SBS 0335–052, A PROBABLE NEARBY YOUNG DWARF GALAXY:
EVIDENCE PRO AND CON

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1Spectroscopic observations presented herein were obtained with the Multiple Mirror Telescope, a facility operated jointly by the Smithsonian Institution and the University of Arizona.
ABSTRACT

The results of Multiple Mirror Telescope (MMT) spectrophotometry of the extremely low-metallicity blue compact galaxy (BCG) SBS 0335–052 (SBS – the Second Byurakan Survey) are presented. The oxygen abundance in central brightest part of the galaxy is found to be $12 + \log(O/H) = 7.33 \pm 0.01$, only slightly greater than the oxygen abundance in the most metal-deficient BCG I Zw 18. We show that the N/O, Ne/O, S/O and Ar/O abundance ratios in SBS 0335–052 are close to those derived in other BCGs, suggesting that heavy element enrichment in the HII region is due to massive star evolution. However, we find an O/Fe abundance ratio close to that in the Sun, in variance with values derived for other BCGs. The helium abundance derived from the HeI λ4471, 5876 and 6678 emission lines, taking into account of collisional and fluorescent enhancement, is $Y = 0.245 \pm 0.006$, close to the value of the primordial helium abundance $Y_p=0.243 \pm 0.003$ derived by Izotov, Thuan & Lipovetsky.

We detect auroral [OIII] λ4363 emission in the inner part of HII region with a diameter of 14″ or 3.6 kpc and find that the HII region inside this diameter is hot, $T_e \sim 20000$K. The oxygen abundance in this region is nearly constant ($12 + \log(O/H) = 7.1 - 7.3$) with a gradual decrease to the outer part of HII region, implying effective mixing of ionized gas on short time-scales. We study the distribution of the nebular HeII λ4686 emission line and find it is not produced by main-sequence O-stars or Wolf-Rayet stars. Possible excitation mechanisms of this line, such as massive X-ray binaries and shocks, are discussed. We also discuss the origin of blue underlying extended low-intensity emission detected in SBS 0335–052 on V, R and I images. The blue $(V - I)$ and $(R - I)$ color distributions suggest that a significant contribution to the extended low-intensity envelope is due to ionized gas emission. This is evidence that SBS 0335–052 is a young galaxy experiencing its very first burst of star formation. However, we find that the observed equivalent width of Hβ emission in the extended envelope is 2–3 times lower than the value expected in the case of pure gaseous emission. Furthermore, we find that the widths of Hγ and Hβ are narrower than the instrumental profiles; this could be explained by presence of underlying stellar absorption from A stars. These findings suggest that, along with the blue young ($\sim 10^7$yr) stellar clusters in the center of the galaxy, an older stellar population with age $\sim 10^8$yr may be present in the extended envelope of SBS 0335–052, having a total mass $\sim 10^7M_\odot$, two orders of magnitude smaller than the neutral gas mass but comparable with the total mass of stars in blue young stellar clusters observed in the center of the galaxy. We conclude that SBS 0335–052 is a young nearby dwarf galaxy with age $\sim 10^8$yr.

Subject headings: galaxies: abundances — galaxies: irregular — galaxies: photometry — galaxies: evolution — galaxies: formation — galaxies: ISM — HII regions — ISM: abundances
1. INTRODUCTION

The blue compact galaxy (BCG) SBS 0335–052 (SBS – the Second Byurakan Survey) was shown by Izotov et al. (1990ab) to have extremely low oxygen abundance: $12 + \log (O/H) = 7.0 - 7.1$. This galaxy has equatorial coordinates $\alpha(1950) = 03^h35^m15.2^s$, $\delta(1950) = -05^\circ12'26''$, apparent magnitude $V = 16.65$ mag (Thuan, Izotov & Lipovetsky 1996), redshift $z = 0.0136$ and absolute magnitude $M_V = -17.02$. Subsequent spectrophotometric observations of SBS 0335–052 confirmed the very low metallicity in its HII region. Terlevich et al. (1992) have derived $12 + \log (O/H) = 7.26$, similar to that of I Zw 18, the lowest metal-deficient BCG known. Melnick, Heydari-Malayeri & Leisy (1992) have obtained $B$, $V$, $R$ and H$\alpha$ images of SBS 0335–052 and found that the galaxy consists of 2 knots, labeled A and B, separated by 1.0". The diameter of the HII region derived from the H$\alpha$ image is $\sim 3$ kpc and shows wisps and filaments. These authors have derived an oxygen abundance $12 + \log (O/H) = 7.64$ and 7.30 for knots A and B. The oxygen abundance in knot B is close to the value derived by Skillman & Kennicutt (1993) for I Zw 18.

The low heavy-element abundance in SBS 0335–052 implies that this galaxy could be a nearby young galaxy experiencing its first burst of star formation. Several new studies found additional evidence for the youth of SBS 0335–052. Garnett et al. (1995) have derived the carbon abundance in this galaxy from Hubble Space Telescope (HST) $UV$ spectra and found a C/O abundance ratio $\sim 5$ times lower than that in the Sun. Such a low C/O ratio is expected from models of chemical evolution for low-metallicity, unevolved galaxies (Carigi et al. 1994). From HST $V$ and $I$ images Thuan, Izotov & Lipovetsky (1996) have found that SBS 0335–052 consists of 6 compact luminous blue clusters surrounded by extended ($\sim 3$ kpc) low-intensity emission elongated in the SE–NW direction with $(V - I)$ color not redder than 0.1–0.2, the color of late B or early A stars. However, its filamentary structure may preclude a stellar origin for this emission. From Very Large Array (VLA) observations in the HI 21 cm emission line (Thuan et al. 1996), a large $64kpc \times 34kpc$ neutral gas cloud was found in the SBS 0335–052 region elongated in the direction E–W. Neutral gas mass estimates give $M_{HI} \geq 10^9M_\odot$, which is significantly larger than the mass of the stellar population or of the ionized gas ($\sim 10^7-10^8M_\odot$). The VLA map shows two peaks in the HI distribution separated by 24 kpc. The optical counterpart of SBS 0335–052 coincides with the eastern peak, while the western peak is found to coincide with a faint ($\sim 2$ mag fainter) HII region which has been shown (Pustilnik et al. 1996; Lipovetsky et al. 1996) to have the same redshift as SBS 0335–052 and a very low oxygen abundance. Therefore, observational evidence suggests that SBS 0335–052 may be a young nearby galaxy, a distinction it shares with I Zw 18. However, even though it has nearly the same oxygen abundance, SBS 0335–052 is $\sim 3$ mag more luminous than I Zw 18 and contains a larger number of young massive stars.

Although it is firmly established from optical spectrophotometric observations that SBS 0335–052 is an extremely metal-deficient galaxy, detailed spectrophotometric studies in the optical range have yet to be undertaken. Such observations are important in that they allow us to estimate the primordial helium abundance of extremely low-metallicity BCGs. Izotov, Thuan & Lipovetsky (1996) have shown that the primordial helium abundance cannot be estimated.
accurately for I Zw 18 because of the peculiarity of its HeI emission line intensities. Hence, SBS 0335–052 is currently the most metal-deficient BCG for which the helium abundance can be measured reliably. The helium mass fraction, Y, in SBS 0335–052 given by Terlevich et al. (1992) is based on measurements of the HeI \( \lambda 4471 \) emission line and has a very low value \( Y=0.215 \), while Melnick, Heydari-Malayeri & Leisy (1992) have derived \( Y=0.211 \) and 0.233 for knots A and B, respectively. These values of the helium abundance are lower than that derived by Izotov, Thuan & Lipovetsky (1994, 1996) for other low-metallicity BCGs.

In addition, spectrophotometric observations of SBS 0335–052 and the determination of the abundances of heavy elements are important to the study of the origin of heavy elements in a low-metallicity environment. Of further interest is the question of the origin of the low-intensity extended emission in SBS 0335–052 which was detected by Thuan, Izotov & Lipovetsky (1996) in HST V and I images and of whether, as they suggested, dust exists in SBS 0335–052. To address these questions we have obtained new high signal-to-noise (S/N) spectrophotometric observations of SBS 0335–052 and use V, R, I photometry obtained by Thuan, Izotov & Lipovetsky (1996) and Lipovetsky et al. (1996).

In §2 we present a description of the observations and data reduction; in §3 the physical conditions and chemical composition in HII region are discussed. In §4 we discuss possible mechanisms which could lead to the appearance of the strong nebular HeII \( \lambda 4686 \) emission line; in §5 the kinematic properties of HII region are discussed; and in §6 we model the color distribution of the underlying low-intensity extended component. We summarize our results in §7.

2. OBSERVATIONS AND DATA REDUCTION

Spectrophotometric observations of SBS 0335–052 with signal-to-noise ratios of S/N = 30 in the continuum were obtained with the Multiple Mirror Telescope (MMT) on the night of 1995, December 20. Observations were made with the Blue Channel of the MMT Spectrograph using a highly-optimized Loral 3072×1024 CCD detector. A 1″×180″ slit was used along with a 500 g/mm grating in first order and an L–38 second order blocking filter. This gives a spatial scale along the slit of 0.3 arcsec pixel\(^{-1}\), a scale perpendicular to the slit of 1.9 Å pixel\(^{-1}\), a spectral range of 3600–7300 Å and a spectral resolution of \( \sim 7\) Å (FWHM). For these observations, CCD rows were binned by a factor of 2, yielding a final spatial sampling of 0.6 arcsec pixel\(^{-1}\). The observations cover the full spectral range in a single frame which contains all the lines of interest. Furthermore, they have sufficient spectral resolution to separate [OIII]\( \lambda 4363 \) from nearby H\( \gamma \) and to distinguish between narrow nebular and broad WR emission lines. Total exposure time was 60 minutes and was broken up into 3 subexposures, 20 minutes each, to allow for more effective cosmic ray removal. All exposures were taken at small airmasses (\( \leq 1.27 \)), so no correction was made for atmospheric dispersion. The seeing during the observations was 1″ FWHM. The slit was oriented in the direction with position angle P.A.\( =-30^\circ \) to permit observations of all stellar clusters and low-intensity extended emission. Figure 1 shows the slit orientation superposed on
the $R$ image of SBS 0335–052. The spectrophotometric standard star PG 0216+032 was observed for flux calibration. Spectra of He–Ne–Ar comparison lamps were obtained before and after each observation to provide wavelength calibration.

Data reduction of spectral observations was carried out at NOAO headquarters in Tucson using the IRAF software package. This included bias subtraction, cosmic-ray removal and flat-field correction using exposures of a quartz incandescent lamp. After wavelength mapping, night sky background subtraction, and correcting for atmospheric extinction, each frame was calibrated to absolute fluxes. One-dimensional spectra were extracted by summing, without weighting, of different numbers of rows along the slit depending on the exact region of interest. The spectrum of SBS 0335–052 in the region 3700Å $\leq \lambda \leq 7300$Å is shown in Figure 2. The continuum was fitted after removal of the emission lines, and line intensities were measured by fitting Gaussians to the profiles.

We have adopted an iterative procedure to derive both the extinction coefficient $C(H\beta)$ and the absorption equivalent width for the hydrogen lines simultaneously from the equation (Izotov, Thuan & Lipovetsky 1994):

$$\frac{I(\lambda)}{I(H\beta)} = \frac{EW_e(\lambda) + EW_a(\lambda)}{EW_e(H\beta) + EW_a(H\beta)} \frac{F(\lambda)}{F(H\beta)} 10^{[C(H\beta) f(\lambda)]},$$

(1)

where $I(\lambda)$ is the intrinsic line flux and $F(\lambda)$ is the observed line flux corrected for atmospheric extinction. $EW_e(\lambda)$ and $EW_a(\lambda)$ are the equivalent widths of the observed emission line and the underlying absorption line, respectively, and $f(\lambda)$ is the reddening function, normalized at H$\beta$, which we take from Whitford (1958).

We used the theoretical ratios from Brocklehurst (1971) at the electron temperature estimated from the observed [OIII](4959 + 5007)/4363 ratio for the intrinsic hydrogen line intensity ratios. For lines other than hydrogen $EW_a(\lambda)=0$ so Eq. (1) reduces to

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

(2)

The observed and corrected line intensities, extinction coefficient, and equivalent widths of the stellar hydrogen absorption lines are given in Table 1 along with the uncorrected H$\beta$ flux and H$\beta$ equivalent width for the brightest part of SBS 0335–052 with an aperture of $1''\times 6''$.

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2IRAF: the Image Reduction and Analysis Facility is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, In. (AURA) under cooperative agreement with the National Science Foundation (NSF).
3. HEAVY ELEMENTS AND HELIUM ABUNDANCES

Since SBS 0335–052 is the second most metal-deficient BCG known after I Zw 18, it is of special interest to determine the heavy element and helium abundance in this very low-metallicity environment. SBS 0335–052 is a chemically unevolved galaxy, so we can expect that the amount of helium synthesized by stars is small and that the helium mass fraction in its HII region is close to the primordial value. As we see from Table 1, emission lines of several heavy elements have been detected in SBS 0335–052. This gives us the opportunity to derive heavy element abundance ratios and to place constraints on low-metallicity stellar nucleosynthesis and chemical evolution models. To derive element abundances we follow the procedure described in detail by Izotov, Thuan & Lipovetsky (1994). It is known that the electron temperature, $T_e$, is different in high- and low-ionization zones of HII regions (Stasinska 1990), and we have chosen to determine $T_e$(OIII) from the [OIII]$\lambda$4363/($\lambda$4959+$\lambda$5007) ratio and $N_e$(SII) from the [SII]$\lambda$$\lambda$6717/6731 ratio. We adopt $T_e$(OIII) for the derivation of He$^+$$^+$, He$^{2+}$, O$^{2+}$, Ne$^{2+}$ and Ar$^{3+}$ ionic abundances. To derive the electron temperature for the O$^+$ ion, we have used the relation between $T_e$(OII) and $T_e$(OIII) (Izotov, Thuan & Lipovetsky 1994), based on the photoionization models of Stasinska (1990). $T_e$(OII) has been used to derive the O$^+$$^+$, N$^+$ and Fe$^+$$^+$ ionic abundances. For Ar$^{2+}$ and S$^{2+}$ we have used an electron temperature intermediate between $T_e$(OIII) and $T_e$(OII) following the prescriptions of Garnett (1992). Total element abundances have been derived after correction for unseen stages of ionization as described by Izotov, Thuan & Lipovetsky (1994).

3.1. Heavy Element Abundances in the Central Part of SBS 0335–052

In Table 2 we show the adopted electron temperatures for different ions and the electron number density for the central 1"×6" portion of SBS 0335–052, along with ionic abundances, ionization correction factors and total heavy element abundances. It is well established theoretically that the oxygen seen in HII regions is a primary element produced by massive stars with $M\geq10M_\odot$. Other $\alpha$-process elements seen in the spectra of HII regions, such as neon, argon, and sulfur, are generally thought to be primary as well. The Ne/O, S/O and Ar/O ratios are independent of O/H (Vigroux, Stasinska & Comte 1987; Garnett 1989; Thuan, Izotov & Lipovetsky 1995; Izotov, Thuan & Lipovetsky 1996). The situation for nitrogen is more complex. While in spiral galaxies spectral observations show that the N/O ratio increases with O/H, in low-metallicity galaxies N/O is found to be constant and independent of O/H (Lequeux et al. 1979; Kunth & Sargent 1983; Campbell, Terlevich & Melnick 1981; Thuan, Izotov & Lipovetsky 1995). Because SBS 0335–052 so metal-deficient it is important to examine whether the trends in heavy element abundance ratios continue to the extremely low oxygen abundances found in I Zw 18 and SBS 0335–052. For SBS 0335–052 we derive an oxygen abundance, $12 + \log (O/H) = 7.33 \pm 0.01$, somewhat larger than value 7.30 derived by Melnick, Heydari-Malayeri & Leisy (1992). The value of $12 + \log (O/H) = 7.0$ –
7.1 found by Izotov et al. (1990ab) was an underestimate caused mainly by nonlinearity of the detectors used and by saturation of strong emission lines.

In Figure 3 we show the N/O, Ne/O, Ar/O and S/O ratios for SBS 0335–052 (filled circles). We also show the data from Thuan, Izotov & Lipovetsky (1995) and Izotov, Thuan & Lipovetsky (1996) (open circles) for a sample of low-metallicity BCGs. We used the [NII] λ6584 emission line to derive the nitrogen abundance for SBS 0335–052. However, our relatively low spectral resolution is insufficient to resolve it from Hα and its intensity was derived after subtraction of the broad Hα wings. Therefore, the derived nitrogen abundance is somewhat uncertain and higher spectral resolution observations are needed to improve this value. As it is evident from Figure 3, the N/O, Ar/O and S/O abundance ratios in SBS 0335–052 are in excellent agreement with those derived for other BCGs, and we confirm the important conclusion by Thuan, Izotov & Lipovetsky (1995) that all these elements in low-metallicity BCGs are primary elements produced by the same massive stars.

This result is especially important for nitrogen. While our data show that nitrogen in low-metallicity BCGs is a primary element, Pettini et al. (1994) found very low N/O ratio in low-metallicity high-redshift absorbing clouds which is at variance with the data for BCGs, suggesting the presence of a significant amount of nitrogen, produced as a secondary element. Timmes et al. (1995) have noted that no primary nitrogen is produced in the standard massive star models. However, if numerical parameters governing convective overshoot are enlarged, primary nitrogen is produced in all low metallicity massive stars with M > 30M⊙. The synthesis of primary nitrogen in these low metallicity massive stars occurs as the convective helium burning shell penetrates into the hydrogen shell with violent, almost explosive consequences. On the other hand, in massive stars with solar metallicity no primary nitrogen is produced even with enhanced overshoot. Thus, chemical evolution models with primary nitrogen production in low-metallicity massive stars can explain the observed lack of secondary nitrogen in BCGs and the small dispersion in log(N/O).

We have detected the [FeIII]λ4658 emission line in the spectrum of SBS 0335–052 and have derived the iron abundance in HII region. Iron is a primary element produced during explosive nucleosynthesis either in Type I supernovae (SN I’s) with low-mass progenitors or in Type II supernovae (SN II’s) with more massive progenitors (Weaver & Woosley 1993; Woosley & Weaver 1995). Due to the difference in evolution timescales of Type I and Type II supernova progenitors, SN I’s begin to contribute only when the age of the system is ≥10⁹ yr. Therefore, the Fe/O ratio provides an important constraint on galaxy chemical evolution models. However, there remain uncertainties concerning models of explosive nucleosynthesis due to the uncertainties in central collapsing core parameters and the initial conditions for the shock wave in the supernova progenitor. It was shown by Thuan, Izotov & Lipovetsky (1995) that O/Fe in BCGs is overabundant by ~0.34 dex, the same overabundance found in galactic halo stars. This implies a similar chemical enrichment history for BCGs and the galactic halo. The comparison of the observed Fe/O abundance ratio and theoretical Fe/O yield ratio in BCGs favors massive
star explosive nucleosynthesis models with reduced iron production. We show in Figure 4 [O/Fe] vs. [Fe/H] for the BCGs in the sample from Thuan, Izotov & Lipovetsky (1995) and Izotov, Thuan & Lipovetsky (1996) (open circles) along with [O/Fe] for SBS 0335–052 (filled circles), derived in this paper. For the solar abundance we adopt $12 + \log(\text{Fe/H})_\odot = 7.51$ consistent with the meteoritic value (Holweger et al. 1991; Biémont et al. 1991; Hannaford et al. 1992). For comparison, we also plot the data for galactic disk and halo stars (points) from Edvardsson et al. (1993), Barbuy (1988) and Barbuy & Erdelyi-Mendes (1989). While other BCGs show significant overabundance of oxygen relative to iron, the O/Fe abundance ratio in SBS 0335–052 is close to solar. The reason for such difference is not clear. We can only propose several possibilities: a) the contribution of iron from type I SNe is large in SBS 0335–052 due to the presence of a significant (but undetected) stellar population with age $\geq 10^9$ yr; however, [FeIII] lines are detected in the region of present star formation and, therefore, we do not believe the significant iron yield from SN I's; b) [FeIII] emission line in the spectrum of SBS 0335–052 is contaminated by Wolf-Rayet CIII $\lambda$4658 emission. However, the $\lambda$4658 line is narrow, atypical of WR lines, and we do not detect any other evidence for WR features in the spectrum of SBS 0335–052; c) iron in other BCGs is significantly depleted due to the dust formation; d) uncertainties in the ionization correction factor (ICF) for iron. ICF(Fe) is large (Table 2) and dependent on the O/O$^+$ ionic ratio, where O=O$^+$ + O$^{2+}$. Therefore, uncertainties in O$^+$ abundance could significantly influence iron abundance. However, this explanation is implausible because ICF(N) also scales with O/O$^+$, whereas N/O in SBS 0335–052 is normal.

3.2. Helium Abundance

The extremely low oxygen abundance in SBS 0335–052 and high surface brightness of its HII region implies that this galaxy is one of the best objects for determining the helium abundance at low metallicity. The high S/N ratio spectrum obtained for SBS 0335–052 (Figure 2) allows us to measure helium line intensities with good accuracy. The HeI line intensities corrected for interstellar extinction are shown in the Table 1. For the helium abundance determination we use the HeI $\lambda$4471, $\lambda$5876 and $\lambda$6678 emission lines. However, HeI line intensities deviate from the pure recombination values (Izotov, Thuan & Lipovetsky 1996) and must be corrected. The main mechanism changing the HeI line intensities from their recombination values is collisional excitation from the metastable $2^3S$ level. This mechanism depends on electron temperature and electron number density and is significant in SBS 0335–052 because of the high electron temperature $T_e=19200K$ in its HII region. The line most sensitive to collisional enhancement in optical range is HeI $\lambda$7065. Another mechanism which could drive HeI line intensities from their recombination values is self-absorption in some optically thick emission lines, such as HeI $\lambda$3889. The emission lines most sensitive to this fluorescence mechanism are HeI $\lambda$3889 and $\lambda$7065. In contrast to collisional enhancement, which increases the intensities of all HeI lines, the fluorescence mechanism works in such a way as to decrease the intensity of the HeI $\lambda$3889 line as its optical depth increases, while increasing the intensities of other lines of interest (HeI $\lambda$4471, $\lambda$5876, $\lambda$6678
and λ7065).

In SBS 0335–052 such fluorescent enhancement could be important. Since HeI λ3889 is blended with H8 λ3889, we have subtracted the latter, assuming its intensity to be equal to 0.106 I(H/β) (Aller 1984). Then the intensity of HeI λ3889 corrected for interstellar extinction is equal to 0.065 I(H/β), which gives an observationally inferred ratio I(λ3889)/I(λ5876) = 0.65 compared to the recombination value of 1.08 at $T_e = 20000$K (Brocklehurst 1972). Taking into account that collisional enhancement factors for HeI λ3889 and λ5876 emission lines are nearly the same (Kingdon & Ferland 1995) we conclude that the intensity of HeI λ3889 is reduced due to self-absorption. To correct HeI emission line intensities for collisional and fluorescent enhancement we follow the approach described by Izotov, Thuan & Lipovetsky (1996). We assume that the electron temperature in He$^+$ zone is equal to that in the O$^{2+}$ zone. However, we do not use the electron number density derived from [SII] $\lambda$6717/$\lambda$6731 for two reasons: 1) the S$^+$ and He$^+$ zones not coincide; 2) although the electron number density $N_e$(SII)=393 cm$^{-3}$ is definitely larger than the low density limit for the [SII] line ratio, we find that the width of [SII]$\lambda$6731 for unknown reasons is 9% larger than that of [SII]$\lambda$6717. Therefore, rather than using $N_e$(SII), we take into consideration 5 HeI emission lines: λ3889, λ4471, λ5876, λ6678 and λ7065 and solve problem self-consistently to reproduce the theoretical HeI line intensity recombination ratios for two unknown quantities: 1) the electron number density in the He$^+$ zone and 2) the optical depth $\tau$(λ3889) in HeI λ3889 line.

The best solution is found for electron number density $N_e$(He$^+$)= 153 cm$^{-3}$ and optical depth $\tau$(λ3889)=1.5. The helium abundance for individual lines along with correction factors for collisional and fluorescent enhancement are given in Table 3. The helium mass fraction in SBS 0335–052, Y=0.245±0.006, is in close agreement with that derived for other low-metallicity BCGs and is close to the primordial helium mass fraction $Y_p$=0.243±0.003 derived by Izotov, Thuan & Lipovetsky (1996).

### 3.3. Oxygen Abundance Distribution

The presence of large number of massive stars in the central part of SBS 0335–052 implies that the enrichment of ionized gas with heavy elements occurred in the short time scale of $\sim$ 10$^6$–10$^7$yr, comparable to the lifetime of massive stars. The scenario of self-enriched giant HII regions has been proposed by Kunth & Sargent (1986), who suggest that new heavy element ejecta originating from stellar winds and supernovae of type II initially mix exclusively with the ionized gas in the HII zone, waiting for further mixing with the cold gas during the long interburst phase. Roy & Kunth (1995) have analyzed different mechanisms of interstellar medium mixing and found that ionized gas is well mixed due to Rayleigh-Taylor and Kelvin-Helmholz instabilities on time scales 1.5×10$^6$ yr within regions of 100 pc size. Martin (1996) has studied the oxygen abundance distribution inside the central 530 pc of the galaxy I Zw 18, where auroral [OIII] $\lambda$4363 is observed and has found that oxygen abundance within the central 530 pc is nearly constant and is within
20% that of the NW HII region \((12 + \log (\text{O/H}) = 7.1 - 7.3)\). She argued that detection of a superbubble establishes a timescale \((\sim 15-27 \text{ Myr})\) and spatial scale \((\sim 900 \text{ pc})\) for dispersing the recently synthesized elements.

The \([\text{OIII}]\lambda 4363\) emission line in SBS 0335–052 is observed within the region of 3.6 kpc. This allows us to measure oxygen abundance and to study processes of interstellar medium mixing in a region 7 times larger than in I Zw 18. In Figure 5a we show intensities of \([\text{OIII}]\lambda 4363\) and \(\lambda 5007\) relative to \(\text{H}\beta\), corrected for interstellar extinction, and the distribution of the interstellar extinction coefficient, \(C(\text{H}\beta)\), in the central 3 kpc region of SBS 0335–052 in the direction NW – SE. The origin is taken with respect to the maximum of the continuum flux near the \(\text{H}\beta\) emission line. Six blue stellar clusters detected by Thuan, Izotov & Lipovetsky (1996), are all located in the region from –250 pc to 250 pc. We find that interstellar extinction is significant in the central 3 arcsec or \(\sim 800 \text{ pc}\) of the galaxy. Sites of enhanced absorption coincide spatially with the red region detected by Thuan, Izotov & Lipovetsky (1996). We argue that their assumption is correct; the red color is caused by presence of dust, however, we find somewhat lower values for extinction coefficient, \(C(\text{H}\beta) = 0.2 - 0.3\), (cf. the value 0.56 derived by Melnick, Heydari-Malayeri & Leisy (1992) for knot A). The maximal value of \(C(\text{H}\beta)=0.27\) is equivalent to a reddening of \(E(B-V) = 0.18\). In Figure 5b we show the distribution of electron temperature \(T_e\) (solid line) and oxygen abundance \(12 + \log (\text{O/H})\) (dashed line) in central 3 kpc of SBS 0335–052. For comparison, the oxygen abundance distribution in I Zw 18 is shown by the dotted line. In the brightest 1 kpc of SBS 0335–052, the temperature is nearly constant and lies in the range \(T_e = 18500 - 20000 \text{ K}\). In this region, the oxygen abundance is also nearly constant and lies in the very narrow range \(12 + \log (\text{O/H}) = 7.30 - 7.35\). This constancy of the oxygen abundance implies that the mixing of oxygen-rich supernova remnants with interstellar medium happened very quickly, \(\sim 10^6 \text{ yr}\). The distribution of the electron temperature in NW direction is characterized by several jumps. The dispersion of \(T_e\) is \(\sim 5000 \text{ K}\), caused mainly by observational uncertainties due to the low intensities of emission lines at the distance greater than 1 kpc from the origin. However, it is probable, that some part of the dispersion in \(T_e\) could be explained by propagation of shocks in NW direction. Indeed, HST images of SBS 0335–052 clearly show elongated structure and several superbubbles in that direction (Thuan, Izotov & Lipovetsky 1996). Some dispersion in oxygen abundance in the NW direction could be in part due to the incomplete mixing at scales larger than 1 kpc. We note the small gradient of oxygen abundance with \(12 + \log (\text{O/H}) \sim 7.1\) at a distance of 2 kpc, which is 1.5 times lower than value at the origin. The size of HII region in I Zw 18 is several times smaller, but the oxygen abundance is nearly in the same range, \(7.1 - 7.3\), as in SBS 0335–052. Therefore, the oxygen abundance distribution in I Zw 18 and SBS 0335–052 is similar, the main difference is caused by different scales – in SBS 0335–052 the population of massive O-stars is one order of magnitude larger than in I Zw 18. The small gradient in oxygen abundance found in SBS 0335–052 on scales \(\sim 3 \text{ kpc}\) is evidence in favor of fast mixing of ionized gas due to turbulent motions produced by fast shocks, moving in the direction SE – NW. However we should adopt the characteristic turbulent velocity of \(\sim 10^3 \text{ km s}^{-1}\) for efficient mixing on these scales. Velocities of order \(10^3 \text{ km s}^{-1}\) have been detected by Roy et al. (1992), Skillman & Kennicutt (1993) and
Izotov et al. (1996) in several dwarf galaxies. In §6 we discuss the existence of such fast gas motion in SBS 0335–052.

4. THE NATURE OF HEII $\lambda 4686$ EMISSION

The strong nebular HeII $\lambda 4686$ emission line has been detected in SBS 0335–052 (Figures 2, 8). Its intensity, $\sim 3\%$ of $H\beta$, is close to that observed in I Zw 18 (Skillman & Kennicutt 1993) and in some other low-metallicity BCGs (Campbell, Terlevich & Melnick 1986; Terlevich et al. 1991; Izotov, Thuan & Lipovetsky 1994, 1996; Izotov et al. 1996) and is several orders of magnitude larger than theoretical values predicted by models of photoionized HII regions. It was suggested by Bergeron (1977), that the HeII emission in dwarf emission-line galaxies could arise in the atmospheres of Of stars. Garnett et al. (1991) presented observations of nebulae in nearby dwarf galaxies with strong narrow HeII $\lambda 4686$ emission lines and examined several possible excitation mechanisms, concluding that the radiation field associated with star-forming regions can be harder than previously suspected. The hottest main sequence stars have temperatures not exceeding values 60000K (Campbell 1988); plane-parallel non-LTE atmosphere models for such stars under-produce the required number of He$^+$ ionizing photons by roughly four orders of magnitude (Garnett et al. 1991). On the other hand, models for massive star evolution which include mass loss predict that the most massive stars evolve blueward to larger effective temperatures and become Wolf-Rayet stars. Schaerer & de Koter (1996) calculated non-LTE atmosphere models taking into account line blanketing and stellar winds and found that the flux in the HeII continuum is increased by 2 to 3 orders of magnitudes compared to predictions from plane-parallel non-LTE model atmospheres and 3 to 6 orders of magnitudes compared to predictions from plane parallel LTE model atmospheres. Including these predictions, Schaerer (1996) synthesized the nebular and Wolf-Rayet HeII $\lambda 4686$ emission in young starbursts. For metallicities $1/5Z_\odot \leq Z \leq Z_\odot$, he predicted a strong nebular HeII emission due to a significant fraction of WC stars in early WR phases of the burst. His predictions of the nebular HeII (typically I(HeII)/I(H$\beta$) $\sim 0.01 - 0.025$) agree well with the observations in Wolf-Rayet galaxies. However, this mechanism is not appropriate for SBS 0335–052 and other low-metallicity BCGs due to the fact that at low metallicities the efficiency of stellar winds is low, as suggested by the lack of the broad WR emission lines in their spectra (Figures 2, 8). It was suggested by Garnett et al. (1991) that radiative shocks in giant HII regions can produce relatively strong HeII emission under certain conditions. The strength of the HeII emission is sensitive mostly to the velocity of the shock, reaching maximum for $V_{\text{shock}} \sim 120$ km s$^{-1}$, dropping rapidly at higher velocities. The third mechanism, discussed by Garnett et al. (1991) is photoionization of HII region by X-rays produced by massive X-ray binary stars.

In Figure 6 we show spatial distribution of continuum and emission line intensities for different emission lines in SBS 0335–052. We note that distribution of continuum intensity measured near the H$\beta$ emission line is shifted by $\sim 200$ pc to NW relative to the spatial distribution of emission lines intensities. The width of continuum distribution at half maximum is $\sim 700$ pc, close to the
diameter of region in SBS 0335–052 where six blue compact clusters are located (Thuan, Izotov & Lipovetsky 1996). Therefore, the optical continuum in the central part of SBS 0335–052 is produced by stars, mainly O and B. Thuan, Izotov & Lipovetsky (1996) found a \((V - I)\) color gradient of clusters in the direction SE–NW with bluest cluster at the SE edge. They explain the color gradient mainly by reddening due to the presence of dust patches. However, some evolutionary effect could be present as follows from Figure 6: the maximum in the emission line intensities coincides with location of bluest and youngest stellar cluster. Other clusters probably have somewhat larger ages; most massive stars have moved away from the main sequence. This conclusion is confirmed by the equivalent widths of the \(H\beta\) emission line: 158\,Å at the origin, where the intensity of continuum is largest, and to 250\,Å at the maximum in the emission line intensity distribution. Consequently, ionizing photon fluxes from the older clusters are smaller. The only exception among nebular emission lines is HeII \(\lambda4686\) emission line. Its spatial distribution is nearly the same as stellar continuum distribution. Therefore, one of the probable mechanisms of HeII emission is hard emission from hot stars which are now at post-main-sequence stage. We exclude the possibility that this emission is produced due to ionization of He\(^+\) by radiation of O stars on the main sequence. If this were the case, the HeII intensity spatial distribution would be coincident with the spatial distribution of other emission lines. Due to the fact that we haven’t detected WR stars in SBS 0335–052, He\(^+\) ionization could be produced by massive X-ray binaries. We can estimate the number of massive X-ray binary systems necessary to produce observed luminosity of \(L(\text{HeII} \lambda4686) = 5.74 \times 10^{38}\,\text{erg s}^{-1}\). Scaling directly from the observed HeII luminosity \(1.5 \times 10^{35}\,\text{erg s}^{-1}\) of the nebula surrounding LMC X-1 (Pakull & Angebault 1986), the HeII luminosity in SBS 0335–052 implies the presence of \(\sim 4000\) massive X-ray binary systems. This value is in agreement with the equivalent number of O7-stars N(O7)=5000 inferred from the luminosity of \(H\beta\) emission line \(L(\text{H}\beta) = 2.06 \times 10^{40}\,\text{erg s}^{-1}\). Additionally, it is follows from Figure 5a, that the origin of HeII \(\lambda4686\) in fast shocks is not ruled out due to the fact that the intensity of this line, 0.04 – 0.05 relative to \(H\beta\), is observed in the NW direction at the distance \(\sim 1\) kpc, beyond the stellar clusters.

5. KINEMATICS OF IONIZED GAS

The presence of filaments and arcs in SBS 0335–052 found by Thuan, Izotov & Lipovetsky (1996) from HST WFPC2 images implies fast moving gas and complex dynamics of the ionized gas in HII region due to the supernovae activity. In Figure 7a we show the velocity distribution of ionized gas from \(H\beta \lambda4861\), [OIII]\(\lambda5007\) and H\(\alpha \lambda6563\) emission lines. For comparison, the night sky [OI]\(\lambda5577\) is also shown. The velocity distribution is similar for all nebular lines. However, contrary to expectations from imaging, the velocity dispersion of ionized gas is very small \(< 10\) km s\(^{-1}\) in the inner part of HII region. We note a small velocity gradient in the NW direction from the brightest part of the galaxy, \(\sim 20\) km s\(^{-1}\)kpc\(^{-1}\). The radial velocity of the central part of the galaxy is in good agreement with the radial velocity, derived from VLA HI \(\lambda21\) cm observations (Thuan et al. 1996). At large distances from the HII region center, the radial velocity is slightly
increased by $\sim 30-40$ km s$^{-1}$. Combining the presence of gaseous filaments with the absence of velocity gradients, we conclude from the radial velocity distribution that the ionized gas motion occurs in the direction perpendicular to the line-of-sight and perpendicular to the edge-on HI gas cloud. Such geometric orientation of the galaxy and large column density of neutral hydrogen in the direction of the stellar clusters could be the reason why Ly$\alpha$ emission was not detected in HST GHRS spectrum by Thuan, Izotov & Lipovetsky (1996). Following Charlot & Fall (1993), even if the dust is absent in the gas, the number of Ly$\alpha$ photons which escape in the plane of edge-on neutral gas cloud is significantly lower than in the direction normal to the gaseous disk plane.

In Figure 7b the full width at half maximum (FWHM) distribution for brightest lines is shown. For comparison, the FWHM for night sky line [OI]$\lambda$5577, which does not show changes along the slit, is also presented. We note that FWHM of the nebular lines increases from SE to NW. If real, this effect could be explained by transformation of ordered motion of supernova shells to chaotic turbulent motion due to instabilities in ionized gas discussed by Roy & Kunth (1995). We can estimate the characteristic FWHM caused by turbulent motion at the NW edge of the galaxy from relation FWHM$^2_{\text{tur}}$ = FWHM$^2_{\text{tot}}$ - FWHM$^2_{\text{inst}}$, where FWHM$_{\text{tot}}$ and FWHM$_{\text{inst}}$ are total and instrumental FWHM, the latter being derived from night sky [OI]$\lambda$5577 line. The FWHM$_{\text{tur}}$ derived from [OIII]$\lambda$5007 at the NW edge of HII region is equivalent to a turbulent velocity of $\sim 50$ to 100 km s$^{-1}$. This turbulent velocity can explain effective mixing of ionized gas on scales of 1 kpc during $\sim 10^7$ yr and nearly constant oxygen abundance.

In Figure 8 we show the part of the spectrum with H$\beta$ and [OIII]$\lambda$ 4959, 5007 emission lines from the central part of the galaxy. The H$\beta$ emission line has broad wings with FWZI$\sim 50$Å; we attribute these to fast moving ($\sim 1000$ km s$^{-1}$) supernovae remnants which, at larger distances, transform to random motions. We suggest that it is the only mechanism for ionized gas mixing at scales of several kpc. The broad wings of [OIII]$\lambda$4959, 5007 emission lines are masked by nearby faint lines and not so evident, but they are possibly present. Roy et al. (1992) and Izotov et al. (1996) have shown that the broad H$\beta$ wings in the low-metallicity BCGs are associated with broad wings in [OIII]$\lambda$4959, 5007 emission lines.

6. THE ORIGIN OF EXTENDED UNDERLYING LOW-INTENSITY EMISSION

The study of photometric and spectrophotometric properties of low-intensity extended emission around star-forming regions in BCGs is of special interest. The low metallicity of these galaxies implies that among them could exist young galaxies where star formation is occuring for the first time (Searle, Sargent & Bagnuolo 1973; Kunth & Sargent 1986). In the majority of BCGs the underlying low-surface-brightness emission component has been detected, characterized by red colors which are consistent with the presence of K and M stars (Loose & Thuan 1985; Kunth, Maurogordato & Vigroux 1988). These galaxies, therefore, are not young and have already experienced several episodes of star formation. It is believed that the best young galaxy candidates are I Zw 18 and SBS 0335–052. Hunter & Thronson (1995) found, on the basis of HST images
for I Zw 18, that the colors of the underlying diffuse component are consistent with those of B or A stars, with no evidence for long-lived red stars. Thuan, Izotov & Lipovetsky (1996) obtained $V$ and $I$ images for SBS 0335–052 and detected a low-intensity extended component $\sim 14''$ in diameter elongated in the SE–NW direction. The color $(V - I)_0$ for this component at large distance ($r > 2''$ or 520 pc in linear scale) from the central part of the galaxy where stellar clusters reside is $0.0 \leq (V - I)_0 \leq 0.2$ which is characteristic of A stars. Several gaseous filaments and arcs are superimposed on this underlying component, which led Thuan, Izotov & Lipovetsky (1996) to suggest that the underlying component is gaseous in nature and SBS 0335–052 is a young galaxy, probably undergoing its very first burst of star formation.

To examine the nature of the underlying diffuse component, Lipovetsky et al. (1996) obtained $R$ and $I$ images with the 3.5 meter Calar Alto telescope. We compare the total $I$ magnitudes and $I$ brightness distributions for SBS 0335–052 obtained with HST and the 3.5 meter Calar Alto telescope and find them to be in good agreement. The difference in total $I$ magnitude is only 0.05 mag inside the 25 mag/arcsec$^2$ isophote. Its rather blue $(R - I)$ color lies in the range $-0.6 - 0.0$ mag (Lipovetsky et al. 1996). From models of stellar population synthesis Leitherer & Heckman (1995) have derived $(V - I) = 0.0$ and $(R - I) = 0.0$ for an instantaneous burst at the age $\log t = 6.5$ and 0.60 and 0.30 at the age $\log t = 8.0$, where time $t$ is in yr. Therefore, both $(V - I)$ and $(R - I)$ colors in SBS 0335–052 are inconsistent with a pure stellar origin for the diffuse component.

Stellar emission in SBS 0335–052 is contaminated by strong nebular emission lines and gaseous continuous emission. In the $V$ band, significant flux arises from [OIII]$\lambda$5007, which has an equivalent width $\sim 500\AA$; in the $R$ band H$\alpha$, with equivalent width $\sim 1000\AA$, dominates. Only the $I$ band is free of strong emission lines, but there free-free and bound-free emission could be important. The emission lines are observed in the region outside the central 4 kpc. We now turn our attention to the results of broad-band photometry and ask whether the $(V - I)$ and $(R - I)$ colors in the external parts of SBS 0335–052 can be explained solely by gaseous emission. To model the pure gaseous color distribution one should obtain the intensity distribution of all lines of interest. Given the electron temperature, the continuous (free-free, bound-free and two-photon) emission of hydrogen-helium ionized gas is a function of only the H$\beta$ line intensity, helium abundance and wavelength (Aller 1984). We synthesize the $UBVRI$ colors of the gaseous emission, deriving the zeropoints for all filters from the spectrum of Vega (Castelli & Kurucz 1994). We find that the zeropoints for the HST F569W ($V$) and F791W ($I$) filters used by Thuan, Izotov & Lipovetsky (1996) differ from the $V$ and $I$ passbands from Bessel’s (1990) $V$ and $I$ by only $-0.03$ and $+0.01$ respectively. Therefore, we can directly compare HST and ground-based observations.

In Table 4 we compare the observed colors of the underlying low-intensity component with those derived from models of pure dust-free gaseous emission at an electron temperature of $Te=20000K$. In the models we adopt the continuous hydrogen-helium emission from Aller (1984) and two values of the observed equivalent widths of H$\beta = 170\AA$ (model II in Table 4) and 350\AA
(model III) which are representative of the outer envelope. We have taken into account in calculations all strong emission lines with observed intensities relative to H\(\beta\). Our calculations are in good agreement with the observations for both \((R-I)\) and \((V-I)\) colors, and thus we infer that \(T_e=20000\)K ionized gas contributes significantly to the extended low-intensity emission. We also calculate \((U-B)\) and \((B-V)\) colors for gaseous emission in SBS 0335–052. These colors provide a good basis for discriminating between different models. However, pure gaseous emission model is complicated by the fact that the observed equivalent widths of H\(\beta\) in the extended envelope do not exceed 350Å with mean value about 200Å, while recombination theory (case B) at \(T_e = 20000\)K gives value \(\sim 800\)Å (Aller 1984), or \(\sim 3\) times larger.

If we assume that the difference between the observed and theoretical equivalent widths results from the presence of some stellar light in the extended envelope, then \(\sim 2/3\) of the continuum near H\(\beta\) could be stellar in origin. The observational data allow us to estimate the upper limit of the stellar mass required to produce the extended low-intensity emission. In Table 4 we show the predicted colors for a gaseous continuum without emission lines at \(T_e=20000\)K (Model I). Except for \((U-B)\), these colors are in good agreement with those for an instantaneous burst with an age \(\log t = 8.0\). This means that the stellar-to-gaseous continuum intensity ratio in V band is the same as at H\(\beta\). The apparent V magnitude of outer envelope with radius \(r>3''\) is \(\sim 17.3\), from which we infer absolute V magnitude of \(\sim -16\) mag. To explain the observed light of the extended envelope with an instantaneous burst at \(\log t =8.0\), we must invoke the conversion of \(\sim 10^7\)M\(\odot\) of gas to stars with a Salpeter IMF and a lower mass cutoff of 1M\(\odot\) (Leitherer & Heckman 1995). This mass is significantly lower than the total mass of the galaxy, but is comparable with the mass converted to stars in the central part of SBS 0335–052 during the present burst of star formation. Therefore, we cannot exclude the possibility that some part of the extended low-intensity emission is due to stars formed during a previous episode of star formation \(\sim 10^8\) yr ago. Additional evidence for an older stellar component comes from the comparison of the H\(\beta\) width with that of \([\text{OIII}]\lambda5007\) and the night sky \([\text{OI}]\lambda5577\) (Fig.7b). The width of the H\(\beta\) emission line is less than that for the other lines and, possibly, could be explained by the presence of underlying stellar absorption from A stars. Corroborative evidence for the reality of this effect is provided by the fact that the H\(\gamma\) \(\lambda4340\) emission line is also narrower than the nearby mercury night sky HgI \(\lambda4358.2\) emission line.

Stellar population synthesis models predict that A stars dominate in the optical range when stars were formed in a single burst with age \(\sim 10^8\)yr. We suggest that, since their formation, these stars have been dispersed by several kpc due to random motions with velocities of \(\sim 10\) km s\(^{-1}\) and could explain the observed size of the region where the extended underlying emission is observed. In order to determine which model for the extended underlying emission is valid – pure gaseous emission in a \(10^7\)yr old galaxy where the equivalent widths of the hydrogen emission lines are reduced by a factor of \(\sim 2–3\) for an unknown reason or combined emission from stars and ionized gas in a galaxy with age \(\sim 10^8\)yr, we need to compare the observed \((U-B)\) color with different model predictions. In the case of an older stellar component (\(\log t = 8.0\)), the \((U-B)\) color would be significantly redder than that from pure gaseous emission (Table 4). \((U-B)\) color observations
of SBS 0335–052 will help to select between these two origins of the underlying emission.

7. SUMMARY

We have presented high S/N MMT spectrophotometric observations of the extremely low-metallicity blue compact galaxy, SBS 0335–052, which the preponderence of evidence suggests is a nearby, young galaxy. In the present paper our main goal has been to examine this hypothesis and to study the physical conditions and chemical composition in the HII region in SBS 0335–052.

From a detailed analysis of these data, we infer that:

1. SBS 0335–052 is an extremely low-metallicity galaxy with oxygen abundance $12 + \log(O/H) = 7.33 \pm 0.01$ in its central brightest region. This value is in reasonable agreement with that derived by Terlevich et al. (1992) and by Melnick, Heydari-Malayeri & Leisy (1992) and is slightly greater than the value of $\sim 7.2$ derived by Skillman & Kennicutt (1993) and by Izotov, Thuan & Lipovetsky (1996) for I Zw 18, most metal-deficient BCG.

2. The abundance ratios $\log(N/O) = -1.59 \pm 0.03$, $\log(\text{Ne}/O) = -0.81 \pm 0.02$, $\log(S/O) = -1.56 \pm 0.03$ and $\log(\text{Ar}/O) = -2.26 \pm 0.04$ in the inner brightest part of SBS 0335–052 are in excellent agreement with mean values for low-metallicity BCGs and confirm the conclusion by Thuan, Izotov & Lipovetsky (1995) that all these elements are primary elements produced in the same massive stars during short time-scales. However, we find that the O/Fe ratio in SBS 0335–052 is a factor $\sim 2–3$ lower than values derived for other low-metallicity BCGs (Thuan, Izotov & Lipovetsky 1995; Izotov, Thuan & Lipovetsky 1996) and is close to that for the Sun. For the moment the reason of this difference is unknown.

3. To derive the helium abundance in SBS 0335–052 we have corrected the HeI $\lambda 3889$, $\lambda 4471$, $\lambda 5876$, $\lambda 6678$ and $\lambda 7065$ emission lines strengths for collisional and fluorescent enhancement using Smits’ (1996) HeI recombination emissivities and Kingdon & Ferland’s (1995) and Robbins’ (1968) correction factors. The abundance of doubly ionized helium derived from the HeII $\lambda 4686$ emission line is also taken into account. The helium mass fraction in the inner part of SBS 0335–052 is shown to be $Y = 0.245 \pm 0.006$, very close to value for primordial helium abundance $Y_p = 0.243 \pm 0.003$ derived by Izotov, Thuan & Lipovetsky (1996) from the sample of 24 low-metallicity BCGs. Since the helium abundance in I Zw 18 cannot be reliably determined owing to the peculiarity of its HeI emission line intensities (Izotov, Thuan & Lipovetsky 1996), SBS 0335–052 is now the most metal-deficient BCG which can be used to infer the primordial helium abundance.

4. The auroral [OIII] $\lambda 4363$ emission line is detected in inner part of SBS 0335–052’ HII region with diameter 3.6 kpc which allows us to obtain an accurate estimate of the electron temperature and oxygen abundance. The diameter of the [OIII]$\lambda 4363$ region in SBS 0335–052 is $\sim 7$ times larger than in I Zw 18 implying, together with an H$\beta$ luminosity one order of magnitude larger number of massive O-stars in SBS 0335–052. We find the HII region in SBS 0335–052 to
have a rather high electron temperature $T_e \sim 20000K$, with evidence for a small positive outward gradient. The oxygen abundance $12 + \log(O/H)$ exhibits a small decrease with increasing radius ranging from 7.1 to 7.3; a similar phenomenon has been reported for I Zw 18 (Martin 1996). The presence of a large number of short-lived massive stars in SBS 0335–052 and the nearly constant oxygen abundance in its inner 3.6 kpc imply that effective mixing of the ionized gas has occurred in the short time-scale of $10^6–10^7$ yr. Nonetheless, kinematical properties of the ionized gas in SBS 0335–052 show little evidence of the fast gas motion needed for effective mixing on observed scales. The only exception is the presence of marginally detected low-intensity broad component of strong H$\beta$ emission line with FWZI~$\sim$50Å.

5. The narrow nebular HeII $\lambda 4686$ emission line is found to be very strong in SBS 0335–052 compared with predictions of photoionized HII region models. The intensity of this line relative to H$\beta$ varies spatially and has a maximum value of 0.06 at 500 pc NW of the brightest part of the galaxy. The large intensity of HeII $\lambda 4686$ implies the presence of a strong HeII continuum beyond the 228Å, which is several orders of magnitude larger than values predicted by plane-parallel LTE and non-LTE stellar atmosphere models. The observed shift in the HeII $\lambda 4686$ intensity distribution along the slit as compared with intensities of other nebular emission lines suggests that its origin is not associated with hot main-sequence O-stars. Schaerer (1996) has proposed that strong HeII $\lambda 4686$ could be produced by Wolf-Rayet stars. However, this would not seem to be the case for SBS 0335–052 where, because of its very low metallicity, WR stars are unlikely to exist. We suggest that the strong HeII $\lambda 4686$ emission line is connected in some way with evolved massive stars; however, the particular mechanism (massive X-ray binaries, shocks from supernovae, and others) is at present unknown.

6. We use emission line intensities along the slit oriented in SE–NW direction to model colors $(U - B), (B - V), (R - I)$ and $(V - I)$ of pure gaseous emission at electron temperature $T_e = 20000K$. Taking into consideration free-free, bound-free, two-photon continuum emission and observed equivalent widths for emission lines we found good agreement between observed and theoretical $(R - I)$ and $(V - I)$ colors suggesting in favor of a significant contribution of gaseous emission in extended low-intensity envelope. However, observed equivalent width of H$\beta$ emission line is $\sim 2$–3 times lower than value expected from pure gaseous emission. Besides that, we found that $(R - I)$ and $(V - I)$ colors of gaseous continuum at $T_e = 20000K$ are close to those for stellar population with age $10^6$yr. At last, widths of H$\gamma$ and H$\beta$ lines are narrower than instrumental profiles, probably, due to presence of underlying stellar absorption from A stars. These arguments suggest in favor of an older stellar population with age $\sim 10^7$yr, which gives $\sim 2/3$ of the light in the stellar continuum outside of the inner region $\sim 500$ pc in diameter where the young clusters reside. We estimate the mass of older stellar population of $\sim 10^7 M_\odot$, which is significantly lower (2 orders of magnitude) than the mass of neutral gas in SBS 0335–052, but it is comparable with mass of present burst of star formation. Hence, observational data suggest that SBS 0335–052 is young galaxy with age of $\sim 10^7$yr experiencing now at least the second short episode of star formation with duration $\leq 10^7$yr, or the first episode of propagating star formation in the direction NW–SE
with duration of $10^8$ yr, as suggested in part by the color gradient for stellar clusters found by Thuan, Izotov & Lipovetsky (1996). To confirm the presence of an underlying stellar component, it is important to derive the $(U - B)$ color, which is very different for gaseous and stellar emission. We also note the importance of spectral observations in analyzing photometric data obtained in searches for young galaxies.

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Fig. 1.— R image of SBS 0335–052, obtained with 3.5 meter Calar Alto telescope. North is up, East is left. The spectrum has been obtained with the slit oriented NW–SE along the major axis of underlying emission with P.A. = –30 degree.

Fig. 2.— MMT spectrum of SBS 0335–052 extracted from the brightest $1''\times6''$ part of the galaxy. The slit is oriented as shown in Figure 1. The spectrum with fluxes reduced by factor 50 is also presented to show strong emission lines.

Fig. 3.— a) Nitrogen-to-oxygen abundance ratio vs. oxygen abundance for the sample of low metallicity blue compact galaxies (open circles) from Thuan, Izotov & Lipovetsky (1995) and Izotov, Thuan & Lipovetsky (1996). The location of SBS 0335–052 is shown with filled circle. The most left point is for I Zw 18. Note the low spread of points and absence of an apparent trend in the N/O vs. O/H diagram, implying that nitrogen is a primary element produced by massive stars. b) Location of SBS 0335–052 in the diagram of neon-to-oxygen abundance ratio vs. oxygen abundance (filled circle). For comparison, the data for the sample of low-metallicity BCGs (open circles) from Thuan, Izotov & Lipovetsky (1995) and Izotov, Thuan & Lipovetsky (1996) are shown. c) Location of SBS 0335–052 in the diagram sulfur-to-oxygen abundance ratio vs. oxygen abundance (filled circle). For comparison, the data for the sample of low-metallicity BCGs (open circles) from Thuan, Izotov & Lipovetsky (1995) and Izotov, Thuan & Lipovetsky (1996) are shown. d) Location of SBS 0335–052 in the diagram argon-to-oxygen abundance ratio vs. oxygen abundance (filled circle). For comparison, the data for the sample of low-metallicity BCGs (open circles) from Thuan, Izotov & Lipovetsky (1995) and Izotov, Thuan & Lipovetsky (1996) are shown.

Fig. 4.— Location of SBS 0335–052 (filled circle) on the diagram of oxygen-to-iron abundance ratio vs. iron abundance. Here $[X]\equiv \log X - \log X_\odot$. For comparison, we also shown the data for low-metallicity BCGs (Thuan, Izotov & Lipovetsky 1995, Izotov, Thuan & Lipovetsky 1996; open circles), for disk and halo stars (points) from Edvardsson et al. (1993), Barbuy (1988) and Barbuy & Erdelyi-Mendes (1989). Solid line is the [O/Fe] vs. [Fe/H] predicted by the chemical evolution model for the Galaxy, dashed lines – chemical evolution model predictions with iron yields two times larger and lower than that for the solid line (Timmes et al. 1995). While there is excellent agreement between the BCG data and that for galactic halo stars, SBS 0335–052 is a significantly deviant point with [O/Fe] which is close to solar value.

Fig. 5.— a) Distribution along the slit in NW–SE direction of $\lambda 4363$ (solid line), $\lambda 5007$ (dashed line) and HeII $\lambda 4686$ (dot-dashed line) line intensities as well as extinction coefficient $C(H\beta)$. The intensity of $\lambda 5007$ emission line is reduced by a factor of 10. Zero-point is chosen at the maximum in continuum flux distribution along the slit. NW direction is to the left, $1'' = 261$ pc. Note that $\lambda 4363$ emission line is observed in region with diameter greater 3 kpc, and allows us to measure the electron temperature along the slit. The maximum in HeII $\lambda 4686$ relative intensity distribution is shifted to NW. We note significant extinction in the brightest part of the galaxy, which coincides with dust lanes detected by Thuan, Izotov & Lipovetsky (1996).
on V and I HST images. b) Electron temperature, $T_e$, (solid line) and oxygen abundance, $12 + \log(O/H)$, (dashed line) distributions in the HII region of SBS 0335–052. For comparison, the oxygen abundance distribution in I Zw 18 (Martin 1996) is shown by a dotted line. Note that both electron temperature and oxygen abundance in SBS 0335–052 are nearly constant across more than 3 kpc suggesting effective mixing inside the HII region during short time scale $\leq 10^7$ yr. While the oxygen abundance in SBS 0335–052 and I Zw 1 is the same, the spatial extent of HII region in SBS 0335–052 is several times greater due to a more powerful burst of star formation.

Fig. 6.— Spatial distribution along NW–SE direction of continuum and emission line intensities, normalized to the unity. While the continuum and HeII $\lambda 4686$ profiles coincide, profiles of other emission lines are shifted in SE direction and coincide with the youngest stellar cluster detected by Melnick, Heydari-Malayeri & Leisy (1992) and Thuan, Izotov & Lipovetsky (1996). Difference in spatial distribution of HeII $\lambda 4686$ and other emission lines implies that ionization of He$^+$ by hard photons with $\lambda \leq 228$ Å is not caused by main-sequence O-stars.

Fig. 7.— a). Spatial radial velocity distribution for strongest emission lines in SBS 0335–052 in NW–SE direction. For comparison, the spatial wavelength distribution for night sky emission line [OI]$\lambda 5577$ is shown; this line does not show significant variations of this line along the slit. We do not detect a significant gradient in velocity distribution except for a slight increase of velocity by 50 km s$^{-1}$ in outer parts of HII region. b). Distribution of full width at half maximum (FWHM) for strongest emission lines in SBS 0335–052. For the H$\beta$ $\lambda 4861$ emission line width, the error bars are also shown. The FWHM for night sky [OI]$\lambda 5577$ emission line is shown for comparison. Note that the H$\beta$ $\lambda 4861$ line is narrower than other lines and could be subjected to underlying stellar absorption from A stars. The gradient in H$\beta$ $\lambda 4861$ and [OIII]$\lambda 5007$ emission line width could be explained by turbulent velocity increasing in NW direction.

Fig. 8.— Fragment of the SBS 0335–052 spectrum showing the presence of low-intensity broad component of H$\beta$ $\lambda 4861$ emission line with FWZI $\sim 50$ Å. Note that HeII $\lambda 4686$ emission line is narrow implying its nebular origin.
Table 1: Emission line intensities.

| Ion               | $F(\lambda)/F(H\beta)$  | $I(\lambda)/I(H\beta)$ | Ion               | $F(\lambda)/F(H\beta)$  | $I(\lambda)/I(H\beta)$ |
|-------------------|---------------------------|--------------------------|-------------------|---------------------------|--------------------------|
| 3727 [O II]       | 0.195±0.003               | 0.233±0.004              | 4713 [Ar IV] + He I | 0.017±0.002               | 0.017±0.002              |
| 3750 H12          | 0.021±0.002               | 0.038±0.005              | 4740 [Ar IV]       | 0.009±0.001               | 0.009±0.001              |
| 3771 H11          | 0.026±0.002               | 0.044±0.005              | 4861 H\beta        | 1.000±0.006               | 1.000±0.006              |
| 3798 H10          | 0.041±0.002               | 0.062±0.005              | 4959 [O III]       | 1.076±0.006               | 1.054±0.006              |
| 3835 H9           | 0.056±0.003               | 0.079±0.005              | 5007 [O III]       | 3.245±0.015               | 3.155±0.014              |
| 3868 [Ne III]     | 0.205±0.003               | 0.239±0.004              | 5876 He I          | 0.115±0.002               | 0.100±0.002              |
| 3889 He I + H8    | 0.136±0.003               | 0.172±0.004              | 6300 [O I]         | 0.008±0.001               | 0.007±0.001              |
| 3968 [Ne III]+H7  | 0.189±0.003               | 0.230±0.004              | 6312 [S III]       | 0.007±0.001               | 0.006±0.001              |
| 4026 He I         | 0.012±0.002               | 0.013±0.002              | 6563 H\alpha       | 3.383±0.015               | 2.745±0.013              |
| 4101 H\delta     | 0.217±0.003               | 0.255±0.004              | 6584 [N II]        | 0.009±0.002               | 0.007±0.001              |
| 4340 H\gamma     | 0.433±0.003               | 0.476±0.004              | 6678 He I          | 0.033±0.001               | 0.027±0.001              |
| 4363 [O III]      | 0.102±0.002               | 0.109±0.002              | 6717 [S II]        | 0.024±0.001               | 0.019±0.001              |
| 4471 He I         | 0.033±0.002               | 0.035±0.002              | 6731 [S II]        | 0.021±0.002               | 0.017±0.001              |
| 4658 [Fe III]     | 0.003±0.001               | 0.003±0.001              | 7065 He I          | 0.051±0.001               | 0.039±0.001              |
| 4686 He II        | 0.028±0.002               | 0.028±0.002              | 7136 [Ar III]      | 0.019±0.001               | 0.014±0.001              |

C(H\beta) dex .................. 0.27
$F(H\beta)^{a}$ ................. 6.06
$EW(H\beta)$ Å .................. 178
$EW(abs)$ Å .................... 1.4

$^{a}$in units of $10^{-14}$ ergs s$^{-1}$cm$^{-2}$
Table 2: Ionic and total heavy element abundances.

| Property | Value       |
|----------|-------------|
| \(T_e (\text{OIII}) \text{ (K)}\) | 19,200 ± 200 |
| \(T_e (\text{OII}) \text{ (K)}\) | 15,400 ± 200 |
| \(T_e (\text{SIII}) \text{ (K)}\) | 17,700 ± 200 |
| \(N_e (\text{SII}) \text{ (cm}^{-3}\text{)}\) | 390 ± 10 |
| \(\text{O}^+ / \text{H}^+ \times 10^5\) | 0.19 ± 0.01 |
| \(\text{O}^{++} / \text{H}^+ \times 10^5\) | 1.96 ± 0.05 |
| \(\text{O}/\text{H} \times 10^5\) | 2.16 ± 0.05 |
| 12+log(\text{O}/\text{H}) | 7.33 ± 0.01 |
| \(\text{N}^+ / \text{H}^+ \times 10^7\) | 0.49 ± 0.02 |
| ICF(N) | 11.17 ± 0.08 |
| log(N/O) | −1.59 ± 0.03 |
| \(\text{Ne}^{++} / \text{H}^+ \times 10^6\) | 3.04 ± 0.10 |
| ICF(Ne) | 1.10 ± 0.01 |
| log(Ne/O) | −0.81 ± 0.02 |
| \(\text{S}^+ / \text{H}^+ \times 10^7\) | 0.37 ± 0.02 |
| \(\text{S}^{++} / \text{H}^+ \times 10^7\) | 1.92 ± 0.28 |
| ICF(S) | 2.65 ± 0.02 |
| log(S/O) | −1.56 ± 0.03 |
| \(\text{Ar}^{++} / \text{H}^+ \times 10^7\) | 0.40 ± 0.02 |
| \(\text{Ar}^{+++} / \text{H}^+ \times 10^7\) | 0.77 ± 0.11 |
| ICF(Ar) | 1.01 ± 0.01 |
| log(Ar/O) | −2.26 ± 0.04 |
| \(\text{Fe}^{++} / \text{H}^+ \times 10^7\) | 0.58 ± 0.20 |
| ICF(Fe) | 13.96 ± 0.10 |
| log(Fe/O) | −1.43 ± 0.04 |
| Property                        | Value       |
|--------------------------------|-------------|
| $N_e$(HeII) (cm$^{-3}$)        | 152         |
| $\tau$(HeI $\lambda$3889)    | 1.5         |
| $(1+\gamma)(3889)$            | 0.956±0.002 |
| $(1+\gamma)(4471)$            | 1.052±0.001 |
| $(1+\gamma)(5876)$            | 1.082±0.002 |
| $(1+\gamma)(6678)$            | 1.022±0.001 |
| $(1+\gamma)(7065)$            | 1.831±0.005 |
| $y^+(4471)$                   | 0.072±0.004 |
| $y^+(5876)$                   | 0.079±0.001 |
| $y^+(6678)$                   | 0.079±0.003 |
| $y^+(\text{mean})$            | 0.078±0.001 |
| $y^{++}$                      | 0.003±0.001 |
| $\eta'$                       | 0.539       |
| ICF(He)                       | 1.003±0.020 |
| $y$                            | 0.081±0.002 |
| $Y$                            | 0.245±0.006 |

Table 3: Helium abundance.
Table 4: Observed and theoretical colors for extended underlying component.

| Color | Observations | Pure gaseous emission | Instantaneous burst<sup>a</sup> |
|-------|--------------|-----------------------|-----------------------------|
|       |              | I<sup>b</sup> | II<sup>c</sup> | III<sup>d</sup> | log t = 6.5 | log t = 8.0 |
| U–B   | ...          | –1.3   | –1.1   | –0.9   | –1.3 | 0.0 |
| B–V   | ...          | 0.4    | 0.5    | 0.5    | –0.1 | 0.4 |
| R–I   | –0.5±0.0<sup>e</sup> | 0.2    | –0.1   | –0.4   | 0.0  | 0.3 |
| V–I   | 0.0±0.2<sup>f</sup> | 0.5    | 0.2    | –0.1   | –0.1 | 0.7 |

<sup>a</sup>Leitherer & Heckman 1995.
<sup>b</sup>Colors for gaseous continuum at $T_e=20000$K.
<sup>c</sup>Colors for gaseous emission with EW(H$\beta$)=170Å and I([OIII]λ4959)/I(H$\beta$) = 0.6.
<sup>d</sup>Colors for gaseous emission with EW(H$\beta$)=350Å and I([OIII]λ4959)/I(H$\beta$) = 0.6.
<sup>e</sup>Lipovetsky et al. 1996.
<sup>f</sup>Thuan, Izotov & Lipovetsky 1996.
