Abstract. The NUclei of GAlaxies (NUGA) project is a combined effort to carry out a high-resolution (<1") interferometer CO survey of a sample of 12 nearby AGN spiral hosts, using the IRAM array. We map the distribution and dynamics of molecular gas in the inner 1 kpc of the nuclei with resolutions of \( \sim 10^{-50} \text{pc} \), and study the mechanisms for gas fueling of the different low-luminosity AGN. First results show evidence for the occurrence of strong \( m = 1 \) gas instabilities in Seyferts. NUGA maps allow us to address the origin/nature of \( m = 1 \) modes and their link with \( m = 2 \) modes and acoustic instabilities, present in other targets.

1. Introduction

The study of interstellar gas in the nuclei of galaxies is key for understanding nuclear activity and circumnuclear star formation. Within the central kiloparsec, most of the gas is in the molecular phase, which makes CO lines the optimal tracers of nuclear gas dynamics. Up to now, however, CO surveys of galaxies made with single-dish telescopes or interferometers were hampered by insufficient spatial resolution. Furthermore, until very recently (Baker 2000; Jogee et al 2001), the published survey samples have included very few AGN.

NUGA aims at filling this gap by carrying out a high resolution/sensitivity CO survey of a moderately large sample of 12 nearby AGN which span the whole sequence of activity types (Seyf 1, 2 and LINERs). We seek to determine the molecular gas distributions and kinematics in the central 1 kpc of the nuclei with resolutions <1" (<10-50 pc), and to study the different mechanisms driving gas infall to the AGN. Observations in the 2–1 and 1–0 lines of \(^{12}\text{CO} \) are carried out with the IRAM interferometer. On the modeling side, N-body simulations are performed to analyse the evolution of stellar/gaseous gravitational instabilities in
the different study cases. NUGA has a multiwavelength approach: the sample is defined based on the availability of high-quality optical and near-infrared images of the galaxies, both from ground-based telescopes and the HST; these are essential to study how star formation proceeds in the nuclear region. The long term aim is to complete a supersample of 25-30 objects observed by consortium members, within and outside NUGA, with the IRAM array.

2. NUGA unveils gravitational instabilities in Seyferts

Analysis of the first NUGA data on 8 targets has produced a set of studies of individual galaxies which represent prototypical examples of the large variety of gravitational instabilities unveiled in the maps, including $m=1$ modes (one-arm spirals, lopsided disks), $m=2$ perturbations (rings, two-arm spirals) and stochastic patterns (non self-gravitating perturbations) (Fig. 1).

The CO maps obtained in 4 galaxies (NGC 4826, NGC 1961, NGC 3718 and NGC 4579) reveal $m = 1$ perturbations, which appear as one-arm spirals and lopsided disks. Asymmetric modes develop from several tens to several hundreds of pc. The maps of NGC 4826 (see García-Burillo et al. 2002) reach so far 16 pc resolution and resolve the inner molecular disk to a radius of 700 pc. Molecular gas mass is distributed in a 40 pc-radius lopsided disk containing 15% of the total gas content, and two $m = 1$ spirals at different radii. A model of the streaming motions associated with the $m = 1$ perturbations suggest that the inner modes are fast trailing waves (Fig. 2). This implies that the lopsided instability may slow down or temporarily halt gas infall. The $\sim 1.4''$ CO(2-1) maps of NGC 1961 (see Baker et al. 2002) partly resolve the circumnuclear disk, showing a very strong one-arm spiral instability from several hundred pc to 1.5 kpc. The Unsharp Masked HST/NICMOS map shows also a similar feature in the dust map.

We have also found examples of $m = 2$ perturbations (two-arm spiral waves and gas bars). NGC 6951 shows a very regular nuclear spiral structure, roughly coincident with the hot-spot circumnuclear ring. NGC 2782, a hybrid starburst-transition object, shows an intricate mixture of instabilities including an outer two-arm spiral, a gas bar, and a nuclear mini-spiral. NGC 3147 shows a nested two-arm spiral structure and a compact source on the AGN.

Most of the nuclear perturbations observed in NUGA targets are self-gravitating gas instabilities. The CO+HST images of NGC 7217 identify self-gravitating perturbations in the disk and, also, stochastic instabilities on the AGN (see Combes et al. 2002). The 1–0 map shows molecular gas confined in a very regular circular ring of 800 pc radius. The 2–1 map shows also a compact unresolved source on the AGN linked to a stochastic mini-spiral seen in the $V−I$ HST color image. Combes et al. (2002) have made self-consistent numerical simulations that account for the CO ring morphology and the onset of central non self-gravitating perturbations. The combination of ring+stochastic waves in NGC 7217’s gas distribution might reflect evolution along the Seyfert sequence, with this galaxy being a more evolved Seyfert.
Figure 1. $^{12}$CO(1–0) (left) and $^{12}$CO(2–1) (right) NUGA images, discussed in text, for NGC 4826 (García-Burillo et al. 2002), NGC 7217 (Combes et al. 2002), NGC 1961 (Baker et al. 2002), and NGC 3718 (Krips et al. 2002). CO maps unveil a large variety of gravitational perturbations: m=1 modes, m=2 modes and stochastic patterns.
3. Conclusions and Prospects

Preliminary results based on still incomplete observations of 8 galaxies of the sample reveal a wide range of gravitational instabilities in the central 1 kpc of NUGA targets. Most remarkably, $m = 1$ modes appear at different spatial scales in some AGNs, although these modes might not universally favor AGN feeding. Point-symmetric $m = 2$ perturbations and stochastic patterns dominate the response in others. Although general conclusions will have to wait for a global analysis of the 30-galaxy supersample, these results already indicate that the correlation between activity type (Seyf 1, 2 or LINERs) and nuclear morphology of the host might be weak at scales of ten-to-hundred pc. If confirmed, the lack of a clear evolutionary scenario may reflect a mismatch between the episodic AGN duty cycle, and the larger time-scales needed to build up nuclear gravitational instabilities which are directly or indirectly involved (by the onset of nuclear starbursts) in fueling AGN.

References

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