^{12}CO AND ^{13}CO J=2-1 AND J=1-0 OBSERVATIONS OF HOT AND COLD GALAXIES

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I. INTRODUCTION

We have observed the nuclear regions of the galaxies NGC 2146 and IC 342 in ^{12}CO and ^{13}CO J=1-0 and J=2-1 lines using the FCRAO 14m telescope. NGC 2146 is a peculiar Sab spiral galaxy. Its complex optical morphology (Pease 1920; de Vaucouleurs 1950; Bevenuti et al. 1975; Young et al. 1988) and strong nuclear radio continuum emission (Condon et al. 1982) suggest that it is experiencing a phase of violent activity and could have a polar ring (Schweizer et al. 1983) which may have resulted from an interaction. IC 342 is a nearby luminous Scd spiral galaxy. Strong CO, infrared and radio continuum emission from the nuclear region of IC 342 indicate enhanced star-forming activity, and interferometric ^{12}CO J=1-0 observations reveal a bar-like structure centered on the nucleus, along the dark lane in the NS direction (Lo et al. 1984). These two galaxies are selected based on their different dust temperatures and star formation efficiencies (SFE) as derived from the IRAS $S_{60\mu}/S_{100\mu}$ flux density ratio and $L_{IR}/M(H_2)$, respectively, with a relatively high SFE and dust temperature of 45K in NGC 2146 and a relatively low SFE and dust temperature of 35K in IC 342.

The data from the different ^{12}CO and ^{13}CO lines are used to study the physical conditions in the molecular clouds in the galaxies. We also consider the radiative transfer to determine whether a warm and optically thin gas component exists in these galaxies, as has been suggested in the case of M82 (Knapp et al. 1980), and whether the warm gas is related to the dust properties. Since optically thin ^{12}CO gas is rarely detected in our own Galaxy (except in outflow sources), to confirm its existence in external galaxies is very important in understanding the molecular content of external galaxies and its relationship to star formation activity.

The present ^{12}CO J=2-1 and ^{13}CO J=2-1 and J=1-0 data for NGC 2146 are the first detections of this galaxy to our knowledge. The ^{12}CO J=1-0 distribution in NGC 2146 has been measured as part of the FCRAO Extragalatic Survey. For the well-studied IC 342, our data are compared with the IRAM 30m observations (Eckart et al. 1989) and other available data. Here we present the observed results.

II. OBSERVATIONS

The observations were carried out during the periods of January - March in 1988 and 1989 using the 14m radome-enclosed FCRAO telescope. In order to avoid the calibration and pointing uncertainties associated with daily heating of the antenna, we only observed during the night time between 6p.m. and 6a.m. The data were calibrated by the chopper wheel method. Pointing was checked periodically on IRC+10216 and Jupiter with an rms of ~5", and confirmed by monitoring the line profile of the central position of the galaxy. The HPBW of the 14m antenna at the ^{12}CO J=1-0 frequency (115.2712 GHz) and J=2-1 frequency (230.5379 GHz) are 45" and 23", respectively. All spectra were taken using double beam switching procedure so that flat baselines were achieved.

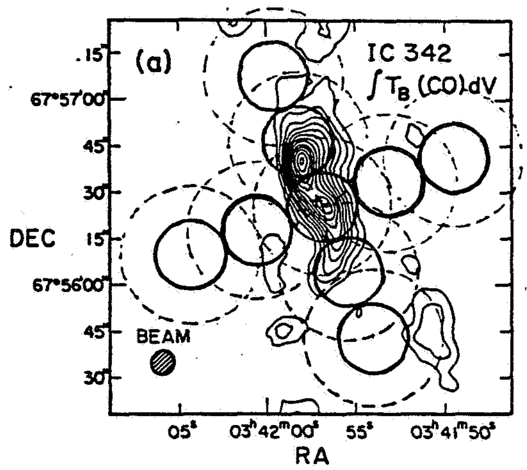

Fig. 1. The locations of our ^{12}CO and ^{13}CO J=2-1 and J=1-0 observations of IC 342 superposed on the integrated contour maps made with OVRO interferometer (Lo et al. 1984). The smaller circles show the 23" beam of the 14m FCRAO telescope for the J=2-1 emission and the larger one is the 45" beam for the J=1-0 line. The shaded circle on the lower left corner indicates the 7" beam of the interferometer. The cross represents the peak of 2.2 μm emission (Becklin et al. 1980).

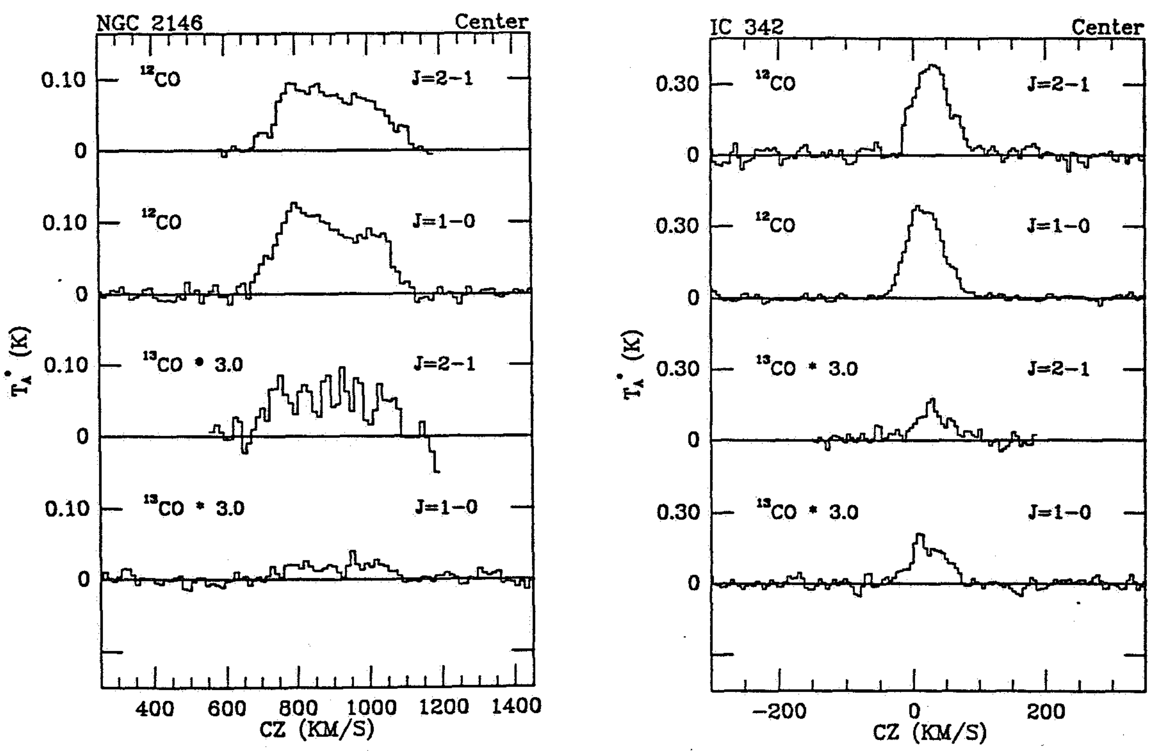

Fig. 2. Spectra of ^{12}CO and ^{13}CO J=2-1 and J=1-0 emission at the centers of the galaxies NGC 2146 and IC 342. The data are smoothed to a final velocity resolution of 15.6 km s^{-1} for NGC 2146 and 7.8 km s^{-1} for IC 342. The vertical scale is the antenna temperature uncorrected for the telescope efficiencies of the 14m antenna at the corresponding frequencies. In order to present the spectra from different species at the same scale, the weaker ^{13}CO emission has been enlarged by a factor of 3.

The coordinates and position angles used for NGC 2146 are same as those used in the FCRAO Extragalactic Survey (position angele of 128°). The central position of IC 342 was chosen based on the interferometer map (Lo et al. 1984) in which there were two peaks spaced by ~15". We selected the peak which was closer to the optical center as our observing center. A position angle of 20° was also adopted based on the interferometer map. Fig. 1 illustrates the locations of our ^{12}CO and ^{13}CO J=2-1 and J=1-0 observations in the galaxy IC 342.

III. RESULTS

The preliminary comparisons of the different lines and isotopes show that:

(1) For IC 342, the ^{12}CO J=2-1 and J=1-0 integrated intensities peak at different positions. The J=1-0 data follow the NS gas bar, with a stronger peak located at about 15" north-east of the center. This is consistent with the Owens Valley Millimeter-Wave Interferometer J=1-0 map (7" resolution; Lo et al. 1984) and the Nobeyama J=1-0 map (15" resolution; Hayashi et al. 1986), which both show a double-peaked structure with the NE component stronger (for example, see Fig. 1). On the other hand, the IRAM 21" resolution J=1-0 map (Eckart et al. 1989) is centrally peaked and differs from the above data. However, since the first three results were obtained independently, we regard the double-peaked structure as real.

The ^{12}CO J=2-1 emission peaks at the center. Although the center position used at IRAM is slightly different from ours, both data show a symmetric distribution in the NS direction. Along the EW direction, we find the emission to be stronger in the west than in the east. The enlongated NS bar-like structure is obvious.

(2) For NGC 2146, both transitions are centrally peaked with a decrease in integrated intensity of a factor of ~2 in 23". The ^{12}CO J=2-1 observations show strong emission along the major axis.

(3) The optical depths for the J=2-1 and J=1-0 lines in NGC 2146 and IC 342 are estimated from the ^{12}CO to ^{13}CO intensity ratios. Fig. 2 shows the spectra of ^{12}CO and ^{13}CO J=2-1 and J=1-0 emission at the centers of the two galaxies. In general, it is found that the ^{12}CO emission is consistent with optically thick gas.

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