Where is the 21-cm Absorption by Hydrogen in the Distant Universe?

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We have recently undertaken a survey for the absorption of radiation by the neutral hydrogen residing in the host galaxies of quasars, using the 30 antennae Giant Metre-wave Radio Telescope (GMRT) in India. At frequencies of < 360 MHz, where the 1420 MHz (21-cm) spin-flip transition of hydrogen is redshifted to $z > 3$, we are looking back beyond 11.5 billion years into the past, where much of the gas in the Universe has yet to be consumed by star formation. However, rather than finding a higher abundance of hydrogen, our survey failed to detect any. This is shown in the top panel of the figure, where our targets lie in the redshift range $z = 2.9$ to 3.8 and the vertical axis/histogram illustrates that our survey has reached sensitivities more than sufficient to detect 21-cm absorption in most of the current detections (which span the range 10^{17} to 10^{20} cm^{-2} K^{-1}.).

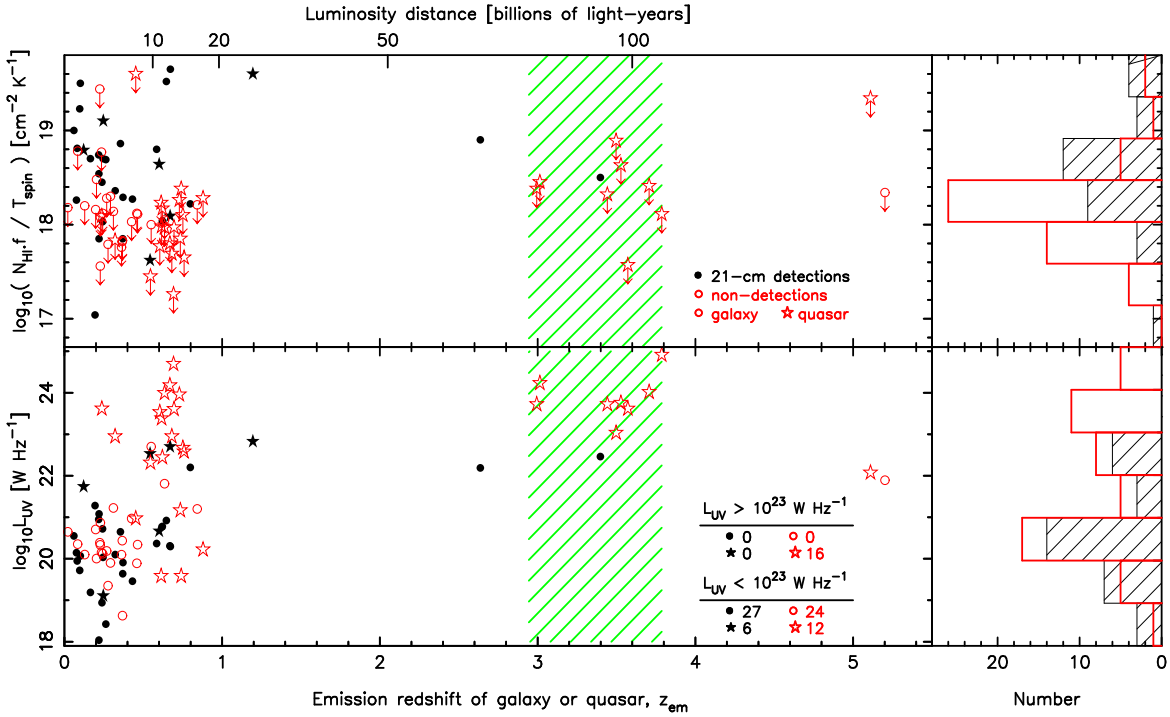

Fig. 1: The neutral hydrogen column density (top) and the ultra-violet luminosity of the quasar (bottom) versus the redshift of the galaxy hosting the quasar. The hollow red symbols/histogram signify the HI 21-cm non-detections (upper limits) and the filled black symbols/hatched histogram the detections. The green hatched region shows the redshift range of our GMRT survey.

Neutral hydrogen is ionised by ultra-violet radiation of wavelengths $\lambda < 912$ Å (where each photon carries over a million times the energy of the 21-cm photons). We have therefore taken the ultra-violet fluxes of all of the searched sources and converted these to the intrinsic ultra-violet luminosity from the material accreting onto the central super-massive black hole, which gives each of these sources their powerful emission. The results are shown in the bottom panel of the figure, where the histogram gives a mix of detections and non-detections at ultra-violet luminosities $< 10^{23}$ W Hz^{-1}, but exclusive non-detections above this luminosity. For our high redshift targets, the result is not surprising, as, at luminosity distances close to 100 billion light-years, only the brightest sources are known. However, the ultra-violet distribution also identifies a class of low redshift ($z < 1$) sources for which the luminosities exceed 10^{23} W Hz^{-1}, which have also never been detected in 21-cm absorption. Previously, all of the non-detections have been attributed to unified schemes of active galactic nuclei (AGN), where for 50% of objects the radiation along our sight-line does not pass through the large column of neutral gas encircling the accretion disk and is thus not seen to absorb. Our result may be consistent with this, but it is clear that we have identified a class of AGN in which the ultra-violet output is typically 100 times brighter than these galaxies and quasars in which neutral hydrogen has been detected. Therefore it is also possible that this intense radiation is ionising all of the neutral gas.