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Molecular Gas in M82: High Resolution CO, HCN, and HCN+ Observations

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INTRODUCTION

The observations of M82 with high spatial and velocity resolutions and wide frequency coverage at BIMA provide the possibility of a detailed study of the kinematics of the molecular gas and of the giant molecular cloud statistics and properties in the edge-on galaxy M82. We briefly report the high resolution BIMA observations of CO(1→0), HCN(1→0), and HCO^+(1→0) emissions from the starburst nucleus of M82.

The CO (1→0) line at 115.2712 GHz was observed towards M82 between December 1993 and February 1994, and the HCN(1→0)/HCO^+(1→0) lines at 88.6319/89.1885 GHz (the two species can be observed simultaneously) were observed between March 1994 and May 1994, with the BIMA 6-element array in Hat Creak, California. Three configurations were used for the observation, leading to a synthesized beam of 2.3" × 2.6" in the combined data for the CO observation with uniform weighting, 5.5" × 4.9" for the HCN images, and 5.1" × 4.7" for the HCO^+ maps with natural weighting. MIRIAD software was used for data reduction and analysis. Continuum emission is subtracted from the HCN and HCO^+ maps in image domain. No continuum subtraction is done to the CO data since the CO emission is much stronger than the continuum.

RESULTS AND DISCUSSIONS

The CO emission comes mostly from two rings, or spiral-like structures, the outer ring is more disrupted than the inner ring, there are gas clumps hundreds of parsecs above the plane of the galaxy. We also find gas outflows with a velocity of about 230 km s^{-1} (Shen and Lo 1995a). Gas traced by CO and the denser gas traced by HCN and HCO^+ are correlated in space. The resolution of the HCN/HCO^+ maps are about a factor of two worse than that of the CO image, but it is still clear that the high density gas, like the gas traced by CO, is distributed mostly in the two rings, with more concentration of denser gas in the inner ring. The peak HCO^+ emission is 1.5 times stronger than the peak HCN emission. The correlation of HCN and HCO^+ emissions is remarkable.

The integrated intensity ratios of HCN and HCO^+ over CO are very high in the starburst galaxy M82, in the range of 1/10 to 1/60 for HCN/CO and of 1/7 to 1/45 for HCO^+; and higher in the inner molecular ring than in the outer molecular ring by a factor of 2.

The 3 mm free-free emissions (Shen and Lo, 1995b), the 12.4 μm continuum (Telesco & Gezari 1992), and the NeII emission (Achtermann & Lacy 1995) all peak within the central 20" (160 pc radius), indicating that the starburst may be younger near the center. This may be consistent with a model proposed by Rieke et al (1993) of two bursts having taken place 3 $\times 10^7$ years and 5 $\times$ 10^6 years ago. P-v diagram of the CO emission (Shen & Lo 1995a) suggests the molecular emission with large velocity dispersion originates in the outer ring, whereas the the inner ring appears to be not highly disrupted. The CO observations are thus consistent with the suggestion that the older starburst was located in the outer ring and that the younger starburst took place in the inner ring recently that not many supernovae have gone off to disrupt the surrounding ISM and the molecular clouds.

The denser gas as traced by HCO^+ and HCN correspond very closely to the ionized gas in the inner ring both spatially and in velocity. The remarkable correlations of the dense gas, the ionized gas, and the 3mm continuum emission in the inner ring, give more evidence to the statement that the inner molecular ring is the recent starburst site.

Simulations of gas flow and theoretical rotation curves in barred galaxies reveal that, there exists two families of barred orbits, x_1 and x_2 orbits . The x_1 orbits exist out to the Lindblad resonance. The x_2 orbits lie inside and are rotated 90^0 from the x_1 orbits, they reside near the inner Lindblad resonance. We think the x_1 orbits are qualitatively consistent with the outer molecular ring, clearly observed in CO emission, and the x_2 orbits are consistent with the inner molecular ring, which just outside the ionized gas ring. High resolution study of the structure and kinematics of dense molecular gas would be helpful to confirm the barred orbits in the nucleus of M82, and to reveal the role of stellar bars in nuclear starbursts.

GIANT MOLECULAR CLOUDS IN M82

We applied the clump fitting algorithm developed by Williams, de Geus & Blitz (1994) to our CO data (Shen & Lo, 1995b). We've found 42 cloud clumps with half-power diameters ranging from 20 pc to 110 pc, similar to the typical sizes of the giant molecular cloud complexes in the Milky Way Galaxy. Velocity widths (full-width half power) of the clumps ranges from 7 km s^{-1} to 67 km s^{-1}, and the typical T_b ranges from 13 K to 34 K.

A power law distribution is found in both the molecular and virial masses. For the mass spectrum derived from CO emission, the index is -1.3 (dN/dM = -160 $M^{-1.3\pm0.2}$) for masses greater than 4×10^5 $M_\odot$, and for the virial mass spectrum, the index is -1.5 (dN/dM = -3.3$\times10^3$ $M^{-1.5\pm0.3}$). The large index indicates that most of the molecular mass is contained in GMCs with large masses.

A power law relationship between the velocity dispersions and the radii of the

GMC complexes is fitted: $V = 0.67\ R^{0.92}$, the index 0.92 is higher than that of the Galaxy and the LMC, indicating that gravitational virial equilibrium may not be well established in the nucleus of M82, and the GMC complexes could be only temporary aggregations of clouds produced by orbit crowding on the molecular rings.

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