Preliminary results from the COLA N sample

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Abstract. We present preliminary radio imaging results for the northern COLA (Compact Objects in Low power AGN) sample. COLA is a large sample of moderate luminosity $10 \leq \log(L_{\rm FIR}/L_{\odot}) \leq 12$ infra-red selected galaxies. Our primary aim is to investigate possible connections between starburst activity and AGN. The sample has been observed in a variety of wavebands searching for correlations between AGN presence, galactic structure, gas content or degree of interaction. VLA A-array observations of half of the Northern sample are presented. From this data we find, consistent with previous studies, an anti-correlation between FIR luminosity and radio size. Unexpectedly we find that amongst sources which lie slightly above the radio-IR correlation, the excess radio emission is mostly in large scale structure ($\geq$ 1kpc). Studies of the southern COLA sample suggest a strong correlation between having a radio excess and the presence of a compact AGN core, even though the core itself only accounts for small fraction of the excess. We speculate that either the bulk of AGN radio emission is on unexpectedly large scales or that AGN presence is correlated with old starbursts; a result consistent with proposed evolutionary models.

INTRODUCTION

The COLA project (Compact Objects in Low power AGN) [1], [2] is an ambitious survey of IR selected galaxies which aims to understand how AGN and starburst activity relate to each other and to global galactic properties. A commonly accepted model for both AGN and starburst triggering invokes galaxy interactions forcing gas into the centre of the host galaxy, forming a nuclear starburst and/or feeding an AGN. Additionally it has been proposed that there might be an evolutionary connection between star formation and AGN activity with the former dying out and leaving a naked AGN [3].

Recent observations of Seyferts [4] have shown that associated nuclear starbursts do exist in many Seyferts, supporting a strong AGN-starburst connection. Studying nuclear star formation in samples of AGN is one way to find and understand possible relations. A complementary approach, adopted by COLA, is to select a sample of starburst galaxies and look for AGNs of different types. The nature of the star formation and the presence and type of AGN activity can then be correlated with the properties of the host galaxy and the presence or absence of companions. We can test whether as predicted AGN activity follows starburst activity in several ways, for instance by seeing if COLA sources with AGNs have more distant companions than those without AGN [5]. Alternatively the shape of the radio spectrum and the relative radio/IR luminosities [6], [7] can be used to determine a starburst age to see if AGN are more likely in older starbursts.

COLA tries to avoid potential luminosity/resolution selection bias affecting other

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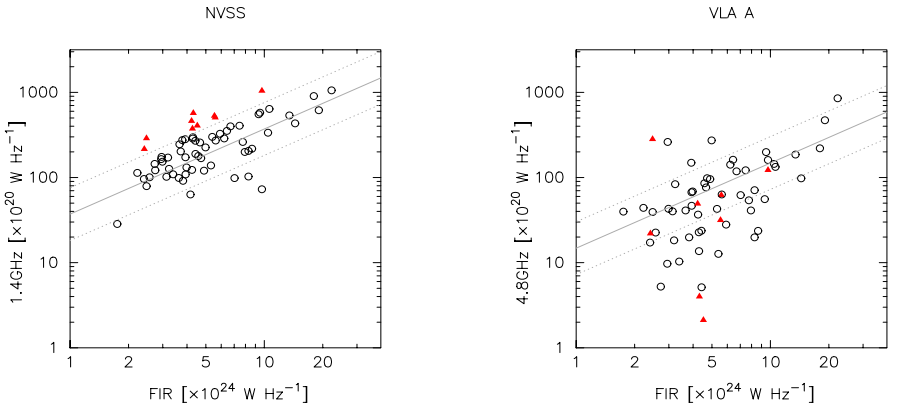

FIGURE 1. **Left:** NVSS v/s FIR luminosities. Triangles represent those sources $> 1\sigma$ above the Radio-FIR correlation. **Right:** VLA A v/s FIR luminosities.

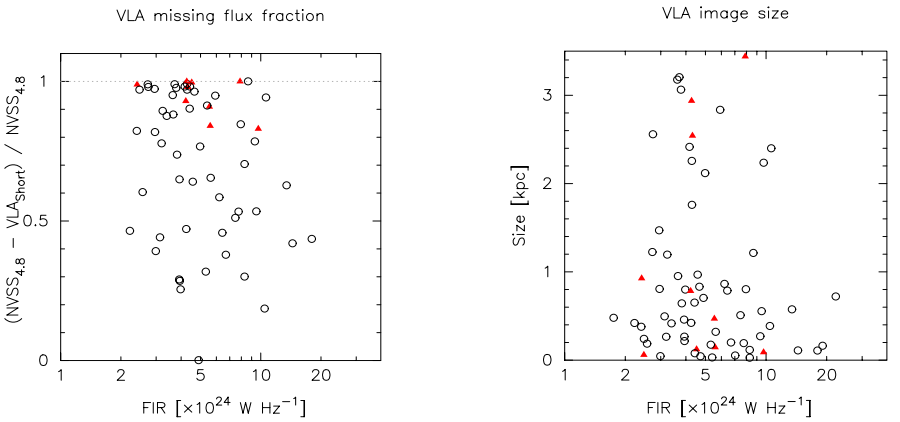

FIGURE 2. **Left:** Fraction of the NVSS flux not recovered on the shortest VLA baselines v/s FIR flux. Triangles indicate the same objects as in Figure 1.**Right:** Deconvolved VLA image size v/s FIR luminosity.

samples by selecting within a narrow redshift shell. The COLA sample consists of all objects in the IRAS catalog with heliocentric velocity between 3500 and 7000 km s^{-1} and with a flux at 60μm greater than 4 Jy. The resulting sample contains 217 objects of which 110 have $\delta > 0°$. A large number of multi wavelength observations of this sample have been undertaken in both hemispheres. Optical spectroscopy and imaging, HI and CO total fluxes and low resolution radio continuum observations are available for the whole sample.

OBSERVATIONS AND DISCUSSION

As a first step to classify radio structures and find accurate positions suitable for VLBI observations, we carried out VLA A configuration observations at 4.8 GHz of COLA-N sources with $\delta > 30^{\circ}$. Figure 1-left shows the radio-FIR correlation for these sources, where NVSS flux was taken as the total flux. Radio excess sources lying more than 1σ above the theoretical RADIO-FIR correlation are indicated by filled triangles. Figure 1-right shows the radio luminosity as recovered from the VLA maps. In this plot the 1σ radio excess objects move closer to the FIR-radio correlation. This result implies that the additional radio emission in these objects occurs in large components ($>$ 1kpc) which are largely resolved out by the VLA. This is seen even more clearly if we look at the fraction of missing flux in our VLA observations Figure 2-left; all eight of the 1σ radio excess objects have large resolved-out missing flux components.

A remarkable result of the COLA-S, observations by Corbett et al. [1] was the strong correlation found between the presence of a compact weak (presumably AGN) radio core and the host galaxy being only 1σ above the FIR-radio correlation. Note that this criterion for radio-excess is much less than that generally used to identify AGNs; yet still a strong correlation with compact radio structure was found. Amongst the 14 1σ radio excess objects, 7 had a detectable compact radio core, and 8 out of 9 objects with detected compact cores presented a 1σ radio excess. Furthermore amongst radio-core objects only a small fraction of the radio excess could be accounted for by the contribution from the radio core itself, indicating the presence of larger scale radio structures. If a similar correlation between radio excess and compact cores/AGNs holds for our Northern sample, our VLA results may imply that AGNs occur preferentially in sources which have $>$ 1kpc sized radio structures. If these components are due to lobes of AGN powered synchrotron emission, that would imply an AGN that has been active for a long time. Another possibility is that the large scale radio excess components associated with AGN instead come from a very extended starburst components. Because AGN galaxies are radio excess objects such extended starbursts cannot exactly follow the radio-FIR correlation but must be somewhat sub-luminous in FIR. This might be expected in a very old starburst where the IR is faded but fossil radio emission remains. The high degree of correlation between such radio excess objects and the presence of radio cores found by Corbett et al. [1] might then be consistent with evolutionary schemes in which AGNs develop as starbursts age.

If we neglect the very extended components, which are not well sampled by our VLA observations, we can estimate sizes for the emission which is successfully imaged. In estimating these sizes we first produced full resolution natural weighed VLA images. For sources undetected in this first pass we made tapered maps and then fitted with a gaussian. The results shown in Figure 2-right indicate larger average sizes for lower luminosity objects. We believe that in nearly all cases our VLA radio maps are dominated by starburst radio emission. It is known [8], [9] that there is a strong luminosity / size anti-correlation for starbursts which extends beyond our luminosity upper limit into the ULIRGs. The origin of this anti-correlation lies in the fact that the physical processes responsible for the triggering of the star formation activity, are intimately related with the density of the environment. What we observe may be part of this general correlation or it might imply an additional population of sources in our sample that are only present at

the low luminosity end. We are investigating whether the galactic and interaction properties of these large sources are in any way distinct. It should be noted that the COLA sample is selected to have a limited FIR range, so seeing any correlation involving IR luminosity implies the correlation must be very strong.

FUTURE WORK

It now seems certain that most of the galaxies contain black holes in their centres [10]. This means that if the necessary fueling mechanism is present, weak AGNs may be common in starbursts. Accretion-disk plus jet models for AGN central engines predict that some associated compact radio emission is always present in AGN, a result which is consistent with observations [11]. Furthermore if the assumption that particle/field equipartition holds even approximately for this radio emission [12], [13] then a core having a flux of 1 mJy should have a size of less than 100μarcsec, motivating high sensitivity VLBI observations. A search for very weak buried AGN in our starburst galaxies can help test the evolutionary starburst/AGN connection; showing for instance how fast a starburst fades while feeding a *baby* AGN. The resulting *adult* AGN may trigger further star formation episodes, affecting once more the SED. We have applied for observing time using the largest antennae in the EVN plus Arecibo aiming to carry out extremely high sensitivity VLBI observations of our sample aiming to probe the low end of the AGN luminosity function and detect any hidden *baby* AGN.

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