Radio Cores in Low-Luminosity AGN: ADAFs or Jets?

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Abstract. We have surveyed two large samples of nearby low-luminosity AGN with the VLA to search for flat-spectrum radio cores, similar to Sgr A* in the Galactic Center. Roughly one third of all galaxies are detected (roughly one half if HII transition objects are excluded from the sample), many of which have compact radio cores. Follow-up observations with the VLBA have confirmed that these cores are non-thermal in origin, with brightness temperatures of $\geq 10^8$ K. The brightest of these are resolved into linear structures. The radio spectral indices of the cores are quite flat ($\alpha \sim 0$), with no evidence for the highly inverted radio cores predicted in the ADAF model. Spectrum and morphology of the compact radio emission is typical for radio jets seen also in more luminous AGN. The emission-line luminosity seems to be correlated with the radio core flux. Together with the VLBI observations this suggests that optical and radio emission in at least half the low-luminosity Seyferts and LINERs are black hole powered. We find only a weak correlation between bulge luminosity and radio flux and an apparently different efficiency between elliptical and spiral galaxies for producing radio emission at a given optical luminosity.

1 Introduction

What powers the nuclei of nearby galaxies? Many of them show evidence for emission-lines similar to those seen in active galactic nuclei (AGN) but on a much lower level (Ho et al. 1997a) — therefore they are called low-luminosity AGN (LLAGN). In some cases broad lines are seen and hence one infers the presence of a central black hole (Ho et al. 1997b). In most cases, however, even a moderate starburst might be able to explain the observed optical spectra (Alonso-Herrero et al. 1999), especially those residing in LINER galaxies (Heckman et al. 1983).

Another method to identify the nature of the activity is to search for compact, flat-spectrum radio cores with high brightness temperatures, since this

[5] In: "Black Holes in Binaries and Galactic Nuclei", ESO workshop, eds. L. Kaper, E.P.J. van den Heuvel, P.A. Woudt, Springer Verlag

is a typical feature of many AGN and cannot be explained by star formation. For LLAGN the nature of these radio cores is largely unclear. It has been proposed that the compact radio emission could be produced either by emission from an Advection Dominated Accretion Flow (ADAF; e.g. Narayan et al. 1998) or from scaled-down AGN jets (Falcke & Biermann 1996; 1999).

We have therefore performed a VLA survey of two samples of nearby galaxies with optical emission-lines to identify such compact radio cores. Follow-up observations with the VLBA of these cores have been made that shed further light on their nature.

2 Samples and Observations

The first sample we observed consisted of 48 galaxies with mainly LINER-like emission spectra that were part of ongoing studies at other wavelengths. In a second project we expanded this sample to a distance-limited sample of galaxies with emission-lines within 19 Mpc.

Both samples were observed with the VLA in its largest configuration at 15 GHz. In the final data reduction we reached a 10 σ detection limit of ~ 1.1 mJy. The resolution was about $0.15''$ which corresponds to a linear scale of 14 pc for a galaxy at a distance of 19 Mpc. All sources which were detected with compact emission above 3 mJy in either sample were then observed with the VLBA at 5 GHz with a resolution of 2.5 mas (~ 0.2 pc at 19 Mpc distance) and a detection limit around 2 mJy.

3 Results

We are going to restrict the following discussion to the detection of compact core emission. The detection rate in our first LLAGN sample was 35% (17 of 48), higher than similar deep surveys of normal galaxies (Wrobel & Heeschen 1991). Only two sources had steep spectra and only one out of eighteen sources with optical classification as transition sources (Ho et al. 1997a) was detected. The other detections are all in LLAGN with either Seyfert or LINER spectra. This is confirmed by the results of our distance-limited survey: 44% of LLAGN with Seyfert or LINER spectra have compact cores, but only 12% of transition objects do.

These results suggest that galaxies with Seyfert and LINER spectra are black hole powered, while transition objects are dominated by star formation. The evidence for black hole powered engines is further strengthened by our VLBA results. Even though our detection limit was close to our selection threshold, 19 out of 20 galaxies[1] showed compact radio emission with brightness temperatures of the order $T_{\rm B} \geq 10^8$ K. The one non-detected source had a steep-spectrum and hence is the exception which confirms the

[1] This includes M81 and M87 which are part of the sample but have well known radio cores and were not observed by us.

rule that also in LLAGN flat-spectrum radio cores are a sign of high-T_{B} AGNs. We find that the six brightest sources in our VLBI sample all show typical core-jet structures. The fainter cores probably have too low dynamic range and signal-to-noise to show any significant extended structure. Figure 1 (left panel) shows the distribution of spectral indices between our total 6 cm (VLBA) and 15 GHz (VLA) flux densities ($S_\nu \propto \nu^\alpha$). Even though comparing VLBA with VLA fluxes and our selection at 15 GHz is biased towards highly inverted spectra, none of the spectral indices has $\alpha > 0.25$, in conflict with the prediction of the ADAF model (e.g. Yi & Boughn 1998) but quite consistent with the predictions of jet models (Falcke & Biermann 1999). The average is $\langle\alpha\rangle = 0.0$.

For the VLBI-sample, i.e. the well-detected cores above 3 mJy, for which we have basically established that the radio emission is AGN-related, we also looked at correlations between radio, emission-line, and bulge luminosities. Figure 1 (right panel) shows that there is a trend for galaxies with higher Hα emission to have more luminous radio cores. Interestingly, elliptical and spiral host galaxies are offset from each other. Does this reflect a radio-loud/radio-quiet dichotomy for LLAGN?

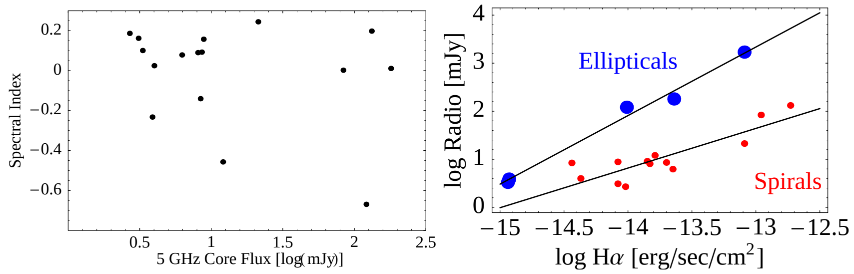

Fig. 1. Left: Spectral indices of LLAGN in our sample with $S_{15\mathrm{GHz}} > 3$ mJy between 5 GHz (VLBI) and 15 GHz (VLA) as a function of radio core flux at 5 GHz. Right: $S_{15\mathrm{GHz}}$ plotted versus narrow Hα flux for the same sample; ellipticals and spirals are distinguished by big and small dots respectively.

However, there is another important factor: the galaxy bulge luminosity. We do see a weak trend for the radio luminosity to be related to bulge luminosity; also the ratio between radio and Hα luminosity tends to increase with increasing bulge luminosity. Hence, galaxies apparently become more efficient in producing radio emission relative to Hα in bigger bulges. This also holds if we look at the enitre VLA detected sample (Fig. 2). Whether this is due to increasing obscuration, effects intrinsic to the AGN, or a selection effect is unclear. Since ellipticals and spirals in our sample are nicely separated between the top and bottom end of the bulge luminosity distribution, an apparent dichotomy in Fig. 1 is a natural consequence of this trend.

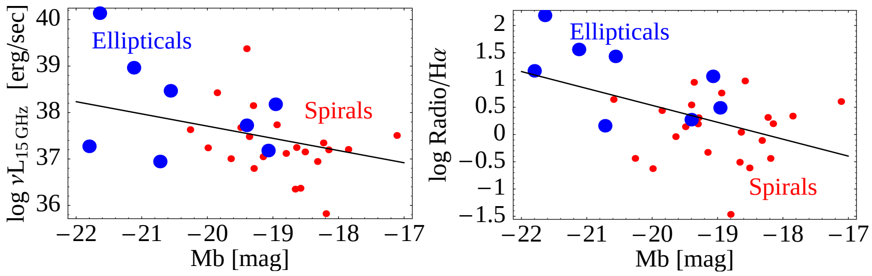

Fig. 2. Left: Radio luminosity (νL_ν) at 15 GHz of LLAGN in our sample with $S_{15\mathrm{GHz}} > 1.5$ mJy as a function of blue bulge magnitude. Right: Ratio between 15 GHz radio core and narrow Hα flux as a function of blue bulge magnitude in the same sample. Ellipticals and spirals are distinguished by big and small dots respectively.

4 Discussion & Summary

We find that at least 40% of optically selected LLAGN with Seyfert and LINER spectra have compact radio cores. VLBI observations show that these cores are similar to radio jets in more luminous AGN with high brightness temperatures, jet-like structures, and flat radio spectra (e.g. Falcke & Biermann 1996; 1999). The radio emission seems to be related to the luminosity of the emission-line gas and hence both are probably powered by genuine AGN operating at low powers. We found no evidence for high frequency components with highly inverted spectra predicted in ADAF models. Hence, for these models one should probably not include radio fluxes in broad-band spectral fits. We also find only a weak correlation between radio and bulge luminosity. Together with the radio-Hα correlation this makes it very unlikely that the black hole mass could be reliably determined from the radio data—in contrast to what is occasionally suggested.

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