The building blocks of young AGNs: A progress report on follow-up projects with the CORALZ sample

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This paper summarizes some of the ongoing projects on the CORALZ sample, the first statistically complete sample of young radio galaxies. The low redshift of the sources in the sample ($z < 0.16$) makes them excellent targets for a comprehensive and homogeneous follow-up in virtually all bands of the electromagnetic spectrum. Here we report on the almost completed radio continuum observations which confirm the relatively young ages of the sources in the CORALZ sample. The radio spectra in addition with new measurements at 250 GHz indicate a large fraction of sources with excess mm-emission, probably due to radiation of cold dust. These sources are also excellent candidates for detection of molecular gas, which we have traced through CO observations in the 3-mm band in several cases. Additional molecules as H$_2$O or OH are being observed. The atomic gas content is disclosed by H I absorption observations.

1 Introduction

We have previously selected a complete sample of nearby compact radio sources based on the combination of comprehensive radio surveys at 325 MHz (WENSS), 1.4 GHz (FIRST and NVSS) and 5 GHz (GB6) with the Automatic Plate Measuring Machine (APM) catalogue of the POSSI. The statistically complete sample (COmpact RAdio sources at Low Redshift; CORALZ) consists of 17 objects at redshifts between 0.005 and 0.16, with an extension of another 7 nearby ($z < 0.232$) sources which are not strictly part of the complete sample but belong in any case to this rare class of young nearby objects. With a completion of 95%, the 17-source CORALZ core sample is the only statistically complete sample of nearby young sources so far. All sources are defined as Gigahertz-Peaked Spectrum (GPS) or Compact-Steepest Spectrum (CSS) sources, with varying ratio depending on whether the spectral (turn-over frequency smaller or higher than 1 GHz) or morphological (linear size larger or smaller than 1 kpc) definition is applied. The details of the sample and its selection have been described by Snellen et al. (2004). The sources in this sample allow for the first time a systematic study of the progression of their morphologies and spectra, the determination of their gas/dust contents and distribution, and a detailed investigation of their X-ray properties, infrared emission, and galaxy/cluster environments. In particular, the low redshift allows the tuning of present spectrometers to the redshifted frequencies and to perform homogeneous observations of the complete sample. In this paper we give a status report on several of the follow-up observational programmes.

2 Spectral ageing analysis

While awaiting the results of multi-epoch measurements essential for the determination of dynamic ages (de Vries et al. 2009a) a reliable alternative way to confirm the young age of these sources is the spectral aging analysis. Most of the sources show in fact significant departure from the classical power law which describes a zero age transparent synchrotron spectrum from a power law energy distribution of a relativistic electron population. The spectral age can in principle be measured from the steepening of the spectral energy distribution at high frequencies caused by particle energy losses. By fitting different models to these curvatures it is possible to determine the injection spectral index and the particle age (from the high-frequency curvature) using

$$l \propto \frac{B_0}{B^2 + B_{IC}^2} \times \frac{1}{\sqrt{(1+z)\nu_{ic}}}$$

where $B$, $B_{IC}$ are the intrinsic (determined from standard equipartition arguments) and the inverse-Compton magnetic field of the microwave background ($B_{IC} = 3.18 \times (1+z)^2 \mu G$), respectively; $\nu_{ic}$ is the break frequency at which the optically thin part of the spectrum starts to steepen.

Fitting the synchrotron losses and the self-absorption turnovers requires the determination of up to 5 free parameters. From our experience with a study on a small sample of...
more distant CSS sources (Murgia et al. 1999) we know the importance of spectral information as copious as possible.

The examples in Fig. 1 show the two most extreme cases of the CORALZ sample which illustrate the observational difficulties for this kind of study. For both fits we have used the Continuous Injection model (Pacholczyk 1970) which takes into account both synchrotron losses e.g. in extended lobes and the continuous replenishment of fresh particles, e.g. from the core or jet. This model is thus well suited for the work with integrated flux densities. The left-hand panel displays the spectrum of J161148+404020, a CSS source with a relatively low break frequency at 471 MHz. This underlines the importance of very low-frequency measurements to have sufficient baseline for the proper determination of the break frequency.

Flux density measurements at several frequencies are even more crucial for the determination of the break frequencies of GPS sources with their typical inverted spectra. The right-hand panel shows J131739+411545, a GPS source with a break frequency at 9.6 GHz. About half of the flux density measurements are affected by low-frequency inversion and can thus not be used for the spectral ageing analysis. In any case for all sources in the CORALZ sample a vast range of flux densities are available for a determination of the break frequencies. With these and assuming equipartition (volumes derived from VLBI observations, de Vries et al. 2009a) for the intrinsic magnetic fields, ages between $10^3$ and $10^4$ years are derived with J161148+404020 being the oldest source with an age less than $1.4 \times 10^6$ years. This is on the average at least 1000 times shorter than normally found for classical extended radio galaxies (e.g. Mack et al. 1998; Parma et al. 1999).

Using the linear dimensions obtained from VLBI observations, these ages allow the determination of average expansion velocities. These turn out to be typically smaller than 0.05 c, i.e. significantly smaller than those found for more distant, and thus more powerful, CSS/GPS sources (e.g. Polatidis & Conway 2003). This also confirms the upper limits derived from the first two-epoch VLBI measurements (de Vries et al. 2009a).

3 The structure of young AGNs

The vicinity of the CORALZ allows for the first time homogeneous measurements of a statistically complete sample of young AGNs. In particular, we have embarked on several projects to study various tracers of building blocks of AGNs.

For the observations of the radio continuum emission high-resolution VLBI is required. For the results of these observations we refer to de Vries et al. (2009a, 2009b). An important ingredient to the structure of AGNs is the dust component, be it in form of a dusty torus or a generally dusty environment in the Interstellar Medium (ISM) around young AGNs. The presence of dust favours the formation of molecules which can serve as fuel for the AGNs. The most easily detectable molecule is CO which under certain
assumptions allows one to estimate the total molecular gas contents. Peculiar molecular tracers are H$_2$O and OH masers, which in some AGNs populate the molecular tori at different radii from its centre. Compact AGNs as GPS/CSS sources also offer the opportunity to search for the atomic hydrogen via H I-absorption line studies.

We have initiated observational programmes to investigate all these tracers which will not only shed light on the specific class of young radio sources, but allow representative studies for the structure of AGNs in general.

3.1 Dust in young radio galaxies

Several projects with all major FIR satellites (e.g. Hes, Barthel & Hoekstra 1995; Fanti et al. 2000; Shi et al. 2005) have been performed in the past to determine the amount of dust in CSS and GPS sources, mainly in the framework of the frustration scenario, in which a dense ISM would absorb radio emission and transform it to the FIR. This scenario requires a total mass of $> 10^8 \, M_\odot$ within 1 kpc around the source centre (De Young 1993; Fanti et al. 2000). In none of the studies to look for dust emission significantly higher detection rates of dust in CSS/GPS sources compared to normal-size radio galaxies have been found. We are using the IRAM 30-m telescope to search for millimetre excess emission possibly caused by cold dust. At the time of writing 14 of the 17 sources of the CORALZ core sample have been observed with the MAMBO bolometer array at 250 GHz. For nine sources excess emission, i.e. with flux densities at least 3σ above the expected value extrapolated from the high-frequency synchrotron emission has been observed. Together with the results from the parallel search for molecular gas (Sect. 3.2) this yields a detection rate of about 75%. Figure 2 shows an example: J083133+460800, a GPS source with radio flux density measurements up to 32 GHz, which suggests a rapid cut-off of the synchrotron emission. Further high-frequency observations up to 43 GHz will ascertain that any additional synchrotron component can be excluded to explain the observed 250-GHz flux density that can thus be attributed to dust emission. Such sources are prime targets for follow-up observations in the sub-mm regime.

For a first idea on the probable dust masses we assume two extreme temperatures of 25 and 50 K and apply a grey body law. The resulting dust masses are between $2 \times 10^8$ at 25 K and $1 \times 10^8 \, M_\odot$ at 50 K. As most of the CORALZ are GPS sources the dust might be concentrated on a smaller volume, which implies higher temperature and consequently lower masses, not enough for the frustration scenario, despite the relatively high detection scenario.

3.2 CO emission in young radio galaxies

The identification of young radio sources containing cold dust allows one to tackle a search for molecular gas in order to investigate the impact and conditions of fueling in radio galaxies at the beginning of their evolution.

Regarding the molecular gas contents in young radio galaxies few systematic studies have been done so far, some sources were observed as part of other samples, revealing molecular masses of a few $10^{10} \, M_\odot$ (e.g. Mirabel, Sanders & Knez 1989; O’Dea et al. 1994, 2005; García-Brumillo et al. 2007). We have embarked on a project to detect CO ($J = 1–0$) emission in the 3-mm band in CORALZ using the 30-m millimetre telescope of IRAM on Pico Veleta. We have observed 15 of the 17 sources of the CORALZ core sample which led to at least 6 detections (Fig. 3 for two examples). Observations of three more tentative detections have to be confirmed yet. The resulting total molecular gas mass heavily depends on the X-factor applied to these measurements, i.e. the CO-to-H$_2$ conversion factor. To allow for a deviation of the X-factor for molecular clouds in our sample from the value determined for our Galaxy, we have used a range of values $(3.7 \times 10^{23}$ to $2.1 \times 10^{24} \, m^{-2} K^{-1} km^{-1} s$). The lower value is determined for the ULIRGs (Solomon & Vanden Bout 2005) whereas the higher value is appropriate for normal galaxies (Braine, Herpin & Radford 2000). The final molecular gas masses range between 0.3 and $430 \times 10^8 \, M_\odot$, i.e. on average about one order of magnitude below the masses found so far. Unfortunately, from these integrated data we cannot be absolutely certain about the true nature of the detected lines, as in several sources (e.g. Fig. 3 left) they could either originate from a rotating disk with the typical U-shaped structure or from a combination of emission and absorption feature. Future high-resolution observations will help to clarify this question.

It is interesting to compare the molecular gas masses of these genuinely young radio galaxies with those of recur-
rent radio galaxies, i.e. young sources embedded in the cocoons of radio galaxies which were formed during a previous activity period. Saripalli & Mack (2007) have observed a representative sample of currently known restarting radio galaxies. Although these are typically at higher redshifts and thus observed at lower sensitivity there is a tendency that genuinely young radio galaxies have higher gas masses than recurrent sources.

4 Summary

This paper summarizes the status of several ongoing projects on the dust and gas contents of the CORALZ sample, the first statistically complete selection of nearby compact radio galaxies. A first step includes the determination of the spectral ages in anticipation of the dynamic ages which can only be obtained via long-term multi-epoch observations. It turns out that none of the CORALZ has spectral ages significantly above 10^{6} years with a medium age around some 10^{4} years, which confirms the general assumption that these sources are definitely about 3 orders of magnitude younger than normal extended radio galaxies. An important aspect of the follow-up work on the CORALZ sample is concerned with the study of the building blocks in young radio sources which can be observed in this type of source for the first time in a homogeneous way. A search for increased mm-emission which can be ascribed to the emission of cold dust yielded a detection rate above 70%. Due to the relatively low redshifts and hence high sensitivity of the observations the derived dust masses are around 10^{8} M_{\odot}, not sufficient to support an efficient containment of the evolving radio source. The presence of dust can also lead to the formation of molecular gas supposed to be one of the major ingredients to fuel the central nucleus. In fact, we find CO line emission in at least a third of the CORALZ sample with average gas masses about one order of magnitude below the masses found to date in the few searches for CO in young radio sources. In addition, we are extending our investigation of the various components of the AGNs to a search for atomic gas through H I absorption and observations of megamasers from H_{2}O and OH molecules.

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