

# The FIR-radio correlation of Wolf-Rayet galaxies and the role of star formation in LINERs

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**Abstract.** We find that a preliminary classification of LINERs' energetics may be made in terms of the FIR-radio correlation of Wolf-Rayet galaxies. The AGN- or starburst-supported LINERs can be distinguished by their FIR-to-radio ratio,  $Q \equiv L(1.4\text{GHz})/L(60\mu\text{m}) >$  or  $< 0.01$ . It is interesting to note that almost all the LINERs with inner rings might be starburst-supported, indicating reduced AGN activities compared with those of the AGN-supported ones. We also find that a shock-heating phase for the warm dust component might be important for some starbursts at the burst age of  $\geq 10^7$  yr, with  $Q < 0.001$ .

**Key words:** galaxies: active – infrared: galaxies – radio continuum: galaxies

## 1. Introduction

Low ionization nuclear emission regions (LINERs, Heckman 1980) are galaxies with strong forbidden lines from low ionization states, compared with those from higher ionization states, typically  $[\text{O II}] 3727 > [\text{O III}] 5007$ . LINER phenomena are the most common activities of galaxies known in the local universe (Ho et al. 1997). If most LINERs are truly low luminosity active galactic nuclei (LLAGN) (Ho 1998), it will be important to understand the nature of AGN by investigating the role of LINERs. However, the origin of LINER phenomena is debated (Maoz et al. 1998; Lawrence 1998; Ho 1998; and the references therein). Maoz et al. (1998) claimed that the young stellar population may provide enough ionizing photons for the observed spectra of a significant fraction of LINERs, and it is also possible that LINERs may be a heterogeneous class. A good example is M 81, one of the nearest bright LINERs. Ho (1998) stressed the incontrovertible, nonstellar nature of M 81, though the stellar contribution cannot be ruled out (Maoz et al. 1998). Recently, Hameed & Devereux (1999) discussed the extended nuclear emission-line regions having a LINER spectrum in M 81, and argued that M 81 is likely a composite object. They also proposed that shock heating or UV-photons from post asymptotic giant branch stars are probably responsible for the extended LINER emission. Further evidence for the “composite” nature for M 81 is provided by the ROSAT HRI data (Colbert & Mushotzky 1998), in which the intensity ratio of the

point-like component to the extended one is about 3/2 (Colbert, private communication).

It has been suggested (Condon et al. 1982) that the AGN activities can be distinguished from starbursts by using the FIR-radio correlation, which is more significant for starbursts than for AGN. The weak FIR-radio correlation of Seyferts may imply the starburst (SB)-dominated bolometric luminosity for Seyferts (Forbes & Norris 1998; also see, Norris et al. 1988). The hypothesis of a close connection between starbursts and Seyferts has been proposed by Terlevich and his collaborators (Terlevich & Melnick 1985; Terlevich et al. 1992). They claim that the radio-quiet AGN are powered by massive nuclear starburst in a metal-rich environment. Recently, Heckman et al. (1997) discovered a powerful nuclear starburst (in the Wolf-Rayet (WR) phase) in Seyfert galaxy Mrk 477. The bolometric luminosity of Mrk 477 in the central region might be dominated by the nuclear starburst. It was remarked by Maiolino et al. (1998) that Heckman et al.'s study would provide observational evidence partly supporting Terlevich's hypothesis.

Following these leads, we have explored the energetics of LINERs by using the FIR-radio correlation for Wolf-Rayet (WR) galaxies, suggesting different energy budgets of LINERs.

## 2. FIR-radio correlation of WR galaxies

WR galaxies are extragalactic sources that exhibit broad emission lines characteristic of WR stars in their spectra (Conti 1991). Their typical burst ages are  $\sim 2\text{--}8$  Myr. The 50 WR galaxies that show a good FIR-radio correlation, as shown in Fig. 1a, have detected flux at 1.4 GHz in NVSS Catalog (Condon et al. 1998) and  $60\mu\text{m}$  in IRAS (Moshir et al. 1992) among 139 known sources (Schaerer et al. 1999). Such a correlation of WR galaxies is apparently nonlinear, with a regression coefficient of about 1.20, as obtained before for other samples of galaxies (e.g. Fitt et al. 1988; Cox et al. 1988).

This correlation can be understood in the framework of starburst phenomenon (Moorwood 1996; Lisenfeld et al. 1996). For simplicity, we take the stars/dust geometry to be close to a star-free shell of dust surrounding a central dust-free sphere of stars (Mas-Hesse & Kunth 1999). In this scenario, the radiation from the nuclear starburst (the optical, ionizing and non-ionizing pho-

tons) heats the dust grains, and the UV photons emitted from the nuclear massive stars photoionize the gas.

The radio flux at 1.4 GHz consists of thermal bremsstrahlung emission from photoionized gas and synchrotron radiation from supernova remnants. The luminosities of the two radiation mechanisms are respectively given by Rubin (1968)

$$L_T^{f-f}(\nu) = 1.59 \times 10^{-32} \left( \frac{\nu}{\text{GHz}} \right)^{-0.1} T_4^{0.45} N_{\text{UV}} \text{ W Hz}^{-1} \quad (1)$$

where  $T_4$  is electron temperature in units of  $10^4 \text{K}$  and  $N_{\text{UV}}$  ionizing photons per second, and by Colina & Pérez-Olea (1992)

$$L_{\text{NT}}^{\text{SNR}}(\nu) = 4.45 \times 10^{22} \left( \frac{\nu}{\text{GHz}} \right)^{-0.7} T_{\text{SNII}} \text{ W Hz}^{-1} \quad (2)$$

where  $T_{\text{SNII}}$  is the Type II supernova rate.

The FIR radiation at  $60 \mu\text{m}$  is assumed to be composed of two parts: the warm dust component caused by the same starburst event, and the cool dust component outside the starburst region heated by the general interstellar radiation. Xu et al. (1994) modelled the contribution of cool and warm components in FIR - radio correlation for late-type galaxies. Several authors have virtually tried correcting or linearizing the FIR-radio correlation (Condon 1992; also see Fitt et al. 1988; Devereux & Eales 1989). The luminosity of the FIR radiation is described by

$$L_{\text{IR}}(\nu) = 4\pi B_\nu(T_{\text{d,w}})Q_{\text{abs}}(\nu)\pi a^2 N_{\text{d,w}} + 4\pi B_\nu(T_{\text{d,c}})Q_{\text{abs}}(\nu)\pi a^2 N_{\text{d,c}} \quad (3)$$

where  $T_{\text{d,w}}$  and  $T_{\text{d,c}}$  are the warm and cool dust temperatures,  $N_{\text{d,w}}$  and  $N_{\text{d,c}}$  the total number of warm and cool dust grains,  $a$  is the average radius of dust grains,  $Q_{\text{abs}}(\nu)$  the absorption efficiency of dust grains, and  $B_\nu(T_{\text{d}})$  the Planck function. We adopt the ‘‘astronomical silicate’’ dust model (Draine & Lee 1984), which is most likely suitable to starburst galaxies (Mas Hesse & Kunth 1999).

Assuming a ‘‘steady-state’’ case for the dust grains, the dust temperatures can be derived from the equilibrium between dust absorption and dust emission,

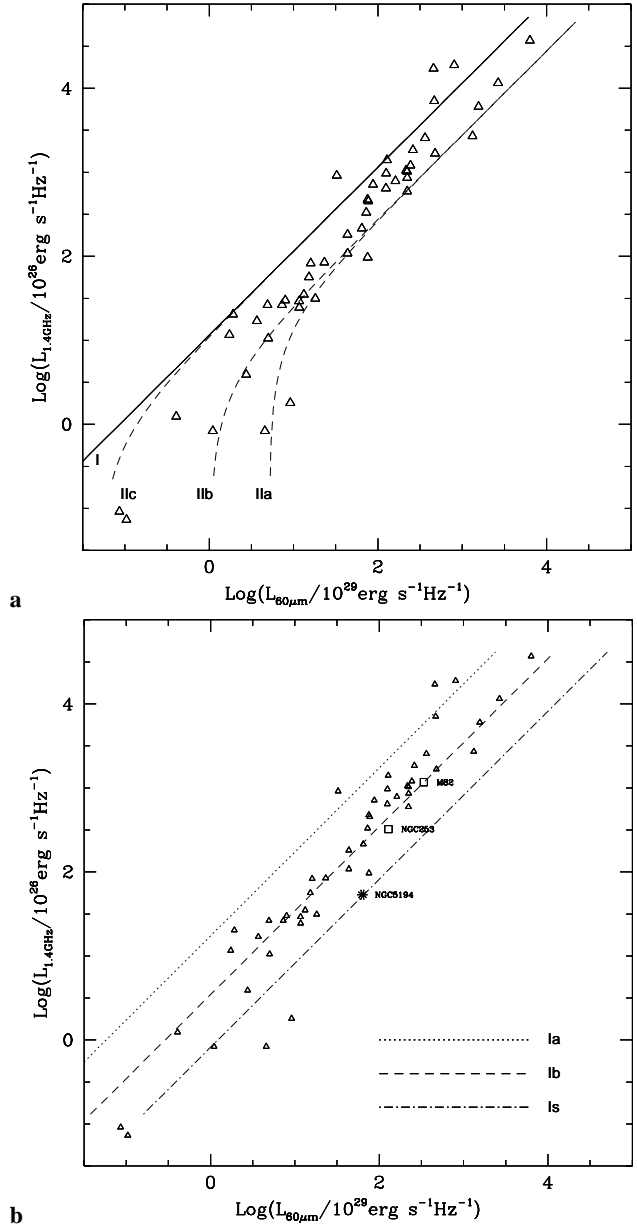
$$c \int_0^\infty U_\lambda Q_{\text{abs}}(\lambda) d\lambda = 4\pi \int_0^\infty B_\lambda(T_{\text{d}}) Q_{\text{abs}}(\lambda) d\lambda \quad (4)$$

where  $U_\lambda$  is the energy density of a diluted radiation field that heats the dust, which is satisfied with

$$U_\lambda = \frac{4\pi}{c} B_\lambda(T_{\text{eff}}) W \quad (5)$$

where  $W$  is the dilution factor, and  $T_{\text{eff}}$  the equivalent effective temperature for the radiation field generated by starburst activities. Using the  $\lambda^{-1}$  dependence for  $Q_{\text{abs}}(\lambda)$ , one can yield the dust temperature from equa. (4):  $T_{\text{d}} \sim T_{\text{eff}} W^{\frac{1}{5}}$  (Spitzer 1978). The FIR luminosity at  $60 \mu\text{m}$  can be obtained from equa. (3), scaling the value of  $Q_{\text{abs}}(\lambda)$  to fit the Draine & Lee (1984) model at  $60 \mu\text{m}$ :  $[\lambda Q_{\text{abs}}(\lambda)/a]_{60 \mu\text{m}} \sim 2.5$ .

At any given burst age, the evolutionary synthesis model, GISSEL95 (Bruzual & Charlot 1996), is used to provide the relevant quantities such as  $N_{\text{UV}}$ ,  $T_{\text{SNII}}$ , and the bolometric corrections for deriving the effective temperatures. Considering the



**Fig. 1a and b.** a FIR-radio correlation of WR galaxies, denoted by open triangles. Model predictions are shown by lines: solid line for warm dust component at the burst age of 6 Myr; dashed lines for models containing both warm and cool dust components, see the text for details. b Same correlation as Fig. 1a, added several sources at the burst age of  $10^7 - 10^8$  yr. Model predictions for the age of  $2 \times 10^7$  yr are indicated by lines: dotted line for dust-to-gas ratio of 1/100; dashed line for dust-to-gas ratio of 1/20; dot-dashed line for containing shock-heating phase but with same parameters as those for dashed line, see text for further details.

discussion by Mas Hesse & Kunth (1999), we have assumed 50% of  $N_{\text{UV}}$  are absorbed by dust.

We have estimated the possible values of the dilution factor in various ways and adopt their average,  $10^{-14}$ , which is compatible with the usual interstellar value (Spitzer 1978). The radiation transfer is not taken into account. A dust-to-gas mass

**Table 1.** Model parameters

	<i>Fig. 1a</i>				<i>Fig. 1b</i>		
	<i>I</i>	<i>IIa</i>	<i>IIb</i>	<i>IIc</i>	<i>Ia</i>	<i>Ib</i>	<i>Is</i>
IMF				Salpeter			
mass range			$0.1M_{\odot}$	$\sim$	$125M_{\odot}$		
metallicity				$Z_{\odot}$			
$T_e$ (K)				$10^4$			
$M_{\text{dust}}/M_{\text{gas}}$	1/100	1/100	1/100	1/100	1/100	1/20	1/20
age (Myr)	6	3	3	6	20	20	20
$M_{\text{cool}}(M_{\odot})$	—	$5 \times 10^6$	$10^6$	$5 \times 10^4$	—	—	—
$n_e$ (cm $^{-3}$ )	—	—	—	—	—	—	300
$v_s$ (km s $^{-1}$ )	—	—	—	—	—	—	200
$T_{\text{d,w}}$ (K) <sup>*</sup>	31	43	43	31	27	27	46 <sup>s</sup> , 27
$T_{\text{d,c}}$ (K) <sup>*</sup>	—	20	20	20	—	—	—

★ derived values

s temperatures of the warm dust in shock region

ratio  $\sim 1/100$  is assumed. We also assume that the gas mass is comparable to the star mass in the starburst region ( $M_{\text{SB}}$ ) (namely the gas-to-star mass ratio is roughly unity). The total grain number is interpreted as  $M_{\text{SB}}/\rho_d a^3$  where the density of the ‘astronomical silicate’ is adopted as  $\rho_d \sim 3\text{g cm}^{-3}$  (Draine & Lee 1984).

For calculating the cool dust temperature, we assume that the cool dust component may be heated by the general interstellar radiation field that arises from a past starburst event with a typical burst age  $\geq 1$  Gyr. The mass of the cool component is a free parameter, and we try fixing its value,  $10^6 M_{\odot}$  or  $5 \times 10^4 M_{\odot}$ , for any  $M_{\text{SB}}$ . It means that the contribution from the cool component is relatively significant for small burst strength (small  $M_{\text{SB}}$ ), and relatively unimportant for ultraluminous infrared galaxies (ULIGs; large  $M_{\text{SB}}$ ). Generally, we have  $T_{\text{d,c}} \sim 20$  K, similar to the assuming cool dust temperature by Fitt et al. (1988).

To perform the calculations, we take  $M_{\text{SB}}$  as an independent variable, which is in the range of  $10^{4.5-10^{10}} M_{\odot}$ . The upper end of  $M_{\text{SB}}$  corresponds to the case of ULIGs (e.g. Genzel et al. 1998). The stronger the starburst (i.e., the larger  $M_{\text{SB}}$ ), the higher the FIR and radio luminosities. With various adopted parameters (burst ages, dust-to-gas ratio, etc.), we obtain *linear* FIR-radio correlations if taking only the warm dust component into consideration, or a *nonlinear* correlations if both the warm and cool dust components. The model curves are plotted in Fig. 1a, the model parameters are listed in Table 1.

The solid line I in Fig. 1a represents the linear part of our model prediction at the burst age of 6 Myr, in which the contribution of cool dust emission is neglected and thermal (bremsstrahlung) emission is dominant at 1.4 GHz. The dashed lines in Fig. 1a illustrate the lower-right envelopes for models, in which the contribution of cool dust emission is taken into account. For lines IIa and IIb, the cool dust mass is taken as  $5 \times 10^6 M_{\odot}$  and  $10^6 M_{\odot}$  at the age of 3 Myr, respectively, and for line IIc, the cool dust mass is  $5 \times 10^4 M_{\odot}$  at the age of 6 Myr. As expected, counting the cool dust emission reproduces

the nonlinear trend in the correlation lines. It is quite reasonable to see in Fig. 1a that the cool dust component makes significant contribution in the case of small burst strength, while it is negligible compared with warm component for large burst strength. Satisfactorily, the majority of WR galaxies are located in a ‘‘passage’’ escorted by the upper and lower envelopes in the diagram. Reasonably, this passage may be considered to be typical of the positions of the SB-dominated galaxies.

In Fig. 1b, we have added two prototypical starburst galaxies, M 82 and NGC 253, corresponding to a burst age of  $10^7$ - $10^8$  yr. The dotted line Ia in Fig. 1b indicates our model prediction (with a dust-to-gas ratio of 1/100) at the burst age of  $2 \times 10^7$  yr, which represents the upper end of age for the supernova, set by GISSEL95. The non-thermal (synchrotron) radiation dominates at 1.4 GHz in this case. Considering the enrichment of the dust grains by supernova explosions at this age, the dust-to-gas ratio can increase by several times, up to an order of magnitude (Hirashita 1999), so it would be reasonable to replace the dust-to-gas ratio of 1/100 with 1/20. As a result, the model curve will shift to a position indicated by the dashed line Ib in Fig. 1b.

In order to fit the galaxies that exhibit ongoing star formation, such as a transition object NGC 5194 (Heckman 1980; Larkin et al. 1998), we tried to add a shock wave (that may be related with the supernova explosions and/or outflowing winds from starburst) as additional mechanism for heating the dust, following Dwek (1986) and Contini et al. (1998). The model curve containing a shock-heating phase is represented by the dot-dashed line Is in Fig. 1b, which is below the lower border of the passage mentioned above. Here, we have adopted a shock velocity  $v_s = 200\text{km s}^{-1}$ , a shock covering fraction 1/10, and a dust-to-gas ratio 1/20 at the age of  $2 \times 10^7$  yr. It is worth noting that a strong near-infrared [Fe II] line has been observed in NGC 5194, and the shock excitation in supernova remnants is probably the mechanism responsible for this line (Larkin et al. 1998). This excitation mechanism may be consistent with our consideration of shock-heating of dust in this galaxy, with  $v_s$  in order  $\sim 100\text{ km s}^{-1}$ .

### 3. Energetics of LINERs

#### 3.1. Classification of LINERs

Recently, more than a dozen of LINERs have been studied with space facilities or large ground-based telescopes. Table 2 lists these sources with claims for their energetics, except for M 81 because of the debate mentioned in Sect. 1. Fig. 2a indicates the positions where these LINERs are located in the FIR-radio diagram of WR galaxies. It is very instructive to see that the LINERs with SB-supported claims or with the existence of nuclear starburst, in notation of SB in Table 2, have a similar distribution to WR galaxies, while the AGN-supported LINERs or those with the existence of AGN are distinctively located in the upper-left part of the FIR-radio diagram. The latter category of objects is found above the upper border (solid line in Fig. 2a) of our models for starburst events.

Furthermore, we investigate two cases of LINERs that are considered to have a composite nature, NGC6240 and M 81.

**Table 2.** LINERs with claims

Name	Type	$\log(L_{60\mu\text{m}})$ ( $10^{29}\text{erg s}^{-1}\text{Hz}^{-1}$ )	$\log(L_{1.4\text{GHz}})$ ( $10^{26}\text{erg s}^{-1}\text{Hz}^{-1}$ )	$D$ (Mpc)	Energetics	References
M 84	.E.1...	0.3	3.7	16.8	AGN	H98
M 87	CE.0...	0.1	6.2	16.8	AGN	H98, Col98
NGC 1052	.E.A...	0.6	3.5	17.8	AGN	B98
NGC 3718	.SBS1P.	0.3	1.7	17.0	AGN	H98
NGC 3998	.LAR0\$.	0.5	2.7	21.6	AGN	L98
NGC 4203	.LX. - *	-0.1	0.9	9.7	AGN	H98, I98
NGC 4278	.E.1 + ..*	-0.1	2.6	9.7	AGN	F98
NGC 4594	.SAS1./	1.3	2.6	20.0	AGN	M98, N98
NGC 4579	.SXT3..	1.3	2.3	16.8	AGN	M98, L98
NGC 6500	.SA.2 * .	1.1	3.5	39.7	AGN	F98, M98
M 81	.L.....	-0.5	0.3	1.4	Composite	H98, M98, Col98
NGC 6240	.I.0. * P	3.4	4.7	98.1	Composite	S98
NGC 404	.LAS - *.	-0.8	-0.6	2.4	SB	M98
NGC 5055	.SAT4..	1.4	1.4	7.2	SB	M98
NGC 4736	.RSAR2..	1.2	1.0	4.3	SB	L98
NGC 5194	.SAS4P.	1.8	1.9	7.7	SB	L98
NGC 7217	.RSAR2..	1.2	1.4	16.0	SB	L98
NGC 4818	.SXT2P*	1.7	2.0	13.5	SB	Coz98
NGC 3310	.SXRAP.	2.2	2.9	18.7	SB	Coz98
NGC 1050	.PSBS1..	2.3	3.0	53.4	SB	Coz98
UGC 03157	.SB?...	2.2	3.0	61.4	SB	Coz98
Arp 220	.S?...	3.9	4.3	73.7	SB	G98

For NGC6240, Schulz et al. (1998) claimed, based on ROSAT data, that both AGN and starburst contribute in roughly equal proportion to the energetics of this galaxy. In our Fig. 2a, both NGC6240 and M 81 are approximately located on the border of our model prediction. Due to the enrichment of dust and the influence of cool dust component as discussed in Sect. 2, the actual position of our model prediction in Fig. 2a might somewhat move to the right and curve up at small burst strength.

Of particular importance to the AGN nature in LINERs is the detection of broad (FWHM  $\sim$  a few thousand  $\text{km s}^{-1}$ ) permitted lines in these sources, which may arise from the broad-line regions (BLR). On the analogy of the nomenclature for Seyferts, Ho (1998) has designated those sources having visible BLR as LINER 1, and others as LINER 2.

It is enlightening to see that the most part of LINER 2's in Terashima (1999) have SB notations in our Table 2, while the majority of LINERs with AGN notations in our Table 2 are listed as LINER 1's in Terashima (1999). Now we have seen a *fact* that these LINER 1's are basically *segregated* from LINER 2's in the FIR-radio diagram. This segregation confirms the early suggestion by Condon et al. (1982) of distinguishing AGN from starburst by use of the FIR-radio correlation.

The majority of sources studied in this paper are at distances of 10 Mpc or beyond, indicating that the FIR-radio diagrams shown in our figures are basically referred to the global properties of galaxies, due to the large resolution/apertures used in the NVSS and the IRAS. Nevertheless, what we have seen in the segregation is the pairing of the observed SB-supported LINERs to modeled SB-dominated passage, *not* in a cross-pair of the

AGN- to SB-dominated passage. It would be hard to understand that the segregation could be just caused by chance.

The studies on LINERs in the IRAS 1-Jy ( $f(60\mu\text{m}) > 1\text{ Jy}$ ) sample of ultraluminous infrared galaxies (LINER ULIGs) by Veilleux et al. (1999) may shed light on the above fact. They conclude that “there is no convincing optical or infrared evidence for an AGN in LINER ULIGs”, and “the main source of energy in these LINERs is a starburst rather than an AGN.” We have put these LINER ULIGs in the FIR-radio diagram in Fig. 2a by symbols of crosses. Their positions are in the SB-dominated passage. Recent studies (see, Veilleux et al. 1999 and the references therein) strongly suggest that the overwhelming part of the bolometric luminosity of ULIGs stems from the inner kpc regions, indicating that the large resolution/apertures used in the NVSS and the IRAS would not make any obvious change in the FIR-radio correlation for LINER ULIGs. In fact, these studies are consistent with the early work by Kennicutt & Kent (1983), which demonstrated that in the case of  $\text{EW}(\text{H}\alpha) \geq 10\text{ \AA}$ , suitable to LINER ULIGs, the  $\text{H}\alpha$  emission observed with a slit is comparable to that obtained using large apertures.

Similar analyses of early-type galaxies (Walsh et al. 1989) suggest no obvious variance in the FIR-radio correlation with the sizes of galaxies. Radio observations of a sample of ellipticals and S0s (Fabbiano et al. 1987) have not found evidence for the extended disk emission, confirming the suggestion that the radiation is from nuclear “starburst” instead of extended disk sources (Dressel 1988). These investigations provide a sound explanation for the statistical study by Walsh et al. (1989), implying that the location of the AGN-supported LINERs (the

majority of which are E/S0 sources) in the upper-left part of FIR-radio diagram (Fig. 2a) may not be significantly influenced by the size of apertures used.

On the other hand, NGC 6500, a spiral far above the border of the starburst events in Fig. 2a, has  $EW(H\alpha) = 27\text{\AA}$  (Ho et al. 1997), indicating little effect of the aperture sizes on the FIR-radio correlation, according to Kennicutt & Kent (1983). The same argument of  $EW(H\alpha) \geq 10\text{\AA}$  holds for NGC 404, one nearby galaxy, and four other LINERs selected from the Pico dos Dias Survey (PDS) (Coziol et al. 1998). Three of the PDS LINERs are classified as transition sources by Coziol et al. (1998), including NGC 3310, designated as starburst in Véron Catalog, that is classified as a transition source, SB/LINER.

The remaining sources, NGC 4736, NGC 5055, and NGC 7217, are three LINERs with  $EW(H\alpha) < 10\text{\AA}$ . For example, the  $EW(H\alpha)$  of NGC 7217 obtained with a slit and a large aperture are about  $3\text{\AA}$  and  $6\text{\AA}$  (Ho et al. 1997; Kennicutt & Kent 1983), respectively. After correcting the aperture effect over this source, the position of NGC 7217 in Fig. 2a may move a bit down- and leftward in the FIR-radio diagram, remaining in the SB-dominated passage. The same argument would be applicable to other sources with  $EW(H\alpha) < 10\text{\AA}$ .

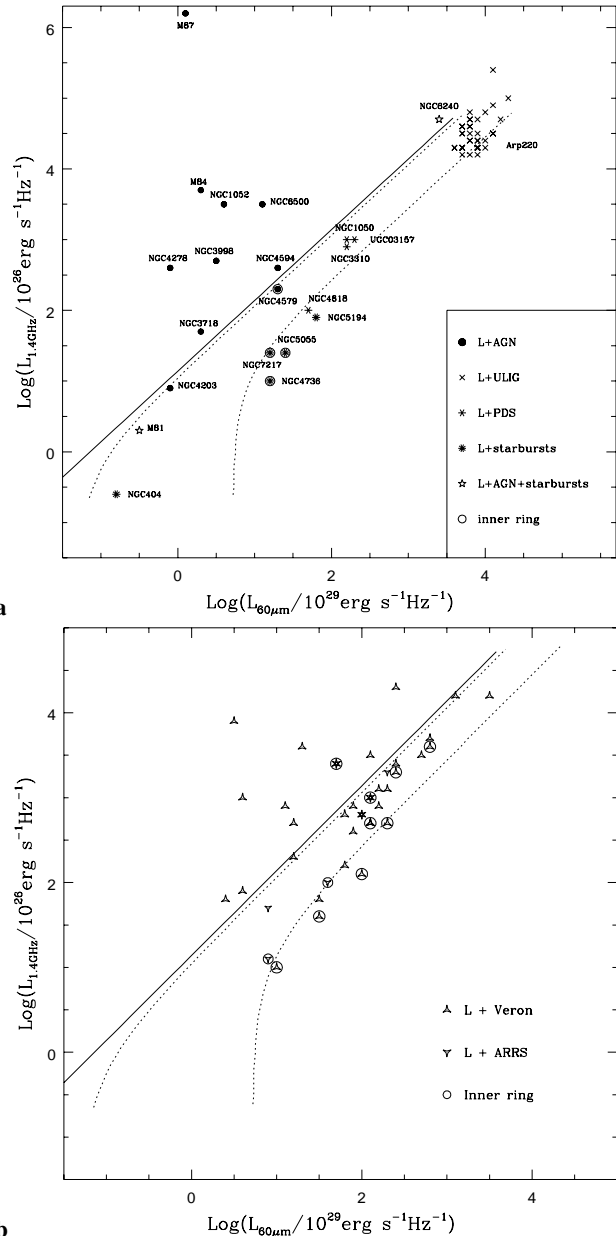
From the above discussion, one can see that the aperture effects may not significantly change the situation of segregation for different types of LINERs shown in Fig. 2a. Therefore, as suggested by Condon et al. (1982), the FIR-radio correlation may provide a *preliminary classification* of LINERs according to their locations in the diagram as we described above. In other words, one may classify LINERs in terms of their FIR-to-radio ratio:  $Q \equiv L(1.4\text{GHz})/L(60\mu\text{m})$ : one has  $Q > 0.01$  for the AGN-supported LINERs and  $Q < 0.01$  for the SB-supported ones.

In Table 3 we list part of LINERs extracted from Véron Catalog (Véron-Cetty & Véron 1996) that have detected fluxes at 1.4 GHz and  $60\mu\text{m}$ , and the preliminary classification of their energetics is given in Column 6. Their distributions in the FIR-radio diagram are shown in Fig. 2b.

As further evidence our classification of the LINERs' types, we mention the new results of Alonso-Herrero et al. (1999). The different types of LINERs identified by these authors are consistent with our predictions for those common ones, as listed in our Table 3. For example, the claimed SB-dominated LINERs in their paper, NGC 3504, NGC 3367, NGC 4569, NGC 4826, and NGC 7743 are all located in our SB-dominated passage, and the AGN-dominated LINER NGC 2639 (Alonso-Herrero et al. 1999) is designated to be an AGN-supported LINER in Table 3. Further observations of these sources are certainly needed, especially for the LINERs located near the boundary of the starburst events shown with solid line in Fig. 2, which might be composite like NGC 6240.

### 3.2. LINERs with inner rings

The effects of rings or bars on Seyfert activities have been studied since the early work in the 1980's (e.g. Simkin, Su, & Schwarz 1980; Arsenault 1989). Recent studies show, however,



**Fig. 2a and b.** **a** Same correlation diagram as Fig. 1a, superposed by LINERs with claims of SB-supported or AGN-supported ones, selected from literature. Dotted lines cover the area where the majority of WR galaxies are located. Solid line illustrates the prediction of starburst event at age of  $10^7$  yr. The notation of L in the lower-right box denotes LINERs. The notation of (L+AGN+Starburst) for M 81 is a symbol of “composite” for this source, see the text for details.

**b** Same as Fig. 2a, but the superposed LINERs are unclassified ones by symbols of starred triangles, extracted from Véron Catalog, and some identified types of LINERs by symbols of inverse-starred triangles, selected from Alonso-Herrero et al. (1999). The symbols of hexa-stars are referred to the common ones between the two sets.

that the frequency of barred systems is the same in Seyferts and in normal spirals (McLeod & Rieke 1995; Ho, Filippenko, & Sargent 1997; Mulchaey & Regan 1997). A latest study on the morphology of the  $12\mu\text{m}$  Seyfert Sample (Hunt et al. 1999) in-

**Table 3.** LINERs from Véron Catalog

Name	Type	$\log(L_{60\mu\text{m}})$ ( $10^{29}\text{erg s}^{-1}\text{Hz}^{-1}$ )	$\log(L_{1.4\text{GHz}})$ ( $10^{26}\text{erg s}^{-1}\text{Hz}^{-1}$ )	$D$ (Mpc)	Energetics
IC 1459	.E.....	0.5	3.9	22.4	AGN
IC 1481	.S?....	2.1	3.5	83.5	AGN
NGC 2639	.RSAR1 * \$	1.7	3.4	44.7	AGN
NGC 2655	.SXS0..	1.1	2.9	24.4	AGN
NGC 2911	.LAS. * P	0.6	3.0	40.8	AGN
NGC 3312	.SAS3P\$	1.2	2.7	35.4	AGN
NGC 4036	.L.. - ..	0.6	1.9	24.6	AGN
NGC 4438	.SAS0P*	1.2	1.3	16.8	AGN
NGC 5675	.S?....	1.3	3.6	55.4	AGN
NGC 7135	.LA. - P.	0.4	1.8	29.9	AGN
Mrk 266NE	.P.....	3.1	4.2	112.7	AGN
Mrk 984	.S.8 * .	2.4	4.3	191.5	AGN
NGC 660	.SBS1P.	2.1	2.7	11.8	SB
NGC 1961	.SXT5..	2.4	3.3	54.1	SB
NGC 2841	.SAR3 * .	1.0	1.0	12.0	SB
NGC 3079	.SBS5./	2.4	3.4	20.4	SB
NGC 3226	.E.2. * P	1.8	2.8	23.4	SB
NGC 3367	.SBT5..	2.1	3.0	39.3	SB
NGC 3561B	.SAR1P.	2.8	3.6	113.7	SB
NGC 3994	.SAR5P\$	2.3	2.7	41.9	SB
NGC 4102	.SXS3\$.	2.2	2.9	17.0	SB
NGC 4192	.SXS2..	1.5	1.8	16.8	SB
NGC 5005	.SXT4..	2.1	2.7	21.3	SB
NGC 5371	.SXT4..	2.0	2.1	37.8	SB
NGC 5851	.S?....	1.9	2.6	87.4	SB
NGC 5921	.SBR4..	1.5	1.6	25.2	SB
NGC 5929	.S.2 * P	2.2	3.1	35.8	SB
NGC 5953	.SA.1 * P	2.0	2.8	27.1	SB
Mrk 313	.PLBS0 * .	1.8	2.2	28.5	SB
Mrk 700	.S?....	2.7	3.5	135.6	SB
Mrk 848B	.L...\$P	3.5	4.2	162.4	SB
IC9 10	.S?....	2.8	3.7	108.6	SB
ESO 568 - G11	.SXS4 * P	1.9	2.9	118.7	SB
UGC 10082S	.SB?...	2.3	3.1	141.1	SB

icates that LINERs have higher rates of inner rings than normal galaxies.

One striking feature in Fig. 2a and 2b is that almost all the LINERs having inner rings are located in the SB-dominated passage. This strong morphological tendency in the LINER sample should have important implication in starburst-AGN connection. Our preliminary analysis shows that the AGN activities of these LINERs are lower than the AGN-supported LINERs located in the upper-left part of the FIR-radio diagram. The reason for the reduced activities might be caused by the reduced fueling gas to the central black holes. We will discuss this topic in a separate paper (Lei et al. 1999), along with the morphological study of Seyferts.

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