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Molecular Gas Kinematics in Nearby Active Galaxies

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Abstract.
Using the OVRO millimeter array, we have mapped the molecular gas in eight nearby Seyfert and LINER galaxies at $1''$ ($\sim 100\,\mathrm{pc}$) resolution. Each system shows a massive nuclear gas concentration, and many show strong evidence for noncircular or noncoplanar gas motions. In the three examples discussed here, warps or bars probably drive steady or episodic fuelling of star formation and accretion at smaller scales.

High-resolution observations of gas dynamics and stellar velocity dispersions have identified many nearby galactic nuclei which host massive black holes. Not all of these are *active* galactic nuclei (AGN), however; one likely reason is that not all have rapid supplies of fuel for accretion. Whether such fuel is stellar, interstellar, or nonexistent depends on the mechanism(s) by which gas is transported from the outer regions of a galaxy into its nucleus, and on how much of this gas turns into stars along the way. As a first step towards understanding the details of AGN fuelling, we have studied the molecular gas in eight nearby systems whose Seyfert or LINER nuclear spectra show broad Hα emission (Ho et al. 1997). We have used the Owens Valley Radio Observatory (OVRO) millimeter array to map the CO(2–1) line at $1''$ ($\sim 100\,\mathrm{pc}$) resolution, as well as the CO(1–0) line at $4''$ resolution or better. Our sample objects contain molecular disks with gas masses of $1 - 20 \times 10^8\,\mathrm{M}_\odot$ and (outer) radii of $150 - 550\,\mathrm{pc}$. For each galaxy, we have simultaneously fit the data cubes for both CO lines to a single model of its gravitational potential and gas emissivity. We find in many cases that the observed gas kinematics can only be reproduced by noncircular or noncoplanar motions, both of which enhance rates of angular momentum loss.

NGC 1068 (Seyfert 1.9, $D = 14.4\,\mathrm{Mpc}$) has a large-scale CO distribution dominated by a pair of spiral arms; these start at the ends of a stellar bar whose total length is 2.2 kpc (Scoville et al. 1988). On these (and larger) scales, the galaxy's kinematic major axis has position angle $\sim 90^\circ$. On smaller ($\sim 1\,\mathrm{pc}$) scales, however, the kinematic major axis defined by H_2O maser spots is 135° (Greenhill & Gwinn 1997). Our model identifies the circumnuclear molecular gas (on scales of $4 - 150\,\mathrm{pc}$) as the missing link connecting structures with very different angular momentum vectors: we can reproduce the complex CO kinematics with a warped disk whose outer annulus is coplanar with the spiral arms, and whose inner annulus is coplanar with the masers. Once gas is driven inward by torques from the large-scale stellar bar in NGC 1068, therefore, its restriction to noncoplanar orbits is likely to increase the rate of dissipative cloud-cloud collisions, and thus the rate of nuclear fuelling.

NGC 5005 (LINER 1.9, $D = 21.3\,\mathrm{Mpc}$) has been mapped at $1''$ resolution in *both* CO lines. In our [larger field-of-view] CO(1–0) map, we see three distinct gas structures: a massive nuclear disk of radius $\sim 1\,\mathrm{kpc}$; a nearly continuous ring at radius $\sim 3\,\mathrm{kpc}$; and an isolated "northwest stream" feature between disk and ring whose velocity is inconsistent with circular motion at its projected radius. As discussed by Sakamoto et al. (2000), we can account for these features if NGC 5005 contains an optically inconspicuous bar running from east to west on the sky. In this case, we can identify the 3 kpc ring with the bar's inner 4:1 Lindblad ("ultraharmonic") resonance, the edge of the nuclear disk with an inner 2:1 Lindblad resonance (ILR), and the northwest stream with gas flowing inward along the bar's leading edge. The discreteness of the northwest stream suggests that inflow into the nucleus is episodic, thus offering a natural explanation for why nuclear star formation (and perhaps ultimately accretion) may occur only intermittently in this and similar nuclei.

NGC 7479 (Seyfert 1.9, $D = 32.4\,\mathrm{Mpc}$) has a highly conspicuous bar (perhaps the result of a recent minor merger: Laine & Heller 1999) with strong streaming motions along much of its $\sim 14.3\,\mathrm{kpc}$ total length. In its inner 2 kpc, however, gas motions are more nearly circular, and we have modelled the CO kinematics with a more general version of the damped epicyclic approximation described by Sakamoto et al. (1999). Our model produces a reasonable match to the data; however, in contrast to the pattern speed derived by Laine et al. (1998) for the large-scale bar of $27\,\mathrm{km\,s^{-1}\,kpc^{-1}}$, our model prefers a pattern speed $\simeq 290\,\mathrm{km\,s^{-1}\,kpc^{-1}}$. We interpret this result as the new detection of an inner, secondary bar which rotates much faster than the outer, primary bar. The rough agreement of the secondary bar's corotation resonance with an ILR of the primary bar offers further support for the suggestion of Shlosman et al. (1989) that nested bars can be responsible for helping to fuel AGN.

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