Lyman-α absorption: links between CSS quasars and high-redshift radio galaxies

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Abstract

Spectroscopy of high-redshift compact steep-spectrum (CSS) quasars shows a high incidence of Ly-α absorption close to the quasar redshift ($z_{\text{abs}} \approx z_{\text{em}}$). Associated absorption systems like these are rare in other types of radio sources, with the notable exception of high-redshift radio galaxies (HZRGs). CSS quasars and HZRGs share many properties; the hypothesis that they are intrinsically similar objects is presented and discussed.

1 Introduction

A substantial population of young radio sources is expected, given the expansion of radio sources and the short-lived nature of radio emission (Alexander & Leahy 1987). This rôle may be filled by a class of intrinsically small objects, compact, steep-spectrum (CSS) sources (as a guide, $l < 30$ kpc and $\alpha > 0.5$ for $S_\nu \propto \nu^{-\alpha}$). Evidence that some CSS sources are indeed young is mounting (Readhead et al. 1996), although the class may also include frustrated sources whose jets are constricted by an unusually dense and/or clumpy interstellar medium (ISM).

The small size of CSS sources means that radio observations probe the dense nuclear environment of the host galaxies. Absorption by H I gas, perhaps from a dense parsec-scale disk, has been reported towards the compact radio components of several CSS sources (Conway 1996). Radio depolarisation is also common (Garrington et al. 1991). Evidence for jet-ISM interactions in CSS sources is strong, including bent, knotty jets and aligned optical emission (de Vries et al. 1997).
Evidence that CSS sources differ optically from larger sources, however, is only now emerging. New differences have been found for CSS quasars, including very red optical continua, large Balmer decrements and large narrow-line equivalent widths which are suggestive of reddening (Baker & Hunstead 1995). One particularly interesting characteristic is that associated absorption by enriched H I gas is exceptionally common in CSS quasars (Baker & Hunstead 1996). In a recent study of the complete Molonglo Quasar Sample (MQS) absorption with \( \tilde{z}_{\text{abs}} \approx \tilde{z}_{\text{em}} \) was found in 80% of CSS quasars with \( z > 1.4 \), where Ly \( \alpha \) and/or C IV was visible.

In this short contribution, I will show that CSS quasars share many similarities with high-redshift radio galaxies (HZRGs), and are arguably intrinsically similar objects. This is based largely on the results of intermediate resolution spectroscopy (with R. Hunstead) of \( \tilde{z}_{\text{abs}} \approx \tilde{z}_{\text{em}} \) absorbers towards high-redshift CSS quasars from the MQS.

## Spectroscopy of CSS quasars

Spectroscopy at 1-Å resolution has been carried out for seven high-\( z \) CSS quasars drawn from the 408-MHz selected MQS (Baker 1997) with the Anglo-Australian Telescope. The Ly-\( \alpha \) emission-line region has been observed for three CSS quasars with \( z > 2 \). These targets were faint (\( b_J > 19 \) on the UKST IIIaJ plates) and required long integration times of several hours per object at this high dispersion.

In all three quasars, strong Ly-\( \alpha \) absorption is seen within 2000 km s\(^{-1}\) of the quasar redshift. The Ly-\( \alpha \) absorption lines are strong but not damped, making estimates of the column density uncertain. Typical column densities of \( N_{\text{HI}} \sim 10^{14} - 10^{18} \text{ cm}^{-2} \) are indicated along the line of sight. Dust is undoubtedly present as well, which may have increased the Ly-\( \alpha \) optical depth via scattering. The Ly-\( \alpha \) absorption lines are both blue- and red-shifted with respect to the Ly-\( \alpha \) emission-line peak, and appear broadened with FWHMs of 100–400 km s\(^{-1}\). Blue-shifted absorption systems are most common, perhaps indicating outflowing clouds from the nucleus. The presence of at least one redshifted absorption system relative to the quasar emission redshift, and the broadened lines, favours an intrinsic origin for the absorbing material rather than absorption by intervening galaxies.

Over the wavelength range observed, many other species are visible, ranging from N v to O I. The variety of species present indicates that the absorbing clouds span a range of density and ionisation. One quasar shows high-ionisation
Figure 1. Spectrum of the Ly-α region at 1-Å resolution for the $z = 2.914$ CSS quasar MQS 0246−231. Absorption lines are marked.

Figure 1 shows an example of a spectrum of a CSS quasar at $z = 2.914$, MQS 0246−231. This quasar is very faint — $b_J = 21.5$ on the UKST IIIaJ plates. Strong Ly-α absorption is clearly seen along with the high-ionisation absorption lines of N V and Si III, which are marked. There is a slight redshift mis-match between Ly-α, N V and Si III, which probably indicates that the Ly-α absorption arises in spatially distinct regions. All four absorption lines are clearly resolved, indicating a relatively large velocity dispersion for the clouds (up to 400 km s$^{-1}$). The Ly-α emission-line profile in this quasar is relatively narrow (1000 km s$^{-1}$ FWHM), a width more typical of radio galaxies.
3 Parallels between CSS quasars and HZRGs

The strong Ly-α absorption found towards CSS quasars is very similar to that reported towards a number of high-redshift radio galaxies (HZRGs) (e.g. van Ojik et al. 1997). In HZRGs, the absorbers are probably related to extended kpc-scale Ly-α emission regions, which indicate that reservoirs of H I gas envelope the radio source. The Ly-α absorbers in HZRGs are observed to cover the entire area of extended Ly-α emission, reaching tens of kpc from the nucleus. The absorbers in HZRGs are also metal-enriched — species including C IV and Si IIII accompany the Ly-α absorption. In HZRGs, Ly-α absorption occurs preferentially towards sources of small linear size (van Ojik et al. 1997) and with bent radio structures (Barthel & Miley 1988), suggesting a link between absorption and radio source size and also direct interactions between the H I halo and the radio jets.

In fact many of the above characteristics of HZRGs are shared with CSS sources, raising the possibility that HZRGs and CSS sources are intrinsically similar objects.

In Figure 2, the 1-Å resolution Ly-α spectrum of a HZRG at $z = 2.9$, MRC0943−242 (Röttgering et al. 1995), has been scaled and plotted on top of Ly-α for the CSS quasar MQS0246−231 (from Figure 1). The similarities in the Ly-α absorption and emission properties are striking. The only obvious difference between the two is the presence of continuum emission in the quasar.

This example strongly supports the idea that many HZRGs are in fact misaligned CSS quasars with their continuum and broad-line regions hidden by a dusty torus. Such a picture is entirely consistent with the inference of hidden quasars in HZRGs through spectropolarimetry (e.g. Cimatti et al. 1997) and the presence of continuum and emission-line light aligned with the radio axis in many HZRGs (e.g. Rush et al. 1997).

4 Discussion

By noting the similarities between HZRGs and CSS quasars, the properties of intrinsically small radio sources can begin to be unified. This spectroscopic study shows that some of the properties of HZRGs are in fact common characteristics of small radio sources, including many CSS sources. Whether these properties are a consequence of youth remains to be confirmed — some fraction of older, frustrated sources is still expected. The similarities between HZRGs and CSS quasars places even more emphasis on the study of CSS sources over
Figure 2. Overlaid restframe spectra (1Å resolution) of a MQS CSS quasar (dotted line) and HZRG (MRC0943−242 from Röttgering et al. 1995) (solid line) at $z = 2.9$. The HZRG spectrum has been shifted upwards to match the quasar continuum level and then scaled to the Ly$\alpha$ emission peak. Note the remarkable correspondence between the emission and absorption profiles.

a wide range of redshifts.

The presence of Ly-$\alpha$ absorption with $z_{\text{abs}} \approx z_{\text{em}}$ preferentially in sources of small linear size suggests that the absorption properties of quasars are linked directly to the evolution of the radio source. It can be postulated that radio sources are born in cocoons of enriched H$\text{I}$ gas which is ionised and pushed aside as the radio source grows. This explains the lower rate of $z_{\text{abs}} \approx z_{\text{em}}$ absorption in larger sources. The origin of the H$\text{I}$ cocoons, however, and their possible rôle in triggering radio emission in active galaxies, remains unknown. Remnants of past galaxy mergers and reservoirs of primordial gas have both been postulated as explanations for the Ly-$\alpha$ haloes around HZRGs.
5 Conclusions

Associated \((z_{\text{abs}} \approx z_{\text{em}})\) Ly-\(\alpha\) absorption is common in CSS quasars. The absorbers may be metal enriched, and span a range of density and ionisation. The properties of these Ly-\(\alpha\) absorbers appear identical to those seen towards HZRGs, especially ones of small linear size. On the basis of their similar H\(1\) environments, as probed by absorption, and other evidence, it is likely that many HZRGs and CSS quasars are intrinsically similar objects.

The properties of small radio sources are crucial for investigating the processes which drive radio source evolution. Associated absorption in particular appears to offer a new way of probing possible intrinsic differences between large and small radio sources.

References

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