 1995 January 27 during cycle 4, after the refurbishment mission, with the HST Wide Field and Planetary Camera 2 (WFPC2) in filters F569W and F791W, which we will refer to as V and I throughout the paper. Two exposures of equal duration were obtained in each filter to permit identification and removal of cosmic rays. The total exposure time was 1800 s in V and 4400 s in I. The scale of the WFPC2 is $0.102''$ per pixel.

The data reduction followed the procedures described in Thuan, Izotov & Lipovetsky (1996a). Preliminary processing of the raw images including corrections for flat-fielding was done at the Space Telescope Science Institute (STScI) through the standard pipeline. Subsequent reductions were carried out at the University of Virginia using IRAF and STSDAS. Point sources in the processed images have a FWHM of $\sim 2$ pixels or $0.2''$. Cosmic rays were removed and the images in each filter were combined. We found that all exposures in a given filter coregistered to better than $\sim 0.2$ pixels. The transformation of instrumental magnitudes to the Johnson-Cousins UBVRI photometric system as defined by Landolt (1992) was performed according to the prescriptions of Holtzman et al. (1995). The resulting measured brightness of the sky background is 22.6 mag arcsec$^{-2}$ in V and 21.8 mag arcsec$^{-2}$ in I.

2.2. UV spectroscopy

Spectroscopic observations were obtained on 1995 January 3-4 using the Goddard High Resolution Spectrograph (GHRS) on board HST, in two separate exposures, one with the G160M grating covering the 1210–1250 Å region around the Ly$\alpha$ line of hydrogen and the other with the same grating covering the 1300–1350 Å region around the resonance line of oxygen at 1302 Å. The exposure time was 7180 seconds for each region. The $2''\times2''$ rectangular Large Science Aperture was used, centered on the brightest knot (corresponding to cluster 1 in Table 2 to be discussed later). The flux and wavelength calibrations were done at STScI through the standard pipeline. The spectral resolution is 0.12 Å.

3. A PROBABLE YOUNG GALAXY

3.1. Young super-star clusters

\footnote{IRAF: the Image Reduction and Analysis Facility is distributed by the National Optical Astronomical Observatories which are operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under cooperative agreement with the National Science Foundation (NSF).}

\footnote{STSDAS: the Space Telescope Science Data Analysis System.}
We display in Figure 1a the V image with the contrast level adjusted so as to show the details of the high-surface-brightness star-forming regions. The latter are seen to contain 6 bright stellar clusters all within a region of ∼ 2 arcsec diameter, or ∼ 520 pc in linear size. It is clear from the contour map (Figure 1b) that the clusters (labeled 1 to 6) are unresolved, with radii ≤25 pc. Aperture photometry of the point-like objects was performed using the package APHOT in IRAF. The magnitudes were obtained using a circular aperture of radius 2 pixels, which is about the FWHM of the stellar profile. To determine the background, we use an annulus centered on the cluster covering 3–5 pixels. The precision of the photometry is good despite the high background because of the relative brightness of the clusters (V ≤ 22 mag).

Table 2 shows the V<sub>0</sub> and I<sub>0</sub> magnitudes, and the (V − I)<sub>0</sub> colors for all six clusters. All magnitudes and colors have been corrected for Galactic extinction which is small in the direction of SBS 0335−052 (A<sub>V</sub>=0.10 mag, A<sub>I</sub>=0.06 mag, Burstein & Heiles 1982). The magnitudes of the stellar clusters vary between V<sub>0</sub> = 19 mag and V<sub>0</sub> = 22 mag, which correspond to absolute magnitudes M<sub>V</sub> between −11.7 mag and −14.7 mag. The (V − I)<sub>0</sub> colors are very blue for all clusters, ranging between −0.61 and 0.31. In fact, the (V − I)<sub>0</sub> color for the bluest and brightest cluster (No.1 in Table 2) is bluer than that of the hottest main sequence O star (−0.33 for a OV star with solar metallicity, Bessell 1990). Models of young (age <3−4 Myr) stellar clusters (Leitherer & Heckman 1995) predict (V − I)<sub>0</sub> in the range 0.0 − 0.1 for a Salpeter or a Miller-Scalo-type initial mass functions (IMF), with an upper mass limit of 100 M<sub>☉</sub> and a metallicity of one tenth that of the Sun, in the two limiting cases of an instantaneous burst and a constant star-formation rate over a time interval of 3×10<sup>6</sup>yr. Thus cluster 1 is ∼ 0.7 mag too blue in (V−I)<sub>0</sub> as compared to the model predictions. Several effects can be thought of which make (V − I)<sub>0</sub> bluer. The most important effect is the contamination by gaseous emission, especially in the V band where several strong emission lines are present. To estimate this contamination, we have used the spectroscopic observations of Izotov et al. (1996) who have measured for cluster 1 equivalent widths of 178 Å, 199 Å, 616 Å and 1138 Å respectively for the Hβ, [OIII]λ4959, 5007 and Hα lines. By convolving the line fluxes with the transmission curve for the V filter (HST WFPC2 Handbook 1995), we estimate the contribution of gaseous emission to the V band to be ∼ 0.5 mag. The remaining small ∼ 0.2 mag difference can be plausibly attributed to contamination by gaseous continuous free-free and free-bound emission and by a metallicity difference between models and observations. Stellar clusters in SBS 0335−052 have Z<sub>☉</sub>/41 (stars have a lower metallicity than the gas) while Leitherer & Heckman (1995)' models were computed for Z = Z<sub>☉</sub>/10. A lower metallicity would result in a lower line blanketing, and hence to bluer colors. Thus we believe that the (V−I)<sub>0</sub> color of cluster 1 is consistent with the model calculations of Leitherer & Heckman (1995): the cluster was created in a starburst with a normal IMF (x = 1.35 where x is defined by dN/d(logM) ∝ M<sup>−x</sup>, M<sub>u</sub> = 100M<sub>☉</sub>, M<sub>l</sub> = 1M<sub>☉</sub>) less than ∼ 3−4 Myr ago.

The clusters listed in Table 2 and labeled in Figure 1b all lie roughly in a SE−NW direction, with cluster 1 at the SE edge. They all have redder (V − I)<sub>0</sub> colors than cluster 1. Figure 2 shows that there is a systematic increase in reddening (although the decrease in brightness is not monotonic) of the clusters away from the brightest cluster (No. 1). The color gradient ∆(V − I)<sub>0</sub>/∆r is nearly constant and equal to ∼ 0.47 mag arcsec<sup>−1</sup> or ∼ 0.18 mag/100 pc. Thus cluster 6 which is furthest away from cluster 1, at ∼2 arcsec or 526 pc, is ∼0.9 mag redder. We
argue that the reddening is not caused by evolutionary effects, but rather by internal extinction by dust. The presence of dust patches is clearly seen in Figure 3 where we show the (V – I) color map of SBS 0335–052. Black pixels denote blue colors while white pixels indicate red colors. Comparison with Figure 1a shows that cluster 1 lies outside the dust patches, but that the other clusters are in the same regions as the dust and are subjected to internal extinction. The dust patches are seen to systematically increase in importance away from cluster 1, confirming visually the effect found in Figure 2. There is quantitative evidence that internal extinction does increase with increasing distance from cluster 1. Melnick et al. (1992) have obtained with the ESO New Technology Telescope (NTT) spectra of two knots in SBS 0335–052, the first knot containing clusters 1 and 2 and the second knot clusters 4 and 5. Although their seeing was excellent for ground-based observations (0.58'' – 0.85'' FWHM), thanks to the adaptive optics of the NTT, Melnick et al. (1992) did not have the necessary angular resolution to resolve those two knots into individual clusters as done here with HST. Those authors found that the extinction coefficient C(Hβ) is only 0.07 dex for the first knot while it is larger for the second one, C(Hβ) = 0.56 dex. This corresponds to a reddening difference of E(B – V) ~ 0.3 mag, which is just about the amount needed to account for the color difference Δ(V – I)0 = 0.45 mag between clusters 1 and 4 (Table 2). Thus there is good evidence that most of the color gradient depicted in Figure 2 is not due to evolutionary effects but to increasing extinction away from cluster 1, from A>V = 0 for cluster 1 to A>V ~ 1.8 mag for cluster 6.

We now discuss the nature of the blue clusters in SBS 0335–052. After correction for internal extinction, gaseous emission and metallicity effects so that each cluster has the same intrinsic (V – I)0 ~ 0.1 as cluster 1, then the cluster absolute magnitudes are in the range −14.1 ≤ MV ≤ −11.9. This is precisely the range of absolute magnitudes found by O’Connell, Gallagher & Hunter (1994) for objects called “super-star clusters” (SSC). SSCs are defined by their combination of very small sizes and high luminosities. They have diameters less than 50 pc, consistent with the radius upper limit of 25 pc set for our stellar clusters. O’Connell et al. (1994) could resolve some of their objects with the HST Planetary Camera and found that their half-light radii R0.5 ≤ 3.5 pc, comparable to radii of normal star clusters and compact HII regions. In spite of their compactness, the luminosities of the SSCs are comparable to those of the physically larger superassociations (MV ≤ −11). This implies that SSCs have surface brightnesses ≥ 100 times those of clusters and associations in normal giant HII regions. They represent particularly intense periods of star formation where gas is transformed into stars at the rate of ~ 1M☉ yr−1 (Thuan 1991). From the Hβ luminosity in knot 1 (clusters 1 and 2) of SBS 0335–052 measured by Melnick, Heydari-Malayeri & Leisy (1992), we found that ~ 10³ – 10⁴ massive O stars are present in that knot. Thus it appears that some BCDs make stars by forming SSCs. This SSC formation appears to be related to the starburst mode of star formation, i.e., to a sharp increase in the star formation rate of a galaxy during a relatively short (~ 10⁷ yr) period.

The advent of HST and its superior angular resolution has permitted the discovery of SSCs with an ever greater frequency, all of them in galaxies undergoing starbursts (see the review by Ho 1996). Examples include the amorphous galaxy NGC 1140 (Hunter et al. 1994), the BCD He2–10 (Conti & Vacca 1994), the peculiar galaxy NGC 1275 (Holtzman et al. 1992), the merging systems NGC 7252 (Whitmore et al. 1993) and NGC 4038/4039 (Whitmore &
Schweizer 1995). Meurer et al. (1995) have studied nine starburst galaxies ranging from BCDs to ultraluminous merging far-infrared galaxies and also conclude that cluster formation is an important mode of star formation in starburst galaxies. Even in galaxies where star formation activity is not dominant, Barth et al. (1995) found SSCs within the circumnuclear starburst rings around the Seyfert galaxies NGC 1097 and NGC 6951.

It has been suggested (e.g. Meurer et al. 1995), mainly on the basis of sizes and luminosities, that these blue SSCs will fade out to become globular clusters, once the starburst is over. We discuss this issue using our own HST data on stellar clusters in several BCDs in various evolutionary stages. Besides SBS 0335–052 which we shall argue, appears to be a young BCD undergoing star formation for the first time, we have also used HST to study the BCD Markarian 996 which is at a much later stage of evolution, having undergone several bursts of star formation before the present one (Thuan, Izotov & Lipovetsky 1996a). Projected against and around Mrk 996, are many pointlike sources which can be interpreted not as young but old ($\geq 10^{10}$ yr) globular clusters, as evidenced by their red color ($(V-I)_0 \sim 0.9$), absolute magnitude range ($-10.4 \leq M_V \leq -6.8$) and unresolved diameters ($\leq 20$ pc). In the $-9.0 \leq M_V \leq -7.5$ range, the cluster luminosity function in Mrk 996 is remarkably similar to that of the Milky Way, with slightly more clusters in Mrk 996 relative to the Galaxy in the magnitude range $-10.5 \leq M_V \leq -9.0$. The presence of red but not blue clusters around Mrk 996 implies that SSC formation does not always accompany a starburst in a BCD. If SSCs are indeed progenitors of globular clusters, SSC formation has occurred not with the present burst but with past ones in Mrk 996. Furthermore, the spatial distributions of clusters in the 2 BCDs are very different. In the case of SBS 0335–052, the SSCs are within the star-forming regions, while in the case of Mrk 996 the red globular clusters surround the galaxy, just as in the Milky Way.

Since SSC formation is associated with merging events, we have investigated the environment of SBS 0335–052. A VLA HI map of the BCD (Thuan et al. 1996b) shows it to be embedded in a very large flattened HI cloud, 4.3' EW by 1.5' NS in angular size or 64 kpc by 24 kpc in linear size. There are two peaks of HI column density, one of which is associated with SBS 0335–052 and the other with a fainter dwarf irregular galaxy (Pustilnik et al. 1996). There is a nearby companion, the face-on Scd galaxy NGC 1376 ($m_B = 12.8$ mag, 2.0'×1.7' ) at $\sim 9.5'$ W $[\alpha(1950) = 03^h 34^m 37.2^s, \delta(1950) = -05^\circ 12' 29'']$ and with a heliocentric velocity of 4159 km s$^{-1}$, only 116 km s$^{-1}$ larger than the velocity of SBS 0335–052. The VLA map shows no evident sign of tidal interaction between the HI cloud and NGC 1376. There are three other galaxies with angular size $\sim 1'$ within an angular distance of 6.5' from the BCD, but they are all background galaxies: MPW1G at 4.3' NE with $v=10779$ km s$^{-1}$, A447 at 5.5' SE with $v=33660$ km s$^{-1}$ and IRAS 03348–058 at 6.2' NW with $v=5556$ km s$^{-1}$. If NGC 1376 moves at $\sim 100$ km s$^{-1}$ relative to the BCD, it will take about $10^9$ yr to go the 150 kpc distance separating the two galaxies, much larger than the $\leq 3$–$4$ Myr age of the SSCs. Thus the formation of SSCs in SBS 0335–052 is probably not triggered by tidal interactions, but by stochastic collisions of small HI gas clouds within the large HI envelope.

3.2. A very blue underlying component

Figure 1a shows that there is a more extended lower surface-brightness diffuse component underlying the SSCs. This is seen better in figure 4 where the contrast has especially been
adjusted to display low-surface-brightness features. The underlying component extends in the same SE–NW direction as the SSCs and is roughly elliptical in shape, with the SSCs located at the SE end. The nature of this underlying component is crucial for determining the age of the galaxy, whether it is undergoing its very first burst of star formation, in which case it satisfies the definition of a primeval galaxy, or whether the present burst is just one after many, in which case the underlying component contains an older stellar population.

We have derived surface brightness and color profiles for the underlying component. Surface photometry was done by fitting ellipses to the isophotal contours using the task ELLIPSE in STSDAS. We show respectively in Figures 5 a,b and c the V and I surface brightness and (V–I) color distributions as a function of log \( r \). Here \( r \) is the equivalent radius of the best fitting elliptical isophote defined as \( r = (ab)^{1/2} \), where \( a \) and \( b \) are respectively the semi-major and semi-minor axes of the ellipse. In Figures 5a and 5b, it can be seen that for \( r \geq 1'' \), the surface brightness distribution is well fitted by a power law (a straight line in this coordinate system) of slope \( n \sim 2.3 \) (where \( n \) is defined as \( I \propto r^{-n} \)) for both V and I bands. The large statistical error bars in the radius range \(-0.45 \leq \log r \leq -0.05 \) or \( 0.4'' \leq r \leq 0.9'' \), is due to light contamination from the shell structure seen clearly in Figure 4. This structure is probably the result of supernova explosions in the SSCs which have carved out a nearly spherical cavity in the ambient interstellar medium (ISM) of the BCD. As for the non-monotonically increasing error bars at radii \( \log r \sim 0.3 \) or \( r \sim 2'' \) and \( \log r \sim 0.7 \) or \( r \sim 5'' \), they are probably due to light contamination from the SSCs at the SE side of the galaxy. Most remarkable is the (V–I) color profile (Figure 5c) which is nearly flat and shows extraordinary blue colors for the underlying low-surface-brightness component. The (V–I) colors vary between \(-0.3 \) and \( 0.2 \), corresponding to foreground extinction corrected colors \( (V–I)_0 \) between \(-0.34 \) and \( 0.16 \).

If the underlying emission is of stellar origin, this range of colors would correspond to spectral types between OV and A5V stars, using the color-spectral type calibration of Bessell (1990). This calibration holds for solar-metallicity stars. For stars with \( \leq 1/41 \) of the Sun’s metallicity, as is the case for SBS 0335–052, the corresponding spectral types at a given (V–I) color are slightly later. In any case, if stars are responsible for the underlying extended emission, they cannot be older than \( \sim 10^8 \) yr. However we do not believe the underlying emission to be of stellar origin. The irregular, blotchy and filamentary structure of the underlying component argues for a gaseous origin. This hypothesis is further supported by the colors of the shell structure which are themselves very blue, as seen clearly in the color map in Figure 3. Aperture measurements at various locations along the shell give \( (V–I)_0 \) between \(-0.75 \pm 0.20 \) and \(-0.18 \pm 0.20 \). The bluest colors are bluer than that of the hottest star \( ((V–I)_0=–0.33 \) for an OV star according to Bessell (1990)), but can be understood if due to gaseous emission. Another line of evidence is provided by the long-slit observations of Izotov et al. (1996) of the underlying component. Those authors detected strong \([\text{OIII}]\lambda 4363\) emission indicating high excitation gas as far as \( \sim 2 \) kpc from the SSCs. Using the observed equivalent widths of the \( \text{H}\beta, [\text{OIII}]\lambda 4959, 5007 \) and \( \text{H}\alpha \) lines and continuum fluxes from free-free and free-bound processes, and convolving with the V and I bandpasses, they were able to reproduce the \( (V–I)_0 \) color range observed for the underlying component. We note here that these very blue colors are not the results of some observational or reduction procedure artifact. We have obtained HST WFPC2 V and I images of the BCD Mrk 996 in exactly the same observational configuration, and reduced them in exactly the same
manner (Thuan et al. 1996a). Yet, Mrk 996 shows a red underlying disk with a system of red globular clusters ((V–I)_0 ∼ 0.9).

### 3.3. A primordial neutral hydrogen intergalactic cloud?

Here we present indirect evidence which also supports the youth hypothesis of SBS 0335–052. We use the BCD as a background light source shining through the HI envelope in which it is embedded (Thuan et al. 1996b) to probe the physical conditions of the surrounding neutral gas. The Lyα line seen in absorption would give the column density of atomic hydrogen, while the OI λ1302 absorption line would give the column density of the most abundant heavy element which remains neutral in the HI cloud. This would allow us to set a limit on the O/H abundance ratio in the neutral gas.

The spectrum showing the spectral region around the resonance line of oxygen at 1302 Å is shown in Figure 6b. The OI line is not seen in absorption. We can place an upper limit of ∼ 200 mÅ (corresponding to 2 times the rms noise) for its equivalent width, which corresponds to a column density of 2.7×10^{14} O atom cm^{-2}, using the relation given by Kunth et al. (1994) between the equivalent width and the column density for an unsaturated line. Since the HI column density is ∼ 10^{21} H atom cm^{-2} from the VLA map (Thuan et al. 1996b), the oxygen to hydrogen abundance ratio is ≤ 2.7×10^{-7}. This is more than 3000 times smaller the N(O)/N(H) of Orion equal to 8×10^{-4} and more than 3 times lower than the oxygen abundance measured in the HI envelope of IZw18, where the OI λ1302 line was clearly detected in absorption (Kunth et al. 1994). This observation provides further support for the youth hypothesis of SBS 0335–052. The HI cloud in which SBS 0335–052 is embedded appears to be composed of primordial pristine gas, uncontaminated by metal-enrichment from previous star formation.

### 4. DISCUSSION

From the (V–I)_0 colors of the super-star clusters and using Leitherer & Heckman (1995)' models, we have concluded that the present burst of star formation did not start until ≤ 3–4 Myr ago. From the very blue and filamentary structure of the underlying low-surface-brightness component, we have concluded that the latter has not a stellar but gaseous origin. Because SBS 0335–052 does not appear to possess an underlying older stellar population, the present starburst is probably the first one in the galaxy’s history, and the BCD is a good candidate for being a young galaxy. Is this conclusion consistent with other observational constraints?

#### 4.1. Dust

We have shown that dust is clearly present in the BCD (see the color map in Figure 3). Can it be made in the short time scale implied by the young galaxy scenario? There is some observational evidence that dust formation can occur in a rather short time scale in supernova ejecta. Lucy et al. (1995) have attributed the brightening of SN 1987A in the IR after day ∼ 450 to condensation of small silicate grains. The dust condensation efficiency is rather low (≤ 10^{-3}), but an efficiency of ∼1 is possible if the dust is clumped. Thus, while the physics of dust formation are still not very well known, the SN 1987A observations do not rule out
the possibility that enough silicate grains can condense out of supernova ejecta to account for the dust observed in SBS 0335–052. The BCD has not been detected in any of the four IRAS bands. If we adopt as upper limit a flux of 0.5 Jy at 100 microns, then using the formula in Sauvage & Thuan (1994) and adopting their mean value $f(100 \text{ microns})/ f(60 \text{ microns}) \sim 2$ for BCDs, we derive an upper limit of $\sim 1.6 \times 10^5 \, M_\odot$ for the warm dust mass.

4.2. The supershell

We next ask whether the size of the shell is compatible with a time scale of $\sim 4 \, \text{Myr}$. The radius of the shell is $\sim 380$ pc, which qualifies it to be a ‘supershell’ according to the definition of Tenorio-Tagle & Bodenheimer (1988). To put constraints on the age of the shell structure, we use the models of shell formation of McCray & Kafatos (1987). These take into account the effects of supernova as the encircled stellar clusters age. We need some estimate of the density of the ambient ISM. The HI mass of the whole cloud (which is much larger than that associated with the BCD) is $\sim 10^9 \, M_\odot$, and the VLA map (Thuan et al. 1996b) shows that most of it is within a projected region $31 \, \text{kpc} \times 7 \, \text{kpc}$ in size (the whole cloud is larger, extending up to $67 \, \text{kpc} \times 24 \, \text{kpc}$, but the outer parts have a very low density and do not contribute significantly to the total mass). Assuming a cylindrical shape for the HI cloud, an inclination angle of 0 degree and a uniform density gives a mean density of $\sim 0.01 \, \text{H atoms cm}^{-3}$. As SBS 0335–052 is associated with one of the two peaks in HI column density which is $\sim 100$ times higher than the mean, we obtain a density of $\sim 1 \, \text{H atom cm}^{-3}$ for the ISM around the BCD. This is comparable to the density of $\sim 1.5 \, \text{H atoms cm}^{-3}$ found by Hunter & Thronson (1995) for the ambient ISM of IZw18. If we use the analytical expressions of McCray & Kafatos (1987) and assume that each supernova explosion produces an energy of $10^{51}$ ergs, then to produce a supershell of radius $\sim 380$ pc in a time of $\sim 4 \, \text{Myr}$, then a total number of stars more massive than $7 \, M_\odot$ (all those massive enough to undergo a type II supernova) of $\sim 14400$ is required. This number is not unreasonable as the total $\text{H} \beta$ luminosity ($\sim 4 \times 10^{40} \, \text{erg s}^{-1}$) gives an equal number of $\sim 10000 \, \text{O7 stars}$. The models predict a shell expansion velocity of $\sim 56 \, \text{km s}^{-1}$.

4.3. The star formation rate

We can obtain an estimate of the SFR from the total $\text{H} \alpha$ luminosity. Using Melnick et al. (1992)’ measurements, we obtain $L(\text{H} \alpha) \sim 5.2 \times 10^{40} \, \text{erg s}^{-1}$. This is a lower limit as Melnick et al. observed only SSCs 1, 2, 4 and 5, but not the fainter SSCs 3 and 6 which do not contribute significantly to the total $\text{H} \alpha$ flux (less than 10%). Extrapolating the Salpeter IMF down to stars of mass $0.1 \, M_\odot$, the SFR is equal to $7.07 \times 10^{-42} \, L(\text{H} \alpha) \, M_\odot \, \text{yr}^{-1}$ (Hunter & Gallagher 1986). Since most of the ionizing photons are produced by $30–60 \, M_\odot$ stars with lifetimes $\leq 3 \times 10^6 \, \text{yr}$, this is the current instantaneous SFR. We obtain a SFR of $\sim 0.4 \, M_\odot \, \text{yr}^{-1}$ for the BCD. This derived SFR is one order of magnitude larger than that in IZw18 ($\sim 0.04 \, M_\odot \, \text{yr}^{-1}$), and is in the upper range of SFRs derived for BCDs (Fanelli, O’Connell & Thuan 1988). The total stellar mass formed during 4 Myr is thus $\sim 1.6 \times 10^6 \, M_\odot$. The total oxygen mass produced is $\sim 6560 \, M_\odot$ (Lequeux et al. 1981).

4.4. The Lyman $\alpha$ emission
To obtain insight into the problem of the non-detection of primeval galaxies at high redshifts by Lyα searches, we have obtained with HST a GHRS spectrum in the spectral region around Lyα at the redshift of SBS 0335–052. The spectrum is shown in Figure 6a. The most striking feature in this figure is the conspicuous absence of strong narrow Lyα emission in SBS 0335–052, just as in IZw18 (Kunth et al. 1994), and in contradiction with the predictions of models of young dust-free galaxies undergoing massive star formation (Charlot & Fall 1993). This problem is not new. Previous Lyα studies of blue compact galaxies (Deharveng et al. 1985, Hartmann et al. 1988, Terlevich et al. 1993, Giavalisco, Koratkar & Calzetti 1996) had already shown that Lyα emission is very weak or absent in the UV spectra, despite the extremely strong optical emission lines. The favored explanation for the reduction of Lyα fluxes from recombination values is absorption of multiply scattered Lyα photons by dust in the HII region or in the surrounding HI envelope. This would imply increasing Lyα fluxes in galaxies with decreasing metallicities, since presumably low-metallicity objects contain less dust, and hence suffer less destruction of Lyα photons. The observational evidence is mixed. Terlevich et al. (1993) did find such a correlation, while Giavalisco et al. (1996) found none. The latter authors concluded that the ISM in BCDs is highly inhomogeneous and that the transport of Lyα photons is primarily controlled by the ISM geometry rather than by the dust amount. The absence of strong narrow Lyα emission in the two most metal-deficient BCDs known, IZw18 (Z⊙/50) and SBS 0335–052 (Z⊙/41), supports the lack of correlation between Lyα fluxes and metallicities found by Giavalisco et al. (1996).

In the case of SBS 0335–052, dust absorption may play some role in Lyα photon destruction since dust is clearly present in the BCD (Figure 3). But it may not play the dominant role. Most of the light in the 2′′×2′′ aperture comes from SSC1 which, as we have argued, does not suffer from extinction. This conclusion is reinforced by the comparison of the observed continuum level near Lyα (∼ 7.5×10^{-15} erg s^{-1} Å^{-1} cm^{-2}) with that near Hβ in the same 2′′×2′′ aperture (Izotov et al. 1996). The ratio is ∼ 100, close to the value predicted for young dust-free starbursts (Charlot & Fall 1993). We favor therefore multiple scattering of Lyα photons in an optically thick gas as the main mechanism of Lyα attenuation. There is observational evidence that the gas surrounding SBS 0335–052 is optically thick for Lyα photons. Figure 6a shows that, contrary to the situation in IZw18 (Kunth et al. 1994), the intensity of the central part of the Lyα absorption caused by the HI envelope does not go to zero. In fact, superposed on the broader absorption, there is a broad (FWZI=20Å) low-intensity emission with a total flux of 2.6×10^{-14} erg cm^{-2} s^{-1}. Broad emission is expected if resonant scattering occurs in a medium with optical depth of ∼ 10^8 for Lyα photons (Bonilha et al. 1979). This optical depth would correspond to a HI column density of ∼ 10^{21} H atoms cm^{-2}, which is about the observed value in the VLA map (Thuan et al. 1996b). Multiple scattering redistributes Lyα emission over the whole extent of the HI cloud which is much larger than the aperture used. By using a very small aperture, most of the re-emitted photons are lost. This explains why the Lyα-to-Hβ ratio in the BCD (∼ 0.45) is so small compared to the case B recombination value of 33.

The geometry of the HI cloud may also play a role. In SBS 0335–052, the HI cloud is seen nearly edge-on, as suggested by its flattened structure (Thuan et al. 1996b). Charlot & Fall (1993) have shown that, because photons escape more easily in a direction perpendicular to the plane than along it, the ratio of the Lyα intensity to its mean intensity changes from a value
of 2.3 for face-on galaxies to 0.0 for edge-on galaxies.

What are the implications of the above observations concerning the problem of the non-detection of high-redshift primeval galaxies in Lyα searches? Dust is clearly present in a very metal-deficient environment such as in SBS 0335–052, so that dust absorption may play a role. Geometrical effects may also contribute. Galaxies seen face-on are easier to detect than those seen edge-on. Also we expect metal-rich galaxies which have undergone repeated bursts of star formation to have a more eroded HI envelope with more holes through which Lyα photons can escape. They would be more detectable than young very metal-deficient galaxies undergoing their very first burst of star formation with a less porous HI envelope. Lequeux et al. (1995) have discussed another mechanism which allows the escape of Lyα photons. They detected attenuated Lyα emission in the relatively metal-rich (Z ≈ Z⊙/3) BCD Haro 2. Some Lyα photons could escape because they are moving at a different velocity from that of the surrounding HI gas, the velocity difference (∼ 200 km s⁻¹) being caused by a galactic wind. In summary, the escape and detection of Lyα photons depends not only on the amount of dust present, but also on the geometry and velocity structure of the surrounding HI envelope.

4.5. Comparison with other nearby young galaxy candidates

Several other nearby objects have been proposed as possible young galaxies. This includes IZw18, the only BCD known to be more metal-deficient than SBS 0335–052, and which also does not possess a low-surface-brightness underlying old stellar population (Kunth et al. 1988, Hunter & Thronson 1995). These two BCDs with no apparent underlying older stellar component constitute the exception rather the rule.

The HI cloud associated with IZw18 is much smaller in intrinsic size (6 kpc × 3 kpc, Viallefond, Lequeux & Comte 1987) than the one in which SBS 0335–052 is embedded. For both BCDs, the starburst region is associated with, but does not coincide exactly with the HI column density peak. This offset of ∼ 1 kpc is a general feature of all BCDs with HI interferometric maps (Viallefond & Thuan 1983). The HI cloud associated with SBS 0335–052 has another HI peak at ∼ 1.5′ west (∼ 24 kpc). There is a faint (V ∼ 19 mag) compact (2.8″×2.2″) dwarf galaxy at the location of the second HI peak. Its redshift (v = 3990 ± 40 km s⁻¹) is about the same as that of SBS 0335–052. Its spectrum shows Hα, Hβ and [OIII], emission, but has lower excitation than that of the BCD (Pustilnik et al. 1996).

The very large size (64 kpc × 24 kpc) of the HI cloud of SBS 0335–052 is very unusual for BCDs. The typical size is more like a few kpc in each dimension (Viallefond & Thuan 1983). This large cloud is more reminiscent of the intergalactic cloud HI 1225+01 with a size of ∼ 100 kpc (adopting a distance of 10 Mpc, Salzer et al. 1991). Both clouds have HI masses of ∼ 10⁹ M⊙. There are also 2 HI peaks in HI 1225+01 separated by ∼ 46 kpc, one of which is associated with a faint (MB ∼ −14.0) and metal-deficient (Z ∼ Z⊙/18) dwarf irregular galaxy. As for SBS 0335–052, the galaxy is very blue (B−V = 0.10, U−B = −0.57) and most (≥ 72 percent) of the B light comes from stars with ages ≤ 40 Myr. Thus, although the burst in SBS 0335–052 is younger than in HI 1225+01, their HI envelopes have remarkably similar properties. It is not yet clear why star formation has been stunted in these HI clouds for so long. In the case of SBS 0335–052, a mean density of ∼ 0.01 H atom cm⁻³ leads to a collapse time of only ∼ 5×10⁸ yr, much shorter than the Hubble time.
5. SUMMARY

We have analyzed WFPC2 V and I images and GHRS UV spectra obtained with the refurbished HST of the extremely metal-deficient ( $Z = Z_\odot/41$ ) blue compact dwarf (BCD) galaxy SBS 0335–052. We have obtained the following results:

1) The underlying extended low-surface-brightness component of the BCD is extremely blue ($-0.34 \leq (V-I)_0 \leq 0.16$). Its color profile is nearly flat. If stars are responsible for this low-surface-brightness emission, they cannot be older than $\sim 10^8$ yr. However, the irregular and filamentary structure of the underlying component supports the case for gaseous emission and no underlying older stellar population. The very blue colors are consistent with gaseous emission. Thus SBS 0335–052 is very likely a nearby young galaxy in the sense that it is undergoing its very first burst of star formation. This conclusion supports the prediction of Izotov et al. (1990) about the youth of SBS 0335–052 on the basis of its very low metallicity.

2) The OI $\lambda$1302 line is not detected in absorption in the GHRS spectrum, setting an upper limit for $N(O)/N(H)$ in the HI envelope of $\sim 3 \times 10^{-7}$, more than 3000 times smaller than the value in Orion and more than 3 times lower than the oxygen abundance measured in the HI envelope of IZw18, and consistent with the youth hypothesis of SBS 0335–052.

3) All star formation occurs in six very blue super-star clusters (SSC) with ages $\leq 3–4$ Myr. SSC formation appears to be related to starburst events in some, but not all, BCDs. The triggering of star formation in SBS 0335–052 is not due to tidal interactions, but is probably caused by stochastic collisions of gas clouds within the large HI envelope.

4) Dust is clearly present and is spatially mixed with the SSCs. While the brightest SSC does not suffer from extinction, there is a systematic increase in reddening away from it. Such dust can probably condense out in supernova remnants in a time scale $\leq 4$ Myr.

5) There is a supershell of radius $\sim 380$ pc delineating a large supernova cavity. Its observed properties can be accounted for by models of shell formation with a time scale of $\sim 4$ Myr.

6) The star formation rate (SFR) is $\sim 0.4 M_\odot$ yr$^{-1}$, in the upper range of SFRs observed in BCDs.

7) Strong narrow Ly$\alpha$ emission is not detected. There is instead low-intensity broad (FWZI=20Å) Ly$\alpha$ emission superposed on broader Ly$\alpha$ absorption from the HI envelope. The low-intensity broad emission is caused by resonant scattering in a dense ambient medium, with optical depth of $\sim 10^8$ for Ly$\alpha$ photons, corresponding to the observed HI column density of $\sim 10^{21}$ H atom cm$^{-2}$.

While dust may play some role in the destruction of Ly$\alpha$ photons, multiple scattering which removes Ly$\alpha$ photons from the small HST aperture and redistributes them over the whole HI cloud, and geometrical effects (the HI cloud is seen edge-on) appear to be the main mechanisms for removal of Ly$\alpha$ photons in SBS 0335–052. Ly$\alpha$ detection of high-redshift primeval galaxies depends thus not only on the amount of dust, but also on the geometry and velocity structure of the surrounding HI envelope.

T.X.T. acknowledges the partial financial support of STScI grant GO 5408.01-93A. Y.I.I. is grateful for the hospitality of the Astronomy Department of the University of Virginia. This
international collaboration was made possible by NATO collaborative research grant 921285 and INTAS international grant 94-2285.

REFERENCES

Baron, E., & White, S.D., 1987, ApJ, 322, 585
Barth, A.J., Ho, L.C., Fillipenko, A.V., & Sargent, W.L.W. 1995, AJ, 110, 1009
Bessell, M.S. 1990, PASP, 102, 1181
Bonilha, J.R.M., Ferch, R., Salpeter, E.E., Slater, G. & Noerdlinger, P.D. 1979, ApJ, 233, 649
Burstein, D., & Heiles, C. 1982, AJ, 87, 1165
Charlot, S., & Fall, S.M. 1993, ApJ, 415, 580
Conti, P.S., & Vacca, W.D. 1994, ApJ, 423, L97
Deharveng, J.-M., Joubert, M. & Kunth, D. 1985, in Star-forming Dwarf Galaxies and related objects, ed. D. Kunth, T.X. Thuan & J.T.T. Van, (Gif-sur-Yvette:Editions Frontieres), 431
Fanelli, M.N., O’Connell, R.W. & Thuan, T.X. 1988, ApJ, 334, 665
Fontana, A., Cristiani, S., D’Odorico, S., Giallongo, E., & Savaglio, S. 1996, MNRAS, in press
Giavalisco, M., Koratkar, A., & Calzetti, D. 1996, STSI preprint No.1021
Hartmann, L.W., Huchra, J.P., Geller, M.J., O’Brien, P. & Wilson, R. 1988, ApJ, 236, 101
Ho, L.C. 1996, Rev. Mex. Astr. Astrofis., in press
Holtzman, J. et al. 1992, AJ, 103, 691
Holtzman, J.A., Burrows, C.J., Casertano, S., Hester, J.J., Trauger, J.T., Watson, A.M., & Worthey, G. 1995, PASP, 107, 1065
HST WFPC2 Handbook 1995
Hunter, D.A., & Gallagher, J.S. 1986, PASP, 98, 5
Hunter, D.A., O’Connell, R.W., & Gallagher, J.S. 1994, AJ, 108, 84
Hunter, D.A., & Thronson, H.A., Jr. 1995, ApJ, 452, 238
Izotov, Yu.I., Lipovetsky, V.A., Guseva, N.G., & Kniazev, A.Yu. 1992, in The Feedback of Chemical Evolution on the Stellar Content of Galaxies, ed. D. Alloin & G.Stasinska (Paris Observatory Publ.), 138
Izotov, Yu.I., Guseva, N.G., Lipovetsky, V.A., Kniazev, A.Yu., Neizvestny, S.I., & Stepanian, J.A., 1993, Astron.Astroph.Trans. 3, 197
Izotov, Yu.I., Lipovetsky, V.A., Chaffee, F., Foltz, C., Guseva, N.G., & Kniazev, A.Yu. 1996, in preparation
Izotov, Yu.I., Lipovetsky, V.A., Guseva, N.G., Kniazev, A.Yu., & Stepanian, J.A. 1990, Nature, 343, 238
Izotov, Yu.I., Thuan, T.X., & Lipovetsky, V.A. 1994, ApJ, 435, 647
Izotov, Yu.I., Thuan, T.X., & Lipovetsky, V.A. 1996, ApJ, submitted
Kunth, D., & Sargent, W.L.W. 1986, ApJ, 300, 496
Kunth,D., Maurogordato,S. & Vigroux,L. 1988, A&A, 204,10
Kunth, D., Lequeux, J., Sargent, W.L.W., & Viallefond, F. 1994, A&A, 282, 709
Landolt, A.U. 1992, AJ, 104, 340
Leitherer, C., & Heckman, T.M. 1995, ApJS, 96, 9
Lequeux, J., Maucherat-Joubert, M., Deharveng, J.-M., & Kunth, D. 1981, A&A, 103, 305
Lequeux, J., Kunth, D., Mas-Hesse, J.M., & Sargent, W.L.W. 1995, A&A, 301, 18
Loose, H.-H., & Thuan, T.X. 1985, in Star-Forming Dwarf galaxies and related objects, ed. D. Kunth, T.X.Thuan & J.T.T.Van (Gif-sur-Yvette: Editions Frontieres), 73
Lucy, L.B., Danziger, I.J., Gouiffes, C. & Bouchet, P. 1991, in Supernovae, ed. S.E.Woosley (New York: Springer-Verlag), 82
Markarian, B.E., Lipovetsky, V.A., & Stepanian, J.A. 1983, Astrofizika, 19, 29
McCray, R. & Kafatos, M. 1987, ApJ, 317, 190
Meier, D.I. 1976, ApJ, 207, 343
Melnick, J., Heydari-Malayeri, M., & Leisy, P. 1992, A&A, 253, 16
Meurer, G.R., Heckman, T.M., Leitherer, C., Kinney, A., Robert, C., & Garnett, D.R. 1995, AJ, 110, 2665
O’Connell, R.W., Gallagher, J.S., & Hunter, D.A. 1994, ApJ, 433, 65
Papaderos, P., Loose, H.-H., Thuan, T.X. & Fricke,K.J. 1996, A&AS, in press
Partridge, R.B., & Peebles, P.J.E. 1967, ApJ, 147, 868
Pettini, M., Lipman, K., & Humstead, R.W. 1995, ApJ, 451, 100
Pritchett, C.J. 1994, PASP, 106, 1052
Pustilnik, S.A., Ugryumov, A.V., Lipovetsky, V.A., Thuan, T.X. & Guseva, N.G. 1995, ApJ, 443, 499
Pustilnik, S.A., Lipovetsky, V.A., Izotov, Yu.I., Brinks, E., Thuan, T.X., Kniazev, A. Yu., Neizvestny, S.I., & Ugryumov, A.V. 1996, Soviet AJ, submitted
Salzer, J.J. 1989, ApJ, 347, 152
Salzer, J.J., Alighieri, S.D.S., Matteucci, F., Giovanelli, R. & Haynes, M.P. 1991, AJ, 101, 1258
Sauvage,M. & Thuan,T.X. 1994, ApJ, 429,153
Searle, L., & Sargent, W.L.W. 1972, ApJ, 173, 25
Searle, L., Sargent, W.L.W., & Bagnuolo, W.G. 1973, ApJ, 179, 427
Tenorio-Tagle, G. & Bodenheimer, P. 1988, ARAA, 26,145
Terlevich, E., Diaz, A.I., Terlevich,R. & Garcia Vargas, M.L. 1993, MNRAS, 260,3
Terlevich, R., Melnick, J., Masegosa, J., Moles, M., & Copetti, M.V.F. 1991, A&AS, 91, 285
Thuan, T.X. 1983, ApJ, 268, 667
Thuan, T.X. 1991, in Massive Stars in Starbursts, ed. C.Leitherer, N.R. Walborn, T.M. Heckman & C.A. Norman, (Cambridge: Cambridge University Press), 183
Thuan, T.X., & Martin, G.E. 1981, ApJ, 247, 823
Thuan, T.X., Izotov, Yu.I., & Lipovetsky, V.A. 1995, ApJ, 445, 108
Thuan, T.X., Izotov, Yu.I., & Lipovetsky, V.A. 1996a, ApJ, 463, 120
Thuan, T.X., Brinks, E., Pustilnik, S.A., Lipovetsky, V.A., & Izotov, Yu.I. 1996b, in preparation
Thuan, T.X., Pustilnik, S.A., Martin, J.-M., & Lipovetsky, V.A. 1996c, in preparation
Viallefonf, F., & Thuan, T.X. 1983, ApJ, 269, 444
Viallefonf, F., Lequeux, J. & Comte, G. 1987, in Starbursts and Galaxy Evolution, ed. T.X. Thuan, T. Montmerle & J.T.T. Van (Gif-sur-Yvette: Editions Frontieres), 139
Weaver, T.A., & Woosley, S.E. 1993, Phys. Rep., 227, 65
Whitford, A.E. 1958, AJ, 63, 201
Whitmore, B.C., & Schweizer, F. 1995, AJ, 109, 960
Whitmore, B.C., Schweizer, F., Leitherer, C., Borne, K., & Robert, C. 1993, AJ, 106, 1354
Yee, H.K.C., Ellington, E., Bechtold, J., Carlberg, R.G., & Cuillandre, J.-C. 1996, AJ, 111, 1783
FIGURE CAPTIONS

Fig.1. (a) A 1800 s V WFPC2 image of the blue compact dwarf galaxy SBS 0335–052 taken with the refurbished HST, with the contrast adjusted to show the high surface brightness super-star clusters (SSCs). At a distance of 54.3 Mpc, 1″ corresponds to a linear size of 263 pc. The orientation is the same as in Figure 1b. (b) A V contour map showing the labeling of the six SSCs listed in Table 2. A supershell delineating a large supernova cavity of radius ∼ 380 pc is clearly seen at the NE end of the galaxy.

Fig.2. The (V–I)₀ color corrected for foreground extinction of the six super-star clusters (SSCs) listed in Table 2 as a function of their separation from SSC1. There is a systematic increase in reddening with increasing distance from SSC1, along the SE-NW direction.

Fig.3. (V–I) grey scale color map. Blue is dark and red is light. The supershell is very blue while the red dust patches are seen to increase in importance away from super-star cluster 1 in the SE-NW direction. Two background red galaxies can be seen to the south of SBS 0335–052.

Fig.4. The same V image as in Figure 1a but with the contrast adjusted to show the low-surface-brightness underlying component of SBS 0335–052. The latter has a blotchy and irregular appearance, suggesting that the light is not emitted by stars but by ionized gas. The supershell delineating the large supernova cavity is clearly seen.

Fig.5. (a) and (b) V and I surface brightness profiles as a function of log r where r is the equivalent radius. A power law is a straight line in this coordinate system. The error bars take into account photon statistics. The large error bars in the radius range −0.45 ≤ log r ≤ −0.05 are caused by light contamination from the shell structure. (c) (V–I) color profile. It is approximately flat and shows an extraordinary blue color for the underlying low-surface-brightness component.

Fig.6. GHRS spectra obtained through a 2″×2″ rectangular aperture with HST and centered on super-star cluster 1. The aperture includes also super-star clusters 2 and 3. The spectral resolution is 0.12 Å. (a) shows the spectral region around Lyα. The strong geocoronal Lyα line can be seen at 1216 Å. The redshifted location of the Lyα line in SBS 0335–052 (v = 4043 km s⁻¹) is marked. There is low-intensity broad (from 1220Å to 1240Å) Lyα emission superposed on even broader absorption. The continuum level is 7.5×10⁻¹⁵ erg cm⁻² s⁻¹ Å⁻¹. (b) shows the spectral region around the OI λ1302 line. Its redshifted location is marked. The line is not detected and an upper limit of ∼ 200 mA can be set for its equivalent width.
Table 1. Observational characteristics of SBS 0335–052

| Parameter | Value |
|-----------|-------|
| $\alpha$ (1950) | $03^h35^m15.2^s$ |
| $\delta$ (1950) | $-05^\circ12'26''$ |
| $l^{II}$, $b^{II}$ | $193^\circ, -45^\circ$ |
| $d_{25}^a$ | $12.6''$ |
| D (Mpc)$^b$ | 54.3 |
| d (kpc) | 3.29 |
| $V^a$ | $16.65 \pm 0.01$ |
| $V-I^a$ | $-0.23 \pm 0.01$ |
| $M_B$ | $-16.70$ |
| $v_{HI}$ (km s$^{-1})^c$ | $4043 \pm 10$ |
| $\Delta v_{20}$ (km s$^{-1})^c$ | $105 \pm 14$ |
| $\Delta v_{50}$ (km s$^{-1})^c$ | $83 \pm 9$ |
| $F_{HI}$ ($10^6$ M$_\odot$ Mpc$^{-2})^c$ | 0.34 |
| $M_{HI}$ ($10^9$ M$_\odot)^c$ | 0.99 |
| $L_B$ ($10^9$ L$_\odot)^d$ | 1.1 |
| $M_{HI}/L_B$ (M$_\odot/L_\odot$) | 0.90 |

$^a$ from this paper. $d_{25}$ is derived from Figure 2. $V$ and $I$ measured in a 12$''$ diameter aperture centered on the brightest knot.

$^b$ redshift distance corresponding to $H_0 = 75$ km s$^{-1}$Mpc$^{-1}$ and a systematic velocity of 4076 km s$^{-1}$, corrected to the Local Group velocity centroid following Thuan & Martin (1981).

$^c$ HI measurements obtained with the Nançay radio telescope by Thuan et al. (1996); $v_{HI}$ is the heliocentric velocity.

$^d$ Adopting $M_B$(sun) = 5.48 mag.
Table 2. Magnitudes and colors of stellar clusters

| No. | $V_0^a$       | $I_0^a$       | $(V - I)_0^a$ |
|-----|---------------|---------------|---------------|
| 1   | 18.93± 0.01   | 19.54± 0.01   | -0.61± 0.02   |
| 2   | 19.24± 0.02   | 19.63± 0.02   | -0.39± 0.02   |
| 3   | 20.55± 0.08   | 20.81± 0.10   | -0.26± 0.12   |
| 4   | 19.71± 0.02   | 19.86± 0.02   | -0.15± 0.03   |
| 5   | 19.50± 0.03   | 19.36± 0.03   | 0.14± 0.04    |
| 6   | 21.96± 0.11   | 21.65± 0.09   | 0.31± 0.14    |

$a$corrected for foreground extinction ($A_V=0.10$ mag, $A_I=0.06$ mag, Burstein & Heiles 1982; Whitford 1958).
