HI absorption and the ISM around radio galaxies

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We present a study, done with the Australian LBA, of H I absorption for two compact radio galaxies (PKS 1549-79 and PKS 1814-63). In both the radio galaxies, the H I appears to give us information about the environment in which the radio sources are embedded, the effect that the ISM can have on the observed characteristics and the possible presence of interaction between the ISM and the radio plasma.

1. Introduction

H I absorption is often detected in compact/small radio galaxies. Indeed, the scale of the radio continuum in these objects represents an effective background against which the absorption can be observed. Although the H I absorption is often interpreted as due to the presence of a nuclear torus/disk, the situation can be more complicated in some (or perhaps many) cases. For example, extended regions of ionised gas have been imaged around compact radio galaxies (e.g. with HST, see Axon et al. 2000). If this gas is also a tracer of the neutral gas, this means that H I absorption can also be produced in the regions around the radio lobes and not only against the nucleus. Moreover, compact radio galaxies (e.g. Compact Steep Spectrum sources) are known to have broad (forbidden) optical emission lines likely due to turbulent motions as result of the interaction between the radio plasma and the ISM (Gelderman & Whittle 1994). This process may "pile up" gas at the edge of the lobes, thus making the detection of H I absorption more likely (see e.g. IC 5063, Oosterloo et al. 2000). In some cases (although a minority) star formation and far-IR emission are observed. Thus, these objects could have a particularly rich ISM that could produce the H I absorption in/around their radio lobes.

A further complication in the interpretation of the H I absorption is the uncertainty in the values of the systemic velocity as obtained from optical data. To unambiguously interpret the kinematics of the neutral gas, better systemic velocities than available in the literature are usually necessary.

We have recently carried out (with the VLA and the ATCA) a survey looking for HI absorption in radio galaxies: 23 galaxies have been observed so far (Morganti et al. 2000a). Two of them are compact radio galaxies and show H I absorption (PKS 1549–79 and PKS 1814–63). Thus, they have been followed up with high resolution observations with the Australian LBA.

2. PKS 1549–79

PKS 1549–79 is a relatively unusual galaxy. At radio wavelengths, it is a compact flat spectrum source ($\alpha = 0.35$, $S \sim \nu^{-\alpha}$) with a one-sided jet on the VLBI scale. The radio structure seems to indicate that the radio jet axis is aligned with our line of sight. The size is 150 mas, about 350 pc †. Because of these characteristics, it was quite surprising to detect H I absorption in this object.

PKS 1549–79 has a redshift of $z = 0.150$ and was therefore observed at 1235 MHz, the frequency of the redshifted H I. At this relatively low frequency we could use only three telescopes Parkes (64m), CA (Tied Array, 5x22m) and Mopra (22m). The latter had technical problems so data on only one baseline was left. The observations were done using 8 MHz band, 512 channels ($\sim$ 3 km s^{-1} velocity resolution). The H I profile is shown in Fig.1. The total of the line is $\sim$ 200 km s^{-1} and the peak optical depth is about 2%. The column density is $\sim 4 \times 10^{18} T_{\rm spin}$ cm^{-2}.

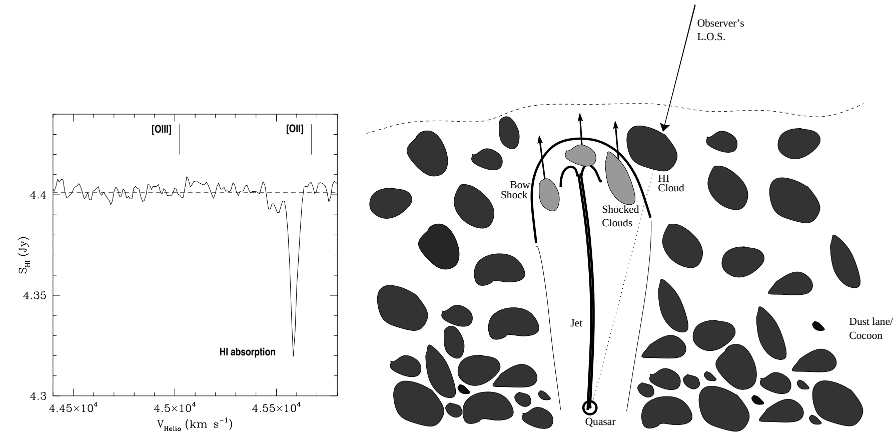

FIGURE 1. *Left:* profile of the H I absorption in PKS 1549–79. The velocities derived from the optical emission lines are indicated. *Right:* cartoon of the possible distribution of the various components in PKS 1549–79, see text for details.

A high quality optical spectrum was taken (see Tadhunter et al. 2000a for details) to allow an accurate comparison between the velocities derived from the optical lines (ionised gas) and from the H I. The spectrum of PKS 1549–79 is characterised by high ionisation "narrow" emission lines with *no evidence for broad permitted lines* (quite unusual for a flat spectrum radio source). Surprisingly, *two redshift systems* were found in the optical: the higher ionisation lines (e.g. [OIII]5007Å) have a significant lower redshift (velocity difference of $\Delta v = 600$ km s^{-1}, see Fig. 1) than the low ionisation lines (e.g. [OII]3727Å). The *high ionisation forbidden line* are also unusually broad (1345 km s^{-1}). *Interestingly, the velocity derived from the low ionisation lines is consistent with the one derived from the HI.* PKS 1549–79 is also one of the few known radio galaxies at low redshift which shows (in the optical continuum) a strong component from young stellar population. This is confirmed also by the strong far-IR emission detected by the IRAS satellite (Roy & Norris 1997).

The likely scenario of what is going on in PKS 1549–79, in order to explain *all* the observed characteristics, is summarised in the cartoon in Fig. 1. PKS 1549–79 is a *young* source where the nucleus is surrounded by a cocoon of material left over from the events which triggered the nuclear activity. The high ionisation lines are formed in a region close to the central AGN, which is undergoing outflow because of interactions, e.g. with the radio jet, while the low ionisation lines are formed in a obscuring region at larger distance and not so disturbed kinematically. As the radio source evolves, any obscuring material along the jet axis is likely to be swept aside by, e.g. jet-cloud interactions. Before this

† In this paper we assume $H_\circ = 50$ km s^{-1}Mpc^{-1} and $q_\circ = 0$.

stage is reached a substantial amount of obscuring material may be present along the radio axis. A major implication of this work is that the simplest version of the unified schemes, in which lines of sight close to the radio axis have a relatively unobscured view of the quasar nucleus, *may not always hold for young, compact radio sources in which the jets and quasar winds have not yet swept aside the warm ISM in the ionisation cones.*

Although the characteristics observed in PKS 1549–79 may not be very common among radio galaxies, we have found at least one other object with remarkable similarities: the compact radio source 4C 12.50 (PKS 1345+12).

3. PKS 1814–63

PKS 1814–63 is a Compact Steep Spectrum (CSS) source with a basic double-lobed structure oriented almost north-south (Tzioumis et al. 1996). The radio spectral index on the VLBI scale is not yet available for this galaxy, thus, no information is available on which of these structures (if any) corresponds to the core. The overall extent of the source is 410 mas corresponding to 328 pc. With ATCA H I absorption was detected that shows a deep profile (∼20 % optical depth) together with a broad, shallow feature (Morganti et al. 2000a). PKS 1814–63 has a redshift of $z = 0.06$ and was observed with the Australian LBA at 1336 MHz using Parkes, CA (Tied Array), Mopra, Hobart with the same setup as for PKS 1549–79.

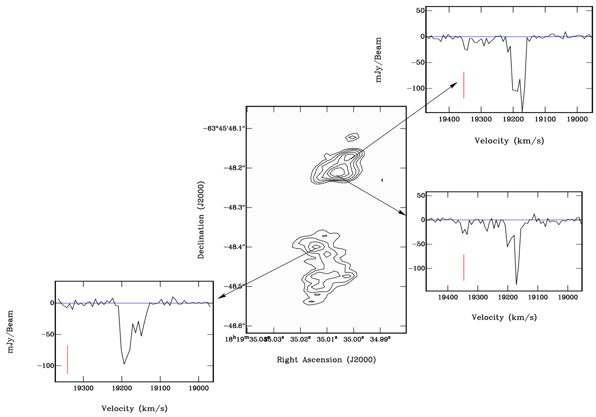

FIGURE 2. Continuum image of PKS 1814–63 at 21 cm (obtained from the line-free channels) and spectra of the H I absorption obtained at three different location in the source. The vertical line indicates the systemic velocity (see text for details).

The results are shown in Fig. 2. The deep absorption appears extended in the VLBI data and is detected against most of the source with the exception of the southern part of the southern lobe. The peak optical depth goes from ∼ 30% in the southern lobe to ∼ 10% in the northern region. The component with lower optical depth (ranging between 2 and 4%) is observed *only* against the northern region. The optical spectra available for this object are not very good. The systemic velocity marked in the plots ($V_{\rm hel}$ = 19350 km s^{-1}) is derived from re-analysing the optical spectrum presented in Tadhunter et al. (1993). This velocity will have to be confirmed by better quality data. However, as it stands now, most of the H I absorption, and in particular the deep component, is blueshifted compared to the systemic velocity. Only the component with low optical depth observed against the northern region has a velocity close to the systemic velocity as derived from the available data.

Thus, one possibility to explain these characteristics is that the shallow component is the one associated with a circumnuclear disk while the deeper component (observed against most of the radio source) could be instead associated with more extended gas, possibly surrounding the lobes and perhaps interacting/expanding with them (if the blueshifted velocity is confirmed).

4. H I absorption and ISM medium

In both the radio galaxies studied, the H I appears to give us information about the environment in which the radio sources are embedded, the effect that the ISM can have on the observed characteristics and the possible presence of interaction between the ISM and the radio plasma.

H I absorption occurring around radio lobes and/or related to interaction between the radio plasma and the ISM is indeed found in a growing number of radio sources. An extreme case of interaction has been found in the Seyfert galaxy IC 5063 where very broad ($\sim$700 km s^{-1}) H I absorption, blueshifted with respect to the systemic velocity has been observed coincident with a radio lobe (Oosterloo et al. 2000). Other possible evidence for interaction between the radio plasma and the ISM has been found in at least two radio galaxies: the superluminal object 3C 216 (Pihlström et al. 1999) and 3C 326 (Conway et al. these proceedings). Moreover, on even larger scale ($>$ 10 kpc), H I absorption against the radio lobes has been found in the radio galaxy Coma A (Morganti et al. 2000b) as well as in the radio galaxy 3C 433. In Coma A, the striking structure of the ionised gas strongly suggests the presence of a complex interaction between the radio structure and the gas around (Tadhunter et al. 2000b) while 3C 433 is an other example of starburst and far-IR bright radio galaxies). If the H I absorption is observed against the lobes of relatively large galaxies situated in a relatively rich environment, this situation could be even more common for compact radio sources. Thus, the study of the H I absorption can tell us about the role of the ISM in the evolution of the sources as well as help in understanding the relation between intrinsic distribution of the gas and ionised gas. Moreover, it can give us clues on the ionisation mechanisms.

This study also shows the importance of having information on as many as possible wavebands and also good enough optical data for a proper interpretation of the H I data.

REFERENCES

Axon D.J. et al. 2000 *AJ*, in press (astro-ph/0006355)

Gelderman R. & Whittle M. 1994, *ApJS* **91**, 491

Morganti R., Oosterloo T.A., Tadhunter C.N. et al. 2000a, *MNRAS* in press

Morganti R., Oosterloo T., Tadhunter C.N., Wills K.A. 2000b, in "Gas and galaxy evolution", Hibbard, Rupen & van Gorkom eds., ASP Conf. Series in press (astro-ph/0009091)

O'Dea C., Baum S. & Gallimore J. 1994, *ApJ* **436**, 669

Oosterloo T.A., Morganti R., Tzioumis A., Reynolds J., King E., McCulloch P., Tsvetanov Z. 2000 *AJ* **119**, 2085

Pihlström Y.M., Vermeulen R.C., Taylor G.B., Conway J.E. 1999, *ApJ* **525**, L13

Roy A.L. & Norris R.P. 1997, *MNRAS* **289**, 824

Tadhunter C.N. et al. 2000a, *MNRAS* submitted

Tadhunter C.N., Villar-Martin M., Morganti R. et al. 2000b *MNRAS* **314**, 849

Tadhunter C.N., Morganti R. et al. 1993, *MNRAS* **263**, 999

Tzioumis A., Morganti R., Tadhunter C. et al. 1996, in 'Extragalactic Radio Sources', Ekers R.D., Fanti C. and Padrielli L. eds., p.73