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The Nature of Composite LINER/H II Galaxies

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Abstract. A sample of 37 nearby galaxies displaying composite LINER/H II and pure H II spectra was observed with the VLA in an investigation of the nature of their weak radio emission. Radio morphological data permit the assessment of the 'classical AGN' contribution to the global activity observed in these composite LINER/H II galaxies. Our results show that about 20% of the latter objects display clear AGN characteristics: a compact, flat spectrum, high brightness radio core. Furthermore, these AGN candidates reside in bulge-dominated galaxies and also stand out in their optical emission-line and infrared properties.

1. Introduction

LINERs are a class of active galaxies characterized by the presence of strong, nuclear, low-ionization emission lines (Heckman 1980; see Figure 1). Like Seyfert nuclei, LINERs emit much stronger optical low-ionization forbidden lines compared to H II nuclei, whose line emission is powered by photoionization from young massive stars, but LINERs have a characteristically lower ionization state than Seyfert nuclei. In a recent optical survey of nearly 500 nearby galaxies, Ho, Filippenko, & Sargent (1995, 1997a, 1997b) find that 20% of all galaxies brighter than B_T = 12.5 mag display LINER-type spectra. An additional 13% of the objects show spectra intermediate between those of 'pure' LINERs and 'pure' H II nuclei. Ho, Filippenko, & Sargent (1993) (see also Ho 1996) dubbed this class as 'transition objects', and they hypothesized that these might be composite systems in which the optical signal of a weak active nucleus (the LINER component) has been spatially blended by circumnuclear star-forming regions (the H II component).

Models have shown that photoionization by hot stars is able to reproduce the optical spectra of LINERs (Terlevich & Melnick 1985; Terlevich et al. 1992; Barth & Shields 2000), especially those of the transition-type variety (Shields 1992; Filippenko & Terlevich 1992). Other researchers have advocated shock-wave heating as a viable excitation mechanism for LINERs (Fosbury et al. 1978;

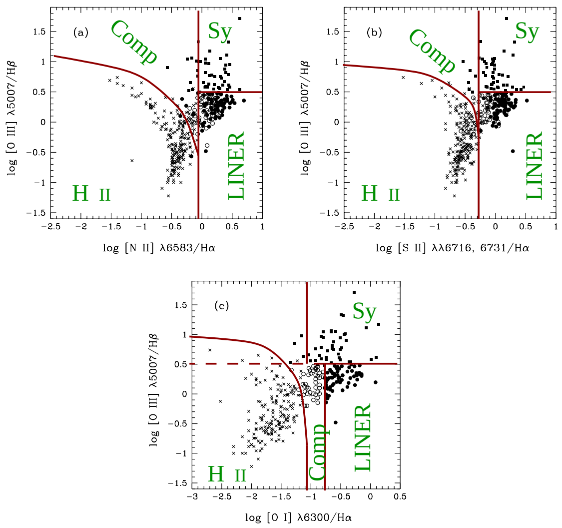

Fig. 1. Diagnostic diagrams used for galaxy classification. Plotted galaxies belong to the Palomar sample (adapted from Ho et al. 1997a).

Heckman 1980; Dopita & Sutherland 1995). At the same time, an increasing body of evidence suggests that a significant fraction of LINERs do contain irrefutable active galactic nucleus (AGN) characteristics (see reviews by Filippenko 1996 and Ho 1999b). Radio surveys, in particular, have shown that many LINERs exhibit weak nuclear radio emission (Heckman 1980; Sadler, Jenkins, & Kotanyi 1989; Wrobel & Heeschen 1991; Slee et al. 1994; Nagar et al. 2000; Falcke et al. 2000; Filho et al. 2000). As discussed in detail by Ho (1999a), weak nuclear radio emission in early-type (elliptical and S0) galaxies is most likely related to accretion-driven energy production in these objects but at a very low level compared to powerful radio galaxies, which are also usually hosted by early-type systems.

Radio observations provide an especially attractive tool to further our understanding of the LINER phenomenon. Since radio frequencies are not plagued by dust obscuration and photoelectric absorption, high-resolution radio observations potentially offer the cleanest and most efficient method to isolate an AGN core. Although radio emission also arises from supernova remnants and H II regions, AGN cores can be identified through their high degree of central concentration, small angular size, flat spectral indices, and high brightness temperatures.

We are therefore conducting high-resolution radio observations of selected LINER samples in order to investigate the interrelation between LINERs and classical AGNs. In this first part of our work, we have concentrated on transition-type LINERs. We report on sensitive Very Large Array (VLA) C-configuration observations of a sample of 25 such transition LINERs at 8.4 GHz. The resulting images, having angular resolution of about $2.5''$, allow us to assess the strength and spatial distribution of the nuclear radio emission. For comparison, we have also observed a small sample of 12 pure H II nuclei.

In the following discussion we adopt a Hubble constant of $H_0 = 75$ km s^{-1} Mpc^{-1} and define the spectral index such that $S \propto \nu^{-\alpha}$.

2. The Sample and Observations

The sample of 25 transition LINER/H II galaxies and 12 pure H II nuclei was extracted from the original magnitude-limited Palomar survey of 486 bright northern galaxies (Ho et al. 1995), following the classification criteria outlined in Ho et al. (1997a). The Palomar sample contains 65 transition nuclei (Ho et al. 1997a), from which we chose a subset of 25 that had little or no arcsec-scale resolution radio continuum data published, and that fell within the observation window assigned to us by the VLA. In addition, we selected for comparison a small sample of 12 pure H II nuclei (out of 206 such objects in the full Palomar sample). These were chosen to mimic the Hubble type distribution of the sample of transition objects, again taking into consideration scheduling constraints.

The resulting sample of composite LINER/H II and pure H II galaxies was observed with the X-band (8.4 GHz) system of the VLA in two observing sessions, on 1997 August 21 and August 25. The array was in its C-configuration, yielding a typical resolution of $2''.5$. Two bands of 50 MHz each were combined, yielding a total bandwidth of 100 MHz. Snapshot observations combining two scans of 8–9 minutes each, at different hour angles, were obtained in order to improve the shape of the synthesized beam. The noise levels reached the theoretical noise level of $\sim$ 0.04 mJy/beam (Perley, Schwab, & Bridle 1989) to within a factor of two. Reduction of the data was performed using standard NRAO AIPS (version 15OCT98) image processing routines.

3. The Radio Morphology

Radio contour maps of NGC 4414, NGC 4713, NGC 4552 and NGC 5354 are presented below, superimposed on grey-scale optical images from the Digitized Sky Survey

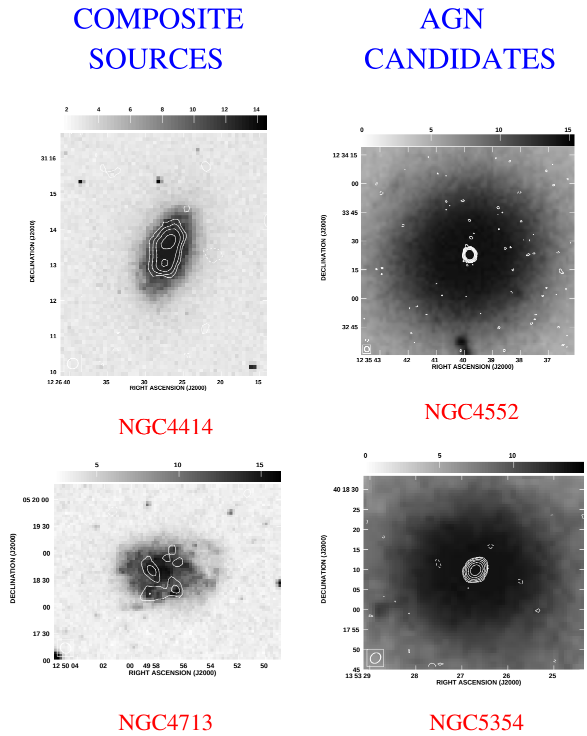

Fig. 2. Examples of non-AGN transition sources (*left*) and AGN candidates (*right*). The radio emission (*contours*) is superimposed on optical images from the DSS (*grey scale.*) See the text for details.

(DSS). Contouring is CLEV × (−3, 3, 6, ..., 96) mJy/beam where CLEV – typical noise level on the radio map – is 0.15, 0.08, 0.08, 0.06 mJy beam^{-1}, for each source. The resolution is 18.70 × 17.70, 12.12 × 10.95, 2.93 × 2.54, and 2.84 2.37 arcsec^2 for each source, respectively, where we have applied a 10 and 15kλ taper to NGC 4414 and NGC 4713.

Purely based on the radio morphology, the transition LINER objects can be divided into two categories. The first is made up of galaxies displaying extended, steep-spectrum, low surface brightness radio emission, usually tracing the optical isophotes of the host galaxy (NGC 4414 and NGC 4713; see Figure 2). The second category refers to objects that, in addition to extended emission, also show compact nuclear radio emission (NGC 4552 and NGC 5354; see Figure 2). The first category displays radio morphologies that are consistent with their being due to large-scale star formation; in several cases the radio morphology is seen to trace the H II regions in the host. However, we stress that the presence of a very weak nuclear component in these objects may still be masked by the more dominant radio emission from star-forming regions. The second category, which we will refer to in the following as AGN candidates, is comprised of NGC 3627, NGC 4552, NGC 5354, NGC 5838, and NGC 5846.

4. AGN Candidate Properties

In Table 1 we compile some AGN candidates properties. By rows we tabulate: Hubble type (Ho et al. 1997a) (1), the core luminosity in units of erg s^{-1} Hz^{-1} (Filho, Barthel & Ho 2000) (2), the radio spectral index (Filho, Barthel & Ho, in prep.) (3), and the far-IR to radio ratio (Ho et al. 1997a; Filho, Barthel & Ho, in prep.) (4).

Table 1. AGN candidate properties.

	N 3627	N 4552	N 5354	N 5838	N 5846
Hubble Type	SAB	E	SA0	SA0	E0
Log L_{core}	26.3	28.4	28.2	27.3	27.8
α	...	0.2	-0.2	0.2	0.6
u	2.2	0	1.6	2.4	<0.7

Inspection of Table 1 readily shows that these AGN candidates are hosted by rather early-type galaxies (E–Sb). The relevant radio core luminosities $L_{8.4\,GHz}$ range from $\sim 10^{26.2} - 10^{28.5}$ erg s^{-1} Hz^{-1}, which is several orders of magnitude less than the core luminosities in FR I or FR II type (Fanaroff & Riley 1974) radio galaxies and quasars, and in the range of the weakest radio cores observed in Seyfert galaxies (Giuricin et al. 1996). This, then, implies that weak LINER AGN preferentially occur in bulge-dominated hosts, not necessarily just in ellipticals, consistent with statistical results from other lines of evidence (Ho et al. 1997b; Ho 1999b). This is in agreement with the case of Seyfert galaxies, for which the radio core emission was also found to be stronger in early-type hosts (Giuricin et al. 1996). As such, these weak AGN differ from the more powerful FR I radio galaxies, which are commonly associated with elliptical galaxies, not seldom brightest cluster galaxies (Zirbel & Baum 1995). They exceed the very weak nuclear source in the nearby transition LINER NGC 7331 (Cowan et al. 1994) by a factor of $\sim$ 15, and are comparable in strength to the well-known variable radio core of the LINER nucleus in M 81 (e.g., Ho et al. 1999). The last four AGN candidates are also characterized by a flat/inverted radio spectral index between 1.4 and 8.4 GHz (Filho, Barthel & Ho 2000). Judging from high-resolution observations which isolate the nuclear emission, the compact nucleus of NGC 3627 also displays a flat radio spectrum (Saikia et al. 1994). The behavior of the so called u-parameter, which measures the radio/far-IR ratio, also supports the weak AGN classification, in the sense that the AGN candidates display a 'radio excess' (Filho, Barthel & Ho, in prep.). Furthermore, the class of AGN candidates indeed displays somewhat stronger [N II] and [S II] lines in their optical spectra than the non-AGN transition sources (Filho, Barthel & Ho, in prep.). Finally, follow-up VLA A-array and VLBA observations have confirmed the presence of compact, flat spectrum, high brightness temperature ($T_B > 10^8$ K) cores (N. Nagar, private communication 2000; Filho et al. , in prep.) in these sources. Hence, it must be concluded that at least some weak LINER AGN reveal themselves by low-power radio cores.

5. Conclusions

A sample of composite LINER/H II galaxies and pure H II nuclei was studied using the VLA (C-array) at 8.4 GHz. On the basis of their radio morphological properties, the composite sources can be divided into objects with low surface brightness emission confined mainly to the plane of the galaxy and objects displaying compact nuclear components. The former objects are similar in radio morphology to the H II nuclei in our sample, whereas the latter show morphologies consistent with AGN, that is, a compact, flat/inverted, high brightness temperature radio core. All five of the LINER AGN are hosted by bulge-dominated galaxies (Hubble type E–Sb) and are different in their optical and infrared properties when compared to non-AGN composite sources. In terms of radio luminosity, the present LINER AGN populate the range of low core radio luminosities, which implies that classical AGN of low luminosity exist in a wide range of galaxy types.

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