CO IN SEYFERT GALAXIES

Timothy M. Heckman
Astronomy Program
University of Maryland
College Park, MD 20742
U.S.A.

ABSTRACT. We present data for Seyfert and normal galaxies in the Revised Shapley-Ames Catalog. The type 2 Seyferts are stronger CO and Far-IR emitters (by factors of 2-4) than either normal galaxies or type 1 Seyferts. The Seyfert CO line-widths correlate with both the 21cm HI and [OIII]5007 line-widths. Interferometer maps show that in many Seyferts the CO emission is strongly concentrated within radii of 100-1000pc of the nucleus. The implications of these results are briefly discussed.

1. INTRODUCTION

1.1 Scientific Motivation

The investigation of molecular gas in active galaxies is directly relevant to many of the "Big Questions" addressed in this Symposium. How and with what is the central engine fuelled? In many spiral galaxies the interstellar medium in the innermost kpc is largely molecular [1]. It is important then to determine whether Seyfert galaxies have an unusually bountiful (or dynamically peculiar) supply of circum-nuclear molecular gas.

What is the relationship between star formation and the Seyfert phenomenon? Star formation could be a cause or effect of nuclear activity [2,3,4], and has even been proposed as the fundamental energy source in Seyferts [5]. The study of molecular gas - potential fuel for the central engine and the raw material for star formation - will play a crucial role in answering this question.

What is the origin of the far-IR emission in Seyfert galaxies? In many, the far-IR dominates the luminous output, yet its origin is controversial [6]. In normal and starburst galaxies the far-IR emission and molecular gas are closely related. Comparing their relationship in Seyfert vs. non-

D. E. Osterbrock and J. S. Miller (eds.), Active Galactic Nuclei, 359–364.

Seyfert galaxies should be enlightening.

1.2 The J=1-0 115GHz Line of CO

This is the line of choice for investigating molecular gas in Seyfert galaxies. First, it is relatively bright and easily observed. Second, there is a large 115GHz CO database for normal galaxies which can be compared to the Seyfert data. Third, the CO line luminosity is a tracer of the total molecular mass. In normal Giant Molecular Clouds (GMC's) in the disk of our galaxy, the CO luminosity can be rather reliably used to measure the GMC mass [7]. This may not be true for molecular gas in the unusual environment of an active nucleus however [cf. 8].

2. THE DATA

2.1 CO Single-Dish Survey

We (Heckman, Blitz, Wilson, Armus, and Miley) have used the NRAO 12m telescope to search with 1 arcmin resolution for CO emission from 43 Seyfert galaxies and have detected 18. Similar data from the literature exists for 12 more Seyferts (8 more detections). We have then assembled CO data for the 29 Seyferts (and for 47 normal galaxies) that are in the Revised Shapley Ames Catalog and which have Hubble types from S0/a to Sbc ("RSA CO Seyferts" and "RSA CO Normals").

2.2 Far-Infrared Data

We (Heckman, Kirkpatrick, and Wilson) have used the IRAS database (co-added or pointed observations) to derive total far-IR (40-120 micron) luminosities for all 42 known Seyferts in the RSA and for a control sample of 42 normal galaxies with the same distribution in Hubble type, absolute magnitude, and distance as the Seyferts ("RSA FIR Seyferts" and RSA FIR Normals).

2.3 Interferometric CO Maps

We (Heckman, Blitz, Meixner, Puchalsky, and Wright) have used the Berkeley-Illinois-Maryland Array (BIMA) at Hat Creek to map the CO emission from three Seyfert galaxies (NGC3227, NGC5033, and NGC7469) with a resolution of 2-3 arcsec. Similar Owens Valley Radio Observatory (OVRO) data exist in the literature for the Seyferts NGC1068 [9], M51 [10], and the Far-IR galaxy Arp220 which may have a "buried" Seyfert nucleus [11,12].

3. RESULTS AND CONCLUSIONS

3.1 Single-Dish CO Survey

We have compared the CO properties of the RSA type 1 Seyferts, type 2 Seyferts, and normal galaxies. Normalized to the blue luminosity of the galaxy, the type 2 RSA Seyferts have (on-average) twice as strong CO emission as the normal galaxies. Normalized to the mass of HI in the galaxy, the type 2 RSA Seyferts 4 times stronger CO emission than the normal galaxies. In contrast, the CO properties of the RSA type 1 Seyferts are indistinguishable from those of the normal galaxies.

We have also compared the line-widths of the CO, HI 21cm, and [OIII]5007 emission-lines for all the Seyfert galaxies with relevant data. The CO line-widths are well-correlated with the HI line-widths and with the sine of the galaxy inclination, suggesting that the CO is configured in a rotating disk that is co-planar with the large-scale HI/optical disk of the galaxy. When the CO line-widths are corrected for inclination, they then correlate well with the uncorrected [OIII]5007 line-widths. This implies that gravity plays an important role in the dynamics of the NLR, but the NLR is evidently not configured as a rotating disk that is co-planar with the galaxy's largescale disk [see also 13,14].

3.2 Far-Infrared Luminosities

We find that the type 2 RSA FIR Seyferts have an average far-IR luminosity that is about 4 times that of the RSA FIR Normal galaxies. The type 1 RSA FIR Seyferts are indistinguishable from the normals galaxies in their far-IR luminosities.

These results are reminiscent of the results presented above for the CO luminosity. Indeed, in normal and starburst galaxies the far-IR and CO luminosities are rather well correlated [e.g. 15]. To understand how the Seyferts fit into this relationship, we have compared the ratio of the CO and far-IR luminosties for Seyfert and non-Seyfert galaxies with similar far-IR luminosities. We find that the Seyferts and non-Seyferts are statistically indistinguishable. This suggests that the mechanism that produces far-IR emission in non-Seyfert galaxies - thermal emission from dust heated by starlight - also dominates the far-IR emission from most Seyfert galaxies.

3.3 Interferometer Maps

The CO maps of NGC3227 and NGC7469 that my collaborators and I have recently obtained with BIMA reveal that the emission consists of two components. The first is an oblong structure across which a velocity gradient of several hundred km/sec is detected. The size of this component is about 1.2 x 0.5 kpc in NGC3227 and 7 X 3 kpc in NGC7469. If interpreted as a rotating structure lying in the plane of the galaxy disks, then each must have a nonaxisymmetric form (the eccentricity of the CO emission is greater than that of the optical disk of the galaxy).

The second component is centered on the nucleus of each galaxy and is only marginally resolved (diameter 200-300pc in NGC3227 and <800pc in NGC7469). Note that these dimensions are similar to those of the classical "Narrow-Line Region" (NLR), a region energized by the central engine. Arp220 also has a strong central concentration of CO emission [11]. However, this component is not present in all Seyfert galaxies. In both NGC1068 [9,16] and M51 [10], the CO brightness peaks in arc-like structures (broken rings and/or spiral arm segments) located 1-2kpc from the nucleus. Even in these two cases, weak CO emission can still detected from within a few arcsec (100-200pc) from the nucleus.

If we use the standard factor to convert J=1-0 CO luminosities into molecular gas masses [e.g. 17], the implied mass within 300pc of the nucleus ranges from 10 million solar masses for NGC1068 to several billion solar masses for NGC7469. The masses within 1kpc of the nucleus are several hundred million solar masses for NGC1068, NGC3227, NGC5033, and M51 and about 10 billion solar masses for NGC7469 and Arp220. It is important to emphasize that these masses could easily be in error by an order-of-magnitude (or more), since they are based on the assumption that the molecular clouds in these active galaxies are similar to those in the disk of the Milky Way. Even allowing for this uncertainty, it appears that the molecular gas dominates the mass of the optically-emitting ionized gas on similar radial scales: the NLR - with a typical mass of only about a million solar masses - may be only a "tip of the iceberg" in Seyfert galaxies.

4. CONCLUSIONS AND IMPLICATIONS

The principal conclusion from the CO and far-IR survey is that the type 2 Seyfert galaxies in the RSA are unusually strong CO and far-IR emitters compared to normal galaxies with similar Hubble types, absolute magnitudes, and HI masses. The type 1 Seyferts - in contrast - have rather normal CO and far-IR properties. The relationship between the CO and far-IR emission in the Seyferts is indistinguishable from that characterizing non-Seyferts, implying that the far-IR emission in these Seyferts is primarily due to dust heated by starlight. These results suggest that the type 2 Seyferts are characterized by abnormally high molecular gas contents and star formation rates.

One potentially important implication of the above is that type 2 Seyferts are intrinsically different from type 1 Seyferts. Could the apparent over-abundance of molecular gas be related to the material that is obscuring the Broad-Line Region in at least some (all??) type 2 Seyferts [18]?

These results also suggest some link between star formation, molecular gas, and the Seyfert phenomenon. The strong central concentration of CO emission seen in the interferometer maps of several Seyferts is very tantalizing evidence that molecular gas might play a key role in fuelling the activity. The molecular gas on scales of several kpc has a "bar-like" morphology in NGC3227 and NGC7469 and is directly observed to have strongly noncircular motions in the ovally-distorted galaxy NGC1068. These results are consistent with models in which an AGN is fuelled by radial inflow of gas driven by a nonaxisymmetric potential [19, 20]. Further mapping of CO in Seyferts is required to test these ideas.

Finally, the CO data provide some fresh clues as to the nature of the Narrow-Line Region. Gravity apparently plays an important dynamical role, but the NLR is not a rotating disk that is co-planar with the largescale galaxy disk. The systematic blue asymmetries of the NLR emission-line profiles [13, 14] tell us that radial motions are important in the NLR. Could the NLR be infalling? Alternatively, is the NLR accelerated outward by a wind whose terminal velocity is determined by the local escape velocity [21]? The interferometer maps also teach us that the molecular gas on sub-kpc scales may play a dominant role in the origin and evolution of the NLR clouds, insofar as the molecular gas often contains most of the gaseous mass in the circum-nuclear region.

5. REFERENCES

[1] Morris, M. and Rickard, L.J. 1982, Ann.Rev.Astr.Ap., 20, 517.

[2] Norman, C. and Scoville, N. preprint.

[3] Sanders, R. and Bania, T. 1976, Ap.J., 204, 341.

[4] van Breugel, W., Filippenko, A., Heckman, T., and Miley, G. 1985, Ap.J., 293, 83.

[5] Terlevich, R. and Melnick, J. 1985, MNRAS, 213, 841.

[6] Soifer, B., Houck, J., and Neugebauer, G. 1987, Ann.Rev.Astr.Ap., 25, 187.

[7] Dame, T.M. etal. 1987, Ap.J., 322, 706.

[8] Blitz, L., Bloemen, J., Hermsen, W., and Bania, T. 1985, Ap.J., 143, 267.

https://doi.org/10.1017/S0074180900141348 Published online by Cambridge University Press

[9] Myers, S.T. and Scoville, N. 1987, Ap.J., 312, L39.
[10] Lo, K.Y. etal. 1987, Ap.J.Lett., 317, L63.
[11] Scoville, N. etal. 1986, Ap.J.Lett., 311, L47.
[12] Becklin, E. and Wynn-Williams, G. 1987, in Star Formation in Galaxies, ed. C. Persson (U.S. Govt. Printing Office), 753.
[13] Heckman, T., Miley, G., Butcher, H., and van Breugel, W. 1981, Ap.J., 247, 403.
[14] Whittle, M. 1985, MNRAS, 213, 1.
[15] Sanders, D. etal. 1986, Ap.J.Lett., 305, L45.
[16] Kaneko, N. etal. 1988, preprint.
[17] Bloemen, J. etal. 1986, Astr.Ap., 154, 25.
[18] Miller, J. 1988, this volume.
[19] Simkin, S., Su, H., and Schwarz, M. 1980, Ap.J., 237, 404.
[20] Schlosman, I., Frank, J., and Begelman, M. 1988, this volume.
[21] Krolik, J. and Vrtilek, J. 1984, Ap.J., 279, 521.