Recent Results of CO Observations of IC342, NGC6946, Maffei2, and M51 with the NMA

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Abstract. We present our recent results of high spatial resolution(2"-6") CO and ^{13}CO(J=1-0) observations with the Nobeyama Millimeter Array(NMA). We observed the central (1-2 kpc) regions of nearby galaxies, IC342, Maffei2, and NGC6946 with 2"-4" resolution (45-90 pc) in CO and ^{13}CO, and the 3' region of M51 with 4"-6" resolution (180-280 pc). We discuss the structures and kinematics of molecular gas in the central region of nearby late-type spiral galaxies, and in spiral arms, and discuss the trigger of star formation from viewpoints of galactic shock, gas fueling by bars.

1. ^{12}CO and ^{13}CO Observations of Nearby Late-type Spiral Galaxies IC342, NGC6946, and Maffei 2

Late-type spiral galaxies, IC342, NGC6946, and Maffei 2, are gas-rich and molecular gas is concentrated to the central 1-2 kpc regions. Aperture synthesis CO observations of the central regions revealed the bar-like distributions of molecular gas (Lo et al. 1984; Ball et al. 1985; Ishiguro et al. 1989). IC342 has been observed in CO (Ishizuki et al. 1990a) and ^{13}CO. IC342 is one of gas-rich nearby galaxies (d =3.9 Mpc) and nearly face-on. VLA radio continuum maps of its central region were obtained by Turner and Ho (1983). We obtained 2.3"x2.4" resolution ^{12}CO image of the central 1 kpc region and 5" resolution ^{13}CO image (Figure 1.). The ^{12}CO map samples 80 - 90 % of a single-dish flux. We have found a pair of CO narrow ridges (500 pc long and 80 pc wide) shifted to leading edges. These ridges show high CO brightness temperature up to 20 K even with a 40 pc linear scale beam and have a large velocity width, 30 - 50 kms^{-1} (FWHM). We have also found a CO ring structure (a radius of 50 - 60 pc) inside of the ridges. This CO ring coincides with the ring feature of the VLA continuum map (Fig. 1c). CO velocity field indicates the existence of a large non-circular motion along the ridges. A total H_2 mass derived from ^{12}CO is 2.6 $\times$ 10^8 $M_\odot$. Our results suggest that the CO ridges are associated with shock waves formed in response to bar-like gravitational potential field and that the gas at the ridges is heated through shock dissipation of kinetic energy (or dissipative cloud-cloud collisions). The large velocity width is likely due to the big change of the velocity field at the shocks. The dissipation, consequently, would fuel nuclear starburst in the inner ring. The distribution of ^{13}CO emission roughly coincides with that of ^{12}CO. There is no clear systematic change of a ^{12}CO to ^{13}CO intensity ratio. In the ^{13}CO map, two distinct peaks are located at ridge-ring interfaces. A total mass derived from ^{13}CO data is 1.6 $\times$ 10^8 $M_\odot$.

F. Combes and F. Casoli (eds.), Dynamics of Galaxies and Their Molecular Cloud Distributions, 160–163.

We have also obtained CO maps of the central regions of NGC6946 and Maffei2 with 3"-4" resolution (Figures 2 and 3). The spatial resolution and sensitivity have been improved compared to the previous CO maps (Ishiguro et al. 1989; Ishizuki et al. 1990b) by adding new data. In the new CO map of Maffei2, an expanding ring feature is the most prominent and the faint bar structure of molecular gas is seen outside the ring. The radius of the expanding ring is 250 pc. In NGC6946, molecular gas is highly concentrated to the central 300 pc region which coincides with a bright HII region and a radio continuum source (Turner and Ho 1983), and a bar structure is also faint in contrast to the prominent bar (CO ridges) in IC342. It is suggested that the central concentration is a massive nuclear disk of molecular gas which has been formed by efficient gas inflow in an oval potential field. The difference of molecular gas distributions among these galaxies may be related to that of the "evolutional" stages (phases) of the "star burst" nuclei; e.g., a gas-infalling phase (IC342), a phase of nuclear gas concentration (NGC6946), and a gas-outflowing phase (post starburst; Maffei2 and possibly M82).

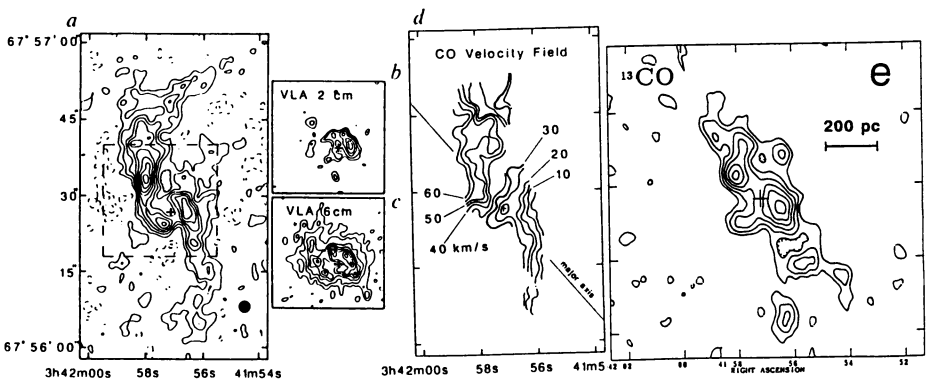

Figure 1. (a) Map of CO integrated intensity in IC342. A cross indicates a peak in 2.2 μm emission (Becklin et al.1980). The dashed box corresponds to the area in Fig.1b and 1c. (b) and (c) VLA maps of 2- and 6-cm radio continuum emission. (d) CO velocity field. (e) Map of ^{13}CO intensity.

https://doi.org/10.1017/S0074180900243842 Published online by Cambridge University Press

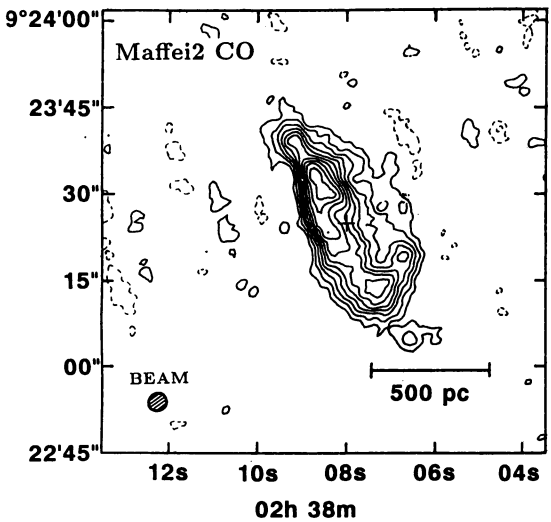

Figure 2. Map of CO integrated intensity in the central region of Maffei2. The beam size is 3.9". A cross indicates a peak of nuclear Hα emission.

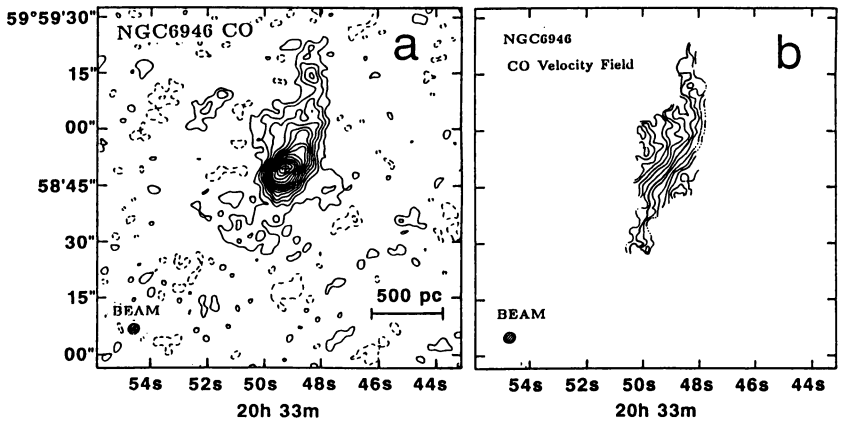

Figure 3. (a) Map of CO integrated intensity in the central region of NGC6946. The spatial resolution is 3.0" × 3.5". A cross indicates a peak position of 2 μm emission. (b) CO velocity field. A thick line shows an iso-velocity contour at the systemic velocity of NGC6946, V_{LSR} of 60 kms^{-1}, and contour interval is 10 kms^{-1}.

2. M51 : Center

We have obtained CO maps in the central 2 kpc regions and the arm regions with high spatial resolution of 4" – 6" and high velocity resolution 10 – 20 kms^{-1}. The obtained maps of the central region show a bar-like distribution of molecular gas with a scale of 2 kpc and a mass of 4 × 10^8 $M_\odot$and the bar is connecting inner edges of spiral arms (Figure 4). The maps sample about 80 % of a single dish CO flux. The position angle of the bar-like structure, -45 deg., is coincident with that of optical and infrared

https://doi.org/10.1017/S0074180900243842 Published online by Cambridge University Press

oval structures (Pierce 1986, Thronson et al. 1988). The central CO velocity structure shows the existence of a non-circular motion, and it is very similar to that obtained IIα emission (Tully 1974). The bar-like distribution is likely caused by an oval gravitational potential field at the center. Inside the bar, there is the depression of molecular gas with a 200 pc scale.

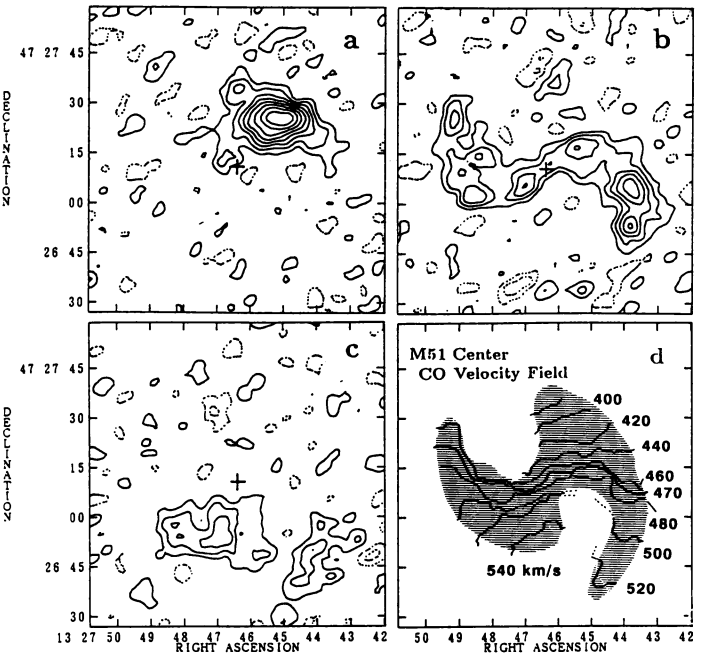

Figure 4. (a),(b), and (c) CO maps in the central 2 kpc region of M51 for three velocity components, V_{LSR}= 440–499 kms^{-1} (a),499–577 kms^{-1} (b), and 557-616 kms^{-1}(c). A cross indicates the position of a radio nucleus. (d) CO velocity field. A thick line indicates an iso-velocity contour at the systemic velocity. The distribution of the CO emission is shown by a stippled area.

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