YOUNG DWARF GALAXIES AND COSMOLOGY

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Abstract

We develop here the theme that extremely metal-deficient Blue Compact Dwarf Galaxies (BCDs), those with $Z \leq Z_\odot/20$, are young galaxies which did not start to form stars until $\sim 100$ Myr ago. They can be thus considered as primeval galaxies in our local volume of the universe, and are excellent laboratories for studying physical processes occurring at the time of galaxy formation in very metal-deficient environments. We use BCDs to derive a new value of the primordial helium abundance $Y_p = 0.244 \pm 0.001$, higher than previous determinations. This corresponds to a baryon mass fraction $\Omega_b h^2_{50} = 0.058 \pm 0.007$. We discuss the problem of dust in a very low-metallicity environment and show how a large fraction ($\sim 75\%$) of the young stars are not visible, and that any derivation of the cosmic star formation rate based only on optical/UV fluxes would be an underestimate. We also show how the loss of Ly$\alpha$ photons from starburst regions puts strong constraints on Ly$\alpha$ searches of high-redshift galaxies.

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; Charlot & Fall 1993). Yet, despite intensive searches, the predicted widespread population of Ly$\alpha$ primeval galaxies has remained elusive (Pritchett 1994).

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. However, most of these candidate PGs already contain a substantial amount of heavy elements, as evidenced by the presence of strong P Cygni profiles and interstellar absorption in their spectra (Steidel et al. 1996; Yee et al. 1996). These spectra are very similar to those of nearby starburst galaxies known to contain old stellar populations (Leitherer et al. 1996). Thus high-redshift galaxies discovered thus far are not truly primeval. Moreover, even if true PGs are discovered at high-redshift, it is difficult to study them in detail because of their extreme faintness and very compact angular
size. We propose here to 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 low-luminosity 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 neutral gas supply of $\sim 10^8 M_\odot$; 2) Optical-infrared colors of BCDs give burst 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 ($\geq 95\%$) 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 (Papaderos et al. 1996, Telles & Terlevich 1997). Thus, most BCDs are not necessarily young galaxies. However, there was a hint that extremely metal-deficient BCDs do not contain an old stellar population and can be primordial. Hubble Space Telescope (HST) imaging of I Zw 18, the most metal-deficient BCD known ($Z/50$, Searle & Sargent 1972), to $V \sim 26$ by Hunter & Thronson (1995) suggests that the stellar population is dominated by young stars and 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 $\sim Z/3$ to $\sim Z/50$, peaking at $\sim Z/10$, and dropping off sharply for $Z \leq Z/10$. Intensive searches have been carried out to look for low-metallicity BCDs but they have met until recently with limited success. Several years ago, a new BCD sample has been assembled by Izotov et al. (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). The most interesting feature of the SBS is its metallicity distribution (Izotov et al. 1992, Thuan et al. 1994): it contains significantly more low-metallicity BCDs than previous surveys. It has uncovered about a dozen BCDs with $Z \leq Z/15$, 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.

In section 2, we use the low-metallicity SBS sample together with other metal-deficient BCDs to study heavy element abundance ratios in very low-metallicity environments and to argue that all galaxies with a metallicity less than about 1/20 of solar metallicity are young, i.e. they did not start to form stars until about 100 Myr ago. In that sense very metal-deficient local BCDs are truly PGs, and their study can shed light on galaxy formation at high
redshift. Because metal-deficient BCDs are young, they constitute excellent laboratories for determining the primordial Helium abundance. We use a large sample of low-metallicity BCDs in section 3 to derive a new value of the primordial helium abundance which is appreciably higher than the previously accepted value, and a baryonic mass density more in agreement with other observations. We discuss next in detail two BCDs with \( Z \leq Z_{\odot}/20 \), SBS 0335–052 (section 4) and SBS 1415+437 (section 5). We show that photometric and spectroscopic data on these two galaxies also point to a young age for the two BCDs, of less than 100 Myr. In the concluding sections we show how BCDs can shed light on cosmological issues such as dust in a very low-metallicity environment (section 6), and the escape of Ly\( \alpha \) photons from starburst galaxies (section 7).

\section{Galaxies with \( Z \leq Z_{\odot}/20 \) are younger than 100 Myr}

2.1 \( \alpha \)-elements

The study of the variations of one chemical element relative to another is crucial for our understanding of the chemical evolution of galaxies and for constraining models of stellar nucleosynthesis and the shape of the initial mass function. In the case of BCDs, it is particularly important for understanding their evolutionary status, whether they are young or old. Izotov & Thuan (1999) have obtained very high-quality ground-based spectroscopic observations of 54 supergiant H II regions in 50 low-metallicity blue compact galaxies with oxygen abundances \( 12 + \log O/H \) between 7.1 and 8.3 \((Z_{\odot}/50 \leq Z \leq Z_{\odot}/4)\). They use the data to determine abundances for the elements N, O, Ne, S, Ar and Fe. They also analyze Hubble Space Telescope (HST) Faint Object Spectrograph archival spectra of 10 supergiant H II regions to derive C and Si abundances in a subsample of 7 BCDs. The best studied and most easily observed element in BCDs is oxygen. Nucleosynthesis theory predicts it to be produced only by high-mass \((M > 9 \ M_{\odot})\) stars. We shall use it as the reference chemical element and consider the behavior of heavy element abundance ratios as a function of oxygen abundance. Figures 1 d,e,f,g show the dependence of the abundance ratios Ne/O, Si/O, S/O and Ar/O on oxygen abundance. The elements neon, silicon, sulfur and argon are all products of \( \alpha \)-processes during both hydrostatic and explosive nucleosynthesis in the same massive stars which make oxygen. Therefore, the Ne/O, Si/O, S/O and Ar/O ratios should be constant and show no dependence on the oxygen abundance. As predicted by stellar nucleosynthesis theory, none of the above heavy element-to-oxygen abundance ratios depend on oxygen abundance. The mean values of these element abundance ratios are directly related to the stellar yields and thus provide strong constraints on the theory of massive stellar nucleosynthesis (Thuan et al. 1995, Izotov & Thuan 1999).

2.2 Iron, Carbon and Nitrogen

Because O, Ne, Si, S and Ar are made in the same high-mass stars, their abundance ratios with respect to O are constant and not sensitive to the age of the galaxy. By contrast, C, N and Fe can be produced by both high and intermediate-mass \((3 \ M_{\odot} \leq M \leq 9 \ M_{\odot})\) stars, and their abundance ratios with respect to O give important information on the evolutionary status of BCDs. The constancy of [O/Fe] for the BCDs and its high value compared to the Sun (Fig.1 c) suggests that all iron was produced by massive stars, i.e. in SNe II only. Since the time delay between iron production from SNe II and SNe Ia is about 1 – 2 Gyr, it is likely that BCDs with oxygen abundance less than \( 12 + \log O/H \sim 8.2 \) \((Z_{\odot}/5)\) are younger than 1 – 2 Gyr.
Figure 1: Left panel: C/O, N/O and Fe/O abundance ratios vs oxygen abundance for the sample of low-metallicity BCDs from Izotov & Thuan (1999). Solid lines for C/O are theoretical predictions from high-mass stars (HMS) evolution (Woosley & Weaver 1995); the dashed line shows the ratio predicted from the evolution of HMS and intermediate-mass stars (IMS) (Renzini & Voli 1981). The solid line for N/O is the mean observed ratio adopted as the primary nitrogen-to-oxygen abundance ratio produced by massive stars. Right panel: Ne/O, Si/O, S/O and Ar/O abundance ratios vs oxygen abundance for the same sample of BCDs. Solid lines are ratios predicted from HMS evolution.

The behavior of the C/O and N/O ratios as a function of oxygen abundance (Fig.1 a,b) puts more stringent constraints on the age of BCDs (Thuan et al. 1995, Izotov & Thuan 1999). The behavior of the C/O and N/O ratios is very different whether the BCG has 12 + log O/H smaller or greater than 7.6 (Z⊙/20). The remarkably small scatter of the C/O and N/O abundance ratios in BCDs with Z ≤ Z⊙/20 rules out any time-delay model in which O is produced first by massive stars and C and N are produced later by intermediate-mass stars, and supports a common origin of C, N and O in the same first-generation massive stars. Thus, it is very likely that the presently observed episode of star formation in BCDs with Z ≤ Z⊙/20 is the first one in the history of the galaxy and the age of the oldest stars in it do not exceed ∼ 40 Myr, the lifetime of a 9 M⊙ star. The conclusion that BCGs with Z ≤ Z⊙/20 are young is supported by the analysis of HST WFPC2 images of some of these galaxies: I Zw 18 (Z⊙/50, Hunter & Thronson 1995), SBS 0335–052 (Z⊙/41, Thuan et al. 1997, see section 4), SBS 1415+437 (Z⊙/21, Thuan et al. 1999, see section 5), T1214–277 and Tol 65 (respectively Z⊙/21 and Z⊙/22, Izotov et al. 1999).

The situation changes for BCDs with Z > Z⊙/20. The scatter of the C/O and N/O ratios increases significantly at a given O abundance, which was interpreted by Thuan et al. (1995) and Izotov & Thuan (1999) as due to the additional production of primary N by intermediate-mass stars, on top of the primary N production by high-mass stars. Thus, since it takes at least 500 Myr (the lifetime of a 2–3 M⊙ star) for C and N to be produced by intermediate-mass stars, BCDs with Z > Z⊙/20 must have had several episodes of star formation before the present
one and they must be at least older than $\sim 100$ Myr. This conclusion is in agreement with photometric studies of these higher metallicity BCDs which, unlike their very low-metallicity counterparts, have a red old instead of a blue young underlying stellar component (Loose & Thuan 1985, Papaderos et al. 1996).

3 The primordial helium abundance

We use the data of Izotov et al. (1994, 1997a) and Izotov & Thuan (1998b) to construct a sample of 45 HII regions appropriate for the determination of $Y_p$. Our sample constitutes one of the largest and most homogeneous (obtained, reduced and analyzed in the same way) data set now available for the determination of $Y_p$. This is the same data as used to analyze heavy element abundances in section 2. Linear regressions of the $Y$ – O/H and $Y$ – N/H relations, with $Y$'s determined from a self-consistent treatment of the five brightest optical He I emission lines, gives $Y_p = 0.244 \pm 0.001$ (Figures 2 a,b, Izotov & Thuan 1998b). This value agrees very well with the mean $Y$ of the two most metal-deficient BCDs known [I Zw 18 ($Y_p = 0.242 \pm 0.009$, Izotov & Thuan 1998a) and SBS 0335–052 ($Y_p = 0.249 \pm 0.004$, Izotov & Thuan 1998b)], which is $\bar{Y} = 0.245 \pm 0.006$. Values as low as $Y_p = 0.234$ or $Y_p = 0.230$, as those obtained by Pagel et al. (1992) and Olive et al. (1997) are excluded. Part of the difference comes from the fact that previous workers have neglected underlying He I stellar absorption which would artificially lower $Y_p$ (Izotov & Thuan 1988a).

Our higher primordial helium mass fraction is consistent with deuterium abundance measurements in high-redshift Ly$\alpha$ absorbing systems by Tytler et al. (1996) as corrected by turbulence effects in the clouds by Levshakov et al. (1998), and lithium abundance measurements in low-metallicity halo stars (Bonifacio & Molaro 1997). Figure 2c gives a baryon-to-photon ratio $\eta = 4.0 \pm 0.5$, which corresponds to a baryon mass fraction $\Omega_b h^2_{50} = 0.058 \pm 0.007$, in good agreement with the value derived from X-ray observations of clusters of galaxies (White & Fabian 1995). We derive a slope $dY/dZ = 2.3 \pm 1.0$, considerably smaller than those derived before. With this smaller slope and taking into account the errors, chemical evolution models with an outflow of well-mixed material can be built for star-forming dwarf galaxies which satisfy all the observational constraints.

4 The young dwarf galaxy SBS 0335–052

4.1 Age of the stellar component

This BCD with $Z = Z_\odot/41$ is the second most metal-deficient galaxy known (after I Zw 18). HST WFPC2 images of the BCD show that most of the star formation in SBS 0335–052 ($M_B = -16.7$, $v = 4076$ km s$^{-1}$) occurs in 6 super-star clusters (SSCs) with $-14.1 \leq M_V \leq -11.9$, within a region $\sim 520$ pc in size (Figure 3, Thuan et al. 1997). Later processing by Papaderos et al. (1998) of the same HST images reveals several fainter clusters (not SSCs). The SSCs are roughly aligned in the SE-NW direction, and there is a systematic reddening of the $V$ – $I$ color of the SSCs away from the brightest one, with a flattening of the color of the clusters beyond 520 pc (Figure 4).

Thuan et al. (1997) and Papaderos et al. (1998) attribute most of the color variation of the SSCs to an age variation resulting from sequential propagating star formation. The $V$ – $I$ colors are consistent with the picture that star formation started at the location of the most distant cluster, some 1.8 kpc away from the location of the brightest and bluest cluster at the
Figure 2: **Left panel:** Linear regressions of (a) the helium mass fraction $Y$ vs. oxygen abundance $O/H$ and (b) the helium mass fraction $Y$ vs. nitrogen abundance for our sample of 45 H II regions (Izotov & Thuan 1998b). The $Y$s are derived self-consistently by using the 5 brightest He I emission lines in the optical range. Collisional and fluorescent enhancements, underlying He I stellar absorption and Galactic Na I interstellar absorption are taken into account. 1σ alternatives are shown by dashed lines. **Right panel:** The abundances of a) $^{4}$He; b) D and c) $^{7}$Li as a function of $\eta_{10} \equiv 10^{10} \eta$, where $\eta$ is the baryon-to-photon number ratio, as given by the standard hot big bang nucleosynthesis model.

South East end of the galaxy, at about 100 Myr ago and propagated through the ISM to the latter, whose age is only $\sim$ 4 Myr, with an average speed of $\sim$ 18 km s$^{-1}$ (Thuan et al. 1997, Papaderos et al. 1998). Thus the star-forming clusters have ages between 4 and 100 Myr. Does SBS 0335–052 possess an underlying older stellar population? The extended underlying component is shown in figure 5 where the contrast has been adjusted to display very low surface-brightness features. The unusually blue colors of this underlying component (see the $U - B$ color profile labeled E in Figure 6) and its irregular, blotchy and filamentary structure suggest that a significant fraction of the light is of gaseous rather than stellar origin. A supershell of 380 pc radius can be seen delineating a large supernova cavity. However Izotov et al. (1997) found that the $H\beta$ equivalent width in the underlying component is $\sim$ 3 times lower than the value expected for pure gaseous emission, implying that two-thirds of the light comes from an underlying stellar population. Papaderos et al. (1998) have modeled the $UBVRI$ colors of this stellar component, after removal of the ionized gas contamination. They found that the colors are consistent with an underlying stellar population not older than 100 Myr.

### 4.2 Age of the neutral component

Thus the stellar component in SBS 0335–052 is extremely young and the BCD is likely undergoing star formation for the first time. If this is the case, the neutral gas envelope surrounding the BCD must also be very metal-deficient. A 21 cm VLA map of the BCD (Pustilnik et al.
Fig. 3 (left): *HST* WFPC2 $V$ image of SBS 0335–052 showing the high surface brightness super-star clusters. At a distance of 54.3 Mpc, 1 arcsec corresponds to a linear size of 263 pc.

Fig. 4 (right): $(V - I)$ color vs. distance from the brightest super-star cluster at the SE tip of SBS 0335–052. The color gets redder with increasing distance.

1999) has shown it to be embedded in an extraordinarily large HI cloud seen nearly edge-on, with dimensions some 64 by 24 kpc. This is to be compared with the typical size of HI envelopes around BCDs which is more like a few kiloparsecs in each dimension. We can use the BCD as a background light source shining through the HI envelope to probe the physical conditions of the neutral gas. The Ly$\alpha$ line seen in absorption would give the column density of atomic hydrogen, while the OI $\lambda$1302 line would give the column density of the most abundant heavy element that remains neutral in the HI cloud. This would allow us to set limits on the O/H abundance ratio in the neutral gas. Figure 7 shows the ultraviolet spectrum of SBS 0335–052 around the Ly$\alpha$ line obtained by Thuan & Izotov (1997) with the Goddard High Resolution Spectrograph aboard the *Hubble Space Telescope* (*HST*). A strong damped Ly$\alpha$ absorption line is seen along with several heavy element interstellar absorption lines such as OI $\lambda$1302, SiII $\lambda$1304 and SII $\lambda$1251, $\lambda$1254, and $\lambda$1259. The HI column derived by fitting the Ly$\alpha$ absorption profile is $N$(HI) = $(7.0\pm0.5)\times10^{21}$ cm$^{-2}$, the highest derived thus far for a BCD, and $\sim$2 times larger than in I Zw 18 (Kunth et al. 1994). Comparison with high-resolution quasar spectra implies that the O I $\lambda$1302 line along with other heavy element interstellar absorption lines such as Si II $\lambda$1304 and S II $\lambda$1251, $\lambda$1254, $\lambda$1259 are not saturated, which allow us to derive abundances. Assuming that these lines originate in the H I gas, we derive extremely low abundances of oxygen, silicon and sulfur, respectively 37000, 4000 and 116 times lower than the solar values. The oxygen abundance is a whole 37 times lower than in the neutral gas of I Zw 18. However, these highly discrepant deficiency factors between different elements suggest that the absorption lines are produced, not in the H I, but in the H II gas. Adopting that hypothesis, the derived abundance from the UV absorption lines are then consistent with that derived from the optical emission lines ($Z \sim Z_\odot/41$). The conclusion that the heavy element absorption lines originate in the H II region is supported by the detection of several systems of blueshifted S II $\lambda$1259, Si II $\lambda$1260, O I $\lambda$1302, Si II $\lambda$1304, C II $\lambda$1335 absorption lines originating in fast-moving clouds with velocities up to $\sim$1500 km s$^{-1}$, and also by the presence of heavy element absorption lines with excited lower levels. If this conclusion holds, then the
Fig. 5 (left): Same V image as in Fig. 3, with the contrast adjusted to show the low surface brightness underlying component of SBS 0335–052. The supershell delineating the large supernova cavity is clearly seen.

Fig. 6 (right): (U – B) color profile (labeled E) of SBS 0335–052. The color is very blue and the profile flat.

H I cloud in SBS 0335–052 is truly primordial, unpolluted by heavy elements (Thuan & Izotov 1997). In summary, all the known observational evidence suggests that SBS 0335–052 is truly a young galaxy.

5 Another young dwarf galaxy: SBS 1415+437

5.1 Age from color-magnitude diagrams

Figure 8 shows the HST WFPC2 I image of SBS 1415+437 ($M_B = -14.0$, $v = 607$ km s$^{-1}$) with the contrast level adjusted so as to show the low surface-brightness underlying extended component (Thuan et al. 1999). The galaxy has an elongated, comet-like shape with a bright H II region on its SW tip. Many point sources identified as luminous stars can be seen. To the SW of the brightest H II region, two stellar clusters with resolved stars are present. The luminous stars and the HII regions are aligned suggesting, just as in SBS 0335–052, propagating star formation (from the NE to the SW). The mode of star formation in the two BCDs is different however. While SBS 0335–052 makes stars in luminous super-star clusters, star-formation in SBS 1415+437 appears to be less extreme and is more similar to that in I Zw 18 (Hunter & Thronson 1995). The superior spatial resolution of the HST allows to resolve individual stars and construct color-magnitude diagrams to study the stellar populations in the BCD. To check the hypothesis of propagating star formation, we have derived stellar ages for 6 separate regions in the BCD, labeled from I to VI as shown in Figure 8.

The $(V – I)$ vs. $I$ color-magnitude diagram (CMD) for each region are shown in Figure 9 together with stellar isochrones by Bertelli et al. (1994) for a heavy element abundance equal to 1/20 the solar value. Each isochrone is marked by the logarithm of the age in years. The region of the asymptotic giant branch (AGB) stars is shown by a dashed line while the observational
limits are shown by dotted lines. We adopt $V = 27.5$ mag and $I = 27$ mag as completeness limits. Although there is evidence for spatial variations of the internal dust extinction, as a first approximation, we correct the CMDs for regions III – VI by a constant extinction as derived by the Balmer decrement. The CMDs for regions I and II have been not corrected for extinction for lack of information.

Inspection of Figure 9 shows that there is a clear age gradient from region I to region VI. Region I is the youngest (about 5 Myr), containing only main-sequence stars. Region II is more evolved. It contains red supergiants and has an age of $\geq 10$ Myr. Region III includes the brightest H II region and shows a mixture of stellar populations. The bulk of the stars in region III have ages ranging between $\leq 10$ Myr and 100 Myr. The red stars with $(V - I)$ between 1.0 and 1.8 are likely to be red supergiants rather than AGB stars. The stellar populations in regions IV - VI are similar to those in region III except for the fact that very young populations with age less 10 Myr are no more present. We emphasize that the properties of the stellar populations in SBS 1415+437 are quite different from those in other nearby low-metallicity dwarf galaxies with HST color-magnitude diagrams. In those dwarfs, very red AGB stars are present indicating a larger age (e.g. Dohm-Palmer et al. 1997; Schulte-Ladbeck et al. 1998).

Two general conclusions can be obtained from the above color-magnitude analysis: 1) star formation in SBS 1415+437 is propagating from the NE to the SW; 2) there is no evidence for stars older than $\sim 100$ Myr in the BCD.

### 5.2 Age from spectral evolutionary synthesis models

The second conclusion is supported by evolutionary synthesis modeling of the spectrophotometric data of regions III to VI. To estimate quantitatively the age of each region, we calculate a grid of spectral energy distributions (SED) for stellar populations with ages varying between
Fig. 9 (left): Color-magnitude diagrams of stellar populations in the different regions of SBS 1415+437 as defined in Fig. 8. There is a systematic age increase from region I to region VI, implying propagating star formation from the NE to the SW. Typical photometric errors are shown in Fig. 9a.

Fig. 10 (right): MMT spectrum of region V (see Fig. 7) of SBS 1415+437. The upper panel shows the spectrum uncorrected for extinction, while the lower panel shows the same spectrum corrected for extinction. The best-fit model gives an age between 30 and 100 Myr.

10 Myr and 20 Gyr and heavy element abundance $Z_{\odot}/20$, using isochrones from Bertelli et al. (1994) and the compilation of stellar atmosphere models from Lejeune et al. (1998). A Salpeter IMF with slope $-2.35$, an upper mass limit of 120 $M_{\odot}$ and a lower mass limit of 0.6 $M_{\odot}$ were adopted. For stellar populations with age less than 10 Myr we use theoretical spectral energy distributions by Schaerer & Vacca (1998) for a heavy element abundance $Z_{\odot}/20$ and a Salpeter IMF. The stellar emission in SBS 1415+437 is contaminated by emission of ionized gas from supergiant H II regions. Therefore, to study the stellar composition in the BCD, it is necessary to produce a synthetic SED which includes both stellar and ionized gaseous emission. It is clear from Figure 10, the best fit to the spectrum corrected for extinction (lower panel) gives an age between 30 and 100 Myr for region V (the models are labelled by the logarithm of the age in years). A similar analysis for the other regions give the same answer: none contains stellar populations older than 100 Myr. Thus SBS 1415+437, just like SBS 0335–052, is also a young galaxy.

6 Dust in an extremely metal-deficient environment

SBS 0335–052, although it is extremely metal-deficient, clearly contains dust. It is seen as white patches in the $V - I$ color map of the BCD (Figure 11), and is spatially mixed with the SSCs. Thuan et al. (1999) have obtained ISO mid-infrared observations of the BCD. With $L_{12\mu m}/L_B$ of 2.15, the galaxy is unexpectedly bright in the mid-infrared for such a low-metallicity object.
**Fig. 11 (left):** \((V - I)\) color map of SBS 0335–052. Blue is dark, red is light. The dust patches on top of the super-star clusters are clearly seen.

**Fig. 12 (right):** The best-fit model (thick continuous line) for the mid-infrared spectral energy distribution of SBS 0335–052 obtained by ISO (Thuan et al. 1999). It is composed of a 260 K blackbody spectrum modified by an emissivity law proportional to \(\nu^{1.5}\) and extinguished by a screen of dust of optical thickness \(A_V = 21\) mag, with an extinction curve similar to that observed toward the Galactic center (Lutz et al. 1996).

The mid-infrared spectrum (Figure 12) is very unusual when compared to spectra of other star-forming galaxies: 1) there is no emission from the so-called Unidentified Infrared Bands, which we interpret as an effect of destruction of carbon-based dust by the very high UV energy density in SBS 0335–052; and 2) there are no evident fine structure ionic lines, even though neon and sulfur lines are usually quite bright in starburst galaxies. The absence of these lines can be explained by a very strong continuum which decreases the equivalent widths of the lines, making them difficult to detect. The spectral energy distribution from 5 to 17 microns can be fitted with a grey-body spectrum modified by extinction. Silicate grains can account for the unusual shape of the MIR spectrum. The required extinction law is similar to that observed toward the Galactic Center and the optical depth is \(A_V \sim 19-21\) mag. Such a large optical depth implies that a large fraction (as much as 75%) of the current star-formation activity in SBS 0335–052 is hidden by silicate dust whose mass is in the range \(3\times10^3 - 5\times10^5\) \(M_\odot\).

Thus nearly primordial environments can contain a significant amount of dust. If the hidden star formation in SBS 0335–052 is typical of young galaxies at high redshifts, then the cosmic star formation rate derived from UV/optical fluxes would be underestimated. This is in fact the result found by Flores et al. (1999) who carried out deep 15 micron ISO surveys of distant galaxies with a median redshift of \(\sim 0.76\). Those authors found that the cosmic SFR derived from FIR luminosities, from 43 to 123 microns, assuming that the FIR luminosity comes mostly from dust heating by young stars, is 2-3 times higher than the SFR estimated previously from optical/UV fluxes (Madau et al. 1996).
7 The escape of Lyα photons

The study of nearby young galaxies can also shed light on a long standing problem concerning the Lyman-alpha emission of primeval galaxies. In any galaxy formation scenario, young galaxies are predicted to show strong Lyα emission (rest frame equivalent width of \(~100\)Å) associated with the formation of a large number of massive ionizing stars (e.g. Charlot & Fall 1993). Yet, despite intensive searches, the predicted population of Lyα primeval galaxies remained elusive (Pritchet 1994). The absence of Lyα emission in high-redshift galaxies is reminiscent of the behavior of Lyα emission in nearby starburst and BCD galaxies, which is either absent or greatly diminished. The Lyα/Hβ line intensity ratio in those galaxies with detected Lyα emission does not exceed 10, significantly lower than the theoretical recombination ratio of 33. Some galaxies show strong Lyα absorption rather than emission. The favored explanation for such a reduction in Lyα emission from recombination values is redistribution of Lyα photons by multiple scattering in the H I envelope or absorption of these Lyα photons by dust in the star-forming region. The latter mechanism would imply increasing Lyα/Hβ line intensity ratios with decreasing metallicities, since presumably low-metallicity objects contain less dust, and hence suffer less destruction of Lyα photons (Terlevich et al. 1993). HST observations of the two most metal-deficient BCDs known, I Zw 18 (Kunth et al. 1994) and SBS 0335–052 (Thuan et al. 1997, section 4), show Lyα not in emission but absorption (Figure 7), which goes against a Lyα strength-metallicity anticorrelation. Lequeux et al. (1995), in their study of the BCD Haro 2 (Z⊙/3) which shows Lyα in emission, have argued that Lyα photons can escape when the neutral material where the absorption occurs is outflowing with a velocity of \(<200\) km s\(^{-1}\) with respect to the star-forming region. The Lyα emission is redshifted with respect to both the H II region and the expanding absorbing shell, the motion of which is probably powered by stellar winds and supernovae. This explanation does not apply to the BCD T1214–277 (Z⊙/23) which is the lowest metallicity galaxy known with detected Lyα emission (Thuan & Izotov 1997). Contrary to Haro 2, Lyα emission is not redshifted with respect to the H II gas velocity. Thus the escape of Lyα photons in T1214–277 is not a consequence of the motions of the neutral H I envelope.

As for SBS 0335–052, dust extinction may play some role as it is directly seen (Figure 11). While there is evidence for fast gas motions in SBS 0335–052 with velocities up to \(~1500\) km s\(^{-1}\), the H I gaseous envelope appears to be static with respect to the H II region, as the 21 cm and emission-line velocities are in good agreement. Thus, with its extremely large H I column density, the redistribution of Lyα photons in SBS 0335–052 by multiple scattering over the large volume of the H I cloud probably plays also an important role in diminishing the intensity of the Lyα line. The orientation of the HI cloud may also play a role. In the case of SBS 0335–052, the HI envelope is reasonably flattened (Pustilnik et al. 1999) suggesting it is seen nearly edge-on. In that case, Lyα photons escape more easily along directions perpendicular to the line of sight than along it. Moreover, as discussed by Giavalisco et al. (1996), the escape of Lyα photons may be controlled not only by the geometry but also by the porosity of the neutral gas.

In summary, there is no unique mechanism which controls the appearance of Lyα emission in nearby young dwarf galaxies. Dust extinction may play a role, but the velocity structure of the H I gas, the orientation of the H I cloud and its porosity may also be important factors. The fact that some BCDs do not show Lyα in emission implies that Lyα searches for high-redshift galaxies will always be incomplete.

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