STRUCTURE OF CIRCUMNUCLEAR REGIONS OF AGNS: STAR FORMATION AND DENSE GAS

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1. Introduction

Our group is undertaking a large scale program of studying the dynamics and energetics of active galactic nuclei (AGN) through high spatial and spectral resolution observations in the millimeter and near infrared wavebands. With millimeter interferometric CO and other molecular line observations, we are studying the physical characteristics and kinematics of the dense, possibly obscuring gas in the circumnuclear environments of these objects. With near-infrared imaging spectroscopy, we are determining the frequency of intense starbursts associated with the AGN and also estimating the age and stellar composition of these bursts. Taken together, these data sets allow us to identify the possible fueling mechanisms for the AGN and/or the starbursts. In the conference talk we discussed our results for the 3 Seyfert/starburst galaxies NGC 1068, NGC 7469 and Mkn 231. Many of the results for our work on NGC 1068 have already been published elsewhere (Tacconi *et al.* 1994; Sternberg, Genzel and Tacconi 1994), and we refer the reader to those papers for more details. Here we present short descriptions for NGC 7469 and Mkn 231.

2. NGC 7469

NGC 7469 contains a classical Seyfert 1 nucleus with a region of prodigious star formation located in a ring or tightly wound spiral arms at a radius of $\sim$1.5″ (500 pc at 40 Mpc). This starburst ring is clearly delineated in a 0.4″ resolution NIR K-band image and produces $\geq$0.5 $L_{\rm bol}$ of the entire galaxy (Genzel *et al.* 1995). Various K-band line diagnostics observed with

Figure 1. Sample spectra from the central 8″ of the CO map. Spectral resolution is 10 km s^{-1}. The numbers in each box are offsets from the nucleus in arcsec.

the MPE 3D camera (Genzel *et al.* 1995) show the existence of both an AGN and a starburst component. The AGN is clearly seen in the compact emission of the highly excited coronal line [SiVI], while the 2.3μm CO bandhead absorption feature, which delineates young stars, peaks in the ring. The Brγ emission line has evidence for both a compact component arising from the AGN, and a more extended ring component, which is likely from the hot ionized gas associated with recent star formation. The 2.12μm S(1) line of H_2 also contains emission from a bright central component, showing there is a substantial concentration of hot ($T \geq 10^3$ K) molecular gas in the nucleus of NGC 7469, as well as a fainter, extended component. Assuming this H_2 emission traces the distribution of the bulk molecular gas in the central few hundred pc, as is the case for the nearby Seyfert 2 galaxy NGC 1068 (Tacconi *et al.* 1994), these data suggest there is a dense concentration of molecular material contained within the narrow line region, similar to NGC 1068 (*e.g.* Blietz *et al.* 1994; Tacconi *et al.* 1994; Helfer and Blitz 1995).

Our CO map made with the IRAM interferometer has 2.5″ (800pc) resolution. The total flux in the map of 280 Jy km s^{-1} is consistent with that observed by Meixner *et al.* (1990) and is roughly half of the single dish flux. The very high S/N of the data and the spectral resolution of 10 km s^{-1} (Figure 1) allow us to glean kinematic details on spatial scales smaller

than the spatial resolution. We see evidence for a rotating ring or disk of molecular gas. Following the method outlined in Tacconi *et al.* (1994), we have constructed kinematic models to explain features observed in the CO maps. Kinematic major and minor axis position-velocity maps are well fit by a model where the intensity distribution has both a compact central component and a ring or disk at a radius of 1.5″. The velocity distribution is a slowly rising (not solid-body) rotation curve out to a radius of 4″. The gas lies in a plane with a low inclination angle of ∼25°. From the above kinematic parameters we have derived a dynamical mass of $\sim 1.4\times10^{10}$ $M_\odot$ in the central kpc. This is ∼3 times greater than the mass in stars over the same region (Genzel *et al.* 1995) and implies that the ISM dominates the mass and kinematics in the circumnuclear region of this Seyfert galaxy.

3. Mkn 231

At a distance of 170 Mpc, this ultra-luminous IRAS galaxy (ULIRG) ($L_{\rm IR}$ = 3.3×10^{12} $L_\odot$) with a Seyfert 1 spectrum is a factor of 4 farther away than NGC 7469. Our aim in studying this galaxy is to determine the main powering mechanisms for the extreme IR luminosity and to estimate the properties of the dense gas in the extreme environment of a ULIRG. MPE 3D NIR imaging spectroscopy shows evidence for both an AGN component and a circumnuclear region of intense starburst activity. The 2.3μm CO bandhead absorption feature peaks in the circumnuclear starburst, while the 2.12μm H_2 emission exhibits a bright central peak and a fainter extended component.

We have also recently detected CO J=6→5 emission from Mkn 231 with the MPE submm heterodyne spectrometer FANATIC on the JCMT. The 6→5 line is roughly half as strong as the 1–0 line (Radford, Solomon, & Downes 1991), assuming all CO lines arise from the same size emitting region. We estimate that the average kinetic temperature of the gas is ≥30 K in our 6→5 beam (7″ or 3 kpc).

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