FAR-INFRARED [C II] PROPERTIES OF LOW-METALLICITY GALAXIES

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1. Introduction

The line flux ratio of the [C II] 158 μm fine-structure ($^2P_{3/2} \rightarrow ^2P_{3/2}$) emission to CO rotational emission is a probe of the intensity of the interstellar UV radiation in galaxies. The largest values for the [C II]/CO (J = 1–0) line ratios are found in starburst galaxies, none of which, however, show values larger than 6×10^3 (Stacey et al. 1991). The exception ([C II]/CO $\simeq 2 \times 10^4$) are galaxies of Magellanic type which have low metallicity, an intense interstellar UV field, and irregular morphology (Table 1).

Mochizuki et al. (1994) showed that the two conditions, a low metallicity and an intense UV field are expected to result in the large [C II]/CO ratios in the Magellanic types. These conditions are likely to be common in more massive galaxies as well, but at an early epoch in their evolution. This suggests that bright [C II] emission can be a good indicator of young galaxies. However, the metal-poor galaxies previously observed in the [C II] line were exclusively Magellanic types. Observations of different types of dwarf galaxies are necessary to help us understand the physical conditions in the interstellar medium of low-metallicity systems.

2. Observations and Results

We observed the dwarf galaxies IC 5152 and I Zw 36 with LWS (the Long Wave Spectrometer) on ISO (the Infrared Space Observatory). The aperture of LWS was approximately 80 arcseconds; the spectral resolution was $\lambda/\Delta\lambda = 300$ in the grating mode we used. Compared to the Magellanic types, IC 5152 lacks intense star-forming activity ($M_B = -14.8$ mag, which is 20 times fainter than

TABLE 1. Metallicity (oxygen abundance) and [C II]/CO (J = 1–0) line flux ratios of galaxies. For our Galaxy and the LMC, the average values are presented.

Object	12 + log[O/H]	[C II]/CO (J = 1–0)	reference for [C II] data
Galaxy	8.91	1.3×10^3	Nakagawa et al. 1995
starbursts		$\simeq 6 \times 10^3$	Stacey et al. 1991
LMC	8.34	2.3×10^4	Mochizuki et al. 1994
Magellanic types	$\simeq 8.3$	$\simeq 2 \times 10^4$	Lord et al. 1995
I Zw 36	7.93	$\lesssim 3 \times 10^3$	this work

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expected from the relation between M_B and metallicity; Skillman, Kennicutt, and Hodge 1989); I Zw 36 is a blue compact.

Our observations show that IC 5152 has a [C II] flux of 7×10^{-16} W m^{-2}; the [C II]/B band flux ratio is 1/3 of that in the LMC, although IC 5152 is faint in the B band. This is an example of a metal-poor galaxy, but without an intense interstellar radiation field, which shows a lack of bright [C II] emission.

For I Zw 36, we obtained an upper limit of 1×10^{-16} W m^{-2} (3σ) in the [C II] line. This, combined with the millimeter observation of Tacconi and Young (1987), implies a line flux ratio of [C II]/CO ($J = 1$–0) $\lesssim 3 \times 10^3$. This upper limit is comparable to the ratio typically observed in our Galactic plane (Table 1), although I Zw 36 has both a very low metallicity and a high UV surface brightness.

3. Discussion

In a metal-poor galaxy, its lower dust abundance allows CO-dissociating UV photons to penetrate deeper into each molecular cloud; this makes for a large [C II]/CO line ratio (Maloney and Black 1988). However, our observations show that the [C II]/CO flux ratio also depends significantly on conditions other than metallicity.

A molecular cloud with a high gas density can produce a small [C II]/CO line ratio even with a low metallicity and an intense UV field, because the high density enhances the $C^+ \rightarrow$ CO conversion rate. The PDR (Photon-Dominated Region) model of Mochizuki (1996) reproduces a line ratio of [C II]/CO ($J = 1$–0) $\lesssim 3 \times 10^3$ at a gas density of $n_{\rm H} \geq 10^4$ cm^{-3} (Table 2), when incident UV intensity is 10 times that of the solar neighborhood value, metallicity is at the LMC value, and each molecular cloud in a galaxy is 10^3 solar masses. Thus we suggest that the smaller line ratio in I Zw 36 results from a high gas density, which is compatible with its compact morphology.

High-J CO rotational lines observed toward distant galaxies (c.f. Ohta et al. 1996) indicate that these galaxies have a large amount of high-density molecular gas. This suggests that young galaxies may have an interstellar medium more similar to that in I Zw 36 than to that in Magellanic types.

TABLE 2. The derived line luminosity ratio of [C II]/CO ($J = 1$–0) based on a PDR model, with the assumed gas densities.

parameter	case 1	case 2	case 3
gas density [cm^{-3}]	10^3	$10^{3.5}$	10^4
[CII]/CO($J = 1$–0)	2.3×10^4	7.5×10^3	2.4×10^3

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