Host galaxies of powerful extragalactic radio sources

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Chapter 9

Summary and Outlook

9.1 Overview

Powerful radio galaxies and quasars have contributed and will continue to contribute significantly to our understanding of galaxy evolution and the evolving AGN phenomenon. The interaction between the radio plasma and the ambient media makes these objects laboratories for galaxy ISM and IGM studies, in the nearby and distant universe. In some respects, e.g., K band luminosity, host galaxy properties have been found to be rather homogeneous, opening the possibility to use these sources as cosmological standard candles. Their powerful radio emission makes finding these objects among the many at high $z$ rather straightforward. With 6 to 10 meter class telescopes becoming on-line, and with the improving (near-IR) detector technology, detailed study of these objects at $z > 1$ is within reach.

The powerful radio source population can be divided into three size classes: 1) the ultra compact Gigahertz Peaked Spectrum sources, with radio sizes smaller than 1 kpc, essentially on the Narrow Line Region (NLR) size scale, 2) Compact Steep Spectrum sources, with radio sizes of $\lesssim 15$ kpc, i.e. of subgalactic proportions, and 3) the large scale FR II sources, where the radio structure has expanded well beyond the host galaxy confines. These sources were originally considered different objects, and their classification is based on radio spectral properties. Until recently, the place of these compact radio sources within the general population of large extended double lobed radio sources (radio galaxies and quasars) was not known: both the hypothesis of young objects in the early stage of their existence and the alternative hypothesis of “frustrated” objects in host galaxies with dense interstellar media confining the radio source were popular. Limited imaging data suggestive of distorted hosts in groups or poor clusters of galaxies argued for the first, but the self-absorbed synchrotron spectra together with measured radio source depolarization and optical reddening signatures argued for the second hypothesis.
Theoretical and observational work during the last couple of years has demonstrated that the youth scenario is more likely. Thus, GPS and CSS radio sources can teach us both about the conditions which result in the birth of a powerful radio source, the conditions of such sources developing in dense interstellar environments, and the way in which those conditions evolve with redshift.

9.2 Summary

This thesis work has concentrated on the following topics:

1. Construction of GPS sample. For a comparative study of class properties, a well defined and large enough sample is essential. Building on the master list of O'Dea et al. (1991), we have compiled a sample of 72 bona fide GPS objects. Several identification and spectroscopy projects were carried out using NOAO and ESO facilities, aimed to complete the redshift and identification information content of this sample (Chapter 2).

2. Radio spectra of GPS objects. GPS and CSS sources are characterized by their radio spectra. We have investigated the canonical GPS radio spectrum, and its dependence on galaxy vs. quasar identification as well as on redshift / luminosity. The measured lack of significant differences in spectral shape argues for, on average, similar nuclear environments in GPS galaxies and quasars. Furthermore, the similarity in the optical thin spectral index across the complete range of radio source sizes (from GPS to large-scale double lobed sources (FRII) ) indicates that free expansion of the GPS sources into the large sources is likely (Chapter 3). Were the GPS sources confined to their small sizes by very dense nuclear ISM, differences in the optical thin spectral shape would be expected (e.g. Barthel & Arnaud 1996).

3. HST imaging of CSS objects. For the large-scale FRII sources it has been known for some time that these sources may display the "alignment effect", whereby the optical and radio symmetry axes have similar position angles (e.g., McCarthy 1993). The current scenario for this alignment is one where the radio structure "plows" through the host galaxy's ISM, with the radio – ISM interaction inducing the aligned optical emission (e.g., Bicknell et al. 1997), either by shock-ionizing the ambient gas, or subsequent star-formation. Scattered blue AGN light is also believed to be an important component. If the alignment effect is mainly due to effects of an expanding radio source through ambient ISM, this effect should also be present in the smaller CSS sources, if they are to be considered precursor FR II objects. With the advent of HST the required high angular resolution was available for the first time. For the CSS sources an alignment effect has indeed been found (scales ~ 1 arcsec), with a higher level of optical – radio structural correspondence as compared to the large FRII sources (Chapter 4). Furthermore, based on ground-based spectral data and HST narrow band imaging (rest frame [O III]), the optical aligned structure is most likely to be shock induced line-emission gas. The inferred radio source expansion speed and ambient density, based on cooling time calculations, are found to be similar to large-scale sources (Chapter 5), and consistent with theoretical models (e.g., Begelman 1998).

4. HST and ground-based near-IR imaging Host galaxy populations and the effect an expanding radio source might have on the overall emission properties are best
studied in the near-IR. Galactic absorption / background and the unknown absorption properties of the host being minimum, the near-IR permits a clean look on the nuclear regions and on the host galaxy stellar populations. Using ground-based J, H, and K band imaging data on a sample of GPS, CSS, and FRII sources, we have investigated the near-IR properties over the whole range of radio source sizes. We found that host galaxies have similar near-IR broadband energy distributions (SED), irrespective of the radio source size. Furthermore, these SED's are best fit with a stellar synthesis model SED consisting of a stellar population with a roughly mean solar metallicity and age of ~5 Gyrs plus an additional hot dust component (around 1000K), perhaps produced by the putative circumnuclear dusty torus. No evidence for intrinsic host galaxy differences in either stellar population or density profiles (indicated by color differences) has been found for our radio size subsamples. This is consistent with powerful radio sources evolving along the GPS–CSS–FRII sequence (Chapters 6 and 7). HST NICMOS profile information confirms this result. The host galaxies of powerful radio sources are found to be mostly field (giant) ellipticals, rather than Brightest Cluster Galaxies. Since FR1 hosts are similar to BCG's in most of their properties, this effectively implies GPS/CSS sources do not evolve into FR1 type sources, even though their decline in radio luminosity would be consistent with this (Chapter 8).

5. H I absorption spectra\(^1\). The high column densities of gas around the radio source, as inferred for instance by the alignment effect, might show up in absorption against the powerful radio lobes, provided the geometry is favorable. A 180 hour H I spectral line program at the WSRT on 12 GPS and CSS sources did indeed detect significant line absorption in 3 cases. The GPS case is by far the deepest line (optical depth more than 20%). Thus, we find H I absorption more often in the GPS and CSS sources than is found in the cores of large-scale sources. However, we do not find evidence for large columns of atomic hydrogen surrounding most GPS and CSS sources. This is consistent with the evolutionary radio source hypothesis.

9.2.1 The Bottom Line

So, in summary, this thesis work lends support to the notion of a radio source evolution along the GPS–CSS–FRII sequence, mainly from the optical and near-IR point of view. Based on radio data and number counts, significant radio luminosity evolution is inferred (O'Dea et al. 1997), so while the optical / infrared properties are more or less constant over the sequence, the source does decline in radio power.

9.3 Ongoing / Future Work

There are still several outstanding problems which need to be addressed with better data. The first puzzle is the apparent dichotomy in redshift space between GPS galaxies and quasars. While from a radio (spectral) viewpoint these sources are identical, the galaxies are uniquely found at low (\(z < 1\)) redshift, and the quasars at \(z > 0.75\). There is no apparent reason for the GPS galaxies not to be found at higher redshifts,

\(^1\)work not included in this thesis
in fact they may be among the current empty field classifications. For a proper study, one needs a reasonable overlap in redshift space of both types of objects, in order to eliminate radio luminosity effects. We therefore have requested observing time on ESO's VLT1 telescope to identify some GPS sources currently without optical counterpart. The large collecting area of an 8m class telescope is needed, especially for the spectroscopic follow-up. The VLT study can be considered a feasibility test, which, if proven successful, should be followed by a full scale program on similar sized telescopes. This program will have to include deep optical and near-IR observations of both the GPS galaxies and quasar hosts, matched in redshift, to compare their host systems.

Another interesting area of current research is the determination of the kinematics and physical properties of the aligned emission line gas in CSS sources, using STIS long-slit spectroscopy. It is clear that the statistical results based on number counts of powerful radio sources are not sufficient by themselves to constrain the models for radio source evolution. A more direct probe of the radio source propagation through the host galaxy is needed. Fortunately, the aligned emission line gas in CSS sources, as imaged by us (and independently by Axon et al. 1998) provides such a powerful diagnostic probe. The close alignment and similar spatial extents of the radio and emission line plasma suggest the existence of a close coupling between the thermal gas and the radio sources. The broad and highly structured [O iii] 5007Å line widths observed by Gelderman & Whittle (1994) strongly suggest that the radio source is dominating the emission line kinematics. We will use diagnostic line ratios to estimate the temperature and density of the gas. From the velocity field, we will derive constraints on the expansion velocity of the radio source and on the radio source lifetime, both of which are fundamental parameters needed to constrain the evolution of powerful radio sources.

Our imaging campaign of a matched sample of GPS, CSS, and FR II sources has to be augmented by HST observations on shorter wavelengths, equivalent to the B, V, and R bands, to provide a similar spectral base line to our previous (ground-based) analysis. The higher data quality will ensure firmer results, especially with respect to the galaxy-AGN decoupling. Adding colors to the current one (F110W-F205W) significantly increases the usefulness of stellar synthesis modeling on these components. Expanding our ground-based imaging effort to include large (6-10m class) telescope facilities, will enable us to push back the median sample redshift towards higher values. The advantage will be twofold: the sample statistics will improve, and with the larger redshift base a useful analysis of cosmological evolution of host galaxy properties will become possible.

With part of this program already underway, a full implementation will yield significant new insights in the environment and radio evolution of powerful radio sources. The new opportunities provided by the 6-10m class telescopes, with their state of the art detectors, will also enable a detailed investigation of the cosmological evolution of the host galaxy properties. These issues are paramount in understanding radio source evolution, and the position of these objects in the current AGN paradigm.