BIMA OBSERVATIONS OF MOLECULAR GAS IN NGC 1068

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1. Introduction

NGC 1068 is the best studied example of a galaxy with prolific nuclear activity as well as a kiloparsec scale starburst; the bolometric luminosity of this Seyfert galaxy is roughly evenly divided between the two components (Telesco et al. 1984). The starburst region and the nucleus appear to be linked by a 2.2 μm stellar bar, the linear dimension of which matches the scale of the starburst (Scoville et al. 1988; Thronson et al. 1989). Since molecular gas is a plausible fuel for the active galactic nucleus (AGN), and since molecular gas must be intimately involved with the starburst activity, it is natural to look to the molecular emitters for clues of a possible connection between these two energetic processes. In this paper, I discuss recent CO and HCN observations of NGC 1068 made with the BIMA array. A more complete description of previous observations of this galaxy as well as the results of the BIMA study is presented in Helfer and Blitz (1995).

2. Distribution of Molecular Gas

The BIMA images of CO and HCN are presented in Figure 1; these maps include zero-spacing data from the NRAO 12m telescope so they are sensitive to structure on large as well as small size scales.

The CO emission is distributed in the form of a molecular bar from which emanate two spiral arms. The linear extent ($r \sim 1$ kpc) and position angle (P.A. $\sim 63°$) of the molecular bar are in good agreement with those of the 2.2 μm stellar bar. As is common with dust lanes within bars in spiral galaxies, the CO emission within the bar is at the leading edge and is probably associated with shocked gas.

Figure 1. BIMA maps of CO emission (left) and HCN emission (right) in NGC 1068. The linear scale is such that 1 kpc $\approx 14''$ at $d = 16$ Mpc; the tick marks are separated by $10''$.

While the bulk of molecular gas traced by CO is associated with the starburst at kiloparsec size scales, there is also a compact distribution of CO emission around the nucleus of NGC 1068. By contrast, *most* of the HCN emission is strongly concentrated towards the nucleus of NGC 1068, though there is low-level emission detected in the region of the starburst. HCN traces gas at densities $> 10^5$ cm^{-3}, which is about two orders of magnitude greater than the critical density required to excite CO; the strong HCN emission suggests that there is a substantial quantity of high density gas near the nucleus.

3. Kinematics

The excellent signal-to-noise ratios of the individual 8 km s^{-1} CO channel maps allow for a detailed study of the kinematics in the inner kiloparsec of NGC 1068. In the region of the spiral arms, the velocity field is well ordered; the gas is in simple rotation with a kinematic line of nodes of 84°. Interior to the bar, the isovelocity contours twist and run parallel to the axis of the bar in the signature kinematic response of gas to a bar potential.

Simple kinematic modeling shows that the bar's influence on the gas kinematics in the spiral arms is modest, with typical noncircular motions of < 30 km s^{-1} in the plane of the galaxy. The noncircular residuals show an ordered spiral structure that lie along the spiral arms; the magnitude and distribution of the noncircular motions are consistent with spiral density

wave streaming. Interior to the spiral arms, noncircular motions dominate the gas kinematics.

4. Extreme Physical Conditions in the Central $\sim$ 200 pc

The ratio of HCN to CO integrated intensities is about 0.6 over the central $r \approx 175$ pc; this is the highest ratio measured in the center of any galaxy. The physical conditions in the molecular gas in this region are well modeled by gas at a kinetic temperature of about 50 K and a density of about 4 $\times 10^6$ cm^{-3}. The pressure implied by this modeling is $P/k \approx 2 \times 10^8$ cm^{-3}K. This pressure is about four orders of magnitude greater than that of the local interstellar medium (Bloemen 1987) and it is some three orders of magnitude greater than the pressure of the self-gravity of a typical giant molecular cloud in the solar neighborhood (Blitz 1993).

5. Comparison With the Milky Way

NGC 1068 shows all the kinematic and morphological characteristics of a classic barred spiral galaxy. What distinguishes this source from the Milky Way, another barred galaxy with a central concentration of molecular gas? Both galaxies have an appreciable quantity of dense gas in their centers (as do most spiral galaxies, Helfer & Blitz 1993 and references therein). Both galaxies have similar gas surface densities ($\sim 600 M_\odot$ pc^{-2}) averaged over their inner $r \sim 200$ parsecs. Both galaxies show evidence for $m = 1$ modes (Blitz, these proceedings). An important difference between the two galaxies may be that in NGC 1068, there is a massive ($> 10^9$ M$\odot$) reservoir of molecular gas in spiral arms that lies within $r = 0.6$–2 kpc of the nucleus; this reservoir may be the source of fuel for the AGN. While the Milky Way has a similar concentration of molecular gas at its center and the same potential mechanism for channeling gas inward from large radii (i.e., bar streaming), there is a distinct lack of molecular gas at radii between 0.3–3.5 kpc in the Milky Way.

References

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