Formation and Evolution of Galaxy Bulges
Proceedings IAU Symposium No. 245, 2007
M. Bureau, E. Athanassoula & B. Barbuy, eds.

doi:10.1017/S1743921308017808

Feeding black holes: tracing gas flows from the outskirts to the centers of galaxies

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Abstract. We analyzed the distribution and kinematics of the atomic gas (HI) in 16 nearby spiral galaxies. Our results indicate that the morphology of the atomic gas and dynamically disturbed outer disks correlate with the AGN type present (Seyfert, LINER). From the combined HI and CO data (from the NUGA project), 2-dimensional maps of the gas flow are computed and gas inflow rates are derived as a function of radius within the disks.

Keywords. galaxies: kinematics and dynamics, galaxies: Seyfert, galaxies: spiral, radio lines: galaxies

1. Introduction

The process of fueling Active Galactic Nuclei (AGN) requires a continual inflow of material. Thus, mapping the gas flow from the outskirts to the very center of galaxies is critical to understand the growth of Super-Massive Black Holes (SMBH) and the origin of nuclear activity. The majority of AGNs show low-ionization narrow emission-line regions (LINERs) with luminosities lower than Seyfert galaxies and quasars. Although Seyferts and LINERs are powered by the same basic process, i.e. accretion of matter by a SMBH, the Seyfert/LINER distribution is bimodal (Groves *et al.* 2006), implying different accretion modes (for a general review see Combes 2001). In order to trace the gas flow on various spatial scales, ranging from a few 10pc in the very center to the outer galactic disk at several kpc distance we have complemented the IRAM key project NUclei of GAlaxies (NUGA; García-Burillo *et al.* 2003) on the molecular gas (CO) with high quality observations of the atomic gas (HI) for a sample of 16 nearby spiral galaxies (low-luminosity AGN and starburst galaxies). The combined HI and CO data are used to determine gas inflow rates as a function of radius and location within the disks.

2. Correlations between HI gas properties and AGN activity type

We have studied the distribution and kinematics of the atomic gas in 16 galaxies using the NRAO Very Large Array (VLA) interferometer in its C- and D-array configuration with ~21″ angular and ~5.2 km s^{-1} spectral resolutions. Our AGN classification (Seyfert, LINER, and Starburst galaxies) is based on the method of Kewley *et al.* (2006). All galaxies are spirals ranging in Hubble type from Sa to Sbc. Note that the mean morphology type is roughly the same for Seyfert (t = 2.7) and LINER host galaxies (t = 2.8). For our sample we find differences between the HI properties of LINERs and Seyfert hosts (Haan *et al.* 2007):

- While the HI morphology shows a large variety, HI gas rings are predominantly present in LINER host galaxies (57%; Seyferts: 0%).
- Kinematically disturbed outer HI disks are prevalent in LINER host galaxies (71%; Seyferts: 14%).
- There is no correlation between the AGN type and the presence of companions (with and without HI gas).

Our findings suggest that the type of nuclear activity is linked to the gas flow present in the entire gas disk. One possible explanation for an abundance of HI gas rings in LINERs may be an AGN evolutionary scenario linked to the presence of a stellar bar. Such a general scenario for self-regulated activity in low-luminosity AGNs was developed by García-Burillo *et al.* (2005), in which the onset of nuclear activity is explained as a recurrent phase during the typical lifetime of a stellar bar in a galaxy. This becomes important as rings are observationally and phenomenologically linked to barred galaxy dynamics (Buta & Combes 1996). Thus, a time evolution of AGN types might be possible, where Seyfert and LINERs represent different phases of a galaxy's activity cycle.

3. Gas flow and feeding efficiencies

The gas inflow rates using interferometric CO and HI data are studied via gravity torque maps derived from NIR/optical images and the gas distributions (see García-Burillo *et al.* (2005)). Recently obtained VLA B-array data results with 7″ resolution were combined with the PdBI CO data from the IRAM NUGA project. A pilot study using the combined molecular and atomic gas distribution was performed on NGC 6951 and NGC 4321. Preliminary results show that 1) the direction of the torques is continuous from the outskirts (HI gas) to the very center (CO gas) of these galaxies implying a common underlying dynamical mechanism and 2) the torque changes sign in different quadrants of the gas disk, which can be attributed to the action of the outer and nuclear bars. We will apply the gravity torque method to 7 galaxies of our sample in order to derive gas inflow rates and to assess the efficiency of the feeding of the central black hole.

Acknowledgements

SH is supported by the German DFG under grant number SCHI 536/2-1.

References

Buta, R. & Combes, F. 1996, Fundamentals of Cosmic Physics, 17, 95
Combes, F. 2001, Advanced Lectures on the Starburst-AGN, 223
García-Burillo, S., *et al.* 2003, *A&A*, 407, 485
García-Burillo, S., Combes, F., Schinnerer, E., Boone, F., & Hunt, L. K. 2005, *A&A*, 441, 1011
Groves, B., Kewley, L., Kauffmann, G., & Heckman, T. 2006, New Astronomy Review, 50, 743
Haan, S., Schinnerer, E., Mundell, C. G., García-Burillo, S., & Combes, F. 2007, *AJ*, submitted
Kewley, L. J., Groves, B., Kauffmann, G., & Heckman, T. 2006, *MNRAS*, 372, 961