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CO Mapping of the Nuclear Region of NGC6946 and IC342 with the Nobeyama Millimeter Array

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INTRODUCTION

CO observations of nearby galaxies with nuclear active star forming regions (and starburst galaxies) with angular resolutions around $7''$ have revealed that molecular bars with a length of a few kiloparsecs have been formed in the central regions of the galaxies¹⁻⁴. The molecular bar is interpreted as part of shock waves induced by an oval or barred potential field. By shock dissipation or dissipative cloud-cloud collisions, the molecular gas gains an infall motion and the nuclear star formation activity is fueled. But the distribution and kinematics of the molecular gas in the nuclear regions, which are sites of active star formation, remain unknown. Higher angular resolutions are needed to investigate the gas in the nuclear regions. We have made aperture synthesis observations^{5,6)} of the nuclear region of the late-type spiral galaxies NGC6946 and IC342 with resolutions of $7''.6 \times 4''.2$ (P. A. = 147°) and $2''.4 \times 2''.3$ (P. A. = 149°), respectively. The distances to NGC6946 and IC342 are assumed to be 5.5 Mpc and 3.9 Mpc, respectively. We have found 100–300 pc nuclear gas disk and ring inside a few kpc molecular gas bars. We present the results of the observations and propose a possible mechanism of active star formation in the nuclear region.

OBSERVATIONS

The observations were made using the Nobeyama Millimeter Array (NMA), which consists of five antennas with a diameter of 10 meters. All antennas are equipped with SIS receivers with system noise temperatures (SSB) around 600 K at the zenith. A Fourier transform digital spectro-correlator FX was used. 10 baselines and 40 baselines are used for the mapping of NGC6946 and IC342, respectively. The field of view is $65''$ in diameter, which corresponds to 1.7 kpc and 1.2 kpc at the distance of NGC6946 and IC342, respectively.

RESULTS

NGC6946⁵⁾: 300 pc Nuclear Molecular Gas Disk and Molecular Gas Bar

Figure 1a shows a map of CO integrated intensity. The galaxy has a strong nuclear concentration of molecular gas with a size of 300 pc and a diffuse feature with north-south extension of ~ 1.5 kpc. The diffuse feature is seen more clearly in a map of CO intensity integrated over a velocity range, $V_{LSR} = 21.4-99.5$ kms^{-1} (Fig. 1b). It shows a bar-like morphology generated at the reading sides. This bar-like structure is interpreted as part of shock waves or a density wave pattern in an oval potential field. A map of CO velocity field (Fig. 1c) indicates that the nuclear concentration is circularly rotating, i.e., a nuclear molecular disk, and that the gas in the bar-like structure has an infall motion. If we assume the conversion equation between molecular hydrogen mass and CO flux density,

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$M(\text{H}_2) = 9000 \times (I_{\text{CO}}/J_y \text{ km s}^{-1}) \times D_{Mpc}^2 M_{\odot}$, D_{Mpc} is the distance to the galaxy, the gas mass in the nuclear molecular disk is estimated to be $3 \times 10^8 M_{\odot}$. This means that about 10 % of the total molecular gas in the whole galaxy is concentrated to the central 300 pc region and 26 % of the dynamical mass inside a radius of 150 pc is in the form of H_2 molecule. The mass of molecular gas in the field of view ($\sim 1.7 \text{ kpc}$) is $4 \times 10^8 M_{\odot}$. A bright HII region with a size of 200 pc⁷⁾ and a radio continuum source⁸⁾ are found at the nuclear region. The nuclear molecular disk is a site of active star formation.

*Ic342*⁶⁾: 100 pc Nuclear Molecular Gas Ring and Molecular Gas Ridges

Figure 2a shows a map of CO integrated intensity. We have found a molecular ring with a diameter of 110 pc and two narrow ridges, each of which has a size of $\leq 80 \text{ pc} \times 500 \text{ pc}$. The map of CO velocity field (Fig. 2d) shows that the gas in the molecular ring is circularly rotating and that the gas in the ridges has an infall motion along the ridges. The mass of the molecular gas in the field of view is estimated to be $1.7 \times 10^8 M_{\odot}$. The molecular ring has a H_2 mass of $0.4 \times 10^8 M_{\odot}$. Figures 2b and 2c show VLA radio continuum maps at 2 cm and 6 cm⁸⁾, respectively. At 2 cm and 6 cm, about 100 % and 50 % of the emission is thermal origin, respectively. The flux density of radio continuum emission corresponds to the number flux density of UV photons from 3.5×10^4 B3-O4 stars⁸⁾. The molecular gas ring just fits to the 6 cm continuum ring. This suggests that active star formation occurs in the nuclear molecular gas ring. The ridges are shifted to the leading side. They are also interpreted as molecular gas in shocks in the oval potential.

DISCUSSION

Here we propose a possible scenario of nuclear active star formation. An oval potential field with a few kpc scale produces shock waves which cause loss of angular momentum of gas and as a result the gas infalls toward the nuclear region. The infall motion of the gas slows down at the inner a few hundred pc region because the oval distortion of the gravitational potential becomes very small. Owing to the efficient gas supply in the oval potential and the slowing down of gas infall, a nuclear gas disk (or a ring) which has a few hundred pc size and a mass of a few $10^8 M_{\odot}$ is formed. In this massive nuclear disk, frequent cloud-cloud collisions probably occur and induce active, massive star formation.

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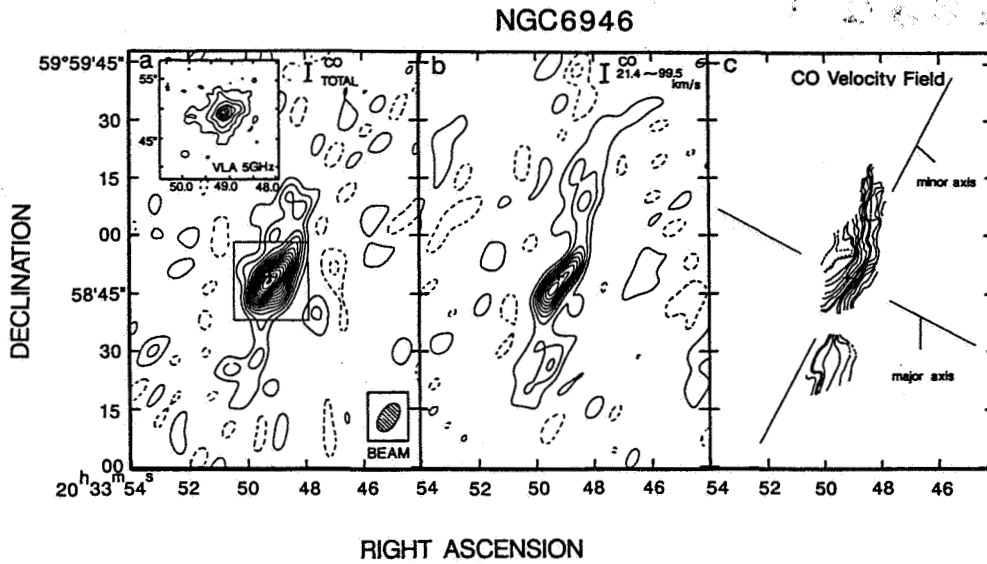


Figure 1 — NGC6946 — ($10''$ corresponds to 270 pc.) (a) A map of the total CO integrated intensity. An inset shows a map of the λ 6cm radio continuum emission⁸⁾. A cross indicates its peak position. (b) A map of the integrated intensity in the velocity range $V_{LSR} = 21.4 - 99.5 \text{ km s}^{-1}$. (c) A contour map of the CO weighted mean velocity. Dashed and solid curves indicate $V_{LSR} = -20, -10, 0, 10, \dots, 120 \text{ km s}^{-1}$ from east to west. A thick solid curve indicates the systemic velocity, $V_{LSR} = 60 \text{ km s}^{-1}$.

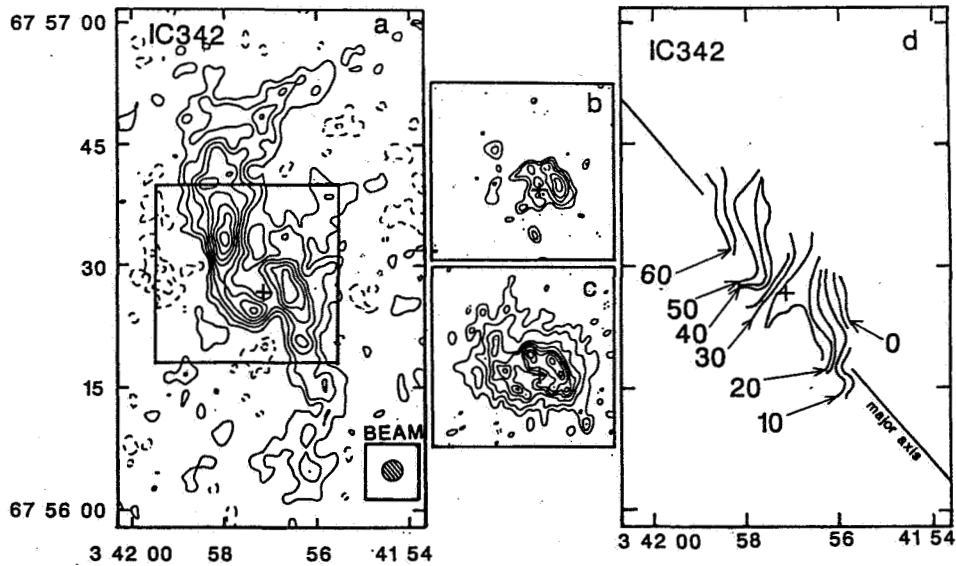


Figure 2 — IC342 — ($5''$ corresponds to 95 pc.) (a) A map of the total CO integrated intensity. A cross indicates the peak of $2.2 \mu\text{m}$ emission. (b,c) Maps of the λ 2cm and λ 6cm radio continuum emissions⁸⁾, respectively. The size of the frames is the same as that of a box shown in Fig. 2a. (d) A contour map of the CO weighted mean velocity. The numbers indicates LSR velocities, V_{LSR} , in unit of km s^{-1} .