GPS and CSS radio sources and space-VLBI

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Abstract. A short overview is given of the status of research on young extragalactic radio sources. We concentrate on Very Long Baseline Interferometric (VLBI), and space-VLBI results obtained with the VLBI Space Observatory Programme (VSOP). In 2012, VSOP-2 will be launched, which will allow VLBI observations at an unprecedented angular resolution. One particular question VSOP-2 could answer is whether some of the High Frequency Peakers (HFP) are indeed the youngest objects in the family of GPS and CSS sources. VSOP-2 observations can reveal their angular morphology and determine whether any are Ultra-compact Symmetric Objects.

1. Introduction: nomenclature for young radio sources

Historically, young radio sources are named according to their observational characteristics. This has evolved into the use of several 'classes' of object, which unfortunately does not make this area of research more transparent. Furthermore, the introduction of new names or classes of object (as will be done in this paper) is not necessarily accompanied by a deeper physical understanding of the subject. Nevertheless, it is probably a good idea to briefly summarize the observational properties of the different classes and their possible connections.

Gigahertz Peaked Spectrum (GPS) sources are compact (typically 10-100 m.a.s.) radio sources characterized by their convex spectrum peaking around 1 GHz in frequency. Their spectral turnover is thought to be due to synchrotron self absorption (e.g. Fanti et al. 1990; Snellen et al. 2000), although free-free absorption may also play a role in some objects (e.g. Sawada-Satoh et al., 2002). Flux density variations in GPS sources are generally found to be small, in particular in those sources optically identified with galaxies. GPS quasars are found at much higher redshifts (z>2), often show more significant variability, having core-jet morphologies. They may not be related to the GPS galaxies and just be a sub-class of flat spectrum quasars. A GPS galaxy typically exhibits a two-component structure with sometimes a weak flat spectrum component in between, interpreted as the core. If such an object is discovered (or observed) with VLBI, it is referred to as a Compact Symmetric Object (CSO). In particular if the overall radio spectrum has not yet been determined. Ignoring one or two galaxies (and the GPS quasars), GPS and CSO are the same beasts. All famous and well studied GPS galaxies are CSO, and vice verse. A powerful radio source of a few tens of milliarcseconds in size will always be synchrotron self absorbed, and when it is observed at a large viewing angle, the lack of significant Doppler
boosting will allow both sides of the radio source to be seen (CSO), which will also result in low flux variability and a stable GHz-peaked spectrum (GPS).

Compact Steep Spectrum (CSS) sources are larger than GPS sources, up to 1 or 2 arcseconds in size, and are characterized by steep spectra (in contrast to other types of compact radio sources). Their spectra typically turn over at about 100 MHz. This is consistent with synchrotron self-absorption, with the spectral turnover of a radio source depending on angular size as $\theta^{-4/5}$. The morphologies of CSS sources seem more complex than those of GPS sources, often showing bends and twists, or bright knots in their jets. This may be biased by the fact that there are more resolution elements available over the size of the source. Furthermore, those sources with strong interaction with their galactic environments will be intrinsically brighter and therefore more prominent in the bright end of the CSS population. Those CSS sources for which both sides of the radio source jets/lobes are observed are sometimes called Medium Symmetric Objects (MSO).

Recently, a new 'class' has been defined in young radio source land, the High Frequency Peakers (HFP; Dallacasa et al. 2000). While CSS sources are peaking at low frequencies and are significantly larger than GPS sources, HFP have a spectral turnover frequency at $>5$ GHz, and are significantly more compact than GPS. As will be discussed below, there is compelling evidence that GPS/CSO and CSS/MSO sources fit into an evolution scheme, where GPS sources are $10^{2-3}$ years old and grow into their CSS phase at an age of $10^{4-5}$ years. It is the question whether HFP also fit into this scheme, at the beginning, as the youngest of the whole family. It is clear that the HFP class is heavily contaminated by Blazar/BL-Lac type objects (see below), but possibly a small fraction of the HFP class are indeed very young. As will be argued in this paper, space-VLBI observations will have the required angular resolution to reveal their morphologies. This will show whether a sub-sample of these sources exhibit double-lobed morphologies, which we here dub (to further confuse the nomenclature in this field) Ultra-compact Symmetric Objects (USO).

2. Determination of radio source ages

Over the last two decades, compelling evidence has been accumulated that GPS/CSO sources are indeed young objects. This was first proposed by Shklovsky in 1965, although in that same period it was also investigated whether the radio emission of the archetypical GPS source, B1934-63, was actually a signal from a possible extraterrestrial civilization (Kellermann 1966). The first important argument is that the spectral turnovers of these radio sources must mean that there is no (or hardly any) radio emission at large scales. Any large scale emission present would not be synchrotron self-absorbed and dominate the flux at low frequencies. This in contrast to most other compact radio sources which have flat spectra, implying the presence of components with a large range of physical scales in these objects. Furthermore, GPS sources were found to exhibit low or no flux density variability. This indicates that relativistic Doppler boosting (as found in Blazars and BL-Lac objects) seems not to be important, implying that these objects do not have a small angular size because they just happen to be observed at a small viewing angle. This was consistent with early VLBI ob-
servations which often showed a double structure interpreted as two mini-lobes (Philips & Mutel 1982). The youth argument was further strengthened by the detection of cores or core/jet structures in the centers of these objects, identifying them as CSO (Wilkinson et al 1994; Conway et al. 1994). However, the most compelling evidence, putting the youth interpretation beyond reasonable doubt, comes from VLBI measurements of the angular separation velocity of the lobes in several of the most extensively studied GPS/CSO (Owsianik & Conway 1998; Owsianik, Conway, & Polatidis 1998; Tschager et al. 2000; Polatidis & Conway 2003). They reveal expansion velocities of 10-20% of the speed of light, implying kinetic source ages for GPS sources of a few hundred to a few thousand years. The ages of the larger CSS sources are estimated using the breaks in their synchrotron spectra, and found to be in the order of $10^{4-5}$ years (Murgia et al. 1999). Although these are indirect age measurements, they are perfectly in line with the larger size of the CSS compared to the GPS assuming similar expansion speeds. Note that the CSS sources are too large and too old to measure their ages directly by means of their expansion.

3. Young radio sources in a broader astrophysical context

Now we know that GPS/CSS sources are young, what can we learn about them that is interesting in a broader astrophysical sense? Three main areas of interest are identified:

- 1) Long-term evolution of AGN activity. First of all, GPS/CSS sources, combined with samples of large size classical FR I and II radio galaxies, will shed light on the growth and long-term evolution of AGN activity and their associated radio sources. Questions that can be raised are, what is the luminosity/energy evolution of a radio outburst? How long do these outbursts last? Do all radio outburst at some point evolve into classical radio sources, or are some outbursts short-lived? And, how often do galaxies undergo cycles of AGN activity? Note that X-ray or optical AGN-related emission provides information on the current state of the AGN activity, while the radio lobes can be tens of millions years of age, storing information from a significant part of the AGN life-cycle (e.g. Vink et al. 2006).

- 2) Trigger and onset of AGN activity. The ages of GPS sources are only $10^{2-3}$ years, a time scale so short that it is insignificant compared to galactic time scales. This means that when we study the host galaxies and environments, we study them at the moment they become active. This provides a unique opportunity to probe the trigger and onset of the AGN activity, as proposed to be caused by gas-rich galaxy mergers.

- 3) AGN feedback mechanisms. A hot topic in current astrophysics is the influence of AGN activity on the evolution of the host galaxy as a whole. It has been suggested that AGN outflows quench star formation and regulate the stellar populations in massive elliptical galaxies (e.g. Silk & Rees 1998; Bundy et al. 2008). The small physical extent (and young age) of a GPS radio source means that the influence of the central AGN activity on its
galactic environment is confined to the inner (few) hundred parsec. We therefore have a clear picture of the galactic environment free of AGN interference. By comparing this to the host galaxies with older central AGN, the influence of the AGN on the host galaxy can be distilled.

It is clear that the answers to these questions can not be found using radio observations alone, but they need studies that make use of observations across the electromagnetic spectrum (e.g. de Vries et al. 2007). In figure 1, the galactic environment of the distant (classical) radio galaxy 3C324 is compared with that of GPS galaxy 2352−0604. The host galaxy of 3C324 shows bright UV/optical emission aligned with the radio jet, possibly caused by quasar-ionization or jet-induced star formation. Also some smaller neighbouring galaxies seem to be visible. In the GPS galaxy 2352−0604 the AGN related light is not present, but clearly showing several (red) galaxy clumps in the vicinity of the GPS host galaxy.

4. Young radio sources at the highest resolution: an outlook for VSOP-2

The first VLBI space observations where made possible through the VLBI Space Observatory Programme (VSOP) with the launch of the Japanese HALCA satellite in 1997. It operated at 5 and 1.6 GHz frequency with a factor three improvement in angular resolution compared to ground-based global VLBI. Since this was an engineering mission, and the sensitivity just enough to observe those sources with the highest surface brightnesses, only a few GPS galaxies were observed successfully. However, the VSOP observations of B2021+614 did led to the dynamical age determination of this GPS galaxies (Tschager et al. 2000).

VSOP-2 will be the next VLBI space mission. The satellite, Astro-G, will host a 9 m. diameter VLBI antenna operational at 8, 22, and 43 GHz. It will be launched in a 30,000 km altitude orbit by the Japanese Space Agency JAXA in 2012. The great improvement compared to VSOP will be in the significant increase in sensitivity by about an order of magnitude, and the increase in angular resolution by up to a factor of 5 due to the higher observing frequencies (Hirabayashi et al. 2004). VSOP could only observe a few of the most compact GPS galaxies, which will be the same for VSOP-2. Although the sensitivity is increased dramatically, the higher observing frequency will mean that the GPS sources are significantly fainter. This in contrast to the general population of compact radio sources which have flat radio spectra. One sub-class of possibly young radio source, for which the high observing frequencies is actually a benefit, are the High Frequency Peakers. VSOP-2 could have a major contribution to to understanding of these objects.

As mentioned before, the class of HFP sources is significantly contaminated by blazar/BLLac type objects. In the case of blazars we observe the radio jets at a very small viewing angle, meaning we look right down the jet. In this case the jet-components (probably shocks) have high gammas and strong relativistic Doppler boosting. When new components emerge, they appear very bright and completely dominate the radio spectrum. Since they are at that stage very compact and synchrotron self-absorbed, they make the overall radio spectrum appear as that of a HFP. While the component expands, the turnover
frequency drops, as does the flux density. For the most Doppler-boosted jets, which are viewed at the smallest angle to the line of sight, the time scales of the outbursts can be weeks or months. But for more modest viewing angles this can be years or decades. In the latter case it is impossible to distinguish them from truly young radio sources. Young HFP would be expected to be less than one-hundred years old, so they would exhibit a flux density evolution at a similar time scale as a HFP Doppler boosted component in a jet. VSOP-2 can distinguish between an overall young radio source and a recently emerged jet component by determining its morphology. While a jet component with a turnover frequency of 20 GHz would have a size of 100-200 µarcsec and be unresolved with the VSOP-2, a young radio source should exhibit a double-lobed morphology, typically ~1 milli-arcseconds in size, dubbed here an Ultra-compact Symmetric Object (USO). Hence the question is whether any of the HFP are USO?

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Figure 1. The host galaxies of classical AGN, such as 3C324 (left panel, from Subaru) are disrupted by the powerful central activity. The white marks indicate the orientation of the radio jets, and the ellipse high-lights the blue-ish aligned light possibly caused by ionisation, scattering, and/or jet-induced star formation processes. The central activity in the galaxy PKSJ2339-0604 (right panel) has just commenced. Here the effects of the AGN activity are still confined to only the central parts of the galactic host, making them key objects to study the environment and trigger of the AGN activity. The host galaxy (K=17.50, R−K=5.41) and a further 7 surrounding objects exhibit the defining properties of Extremely Red Objects (ERO) with R−K=4−5.
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