Radio – FIR Spectral Energy Distribution of Young Starbursts

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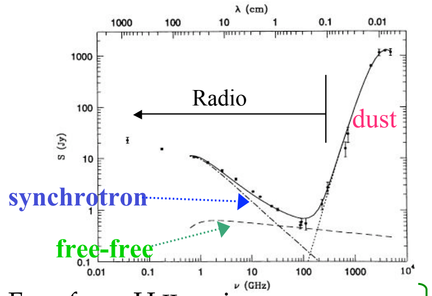
Abstract: We investigate the radio spectral energy distributions (SEDs) of young star-forming galaxies. The duration and luminosity of the nonthermal radio emission from supernova remnants (SNRs) are constrained by using the observed radio SEDs of SBS 0335–052 and I Zw 18, which are the two lowest-metallicity blue compact dwarf galaxies in the nearby universe. The typical radio energy emitted per SNR over its radiative lifetime in SBS 0335–052 is estimated to be ~ 6–22×10^{22} W Hz^{-1} yr at 5 GHz. On the other hand, the radio energy per SNR in I Zw 18 is ~ 1–3×10^{22} W Hz^{-1} yr at 5 GHz. We discuss the origin of this variation and propose scaling relations between synchrotron luminosity and gas density. These models enable us to roughly age date and classify radio spectra of star-forming galaxies into active (e.g., SBS0335–052)/passive (e.g., I Zw 18) classes.

1. Introduction

Typical radio spectral energy distribution (SED) of galaxies



Condon (1992)
M82

Free-free: H II regions
Synchrotron: Supernova Remnants

Related to star formation activity of galaxies

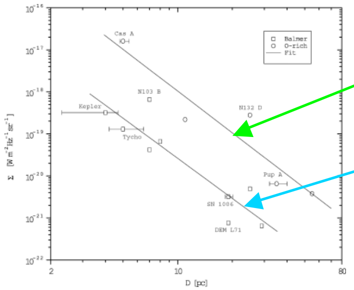
Synchrotron Component

Radio synchrotron emission from supernova remnants (SNRs) can be estimated as
(supernova rate) × (radio energy per SNR)
↑
Estimated from the Σ (radio surface brightness) – *t* (age) relation

Recently, Arbutina et al. (2004) have found that the Σ – *t* relation depends on density.

Density-Dependent Σ – *t* Relation

Arbutina & Urošević (2005)
Supernovae in high-density environments tend to have high radio surface brightness.



Roughly representative of dense regions

Roughly representative of thin regions

Aim of This Work

To reexamine the radio SED of galaxies, especially the nonthermal part originating from supernovae: e.g., dependence on the ambient ISM density

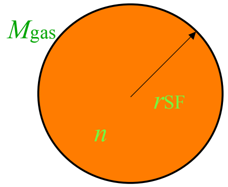
➤ ***Young galaxies are favorable*** for an observational sample. ← The diffuse radio synchrotron component has not yet been established, and the synchrotron component comes from supernovae.

⇨ We use ***metal-poor blue compact dwarf galaxies (BCDs)*** to constrain the radio energy of SNRs.

2. Radio SED Model

We assume a spherical star-forming region a constant density.

Parameters
Gas Mass: M_{gas}
Number density: n



Star formation rate (SFR)
$\sim \varepsilon M_{gas} / t_{ff}$
with $t_{ff} \sim 1/(G\rho)^{1/2}$

Evolution of Ionized Region (free-free radiation source)

- Size is determined by the Strömgren radius.
- Dynamical expansion due to the pressure excess is also included (Spitzer 1978).
- Star formation is stopped if the entire region is ionized.

Synchrotron Radiation

Luminosity = $l(\mathrm{SN})\tau\gamma$

- l(SN): Radio luminosity per supernova remnant (SNR)
- τ: Lifetime of radio radiation of SNR
- γ: supernova rate (← given by SFR)

l(SN) and τ are constrained observationally.

3. Comparison with BCDs

blue compact dwarf galaxies (BCDs)

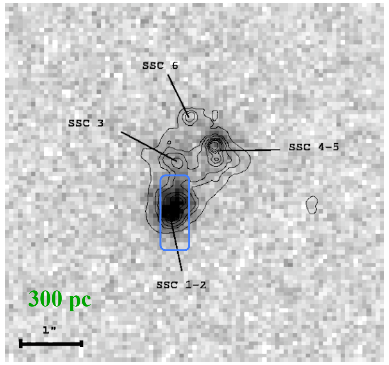
● Typical age is young. ⇒ easy to constrain the radio emission from Type II supernovae, since the diffuse radio emission has not been established.

● Low metallicity (<~1/10 Z_{sun})

● Lower complexity than giant galaxies ← One one-zone model is easy to apply.

SBS 0335–052

D = 53 Mpc



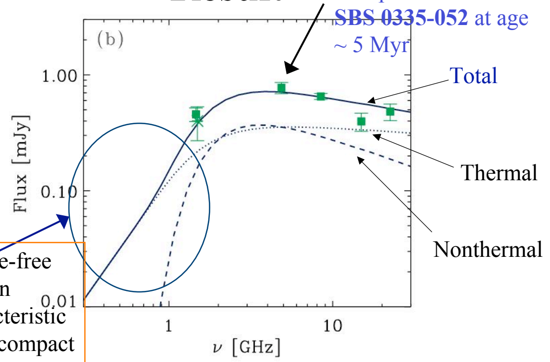
Age < 5 Myr

Metallicity 1/41 Z_{sun}

Vanzi et al. (2000)

Result

Comparison with **SBS 0335-052** at age ~ 5 Myr



Large free-free absorption ⇒ characteristic of dense/compact (“active”) class

l(SN) τ = (1 – 5) × 10^{23} W yr / Hz @ 1 GHz

Estimate of Physical Quantities

Theoretical prediction

■ l(SN) τ ~ 4.4 × 10^{27} erg/s/Hz·yr × $(E_e/10^{48}$ erg$)$ $(B/10\ \mu G)^{1.5}$ $(\tau/10^5$ yr$)$

Observationally derived value by us

■ l(SN) τ ~ 1 – 5 × 10^{30} erg/s/Hz·yr (for SBS 0335)

⇓

B = 100 μG ← 1/10 of the gas pressure

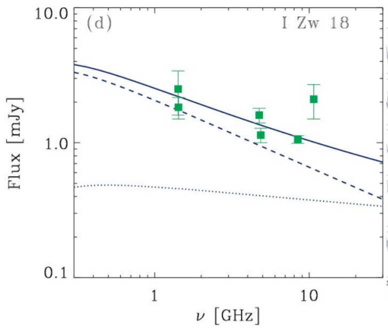
E_e = 10^{49} erg ← 1% of E_{SN} contributes to the production of energetic electrons

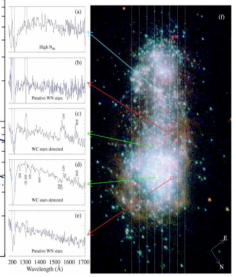
τ = 10^5 yr ← duration of SN shock

I Zw 18

D = 12.6 Mpc

I Zw 18 (Brown et al. 2002)





Small free-free absorption
⇒ characteristic of
diffuse (“passive”) class

$n \sim 100$ cm^{-3}

Best-fit l(SN) τ is consistent with scaling $B^2 \propto n$

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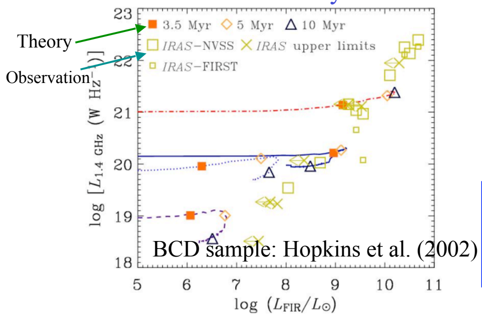
Application to the Far-Infrared – Radio Correlation

Evolution of radio luminosity ← Model in this poster

Evolution of FIR luminosity ← Hirashita & Hunt (2004)



Dust enrichment occurs on a timescale of dust enrichment by supernovae.

The correlation is established on < ~ 5 Myr.

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4. Summary

(1) The radio SEDs of representative low-metallicity BCDs are dominated by synchrotron radiation.
- ➢ Magnetic fields have already been amplified.
- ➢ Energetic electrons have been accelerated.

(2) The FIR – radio correlation is also explained by
   a. Radio emission from supernova remnants, and
   b. FIR emission from dust produced by supervnovae.

   ← The correlation is established in 3 – 5 Myr.

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