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Dynamical condition of neutral hydrogen envelopes of dwarf galaxies and their possible morphological evolution

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Abstract. We investigate the star-formation history of gas-rich dwarf galaxies, taking account of the dynamical evolution of their neutral hydrogen (H I) envelope. Gas-rich dwarfs are classified into blue compact dwarfs (BCDs) and dwarf irregulars (dIrrs). In this paper, their H I envelope is clearly shown not to be blown away by their stellar feedback. This is concluded since the observed star-formation rate (SFR) of gas-rich dwarfs is generally smaller than a critical SFR, $\psi_{\rm crit}$, at which stellar feedback accelerates the H I envelope to the escape velocity. From this standpoint and the chemical property of sample BCDs, we suggest two possibilities; (1) the H I gas in the envelope of BCDs is consumed to fuel their star-formation; and (2) BCDs have a similar star-formation history. We also discuss morphological evolution among dwarf galaxies. As long as gas-rich dwarfs are isolated, it is difficult for them to evolve into dwarf ellipticals (dEs). When the H I envelope in gas-rich dwarfs is consumed in subsequent star-formation, a morphological exchange between BCDs and dIrrs is still expected, consistent with previous studies. If the SFR of gas-rich dwarfs was much higher than $\psi_{\rm crit}$ in the past, interestingly, an evolutionary scenario from dEs to gas-rich dwarfs is possible.

Key words. ISM: evolution – ISM: structure – stars: formation – galaxies: dwarf

1. Introduction

For a hierarchical cosmic structure formation scenario, the star-formation history of dwarf galaxies, which are building blocks of the structure, needs to be known. To determine their star-formation history, the effect of stellar feedback (e.g., supernova-driven winds and stellar winds) on the dynamical condition of the interstellar medium (ISM) of dwarf galaxies is essential, since their gravitational potential well is rather shallow (Skillman & Bender 1995 for a review). Thus, the dynamics of the ISM in dwarfs is a central issue for their evolution. In this paper, we study isolated dwarf galaxies to investigate their evolution, and examine the effect of stellar feedback on the star-formation rate (SFR) (Larson 1974; Saito 1979; Dekel & Silk 1986).

Dwarf galaxies whose star-formation is currently observable have sufficient amounts of H I gas, compared to their dynamical mass (e.g. Thuan & Martin 1981). These gas-rich dwarfs are categorized as dwarf irregular galaxies (dIrrs) and blue compact dwarf galaxies (BCDs) by their SFR relative to their size. Since their H I gas mostly surrounds their central star-forming regions (e.g. van Zee et al. 1998), we call it an H I envelope in this paper. Although it is widely believed that the H I envelope is gravitationally bound to host galaxies, the dynamical

evolution of the H I envelope is not completely understood. This is not only because the peaks of the rotation curves in the H I envelopes are not always satisfactorily determined (e.g. Pustilnik et al. 2001), but also because there is no confirmation that the H I gas in the envelope is used for a subsequent star-formation (e.g. Thuan 1985). Therefore, it is useful to investigate the dynamical evolution of the H I envelope from another point of view, that is, in the framework of a star formation history (see also Legrand et al. 2001).

Indeed, it has been suggested that the H I envelope is related to star-formation activity (e.g. Thuan 1985), which results in the morphological exchange among dwarf galaxies (e.g. Kormendy 1985). Concerning the morphological evolution, Thuan (1985) suggested from photometric observations that gas-rich galaxies like BCDs and dIrrs evolve into gas-less galaxies like dwarf ellipticals (dEs). The inverse evolution is also theoretically expected: dEs acquire H I gas from the ambient intergalactic medium (IGM), and evolve into dIrrs and BCDs (Silk et al. 1987). According to Saitō et al. (2000), the morphological exchange between BCDs and dIrrs is also expected, if H I gas in the envelope is channeled into star-forming regions. Contrary to the above suggestion, it is also shown from the difference of their surface brightness (Bothun et al. 1986) and their dynamical (van Zee et al. 2001) properties that gas-rich dwarfs do not easily evolve into dEs. Thus,

it is still premature to judge which model is correct. In this paper, we investigate this unclear star-formation history of gas-rich dwarf galaxies, considering the dynamical condition of the Hi envelope which is affected by stellar feedback.

This paper is organized as follows: in the next section, we construct a dynamical model of the Hi envelope from a momentum conservation law. The observational data are compared with the model in Sect. 3. The implications for the morphological evolution of dwarfs are given in Sect. 4. In the last section, we summarize our conclusions and comment on Legrand et al. (2001), whose conclusions are very similar to and consistent with those in this paper.

2. Model description

In this paper, we try to connect the dynamical condition of the Hi envelope and star-formation history of gas-rich dwarf galaxies. For such a complicated problem, a simple analytical model is very useful. Indeed, this would allow us to predict the critical limit of a SFR where gas-rich dwarfs can sustain the Hi envelope. If a SFR is larger than the critical one, the Hi envelope will be blown away by stellar feedback (e.g. Saito 1979; Dekel & Silk 1986). Ferrara & Tolstoy (2000) analyze similar dynamical conditions of Hi envelopes in dwarf galaxies with their dynamical mass being blown-away (all gas is removed), blown-out (partial gas is removed), or no-mass-loss (no gas is removed) (classification proposed by De Young & Heckman 1994). These hydrodynamical processes are numerically examined in Mac Low & Ferrara (1999), and their results are confirmed by Silich & Tenorio-Tagle (2001). Silich & Tenorio-Tagle (2001) have also shown that the low density halo suppresses the outflow of gas from the main body of a galaxy. From this standpoint, the circulation of the ISM is expected to be like a chimney (Kunth & Östlin 2000 for a review). This means that a closed box approximation is adequate to consider the evolution of gas-rich dwarfs whose ISM is not blown out or blown away. To confirm these results with a SFR that can be easily observed compared to dynamical mass (Pustilnik et al. 2001), we reformulate a critical value that determines a condition for the Hi envelope. Consequently, as shown in the following, we can get intuitive pictures of the star-formation history and dynamical properties of the Hi envelope. We have newly considered this useful representation which is similar to that of Legrand et al. (2001).

Before discussing the critical SFR, we review the stellar feedback (i.e., supernovae and stellar winds) effect on the Hi envelope. Stellar feedback causes turbulence in the ISM, and can make super-bubbles. Indeed, turbulence in the Hi envelope is observed (van Zee et al. 1998), and super-bubbles are also observed in some BCDs (e.g. Gil de Paz et al. 1999). In a BCD, the typical size of a super-bubble is larger than that of its star-forming regions, but is smaller than that of its Hi envelope. Martin (1996) thus suggested that the Hi envelope must suffer from the stellar feedback. From the fact that the Hi envelope is not blown away, we are able to deduce the allowed strength of the stellar feedback, the critical SFR, $\psi_{\rm cirt}$ (e.g. Silich & Tenorio-Tagle 1998). Legrand et al. (2001) have considered a similar condition and developed a self-consistent model that treats together both the Hi envelope and the low density halo (including dark matter). On this point, our discussion can provide further insight into the dynamical evolution of the Hi envelope.

To determine $\psi_{\rm crit}$, we deduce the following dynamical condition between the momentum of the Hi envelope, $p_{\rm gas}$, and that supplied from the total stellar feedback by supernovae, $p_{\rm SN}$ (Lamers & Cassinelli 1999), as being

$$(1 + A_{\rm halo})p_{\rm gas} > p_{\rm SN}, \tag{1}$$

where $A_{\rm halo}$ denotes the contribution from the low density halo. It can reach at most 1 when a closed box model is satisfied (Legrand et al. 2001), which is a good assumption, as confirmed in the next section. This inequality is called "the momentum condition" (e.g. Ferrara & Tolstoy 2000). Here, we assume that the feedback energy from stellar winds is comparable to that of supernova explosions.

The momentum of the Hi envelope is expressed as $p_{\rm gas} = M_{\rm gas}\,v_{\rm gas}$, where $M_{\rm gas}$ is the total mass of the Hi envelope, and $v_{\rm gas}$ is the out-going velocity of the Hi gas. For simplicity, we adopt the same velocity for the low density halo to use Eq. (1), which does not alter our main conclusion since the escape velocity of the low density halo is generally larger than $v_{\rm gas}$. In order to estimate $p_{\rm SN}$, we consider the evolution of a supernova remnant in the Sedov phase. As is discussed in Chevalier (1976), the Sedov phase of expanding supernova remnants starts when the swept-up mass of a shell of ISM or circumstellar medium is comparable to the ejected mass of a supernova (e.g. Jones et al. 1981). Thus, the total momentum supplied from supernova remnants during a single generation of star-formation is expressed as $p_{\rm SN} = \eta M_{\rm SN}\,v_{\rm SN}^2/v_{\rm s}$, where $M_{\rm SN}$ is the total mass of supernova remnants during the generation, $v_{\rm SN}$ is the typical velocity of the initial expansion of the remnants, and $v_{\rm s}$ is the final expanding velocity of the shell. Here, η is a coefficient whose value is adopted as $15/77$ from Mac Low & McCray (1988) and which denotes net energy reduction owing to the shell formation and the energy conversion to the thermal energy of the inner coronal gas. Therefore the momentum condition is re-written as being

$$(1 + A_{\rm halo})M_{\rm gas}\,v_{\rm gas} > \frac{15}{77}\frac{M_{\rm SN}\,v_{\rm SN}^2}{v_{\rm s}}. \tag{2}$$

We can relate the right hand side of Eq. (2) to a current SFR. Assuming a mass function, $\phi(m)$, we estimate $M_{\rm SN}$ as

$$M_{\rm SN} = \frac{\psi t_{\rm SF}\displaystyle\int_{8\ M_\odot}^{100\ M_\odot} m\phi(m)\,{\rm d}m}{\displaystyle\int_{0.1\ M_\odot}^{100\ M_\odot} m\phi(m)\,{\rm d}m}, \tag{3}$$

where ψ is a current SFR in the unit of $M_\odot \, \mathrm{yr}^{-1}$, and t_{SF} is the duration of a single generation of star-formation in the unit of yr.

The gas mass of the H I envelope is known to be dominated by the H I compared to H$_2$ (Barone et al. 2000). This also means that the direct contribution of halo gas to the H I envelope is small. However, we take into account halo gas using a coefficient of $(1 + A_{\mathrm{halo}})$ in Eq. (2), because we consider the whole gas system under a closed box approximation. The out-going velocity v_{gas} is assumed to be about the escape velocity of the dwarfs with a flat rotation curve, given as

$$v_{\mathrm{gas}} \sim \sqrt{\frac{2G}{R_{\mathrm{gal}}} \frac{M_{\mathrm{gas}}}{F}} = 2.6 \times 10^1 \left(\frac{M_{\mathrm{gas}} (1 + A_{\mathrm{halo}})}{10^8 \, M_\odot} \right)^{2/7}$$

$$\times \, (1 + A_{\mathrm{halo}})^{-2/7} \left(\frac{F}{0.5} \right)^{-2/7} \mathrm{km \, s}^{-1}, \qquad (4)$$

where we adopt the Burkert profile of gas-rich dwarf galaxies (Burkert 1995) using a radius, $R_{\mathrm{gal}} = 6.9 \times 10^{-4} \, M_{\mathrm{gas}}{}^{3/7} F^{-3/7}$ kpc. Here, G is the gravitational constant, and F is the gas mass ratio to dynamical mass of a galaxy. The typical parameters are taken from the data of BCDs in Table 1. It should be noted that the value of F used is a larger than F in Burkert (1995), 0.2, and thus that our underestimated ψ_{crit} reinforces all gas-rich dwarfs.

Equating both sides of the momentum condition, we obtain ψ_{crit} once a mass function has been determined. The Salpeter mass function, $\phi(m)$; $\phi(m) \propto m^{-2.35} \, (0.1 \leq m \leq 100 \, M_\odot)$ (Salpeter 1955) is assumed here. Hence,

$$(1 + C_{\mathrm{csf}}) \psi_{\mathrm{crit}} = 1.1 \times \left[\frac{M_{\mathrm{gas}} (1 + A_{\mathrm{halo}})}{10^8 \, M_\odot} \right]^{9/7}$$

$$\times \, (1 + A_{\mathrm{halo}})^{-2/7} \, M_\odot \, \mathrm{yr}^{-1}, \qquad (5)$$

where we adopt the typical values $t_{\mathrm{SF}} = 10^7$ yrs, $F = 0.5$, $M_{\mathrm{gas}} = 10^8 \, M_\odot$, $v_{\mathrm{SN}} = 1000 \, \mathrm{km \, s}^{-1}$, and $v_{\mathrm{s}} = 100 \, \mathrm{km \, s}^{-1}$. A correction coefficient of C_{csf} is for the component of continuous star-formation, $C_{\mathrm{csf}} = t_{\mathrm{age}} \psi_{\mathrm{cont}} / t_{\mathrm{SF}} \psi_{\mathrm{crit}}$, while ψ_{cont} is a continuous SFR and t_{age} is galaxy age. Here C_{csf} is generally less than $1/10$ the size of the component of current star-formation (Legrand et al. 2001; their Table 2). Thus, we neglect it since we are interested in the current condition of the H I envelope. As long as the observed SFR is well below ψ_{crit}, the H I envelope is not blown away by stellar feedback. If we adopt another IMF and another set of mass ranges, there is generally 20 percent uncertainty (e.g., Inoue et al. 2000).

In the next section, we compare ψ_{crit} with the SFR of dwarfs that is estimated from observations. For this purpose, we deduce ψ_{crit} with luminosity of Hα, $L_{\mathrm{H}\alpha}$ (e.g. Kennicutt 1983), using the relation $\psi = 2.32 \times 10^{-42} L_{\mathrm{H}\alpha} \, M_\odot \, \mathrm{yr}^{-1}$ that is compiled in and used by Legrand et al. (2001) and based on Leitherer & Heckman (1995). Thus, we can obtain a critical $L_{\mathrm{H}\alpha}$ from Eq. (5):

$$L_{\mathrm{H}\alpha, \, \mathrm{crit}} = 4.1 \times 10^{41} \left[\frac{M_{\mathrm{gas}}}{10^8 \, M_\odot} \right]^{9/7} (1 + A_{\mathrm{halo}})^{9/7} \, \mathrm{erg}. \quad (6)$$

3. Observational investigation

3.1. H I envelope and star-formation rate

We compare the observational data of $L_{\mathrm{H}\alpha}$ with Eq. (6). The sample galaxies are selected from van Zee et al. (1998), Sage et al. (1992), van Zee (2000), and van Zee (2001), according to the condition that they are isolated systems. Regarding four galaxies found in the several papers, the latest data of each galaxy are adopted. We also plot dIrrs in the primary sample of van Zee (2000) and van Zee (2001) to present how well our criterion is satisfied by dIrrs as well as BCDs. The sample BCDs are summarized in Table 1. The result is depicted in Fig. 1. Filled circles are BCDs and the pluses are dIrrs. We draw four model lines. The main line is the thick solid line from Eq. (6) with $A_{\mathrm{halo}} = 0.0$. Clearly, all the sample BCDs are located below this line. That is, all the H I envelopes are not blown away by the current stellar feedback. This result is the same as Ferrara & Tolstoy (2000), since the dynamical mass-range of our sample galaxies is from $\sim 10^7 \, M_\odot$ to $\sim 10^9 \, M_\odot$. The thick dashed line is from Eq. (6) with average internal extinction of gas-rich dwarf galaxies $(E(B-V) = 0.2)$ (Hunter & Gallagher 1986) and $A_{\mathrm{halo}} = 0.0$. Even if we consider the effect of extinction, the conclusion is not altered. The thin lines are the cases with $A_{\mathrm{halo}} = 1.0$. The thin lines are also sufficiently above the sample BCDs. This strongly indicates that the H I envelope is not blown out by the support of the low density halo as predicted in Silich & Tenorio-Tagle (1998).

We find one interesting sample galaxy, Mrk 67, which is plotted at $(M(\mathrm{H \, I}), L(\mathrm{H}\alpha)) = (10.0^{7.4} \, M_\odot, 10.0^{39.9})$ in Fig. 1. It is a Wolf-Rayet galaxy (Conti 1991). This galaxy is located near the solid line. The H I envelope is strongly affected by stellar feedback. Thus, if we want to know the precise effect of the low density halo, the detailed observation of the more extended H I envelope of Mrk 67 is important.

3.2. Star-formation history of BCD

In this paper, we are interested in the star-formation history of isolated BCDs, which can be given by their chemical abundance in their star-forming region. We present this in Fig. 2, while the data of sample galaxies is listed in Table 1. In panel (a), we plot the metallicity of BCDs and the gas mass to the dynamical mass ratio. The metallicity is determined in the current star-forming region (van Zee et al. 1998; Izotov & Thuan 1999). The figure shows that the mass ratio becomes smaller as the metallicity grows larger. Thus, panel (a) supports a closed box assumption for the isolated BCDs, as is originally found in Lequeux et al. (1979). For a detailed review, see Kunth & Östlin (2000). Furthermore, as long as a closed box assumption is satisfied, it can suggest that the H I gas in the envelope is used for the subsequent star-formation in the current star-forming region. This is consistent with Fig. 1, as long as H I gas is generally bound to the host galaxies.
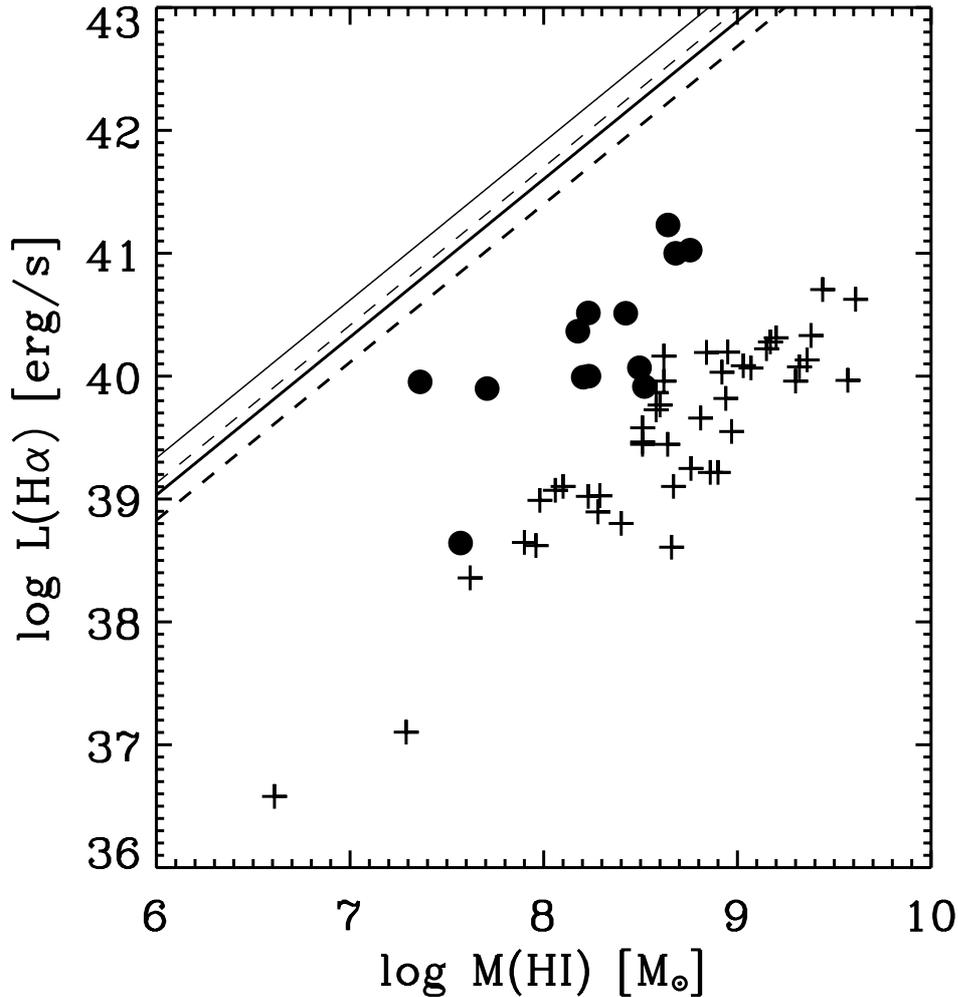
Fig. 1. The luminosity of Hα and the mass of H I gas instead of M_{gas}. The filled circles are BCDs and the pluses are dIrrs. The solid lines are from Eq. (6) and the dashed lines are from Eq. (6) with average internal extinction in dwarf galaxies ($E(B - V) = 0.2$). The thick and thin lines are from Eq. (6) at $A_{halo} = 0$ and $A_{halo} = 1$, respectively.

It should be noted that higher mass ratios than 1 are obtained simply from observational uncertainties of H I gas and/or estimation of dynamical mass (Thuan & Martin 1981). Panel (b) represents the metal abundance and the same mass ratio. This is also interesting since there are no significant differences in abundance among the BCDs (the abundance is located around 0.4, which is a typical value of SN II). Panel (b) suggests that the star-formation histories of BCDs are not very different from each other, as discussed in Kinman & Davidson (1981). Thus, we can conclude that almost all BCDs have experienced a similar star-formation history.

4. Discussion

Our results can provide some insight into a morphological evolutionary model among dwarf galaxies (Kormendy 1985). The most standard model for this kind of research, which discusses the H I envelope, is Thuan (1985). They predict that gas-rich dwarfs evolve into dEs after the H I envelope is stripped for some reasons, such as: (1) interaction with clusters and/or galaxies; and (2) stellar

feedback. Since the gas-rich dwarf sample in this paper is isolated, only the stellar feedback effect is expected to be important for the morphological exchange. Importantly, the current stellar feedback does not blow away the H I envelope as shown in Fig. 1. Presumably, it does not blow out the H I envelope because of the effect of the low density halo (see also Legrand et al. 2001). Thus, we conclude that the isolated gas-rich dwarfs can keep their morphological type, until they no longer experience any interactions. As long as the the H I envelope has been retained, the kinematics of H I envelope is expected to be different from that of stars in dEs. This is checked by estimating the specific angular momentum, and indeed a difference exists (van Zee et al. 2001). Thus, our conclusion is consistent with other studies, since isolated BCDs never evolve into dEs.

In Fig. 2, we suggest that the H I gas is used for the subsequent star-formation. This might permit BCDs and dIrrs to evolve to dEs. However, the consumption time-scale, which is defined as the mass of the H I envelope divided by the current star-formation rate, should be longer
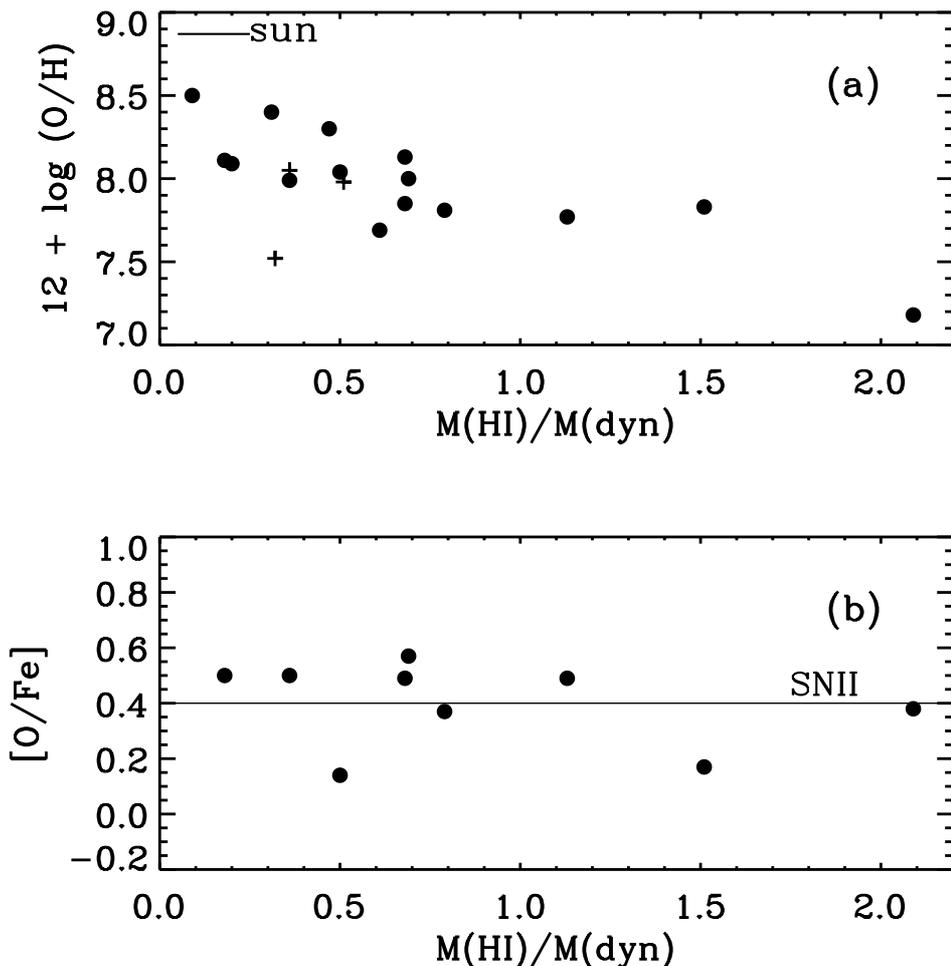
Fig. 2. a) The anti-correlation between the metallicity and the ratio of H I gas mass to the dynamical mass of samples in Table 1. The filled circles denotes samples with the mass ratio from Thuan & Martin (1981), and the plus denotes those of van Zee et al. (1998). **b)** The flat distribution of metallicity abundance to H I gas mass ratio. The metal enrichment is determined at the current star-forming region.

than 10^{10} years. It is difficult for current BCDs and dIrrs to evolve into dEs. Our discussion may confirm the observational implication on its difficulty (Ferguson & Binggeli 1994) in terms of a SFR. We comment that the photoionization effect can be important during the evolution from dIrrs to dEs (Ferrara & Tolstoy 2000), while this effect cannot be examined in our framework. This possibility, related to photoionization effects, will be discussed in a future work.

There is another possibility for the morphological change between dIrrs and BCDs. According to Saitō et al. (2000), gas-rich dwarfs change their morphology between BCDs and dIrrs. This means that the star-formation activity is related to the extent of the H I envelope. Here, we re-consider this evolution in Fig. 1: dIrrs with massive H I gas move upper-leftward in Fig. 1 and are recognized to be BCDs, when the H I gas falls onto galaxies and is consumed for the successive star-formation period. On the contrary, when BCDs decrease their star-formation, they move downward in Fig. 1, and are recognized as dIrrs. Thus, our plot of Fig. 1 is consistent with the preliminary

idea of Saitō et al. (2000). The trend of consumption of H I mass in Fig. 2a may support this evolutionary model of gas-rich dwarfs.

An inverse evolutionary scenario from dEs to gas-rich dwarfs has been suggested by Silk et al. (1987). The IGM was heated and enriched by galactic winds at higher redshift. When galaxy groups formed recently, this gas was compressed, cooled and accreted onto dwarf galaxies with some metallicity. Thus, dEs evolve into dIrrs and BCDs. This scenario is re-interpreted if we exchange the IGM for the low density halo around the BCDs. Since the low density halo is expected to be bound to the galaxy, a closed box assumption can also be invoked here. Furthermore, both IGM and the low density halo have a similar role in the dynamical evolution of H I envelope (Silich & Tenorio-Tagle 1998). Also, if a past SFR was larger than $\psi_{\rm crit}$, the H I envelope could have been blown away from the host dwarf galaxy, while being retained in the galaxy by the low density halo. Hence, when future observations will reveal the large past SFR of BCDs, unlike current observations of their spectral energy distribution, then,

Table 1. BCD sample galaxies. The date are taken from a (van Zee et al. 1998), b (Sage et al. 1992), c (Izotov & Thuan 1999), d (Thuan & Martin 1981) and e (Van Zee 2000) and (van Zee 2001). Blanks mean no data.

galaxy	$\log M(\mathrm{HI})[M_\odot]$	$\log L(\mathrm{H}\alpha)[\mathrm{erg}]$	F	$12 + \log(\mathrm{O/H})$	[Fe/O]	Ref
IIZw40	8.64	41.23	0.68	8.13		a, d
UGC 4483	7.57	38.64	0.32	7.52		a
UM439	8.49	40.07	0.36	8.05		a
UM461	8.23	40.00		7.74		a
UM462	8.42	40.52	0.51	7.98		a
Haro2	8.68	41.00	0.31	8.4		b, d
Haro3	8.76	41.03	0.47	8.3		b, d
UM465	7.71	39.90		8.9		b
Mrk 67	7.36	39.95	0.20	8.09		b, d
Mrk 900	8.18	40.37		8.5		b
Mrk 328	8.23	40.51	0.09	8.5		b, d
UGC 11755	8.20	39.99				e
UGC A439	8.52	39.87	0.66			d, e
Mrk 600	8.52		1.51	7.83	0.17	c, d
Mrk 5	8.11		0.50	8.04	0.14	c, d
Mrk 71	9.00		0.68	7.85	0.49	c, d
IZW18	7.81		2.09	7.18	0.38	c, d
Mrk 22	8.18		0.69	8.00	0.57	c, d
Mrk 36	7.28		0.79	7.81	0.37	c, d
VIIZw403	7.58		0.61	7.69		c, d
Mrk 750	7.23		0.18	8.11	0.50	c, d
Mrk 209	7.70		1.13	7.77	0.49	c, d
Mrk 59	8.66		0.36	7.99	0.50	c, d

it will be interesting for us to re-examine the possibility of the morphological evolution model of Silk et al. (1987) with caution.

5. Summary

In this paper, we have shown that the HI envelope are not easily blown away by stellar feedback without the low density halo but with dark matter, since the envelope is not accelerated to the escape velocity (see also Legrand et al. 2001). This dynamical state is observationally confirmed for isolated gas-rich dwarfs. Furthermore, we have confirmed the possibility that all the isolated BCD samples have a similar star-formation history, as is suggested from their metallicity and HI mass consumption. Our results support that (1) it is difficult for the isolated gas-rich dwarfs to evolve into dEs, since the present SFRs of gas-rich dwarfs are not so large. They will change their morphological types only when they suffer exceptionally intense star-burst and/or interaction among galaxies, and/or clusters of galaxies. (2) The morphological exchange among gas-rich dwarfs may be possible. But, as a future work, we must describe the star-formation mechanism due to the HI gas fueled into star-forming regions, suggested from the anti-correlation between HI mass and metallicity. The effect of the low density halo may be essential. (3) A morphological evolutionary model from dEs to gas-rich dwarfs is possible if the HI gas falls onto the host galaxy. But, even in this case, the low density halo should be investigated further. Recently, Legrand et al. (2001) has reported a very similar result to our Fig. 1.

The essential meaning of the two results are the same and consistent with each other, such that the ISM is sustained in the BCDs themselves. However, we consider especially the HI envelope, and find that the HI envelope is neither blown away nor blown out from BCDs by means of the current stellar feedback.

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