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The Z-L relationship of dwarf irregular galaxies

I. First results

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Abstract. We have revisited the stated relation between the metallicity and the luminosity for nearby dwarf irregular galaxies. A sample based on the absolute magnitude and the radius of the galaxies as observable criteria was selected. New and better distance determinations from the literature were used and the metallicities were recalculated from published spectra. The derived distribution of dwarf galaxies in the Z-L plane is different from the ones previously obtained. A factor which could have bearing on the Z-L relation is the different environment where the galaxies reside. This was investigated using the selected sample but no firm conclusion could be drawn and a more elaborate study should be made using a larger sample. The two parameters mostly used for determining the metallicity and the luminosity are the oxygen abundance and the absolute blue magnitude. In this analysis it is suggested that the nitrogen abundance and the near-infrared absolute magnitude should be used instead. These are less affected by the recent star formation history of the galaxy.

Key words: galaxies: evolution – galaxies: abundances – galaxies: dwarf – galaxies: irregular

1. Introduction

Dwarf galaxies are becoming more interesting, not only for understanding our Local Universe but also from a cosmological point of view. The spatial distribution of dwarfs in the Universe could give clues about the formation of galaxies (Dekel & Silk, 1986). These authors proposed that dwarf and normal sized galaxies were formed from different density fluctuations which could generate a bias in the large-scale distribution of galaxies. Observational efforts in order to clarify this situation have not been conclusive (Thuan et al., 1987; Binggeli et al., 1990). In our local environment more than 60% of the galaxies are dwarfs. If this proportion is kept in the distant Universe, it is clear that this play an important rôle in understanding the formation and evolution of galaxies.

Two parameters which are very crucial in order to understand the behavior of galaxies are the luminosity (L) and the metallicity (Z). Many attempts have been made in order to establish a relationship between these two basic parameters (hereafter the Z-L relationship). The existence of such a relationship is easily understood using a “closed-box” model of chemical evolution (Tinsley, 1978). The results indicate that the metallicity is proportional to the luminosity. Observationally, for the case of the Hubble sequence the attempts have been fruitful (Terlevich et al., 1981; Vigroux et al., 1981; Vila-Costas & Edmunds, 1992). The situation regarding dwarf galaxies is more confusing. Aaronson and Mould (1985) found a strong correlation for a sample of local dwarf Spheroidal (dSph) galaxies and this also applied to a sample of nearby dwarf Irregular galaxies (dI’s) (Skillman et al., 1989. hereafter “SKH”). Recently, Richer and McCall (hereafter “RM”) (1995) found a weaker correlation for the nearby dI’s than the latter. No trend could be found for Blue Compact Dwarfs (BCD’s) (Peña and Ayala, 1993; Campos-Aguilar et al., 1993) or Low Surface Brightness Galaxies (LSBG) (Rönnback & Bergvall, 1994; McGaugh, 1994).

In this paper we revisit the Z-L relationship of dI galaxies. The aim is to reanalyze, critically, published spectra of dI’s used for metallicity determinations and investigate the methods used for determining the luminosity of the objects. The latter is derived from the absolute magnitude which in turn is crucially dependent on accurate distance determinations.

Throughout the paper the luminosity will be referred to as the absolute magnitude in the B band and the metallicity as the oxygen abundance. In Sect. 2, a definition of a dwarf galaxy is suggested and the selection criteria of the empirical sample is discussed. Sect. 3 outlines how the distance and the metallicity were calculated and contains a discussion on the existence of this relationship for the dI’s. In Sect. 4 there are comments on the results and in Sect. 5 the rôle of the environment is studied. Sect. 6 is devoted to a summary and future perspectives.

2. Definition of dwarf galaxy

No clear definition of a dI is found in the literature and different criteria obtained from different sets of parameters are used. Occasionally, the term dI is used for objects classified by other investigators as BCD’s or LSBG’s. A new more general definition is suggested after a careful study of the relations between

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Table 1. The sample of nearby dwarf irregular galaxies. The identification is presented in column 1. Columns 2 and 3 report the absolute magnitude in the B-band calculated according to the relation presented in Sect. 2 and the uncertainties, respectively (see Sect. 3.2). The radius of each galaxy, obtained with Eq. (3), and the uncertainties are given in columns 4 and 5. Columns 6 and 7 present the surface brightness, according to Eq. (4), and the uncertainties, respectively. The distance and its uncertainty are reported in columns 8 and 9. Column 10 gives the method used for the distance determination (see Sect. 3.2). Column 11 presents the morphological type from the Tully catalogue, where 9 correspond to the spiral/irregular classification and 10 to irregulars. A and B mean non-barred and barred and galaxies, respectively. Finally, column 12 presents the references for the distance determination. For three of the galaxies only one measurement of the distance were available and the uncertainty was tabulated as 0.00. For two other galaxies (DDO 167 and Sag Dig) the values of M_b was taken from SKH (1989) since these were not available in the RC3. For UGC 8215, no value of the magnitude was found. *References for the distance:* (1) Saha et al., 1996; (2) Wilson et al., 1996; (3) Klein, 1986; (4) Tully, 1988b; (5) Huchtmeier & Richter, 1988; (6) Tully, 1988a; (7) Melisse & Israel, 1994; (8) Balkowski et al., 1974; (9) Freedman, 1988; (10) van der Bergh, 1977; (11) McAlary et al., 1983; (12) Madore & Freedman, 1991; (13) Huterer et al., 1995; (14) O'Connell et al., 1994; (15) Krismer et al., 1996; (16) Tikhonov et al., 1992; (17) Tolstoy et al., 1995; (18) Freedman, 1994; (19) Krann-Korteweg & Tammann, 1979; (20) Georgiev, 1997; (21) Karachentsev & Tikhonov, 1994; (22) Pierce & Tully, 1992; (23) Strobel et al., 1990; (24) Meurer et al., 1994; (25) Madore et al., 1995; (26) Kennicutt, 1988; (27) Hoessel & Danielson, 1984; (28) Hoessel et al., 1994; (29) Sandage, 1986; (30) Sandage & Carlsson, 1985; (31) Sakai et al., 1996; (32) Tyson & Scalo, 1988; (33) Broeils & van Woerden, 1994; (34) Donas et al., 1987; (35) Staveley-Smith et al., 1992 (36) Richter & Huchmeier, 1984; (37) Alteschuler et al., 1984; (38) Hunter et al., 1993; (39) Thuan et al., 1987; (40) Krumm & Burstein, 1984; (41) Carignan & Beaulieu, 1989; (42) Bresolin et al., 1993; (43) Mould et al., 1986; (44) Aparicio et al., 1988; (45) Hunter & Gallagher, 1985; (46) Heydari-Malayeri et al., 1989; (47) Lee et al., 1993; (48) McAlary et al., 1985; (49) Greggio et al., 1993; (50) Tacconi & Young, 1987. *Methods of distance determination:* (1) Cepheid measurements (2) The Tully-Fisher relation (3) The colour-magnitude diagram (4) Brightest star (5) Heliocentric motion, (6) Non specified, taken from previous bibliography by the authors or a mixing of different methods.

Galaxy	M_b	±	R (kpc)	±	μ_{SB} (mag arsec^{-2})	±	D (Mpc)	±	Method	Type	references
IC 10	-16.617	0.007	0.76	0.02	20.2	0.3	0.825	0.005	1	9	1,2
DDO 226	-13.8	0.3	1.1	0.2	24	1	3.5	0.5	6	10	3,4,5,6
DDO 6	-12.7	0.3	0.8	0.1	23.8	0.8	3.4	0.5	6	10	3,4,7,8
IC 1613	-14.36	0.02	1.716	0.005	24.4	0.1	0.722	0.008	1	10B	9,10, 11,12,13
ESO 245-5	-15.5	0.2	2.2	0.2	24.0	0.7	4.2	0.3	6	10	4,5,7
NGC 1569	-17.4	0.4	1.35	0.02	20.00	0.09	2.5	0.5	3	10B	14
UGCA 105	-16.3	0.2	3.2	0.6	24.6	0.6	4.0	0.3	4	10	6,7,15,16
NGC 2366	-17.09	0.03	4.18	0.08	23.0	0.2	3.54	0.05	1	10B	17,18
DDO 47	-14.4	0.2	1.5	0.2	25	1	3.5	0.3	6	10B	5,7,9,20
UGC 4115	-13.9	0.5	1.0	0.2	23	1	3.8	0.8	6	10	5,6,7
DDO 50	-16.74	0.02	3.94	0.05	23.6	0.3	3.41	0.03	1	10A	4,7,19,21, 22
NGC 2915	-15.3	0.4	0.94	0.04	22.4	0.3	3.4	0.7	3,5	10B	6,7,24,25
DDO 53	-13.35	0.05	0.73	0.02	21.1	0.3	3.53	0.07	1,3	10	21,23
DDO 63	-15.1	0.2	2.2	0.2	24.4	0.7	4.1	0.3	3,4	10	4,5,6,21,26,27
DDO 69	-14.02	0.04	1.49	0.04	24.8	0.3	2.00	0.04	1,3	10	28,29
DDO 70	-13.90	0.02	0.98	0.01	23.3	0.5	1.31	0.01	1	10B	12,21
DDO 75	-13.94	0.07	1.144	0.008	23.9	0.1	1.37	0.04	1	10B	12,21,30, 31
Mrk 178	-14.36	0.05	0.70	0.02	22.5	0.2	3.90	0.09	6	10	5,7
DDO 99	-14.9	0.3	2.4	0.3	24.6	0.9	4.1	0.5	6	10	3,4,5,6,7,32
NGC 4068	-15.4	0.2	1.9	0.2	23.8	0.7	3.9	0.3	5,6	10A	5,6,7,33,34
NGC 4163	-14.8	0.5	1.0	0.2	23.9	0.5	3.7	0.9	6	10A	3,4,6
DDO 126	-14.1	0.3	2.0	0.3	25	1	4.3	0.6	6	10B	3,4,5,6,7
DDO 125	-15.4	0.3	2.7	0.4	24.5	0.8	4.3	0.6	2,5	10	3,4,6,7,36
UGC 7605	-13.4	0.2	0.74	0.05	23.6	0.5	4.4	0.3	5,6	10	4,5,6,7,35
DDO 133	-15.4	0.2	4.5	0.5	25.4	0.9	4.8	0.5	5,6	10	3,4,5,6,7,32,36,37,38,39
DDO 141	-15.4	0.3	2.6	0.3	25.0	0.5	5.2	0.6	6	10	3,4,5,6
DDO 154	-14.5	0.3	1.8	0.2	24.4	0.8	7.1	0.6	2,4,5	10	3,5,6,7,32,40, 41
DDO 155	-12.13	0.00	0.350	0.001	23.14	0.09	2.24	0.06	1	10	17
DDO 165	-15.0	0.1	1.7	0.1	23.9	0.5	3.4	0.2	6	10	3,4,5,6,7,21
UGC 8215	-	-	0.59	0.01	-	-	4.07	0.05	5	10	6,7,35
DDO 167	-13.3	-	0.69	0.09	-	-	4.2	0.05	6	10	3,6,7,38
DDO 168	-16.0	0.2	2.4	0.2	23.6	0.6	4.6	0.4	5,6	10B	3,4,5,6,23,33,38, 42
DDO 169	-14.6	0.2	2.2	0.2	24.4	0.7	5.2	0.5	6	10A	3,5,6,7,38
ESO 324-24	-15.77	0.05	2.10	0.06	23.4	0.3	4.3	0.1	2,6	10	5,6,7,36
UGC 8508	-14 1	0.4	1.2	0.3	23	2	5	1	6	10A	4,5,6,7,43

Table 1. (continued)

Galaxy	M_b	±	R (kpc)	±	μ_{SB} (mag arsec^{-2})	±	D (Mpc)	±	Method	Type	references
DDO 181	-14.3	0.1	1.4	0.08	24.6	0.7	4.1	0.2	6	10	3,4,5,6,7
DDO 183	-14.3	0.2	1.2	0.1	23.7	0.6	3.9	0.4	6	10	3,4,5,6,7,38
DDO 187	-13.8	0.5	1.1	0.3	24	2	4.4	0.00	3	10	44
DDO 190	-15.1	0.1	1.24	0.08	23.0	0.5	4.7	0.3	6	10A	3,5,6,7,32, 45
IC 4662	-15.67	0.02	1.00	0.01	21.2	0.5	2.50	0.02	4,5	10B	5,7,46
Sag Dig	-10.5	-	0.38	0.04	-	-	0.9	0.1	6	10	4,5,6,7,23
NGC 6822	-14.746	0.002	1.081	0.003	23.0	0.6	0.4800	0.0005	1	10B	10,11,21,47,48
DDO 210	-12.1	0.4	0.5	0.1	24	2	1.4	0.3	2,3,4	10	3,4,5,6,7,49,50
IC 5152	-15.4	0.5	1.8	0.4	23	1	2.3	0.5	6	10A	4,7
DDO 216	-13.22	0.00	1.28	0.003	24.9	0.6	1.75	0.00	1,2	10A	28
DDO 221	-14.143	0.002	1.641	0.008	23.0	0.1	0.983	0.001	1	10	12,21,30,47

the most common parameters used for defining a dwarf galaxy: the optical radius (r), the absolute magnitude (M_b) and the surface brightness (μ_{SB}). A clear and homogeneous sample of dwarf galaxies is necessary for the present study. The inclusion of other types, e.g. magellanic irregulars, could mask a possible relationship between Z and L for the dI's.

A sample of 176 irregular galaxies was selected from the Tully (1988a) catalogue without any further restrictions. Galaxies classified in Tully's catalogue as spiral/irregular and irregular were chosen. Those with code number 12 were not selected since their classification was marked as uncertain. The absolute magnitude, radius and surface brightness are calculated as:

$$M_b = B_t - \mu_D \tag{1}$$

where

$$\mu_D = 5 \log D + 25 \tag{2}$$

D is the distance to the galaxy, in Mpc, obtained from published literature (see Sect. 3.2). B_t is the apparent blue magnitude, corrected for reddening, taken from Tully's catalogue (1988a). The radius, in kpc, is defined as

$$r = 1.454 \times 10^{-5} 10^x D \tag{3}$$

where x is the logarithm of the diameter of the galaxy at the 25:th isophote as given in the RC3 (de Vaucouleurs et al., 1991) and the surface brightness, in mag arcsec^2, is given as

$$\mu_{SB} = B_{25} + 2.5 \log \pi a^2 + 2.5 \log \cos i \tag{4}$$

i is the inclination of the galaxy from Tully, a the angular radius in arcseconds from RC3 (de Vaucouleurs et al., 1991) and B_{25} the magnitude at the 25:th isophote. The latter value is difficult to derive from the bibliography, therefore B_T^0 from RC3 was used instead. B_T^0 is the total magnitude in the B-band, corrected for extinction. When both values were available for the same galaxy, we compared the surface brightnesses calculated with each of them. The difference was found to be negligible. The distances were extracted from the Tully catalogue in order to get an homogeneous set of values and to minimize the unphysical scatter in the diagrams.

Fig. 1 shows the relationship between the absolute magnitude and the radius of the galaxies. A correlation between these two parameters seems to be evident. The linear correlation coefficient is r_l = -0.89 and

$$\log r_l = -0.15(\pm 0.01) M_b - 2.0(\pm 0.1) \tag{5}$$

A relationship between the luminosity and the size is expected for gas-rich objects, because objects of larger sizes are likely to contain a larger number of star forming regions each contributing to the light in the blue.

In Figs. 2 and 3 the surface brightness is plotted as a function of the M_b and the radius, respectively. It is clear than no correlation could be inferred and only scattered diagrams result. It should be emphasized that the surface brightnesses calculated in this study are the integrated ones including the whole galaxy and not the ones derived from photometric observations. An averaged surface brightness would unfortunately mix the old stellar population with the present one (Papaderos et al., 1996). However, due to the lack of surface photometry of all the 176 galaxies in the sample the average surface brightness was used in this analysis. The final sample of dI's was restricted in surface brightness (see below). Contrary to the claims of Binggeli (1994) no correlation was found between M_b and μ_{SB} (Fig. 2). The reason for the discrepancy could be that he used the central surface brightness of each object. Moreover, his plot covered a wide range in both M_b (20 magnitudes) and in μ_{SB} (14 units), while the one used here should be considered a subset of his. It should be noted that the data presented could be influenced by some bias in the μ_{SB} because of selection effects in the catalogued data.

It can concluded that the two parameters which seem to be related are the magnitude and the radius, while the surface brightness is not playing any significant rôle.

The major source of uncertainty in these calculations is inherent in the distance determinations. As mentioned before, a single value of the distance is used in these calculations and no

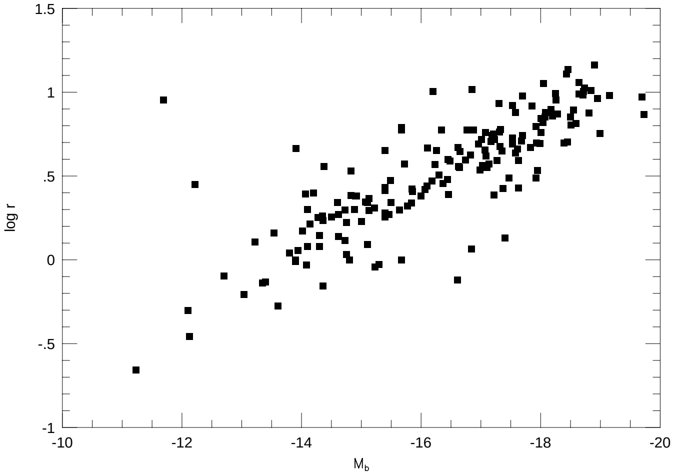

Fig. 1. The logarithm of the radius vs. the absolute magnitude in the blue. The squares represent the total sample of 176 irregular galaxies of all sizes. The parameters were obtained as described in Sect. 2. The linear correlation coefficient is r= -0.89 for the whole sample.

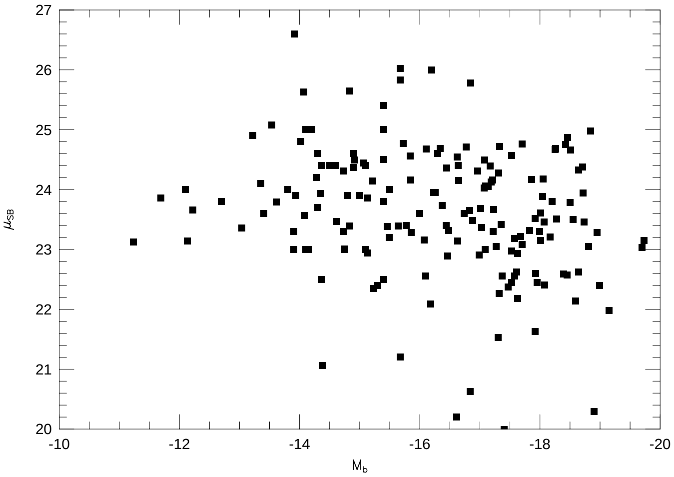

Fig. 2. The surface brightness vs. the absolute magnitude in the B-band for the sample of 176 irregular galaxies.

uncertainties were reported in the Tully catalogue. Therefore, errorbars are not presented in the figures. Considering typical values of these parameters (see Sect. 3.2), typical uncertainties are estimated to be ΔM$_b$ = 0.2 mag, Δr = 0.3 kpc, and $\Delta\mu_{SB}$ = 0.5 mag arcsec^{-2}.

A dwarf irregular galaxy is defined such that the absolute magnitude and the optical radius should be $M_b \geq -17$ and r $\leq$ 3 kpc, respectively. This definition was based on the relation for determining r; for M_b = -17 the radius is 3.5 kpc which is close to the idea of small sizes connected with this kind of galaxies. The value of μ_{SB} was restricted to 22 mag arcsec^{-2} $\leq\mu_{SB}\leq$ 25 mag arcsec^{-2}, in order to avoid the BCG and the LSBG. This would in turn restrict the sample to dI's only. The values of μ_{SB} of four of the objects, IC 10, NGC 1569, DDO 53 and IC 4662, are brighter that the imposed limits. However, Hα images of these galaxies indicate that their morphologies are closer to those of dI's.

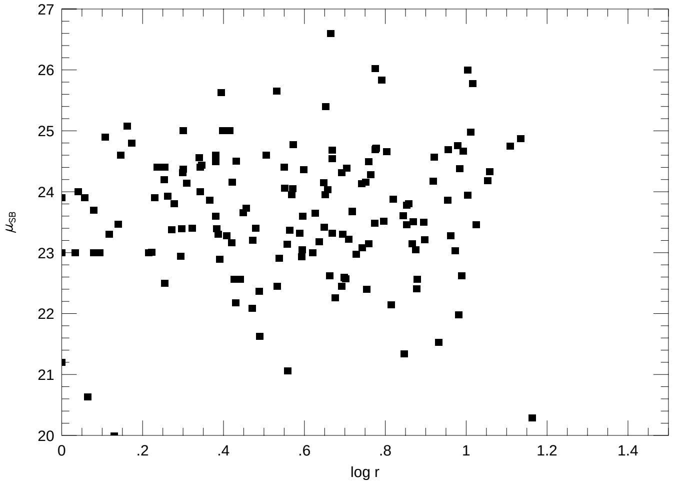

Fig. 3. The surface brightness vs. the logarithm of the radius for the sample of 176 irregular galaxies.

The criteria for removing a galaxy from the list was that the value of one of the parameter involved was larger than 2σ, where σ is the typical uncertainties estimated previously. Three objects, NGC 2366, DDO 50 and DDO 133, were included in the final sample despite the fact that they did not fulfill one of the criteria.

With this definition of a dwarf galaxy a sample of 45 galaxies were selected all within a distance of 5 Mpc from the Galaxy (Table 1). The uncertainty in the distance determination was calculated as Δr = 1.454 10$-$5 [D x 10$(x-1)$ Δx + 10x ΔD], x is the value of the log D_{25} from RC3. The uncertainty associated with the surface brightness was calculated according to $\Delta\mu$ = ΔB_t + 5 Δr/r.

3. The Z-L relationship

3.1. Is a Z-L relationship expected for dI's?

Baum (1959) established a relation between the broadband colours (B-V) and the M_b for a sample of elliptical galaxies of all sizes as well as globular clusters. Faber (1973) also studied a sample of elliptical galaxies, including dwarfs, in pairs and found that the differences in colours could be attributed to a difference in the metallicity. These two investigations clearly indicate the presence of a relationship between the metallicity and the luminosity for this type of object. Moreover, through the M/L ratio, a metallicity-mass relationship was established. The latter was very well explained with a "closed-box" chemical evolutionary model (Tinsley, 1978) and was empirically established by Mould (1984) for a sample of giant elliptical galaxies.

There are two critical points when extrapolating this situation to dI's. The first concerns the fact that these systems are of small size and could probably not be considered as closed and that galactic winds may well occur because of the weakness of the potential well. The effectiveness of this phenomena should be closely linked to the mass and morphology of the system. The models of de Young and Gallagher (1990) give support for the idea of energetic sweeping of newly synthesized heavy el-

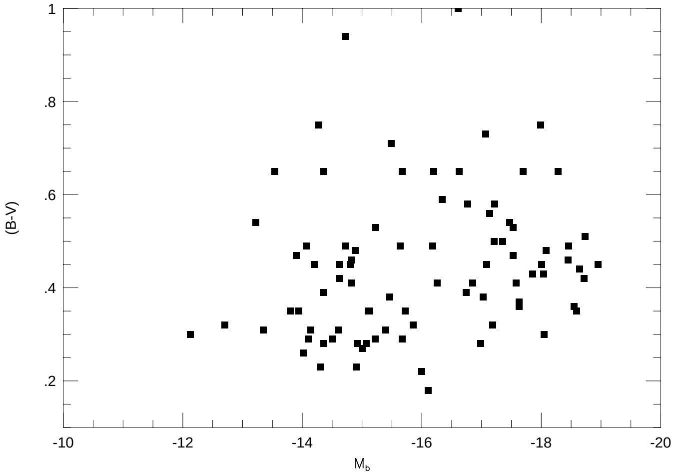

Fig. 4. The broadband B-V colour vs. absolute magnitude in the B-band of a total of 89 irregular galaxies is plotted. The colours are from Melisse and Israel (1994) and the M_b is the one calculated in Sect. 2. The correlation coefficient is r_l = -0.31.

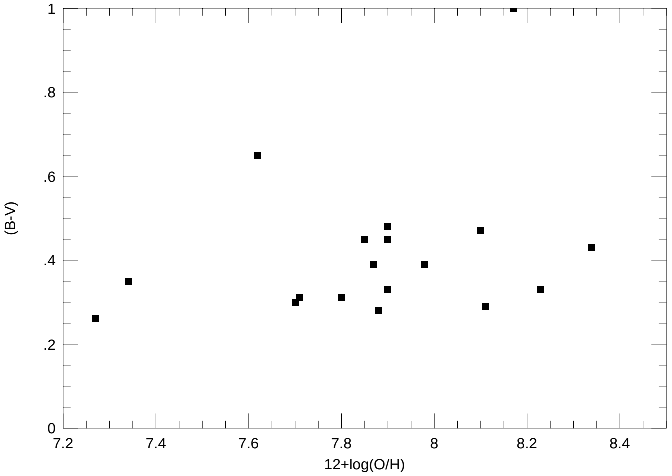

Fig. 5. The broadband B-V colour vs. metallicity diagram. Data for 15 irregular galaxies is plotted. The correlation coefficient is r_l= 0.05. If only the dI's subsample is considered the coefficient is slightly improved to $r_l = -0.16$.

ements from a galaxy although the models apply to disk-like galaxies.

The second question concerns the relationship between colour, metallicity and luminosity of dI's. These objects are observed in the starbursting or post-starbursting phases and are therefore in different stages of evolution. Observations show that there are traces of an old stellar population underlying the young stars (Aparicio & Gallart, 1995). Therefore, no relationship between the colour and the magnitude would be expected nor between colour and metallicity. As a check, a subsample comprising objects with colour and metallicity measurements was studied. The results are shown in Figs. 4 and 5. The broadband colour indices (in the Johnson system) are taken from Melisse and Israel (1994). No proper treatment of the uncertainties was made due to the lack of colour measurements reported. Neither the (B-V) vs. M_b nor the (B-V) vs. metallicity diagrams show any relations between these parameters.

Based on the results of Figs. 4 and 5 it can be concluded that no relationship between Z and L is expected. In order to check if this conclusion is the correct one, the Z-L relationship was investigated again with a new and more carefully study of the parameters involved.

3.2. The distance

Reliable distances to the dI's are needed because, as was outlined earlier, it is the major source of uncertainty in the determination of the M_b. For example, an uncertainty of 1 Mpc in the distance would result in an uncertainty as much as 25% in the M_b.

For the Local Universe the distances could not be obtained through the redshift of the spectra due to the effects of local dynamics (e.g. Virgo infall). A number of methods for calculating the distances in such cases are known: e.g. pulsating stars, the tip of the red giant branch, supernovae, the luminosity function of planetary nebulae, the Tully-Fisher relation, the absolute magnitude of red and blue supergiants etc. (see Jacoby et al., 1992 for a review). However, not all of them are useful for dI's. There are mainly three methods available for measuring the distances in the local neighbourhood, each with various levels of reliability.

The method with the smallest intrinsic uncertainties is probably the one based on pulsating stars such as Cepheids and RR Lyrae. Cepheids are young pulsating stars which are located in the disks and in regions of recent star formation. They can be used as standard candles due to the correlation between their colours, periods and luminosities (Feast & Walker, 1987). The uncertainties arise from the determination of the zero point of the correlation and they are normally not larger than 7% (Jacoby et al., 1992).

Another method is the Tully-Fisher relation (Tully & Fisher, 1975). This is an empirical relation between the luminosities and the rotational velocities of the galaxies (L $\propto v^4$). In addition to the large scatter in the blue luminosity, the rotation velocity is not very easy to obtain for dI's. Another source of uncertainty is the inclination of these galaxies which are not very well known. All these factors conspire in order to increase the total scatter in the Tully-Fisher relation for dI's (Jacoby et al., 1992) and therefore also in the total uncertainties in the distance determination. Moreover, there is no analytical expression for dI's and the one for spiral/irregular calibrated by Pierce and Tully (1992) is used. Recently, Rauzy (1997) has proposed a new technique for calibrating the slope of the zero-point of the Tully-Fisher relation and he used one of the dI's in our sample for this purpose.

A third method used is based on the correlation between the average absolute magnitude of the brightest red and blue stars of a galaxy and the luminosity (Karachentsev & Tikhonov, 1994). The main flaw using this method is probably the large uncertainties in the photometric calibration. However, with better and more accurate calibrations, the distance determinations could be useful (Piotto & Capaccioli, 1992).

Good distance determinations could only be found in the bibliography for half of the galaxies in our sample. Cepheids were detected in only ten galaxies. When more than one value of the distance, using Cepheids, were reported the most reliable was selected or an average value was used. For the other 35 dI's some of the measurements were rejected because the uncertainties are too large and the values obtained deviate strongly from more recent ones. With the remaining a weighed average of the distance was obtained and used in this investigation. The standard deviation in the distance determination, ΔD, is obtained and the uncertainty in the M_b is calculated as

$$\Delta M_b = \frac{5 \log e}{D} \Delta D$$

where ΔD was chosen because most of the published distances give no uncertainties in the measurements.

3.3. The metallicity

Generally, since the dI's are rather gas-rich, the metallicity is deduced from the nebular component excited and ionized by hot OB stars. The element normally used to study the Z-L relationship is oxygen since it is easily attained in the optical part of the spectrum. The lines used are the forbidden [OII] and [OIII] in emission. This normally requires a determination of the electron temperature of the region (Osterbrock, 1989).

The main problem is that normally one of these lines, [OIII]λ4363Å, is very weak and only appear in very high excitation spectra. In the absence of the [OIII]λ4363Å line some other methods must be employed. The so called semi-empirical methods (Pagel et al., 1979; Skillman, 1989; McGaugh, 1994) have been used frequently. However, the uncertainties in the derived oxygen abundance is high and even using very elaborate calibrations (Olofsson, 1997) the uncertainty is at least $\pm$ 0.1 dex. The latter method used for determining the oxygen abundance is referred to as the "bright-line" method and rests upon the relation ([OII]+[OIII])/Hβ vs. oxygen abundance. It is found that this relation is bi-valued with two distinctive sections often named the lower and upper branches. It is possible to discriminate between these two branches with the aid of the optical oxygen-over-nitrogen emission line ratio [OIII]/[NII] (Alloin et al., 1979).

Whenever the oxygen abundances could be determined using both methods, large differences in the values often resulted. The temperature-sensitive method is probably less affected by intrinsic uncertainties provided the data are of good quality. Therefore, the oxygen abundances derived in this analysis was calculated using this method, only. Out of the 45 galaxies in the final sample only 15 had published spectra which contained measurements of the line [OIII]λ4363Å. The raw spectra were corrected for internal extinction whenever such information was available. The lack of such information is of course a major flaw especially for the determination of the oxygen abundance since the lines used for this exercise are far apart in wavelength.

It was only possible to estimate the uncertainty in the oxygen abundance in eight galaxies. In additional three, no uncertainties of the measurement of the intensity of the lines were reported in the literature and for the remaining four a special code was used in order to present them. For two of the galaxies (Sext B and Gr 8) the uncertainty is published only for the [OIII]λ4363Å line. The uncertainties were calculated from the mathematical expression

$$\Delta x = \sum_i \frac{\delta x}{\delta y_i} \Delta y$$

where x and y symbolize the dependent and independent variables, respectively. The uncertainties in the intensity of the line [OIII]λ4363Å reported in the bibliography fluctuate between 11 and 120 %. In the best case, an uncertainty of 10 % in the O/H abundance is obtained using this expression. It is important to realize that the uncertainties derived through this expression are probably only lower limits to the total ones.

4. Results

The data of the sample of dI's for which the oxygen abundance could be determined is given in Table 2. The revised Z-L diagram is obtained and shown in Fig. 6. We have also plotted the relationship obtained by SKH (1989) as well as a 1σ deviation from this. It is obvious that the results derived in this analysis deviate strongly from the ones obtained by SKH (1989) (75% of the common galaxies in both samples fall outside their relationship) and RM (1995). Some points need to be commented on.

First of all, each data point correspond to an H II region in a dI galaxy. In some cases several H II regions in a particular galaxy are plotted. When calulating the correlation coefficient, r$_l$, the global properties were used i.e. the global absolute magnitude of the object was compared with the averaged oxygen abundance. The oxygen abundances calculated from the published results are not averaged over the whole galaxy because much more information than the published one is needed. In order to average the metallicity for all the H II regions in a galaxy at least the S/N or any other indication of the quality of each spectrum is needed and a weighted average value could therefore be obtained. This information is normally not available in the published spectra.

Moreover, remarkable differences in the values for the oxygen abundances of a certain galaxy is noticeable, not only when data are reported from various authors, which is expected, but also between the H II regions of a galaxy from the same set of observations This could possibly reflect physical variations in the oxygen abundance or different excitation and ionization conditions.

Whenever results of several investigations of the same galaxy was available the data of the highest quality was chosen.

As mentioned in the previous section, the [OIII]λ4363Å line which is used in order to determine the oxygen abundance only appear in high excitation spectra. It has been claimed that this could introduce a bias in the sample which affects the Z-L relationship (Pagel, 1995). In order to check this statement the abundances were calculated using the semi-empirical method (Pagel

Table 2. Data on H II regions in the sample of dI's. Column 1 presents the identification of the galaxies, columns 2 and 3 the absolute magnitudes with uncertainties, respectively. Column 4 gives the references used and column 5 the H II region studied in each galaxy. The H II regions are named according to the referenced paper for an easy identification. Columns 6 and 7 present the oxygen abundances and the uncertainties calculated with the temperature-sensitive method. The last column gives the references for the metallicity. Galaxies marked with an asterisk are those with gravitational companions (See Sect. 5.2). *References for distance determinations:* (1) Saha et al., 1996; (2) Wilson et al., 1996; (3) Freedman, 1988; (4) van der Bergh, 1977; (5) McAlary et al., 1985; (6) Madore & Freedman, 1991; (7) Huterer et al., 1995; (8) O'Connell et al., 1994; (9) Tolstoy et al., 1995; (10) Freedman, 1994; (11) Richer & McCall, 1995; (12) Hoessel et al., 1994; (13) Sandage, 1986; (14) Karachentsev & Tikhonov, 1994; (15) Sandage & Carlsson, 1985; (16) Sakai et al., 1996; (17) Melisse & Israel, 1994; (18) Tully, 1988b; (19) Krann-Korteweg & Tammann, 1979; (20) Huchtmeier & Richter, 1988; (21) Georgiev, 1997; (22) Heydari-Malayeri et al., 1990; (23) van der Bergh, 1979; (24) Lee et al., 1983; (25) McAlary et al., 1985. *References for metallicity:* (1) Lequeux et al., 1979; (2) Talent, 1980; (3) Masegosa et al., 1991; (4) Skillman et al., 1989; (5) Moles et al., 1990; (6) Webster et al., 1983; (7) Gonzalez-Riesta et al., 1988; (8) Heydari-Malayeri et al., 1990; (9) Pagel et al., 1979; (10) Hodge & Miller, 1995.

Galaxy	M$_b$	ΔM$_b$	M_b ref.	Region	12 + log (O/H)	Δ(12 + log (O/H))	12+log(O/H) ref.
IC 10 *	-16.612	0.007	1,2	1	8.05	-	1
				2	8.28		1
IC 1613 *	-14.36	0.02	3,4,5,6,7		7.619	-	2
NGC 1569	-17.4	0.4	8	SEN	8.16	-	2
				NK	7.955	-	2
NGC 2366	-17.09	0.03	9,10	IIA	7.9	0.1	3
				IIA1	7.8	0.1	3
				IIΣ	7.98	0.06	3
				IIIA	7.9	0.3	3
				IIIΣ	7.7	0.2	3
DDO 47	-14.4	0.2	17,19,20,21	1	7.88	0.08	4
DDO 50 (Ho II)	-16.74	0.02	11	AA	7.85	0.05	3
				AA1	7.94	0.06	3
				AΣ	7.82	0.07	3
DDO 69 (Leo A)*	-14.02	0.04	12,13		7.27	0.02	4
DDO 70 (Sext B)*	-13.90	0.02	6,14		8.11	0.2	5
DDO 75 (Sext A) *	-13.94	0.07	6,14,15,16	A	7.34	0.03	4
Mrk 178	-14.36	0.05	17, 22	A	7.94	-	7
				B	7.83	-	7
DDO 155 (Gr 8) *	-12.13	0.00	9	Hodge 2b	7.71	0.09	5
IC 4662	-15.67	0.02	17,20,22	A1	8.11	-	8
				A2	8.00	-	8
NGC 6822 *	-14.746	0.002	4,5,14,23,24,25	Hu X	8.10	-	9
				Hu V	8.17	-	9
				Ho 15	8.07	-	9
IC 5152	-15.4	0.5	17, 18	A	7.71	-	6
DDO 221 (WLM)*	-14.143	0.002	6,14,15,24	7	7.6	0.1	10
				9	8.0	0.4	10

et al., 1979) for the 15 galaxies of Table 2 for which the abundances were calculated with the aid of the [OIII]+[OII] lines and some additional objects for which the line [OIII]λ4363 was absent. The result is shown in Fig. 7. When no nitrogen emission line measurements were reported in the spectra the discrimination between the upper and the lower branches was done by using the values calculated previously from the temperature-sensitive method. For five objects this was not possible and it was assumed that they were situated on the lower branch. As evident from the figure, the inclusion of objects with low excitation, where the oxygen abundance has been determined using the semi-empirical method, does not change the situation significantly. Other semi-empirical calibrations (McGaugh, 1994; Skillman, 1989) gave the same result.

The reliability of the distance determinations as well as the influence of the uncertainties were investigated. Only galaxies for which distances were calculated using the Cepheid light curves were chosen. An inspection of Fig. 8 indicates that even if the uncertainties in M$_b$ could be responsible for some of the scatter of the diagram, the uncertainties in the distance determinations cannot explain the lack of a relationship between metallicity and luminosity.

From these results it could be confirmed that a relationship between Z and L using the oxygen abundance and the abso-

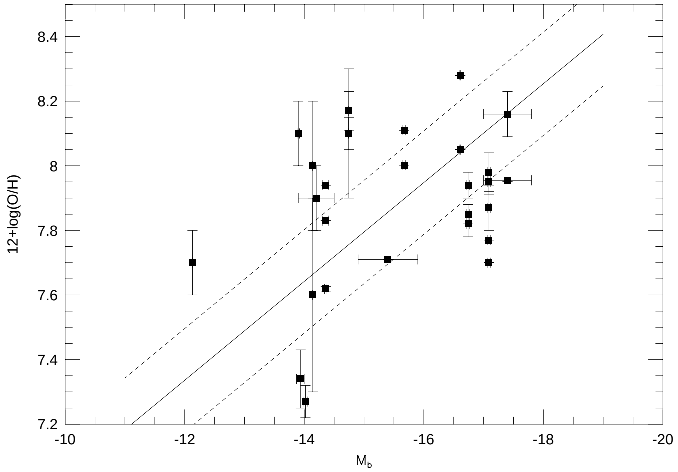

Fig. 6. Z-L relationship of dI's. The diagram shows a total of 28 H II regions corresponding to 15 galaxies for the sample of dwarf irregular galaxies. The oxygen abundance was determined using the temperature-sensitive method, only. The correlation coefficient is r_l = -0.52. The symbols without errorbars in M_b correspond to galaxies for which the distance was obtained from Cepheid light curves. The line is the relationship obtained by SKH (1989) and the dotted lines correspond to a 1σ deviation.

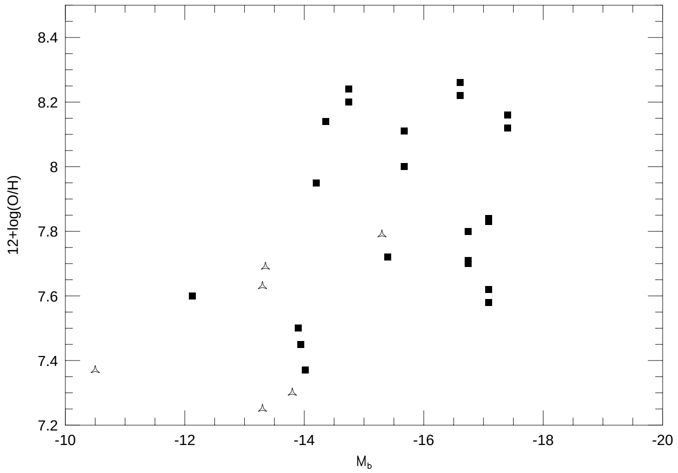

Fig. 7. The Z-L relationship of dI's. The metallicity was calculated using the semi-empirical method by Pagel et al., (1979). The filled squares represent the galaxies from Table 2 and the open triangles are galaxies from the sample but where the [OIII]λ4363Å line was absent in the spectra. For two of these galaxies the M_b was extracted from SKH, (1989) while in other cases it was calculated as described in Sect. 3.2. The correlation coefficient is r_l = -0.44 for a total of 32 H II regions.

lute magnitude in the B-band as indicators does not exist for dI galaxies. However, one can ask whether these two indicators are the proper ones to use. Perhaps there are better indicators which hold a more direct link between the luminosity and the metallicity of a dI galaxy. This will be discussed in Sect. 5.

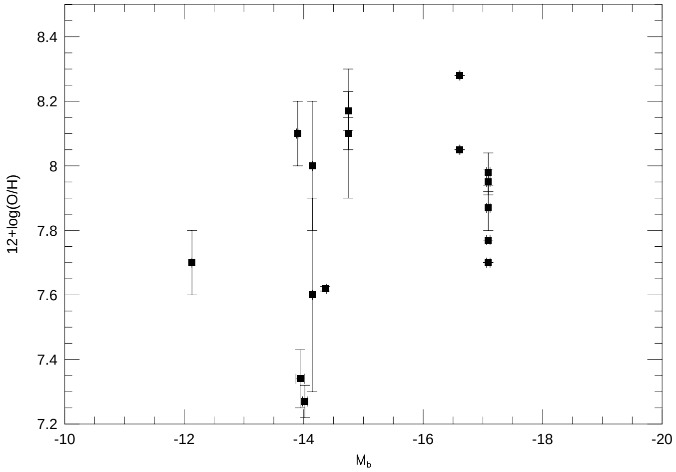

Fig. 8. The Z-L relationship of dI's. In this case the metallicity was calculated using the temperature-sensitive method (Osterbrock, 1984), i.e. where [OIII]λ4363Å line was measurable, and the M_b was derived by Cepheids light curve measurements. For the 20 H II regions in 10 galaxies a r_l = -0.20 was derived.

4.1. Comparison with the Skillman et al. and Richer and McCall samples

By studying the data used in this investigation it is clear that 12 and 13 galaxies are common with the SKH and RM samples, respectively. The main difference, besides new data in this analysis, is the use of the temperature-sensitive method, only, for determining the oxygen abundances. It should be also stressed that no averaged oxygen abundances for the whole galaxy was used in this investigation.

Table 3 presents a comparison between the data in this analysis and those of SKH and RM. As seen, five galaxies have a difference in oxygen abundance between this work and SKH in excess of 0.1, but only two comparing the RM sample The latter used more updated oxygen abundance data.

5. Discussion

One explanation for the different conclusions reached in this study and the previous ones could involve the handling of the sample itself. As pointed out earlier, only dI's galaxies are included in the sample. This is not the case in the previous studies. The inclusion of more luminous galaxies (the so-called magellanic irregulars) could mask the real trend in the Z-L plane for dI's. In Fig. 9 is visualized the Z-L relationship for a sample including non-dI's galaxies as well as the sample of dI's. These non-dI's are galaxies brighter and/or larger than the limits imposed in the definition of dwarf galaxies. Two of the galaxies (NGC 5408 and ESO 381-G20) have high surface brightnesses. This, together with the small sizes and relatively faint magnitudes, classifies the galaxies as blue compact's rather than dI's. The relationship seems to be more in line with the results of SKH and RM if the correlation coefficients are compared (r_{HGO} = -0.79, r_{SKH} = -0.88). Even if the diagram shows a consider-

Table 3. Comparison between the galaxies in this work and the SKH and RM samples. The identification of the common galaxies is given in column 1. Columns 2 and 3 give the difference in the absolute magnitude between this work (HGO) and that of Skillman et al. (HGO-SKH), this work and Richer and McCall (HGO-RM) as well as between the comparison samples (SKH-RM). Columns 5, 6 and 7 give the same differences for the oxygen abundance. It should be noted that averaged values were used in this table for the purpose of comparison.

Galaxy	$\Delta M_{b(HGO-SKH)}$	$\Delta M_{b(HGO-RM)}$	$\Delta M_{b(SKH-RM)}$	$\Delta Z_{(HGO-SKH)}$	$\Delta Z_{(HGO-RM)}$	$\Delta Z_{(SKH-RM)}$
IC 10	0.41	-0.18	-0.59	-0.04	-0.05	-0.02
IC 1613	-0.24	-0.06	0.18	-0.17	-0.02	0.15
NGC 1569	-0.50	1.06	1.59	-0.10	-0.10	0.0
NGC 2366	0.29	1.30	1.01	-0.10	-0.06	0.04
DDO 47	-1.40	-	-	0.03	-	-
DDO 50	-	0.61	-	-	-0.05	-
DDO 69	0.92	1.93	0.17	-0.03	-0.09	-0.06
DDO 70	-0.70	0.17	0.87	0.55	-0.01	0.56
DDO 75	-0.66	0.41	1.07	-0.15	-0.21	-0.06
Mrk 178	-	1.12	-	-	0.02	-
Gr 8	-0.37	1.61	1.98	0.28	0.08	-0.20
IC 4662	-	0.03	-	-	-0.03	-
NGC 6822	-0.34	-0.13	0.32	-0.02	-0.11	-0.09
IC 5152	1.0	-	-	-0.65	-	-
WLM	-0.06	0.41	0.27	0.06	0.0	-0.06

able scatter, the most luminous galaxies tend to have higher metallicities.

Another problem, mostly neglected, deals with the proximity of these objects. Slit spectroscopy of H II regions in relatively distant galaxies often include the whole region. This means that the total ionization structure is observed and accounted for. In nearby dI's the situation is somewhat different since the H II regions appear much larger in size. Therefore, only part of the region is observed which under the most unfavourable situation could emulate a density-bounded region since e.g. the [OII] region could be outside the spectroscopic slit. This would result in odd emission line strengths not representative of the whole Strömgren sphere, which in turn would influence the determination of the oxygen abundance.

A number of physical realities could influence the measurements of the metallicity of dI's. The two most important ones will be outlined in the following.

5.1. Ejection of chemical elements and the star formation history

One condition which could affect the Z-L relationship is inhomogeneities in the metallicity throughout the face of the galaxy or even variations within a given H II region. This is easily understood in terms of time-dependent ejection of chemical elements e.g. oxygen-rich ejecta from supernovae or stellar winds, in particular from massive stars. Oxygen is synthesized by, mainly, massive stars with short lifetimes. These will end as supernovae, a few million years after the onset of star formation, ejecting large amounts of oxygen into the interstellar medium. The ejection of oxygen is therefore closely linked to the onset and cessation of star formation (Olofsson, 1995). Nitrogen is released much more quietly since it is mostly a product of intermediate mass stars with life-times of a few billion years, and the abundance of nitrogen in the interstellar medium is therefore less sensitive to the star formation history of the object. The same is true for the magnitude because the blue band gives the luminosity connected with the most recent burst of star formation and the B-magnitude of the object will be strongly dependent on the evolutionary state of the galaxy. The near-IR magnitude is probably more suitable as a luminosity indicator since it traces the older stellar population of the galaxy, despite the problem of avoiding the young red supergiants.

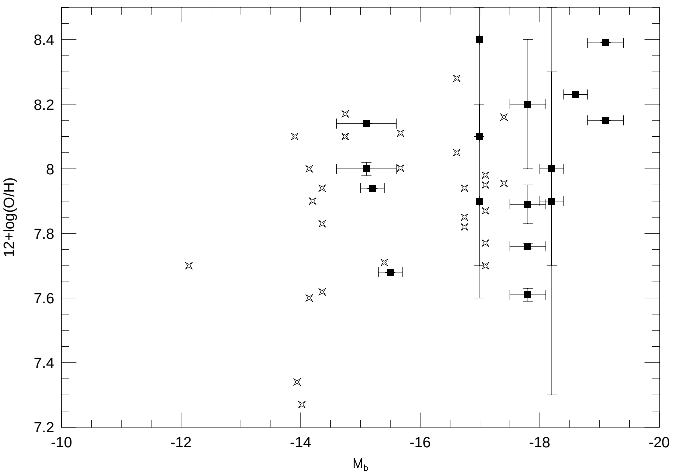

Fig. 9. The Z-L relationship of non-dwarf irregular galaxies (filled squares) and the dI's (open stars). Both parameters were calculated as for the dI's sample. A total of 17 H II regions from 10 galaxies and with a correlation coefficient of r_l= - 0.79.

Table 4. Data of non-dwarf galaxies. The columns are the same as in Table 1 as well as the comments to the table. *References for distances*: (1) Melisse & Israel, 1994; (2) Tully, 1988b; (3) Huchtmeier & Richter, 1988; (4) Richter & Huchtmeier, 1984; (5) Hunter et al., 1993; (6) Sandage & Tammann, 1982; (7) Tully, 1988a; (8) Hunter & Thronson, 1996; (9) Webster et al., 1983; (10) Pritchet et al., 1987; (11) Karachentsev & Tikhonov, 1996; (12) Richer & McCall, 1995 *References for metallicity*: (1) Masegosa et al., 1994; (2) McCall et al., 1985; (3) Webster et al., 1983; (4) Stasinska et al., 1987; (5) Masegosa et al., 1991.

Galaxy	r (kpc)	Δr	M_b	ΔM_b	References	Region	12+log (O/H)	Δ(12+log (O/H))	References
NGC 5408	0.52	.006	-15.1	0.5	1,2,3,4	A	8.00	0.02	1
						B	8.1400	0.0005	1
NGC 4214	5.82	.09	-18.2	0.2	1,2,3,4,5,6,7	IA	7.9	0.6	5
						IΣ	8.0	0.3	1
NGC 4449	4.21	.3	-18.6	0.2	1,2,3,4,5,7,8	2	8.23	-	2
UGCA 65	5.38	.02	-15.5	0.2	7,9	1	7.68	-	3
ESO 381-G20	2.57	.01	-15.2	0.2	1,3,4,7	A	7.94	-	3
NGC 55	9.88	.003	-19.1	0.3	1,2,3,4,7,8,10	HK3	8.15	-	4
						HK10	8.39	-	4
						HKC	8.53	-	4
IC 2574	6.88	.003	-16.986	0.002	11,12	IIA	7.9	0.3	5
						IIB	8.4	0.3	1
						IIΣ	8.1	0.4	1
NGC 4395	9.39	.002	-17.8	0.3	1,2,3,4,7	1	7.760	0.008	2
						2	8.2	0.2	2
						4	7.89	0.06	2
						5	7.61	0.02	2

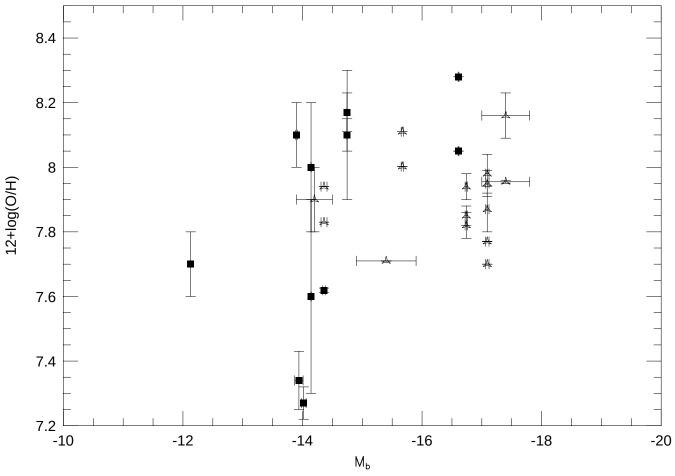

Fig. 10. The Z-L relationship of dI's with and without companions. The filled squares correspond to galaxies with gravitational companions. The correlation coefficient is r_l= - 0.45 for this subsample (including 12 H II regions). The unfilled triangles represent gravitationally isolated galaxies. r_l= -0.29 in this case for a total of 14 H II regions.

5.2. The rôle of the environment

The environment in which these galaxies resides could influence their position in the Z-L plane. Support for this has been given by Vílchez (1995). It is thought that star formation in gas-rich galaxies could be triggered by encounters with other galaxies. The increase in the rate of star formation could affect the Z-L relationship and acts in accordance with a non-closed box scenario.

A search for companions which could affect the star formation process by gravitational influence was made. All the galaxies in a sphere centered on the Milky Way with a radius of 9 Mpc were selected which means that all the dI's in the sample were included. The distances were taken from the Tully catalogue (1988a). In order to check for possible gravitational companions to the dI's in the sample we defined a quantity, A, such that

$$A = \frac{r_{rel}}{d} (Mpc^{-1})$$

d is the separation between the objects in Mpc and was calculated using software derived by Márquez (1996). r_{rel} is the relative radius and is defined as

$$r_{rel} = \frac{r_{comp}}{r_{dwarf}}$$

where r_{comp} and r_{dwarf} are the radii of the companion and the dI, respectively, to the 25:th isophote in the B-band. Following Campos-Aguilar (1992), the maximum distance of gravitational influence between a dwarf galaxy and a normal size companion was assumed to be 100 kpc. Galaxies at larger distances are considered not to be interacting gravitationally. With r_{rel} = 1, the turn-off value of A is 10 Mpc^{-1} by this definition. Hence, galaxies with $A \leq 10$ are negligible as gravitational influencer of star formation on the dI.

The A parameter naturally divided the sample in galaxies with companions and those without. It is found that about half of the galaxies have no gravitational companions. This is in agreement with studies of the environment of BCG's (Campos-Aguilar et al., 1993; Telles & Terlevich, 1995). The Z-L relationship is shown in Fig. 10 with the sample divided into these two categories. As evident from the figure no clear distinction can be made between the two categories although the total sample is somewhat restricted. Such a study should inevitably involve modelling of the dynamical evolution of galaxies with companions since the timescales involved should have great impact on both the metallicity and the luminosity of the objects.

6. Conclusions and future work

We have revisited the metallicity-luminosity relationship of dI galaxies. Previous investigations have indicated that such a relationship exists, the more luminous the object is, the higher the metallicity, in accordance with a closed-box scenario of galaxy evolution. For many of the galaxies these conclusions are based on metallicities obtained from spectra as early as in the late 70's and many are of rather poor quality. We recalculated the metallicity from the published spectra and the absolute magnitude was obtain with the most up-to-date distance determinations. Some conclusions can be inferred from these results.

1- Firstly no relationship between the oxygen abundance and the absolute magnitude in the blue band for dI's was found. The situation could change if more appropriate parameters are used; nitrogen is probably a better element as metallicity indicator because it is not so strongly affected by the history of star formation. The same is true for the absolute magnitude because the blue band gives the luminosity connected with the most recent burst of star formation. The nitrogen abundance vs. absolute near-IR magnitude is probably more appropriate to use when studying the possible relation between metallicity and luminosity since the near-IR magnitude is more linked to the older relaxed stellar population of the galaxy.

2- Secondly, about half of the galaxies are gravitationally isolated. This is in line with other studies of classes of dwarf galaxies. It is recognized that galaxy-galaxy interactions could trigger star formation and by modelling these systems dynamically in time the star formation history could be extracted and the effects on the position in the Z-L plane could hopefully be better understood.

Obviously, a lot of work remains to be done. We are in the state of obtaining high quality spectra for a large number of nearby dI galaxies. These new data can hopefully give a more conclusive answer to the existence or non-existence of a Z-L relationship of dI galaxies.

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