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Where is the cold neutral gas in the hosts of high redshift AGN?

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Abstract. Previous surveys for H I 21-cm absorption in $z > 0.1$ radio galaxies and quasars yield a $\approx 40\%$ detection rate, which is attributed to unified schemes of active galactic nuclei (AGN). In this paradigm absorption is only witnessed in (close to) type-2 objects, where the central obscuration is viewed (nearly) edge-on and thus absorbs the rest frame 1420 MHz emission along our sight-line. However, we find this mix of detections and non-detections to only apply at low redshift ($z < 1$): From a sensitive survey of eight $z \gtrsim 3$ radio sources we find no 21-cm absorption, indicating a low abundance of cold neutral gas in (the sight-lines searched in) these objects. Analysing the spectral energy distributions of these sources, we find that our high redshift selection introduces a bias where our sample consists exclusively of quasars with ultra-violet luminosities in excess of $L_{\rm UV} \sim 10^{23}$ W Hz^{-1}. This may suggest that we have selected a class of particularly UV bright type-1 objects. Whatever the cause, it must also be invoked to explain the non-detections in an equal number of $z < 0.7$ sources, where we find, for the first time, the same exclusive non-detections at $L_{\rm UV} \gtrsim 10^{23}$ W Hz^{-1}. These objects also turn out to be quasars and, from these exclusive high UV luminosity–21-cm non-detections, it is apparent that orientation effects alone cannot account for the mix of 21-cm detections and non-detections at any redshift.

Key words. radio lines: galaxies – galaxies: active – quasars: absorption lines – cosmology: observations – galaxies: abundances – galaxies: high redshift

1. Introduction

Observations of the redshifted 21-cm transition of neutral hydrogen (H I) provide a powerful probe of the nature and contents of the early Universe. For example, this line can be used to:

1. Measure the baryonic content of the young Universe, when, before its consumption by star formation, neutral gas outweighed the stars.
2. Probe the evolution of large-scale structure and galaxy formation. At high redshifts, interactions occur more frequently and H I observations provide an indispensable means to studying the dynamics of galactic mergence and accretion.
3. Provide a lower limit the time of the epoch of reionisation, when neutral hydrogen collapsed forming the first galaxies and igniting the first stars.

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4. Measure any changes in the values of the fundamental constants of nature: Comparing the redshifted frequencies of the 21-cm transition with those of metal-ion and molecular lines against laboratory values, can in principle yield measures of various combinations of fundamental constants at large look-back times (see Curran et al. 2004).

However, redshifted H I 21-cm absorption systems are currently very rare with only 67 known at $z \gtrsim 0.1$ (see table 1 of Curran et al. 2008). We have therefore embarked upon a large survey to search for this transition in both systems intervening the lines-of-sight to background radio sources (Curran et al., 2005, 2007) and within the sources themselves (i.e. for absorption "associated" with the host, Curran et al. 2006, 2008). From a recent survey for associated absorption in $z = 2.9 - 3.8$ radio sources with the Giant Metrewave Radio Telescope (GMRT), 21-cm was not detected in any of the eight targets for which good data were obtained. We discuss the reasons for this here.

2. Results and discussion

Our observations are discussed in detail in Curran et al. (2006, 2008) and in Fig. 1 we show the derived 21-cm line strengths, indicating the upper limits of our and the previous surveys. As seen from the figure, our limits are comparable to the vast majority of detections (which are primarily at low redshift)[1]. Currently, the known mix of detections and non-detections (until our survey, mostly at $z \lesssim 1$) are attributed to unified schemes of active galactic nuclei (AGN), where the observed properties of the active galaxy or quasar are due to the orientation at which the active nucleus is viewed (see Antonucci 1993; Urry & Padovani 1995): In type-1 objects, the AGN is viewed directly and in type-2 objects through a large column of dense obscuring gas, thus giving rise to the 21-cm absorption by the cold neutral gas located along our line-of-sight (e.g. Jaffe & McNamara 1994; Conway & Blanco 1995, Fig. 2).

However, for our sample we obtain exclusive non-detections, where, according to unified schemes, we may expect the ≈ 40% (31 out of 73) mix seen at $z \lesssim 1$[2]. With two detections already obtained at $z = 2.64$ and 3.40 (Fig. 1), it is clear that our high redshift selection (alone, at least) cannot be responsible for the lack of 21-cm absorption in our targets. If we consider the ultra-violet ($\lambda \sim 1000$ Å) luminosities, however (which we have estimated from the available optical and near-infrared photometry, Curran et al. 2008), we see that all our targets have luminosities of $L_{\rm UV} \gtrsim 10^{23}$ W Hz^{-1} (Fig. 3). Furthermore, although there is a roughly equal mix of detections (33 objects) and non-detections (36 objects) at $L_{\rm UV} \lesssim 10^{23}$ W Hz^{-1}, the exclusive non-detections at high UV luminosities relation is also seen for the low redshift sources.

We therefore suspect that the high UV fluxes are ionising the neutral gas, rendering this undetectable through the 21-cm transition of hydrogen. This is the first time such a correlation has been noted and, if indeed the case, perhaps exclusive 21-cm non-detections should have been expected for our sample, which at luminosity distances of 26 to 34 Gpc are severely flux limited. That is, at such large distances only the most UV luminous sources are known[3]. It should be noted, however, that our main selection criterion was choosing radio-loud sources with $B \gtrsim 19$. This introduces a luminosity "ceiling" of $L_{\rm UV} \lesssim 3 \times 10^{24}$ W Hz^{-1}, thus causing us to select the *dimmer* ultra-violet sources known at these redshifts.

With hindsight, a high redshift selection yielding high luminosity objects undergoing a large degree of ionisation may be expected, although, what is surprising is the discovery of the eight 21-cm non-detections at low redshift

[1] Note that most of the low redshift non-detections have been searched sufficiently deeply to detect 21-cm in most of the known absorbers.

[2] Perhaps more, since the density of H I at $z \sim 3$ is expected to be higher than it is presently (e.g. Péroux et al. 2001).

[3] The quasar frame UV flux being redshifted into the optical band in these cases.

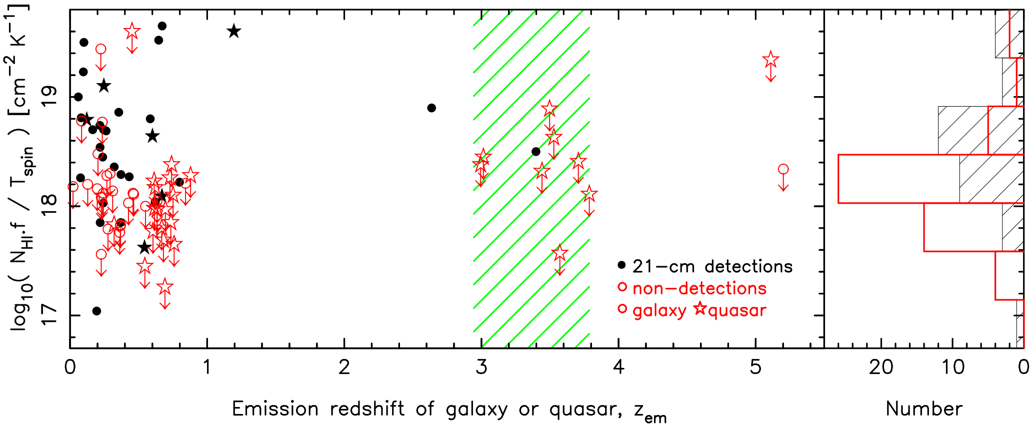

Fig. 1. The scaled velocity integrated optical depth of the H I line ($1.823 \times 10^{18} . \int \tau dv$) versus the host redshift for the published $z \gtrsim 0.1$ searches for associated 21-cm absorption. The filled symbols represent the 21-cm detections and the unfilled symbols the non-detections, with stars designating quasars and circles galaxies. The hatched region shows the range of our recent survey. The detections in this range are from Uson et al. (1991); Moore et al. (1999) and the two $z_{em} > 5$ non-detections are from Carilli et al. (2007).

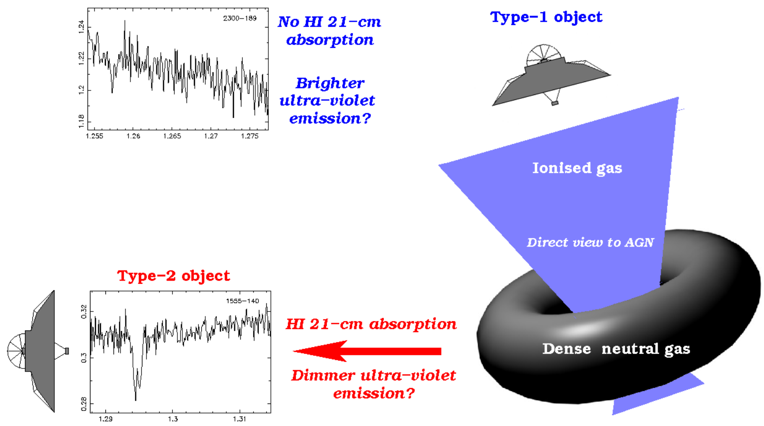

Fig. 2. Schematic showing the lines-of-sight to an AGN, where according to unified schemes the object type depends upon the orientation at which the nucleus is observed: In type-1 objects we view the AGN directly and in type-2s this is obscured by a circumnuclear torus of dense neutral gas. The 21-cm absorption detection shown is in PKS 1555–140, a known type-2 object, and the non-detection is in PKS 2300–189, a known type-1 object (the spectra are taken from Curran et al. 2006, where the ordinate is the flux density in Jy and the abscissa the observed frequency in GHz).

(all at $z \leq 0.7$, Fig. 3) for which the UV luminosity also exceeds $L_{UV} \sim 10^{23}$ W Hz^{-1}. These objects could be understood in terms of unified schemes (Fig. 2), where we may expect high UV luminosities to go hand-in-hand with 21-cm non-detections (i.e. all are type-1 objects), if it were not for the non-detections at $L_{UV} \lesssim 10^{23}$ W Hz^{-1} (in fact down to $L_{UV} \approx 4 \times 10^{18}$ W Hz^{-1}). Again, this is the first time that such a segregation has been noted and suggests that the $L_{UV} \gtrsim 10^{23}$ W Hz^{-1} targets (which are all flagged as quasars) are different from their low luminosity counterparts in which 21-cm also

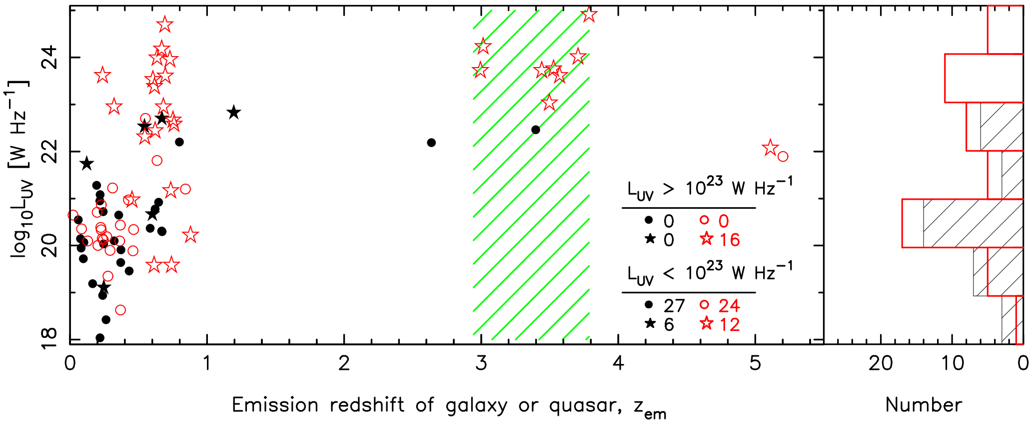

Fig. 3. As per Fig. 1, but with the calculated ultra-violet luminosities on the ordinate.

remains undetected (which comprise of a mix of galaxies and quasars).

3. Summary

We have undertaken a survey for H I 21-cm absorption in the hosts of $z = 2.9 - 3.8$ radio sources. Although this has previously been detected at $z = 2.64$ and 3.40, we detect no absorption in any of the eight sources searched. Upon examining the ultra-violet luminosities of our targets, we find that all have $L_{\rm UV} \gtrsim 10^{23}$ W Hz^{-1} (which the two high redshift detections do not), a relation we find also to apply to the low redshift searches in the literature. This suggests that the high ultra-violet fluxes are ionising the hydrogen to neutral column densities below our detection threshold. If this is only occuring along our line-of-sight to the active nucleus, our findings are consistent with these being exclusively type-1 objects (all are flagged as quasars according to their morphologies, although there are quasars detected in 21-cm). However, the fact remains that there exists a roughly equal mix of 21-cm detections and non-detections below $L_{\rm UV} \sim 10^{23}$ W Hz^{-1} (which are a mix of quasars and galaxies). The orientation effects invoked by unified schemes of active galactic nuclei are generally believed to be responsible for this mix, although our result would suggest that there are both low and high UV-luminous type-1 objects, while type-2 objects exclusively have $L_{\rm UV} \lesssim 10^{23}$ W Hz^{-1}.

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