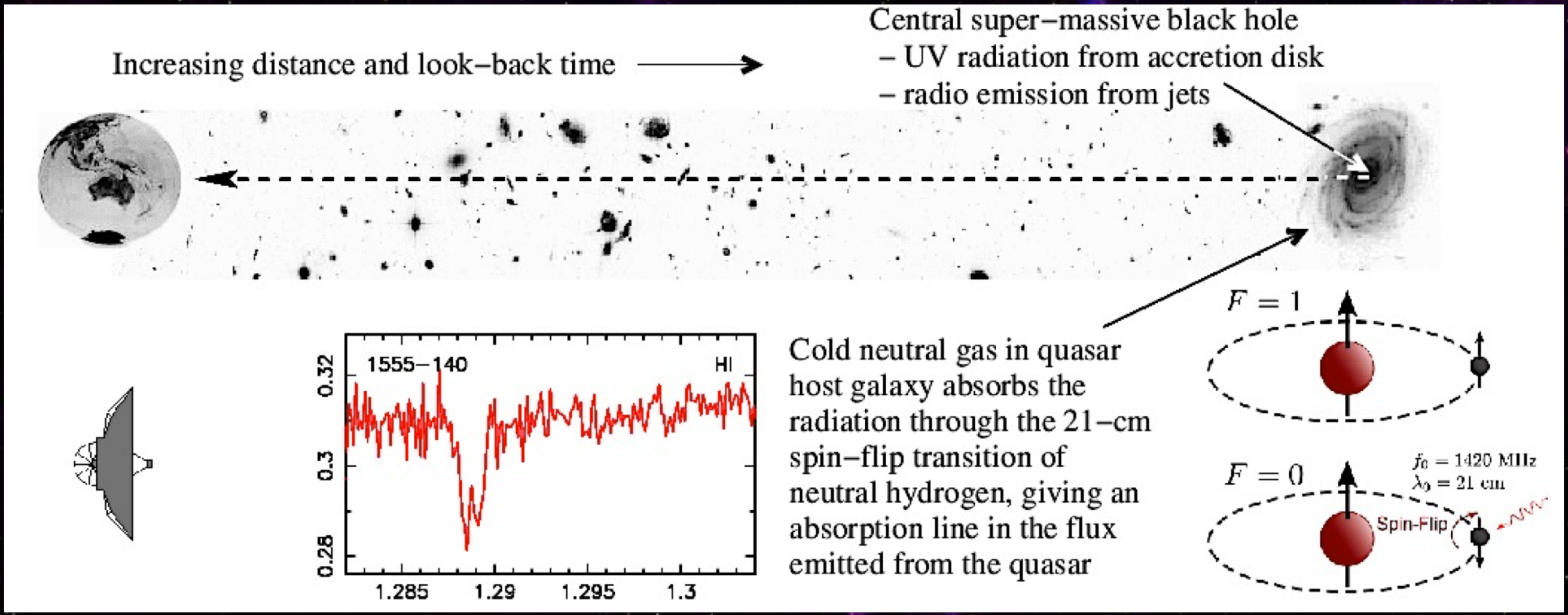
Absorption of the 21-cm transition of neutral hydrogen (HI) traces the cool component of the neutral gas, the reservoir star formation history. Also provides a useful probe of

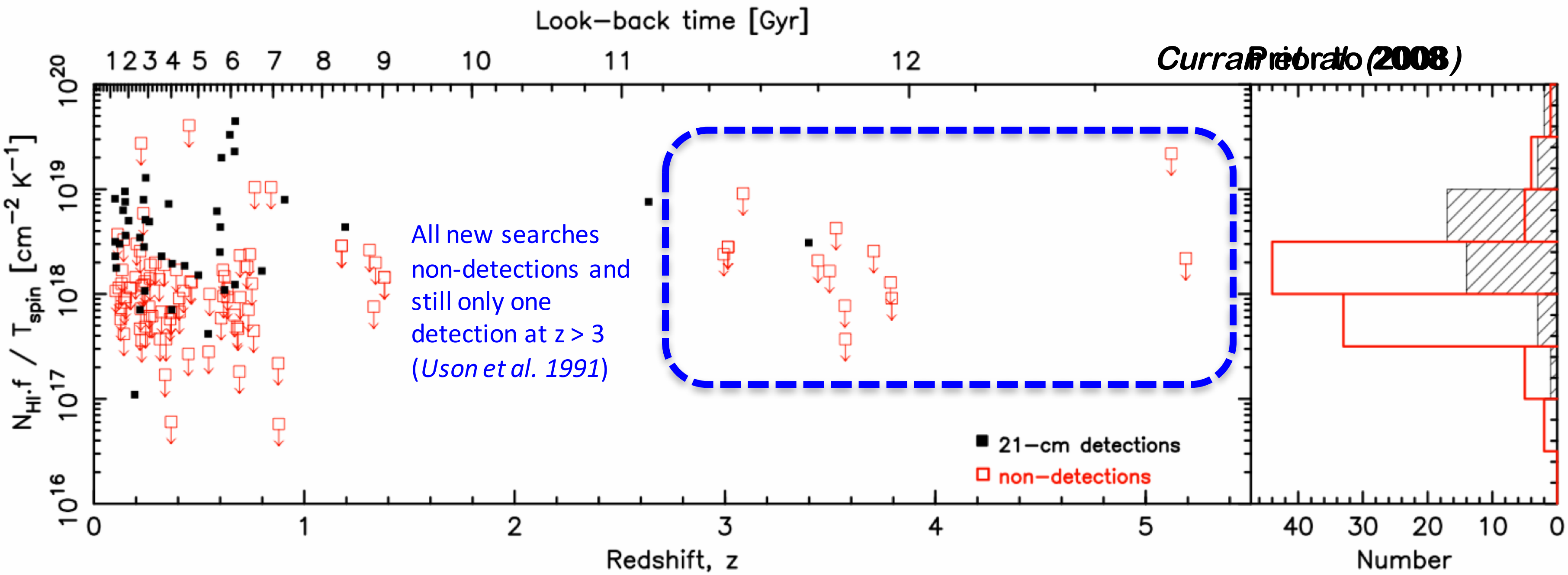
- Baryonic mass density
- Evolution of large-scale structure
- Epoch of Reionisation
- Variations on the fundamental constants (α, μ, g_p)

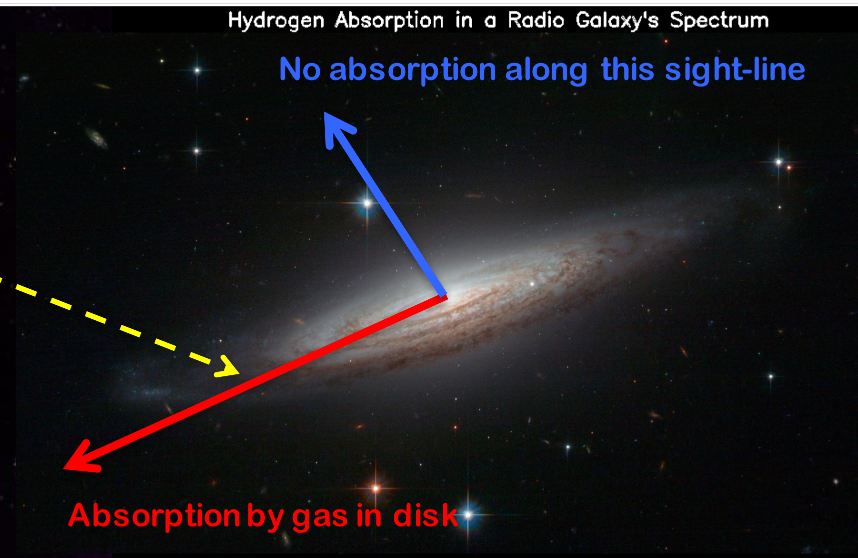
Unlike the Lyman-α transition of HI (λ = 1216 Å), 21-cm can be observed at z = 0 (cf. z > 1.7) by ground-based telescopes day or night.

Unlike 21-cm emission, can be readily detected at z > 0.4, since absorption strength only dependent upon column density and background flux.

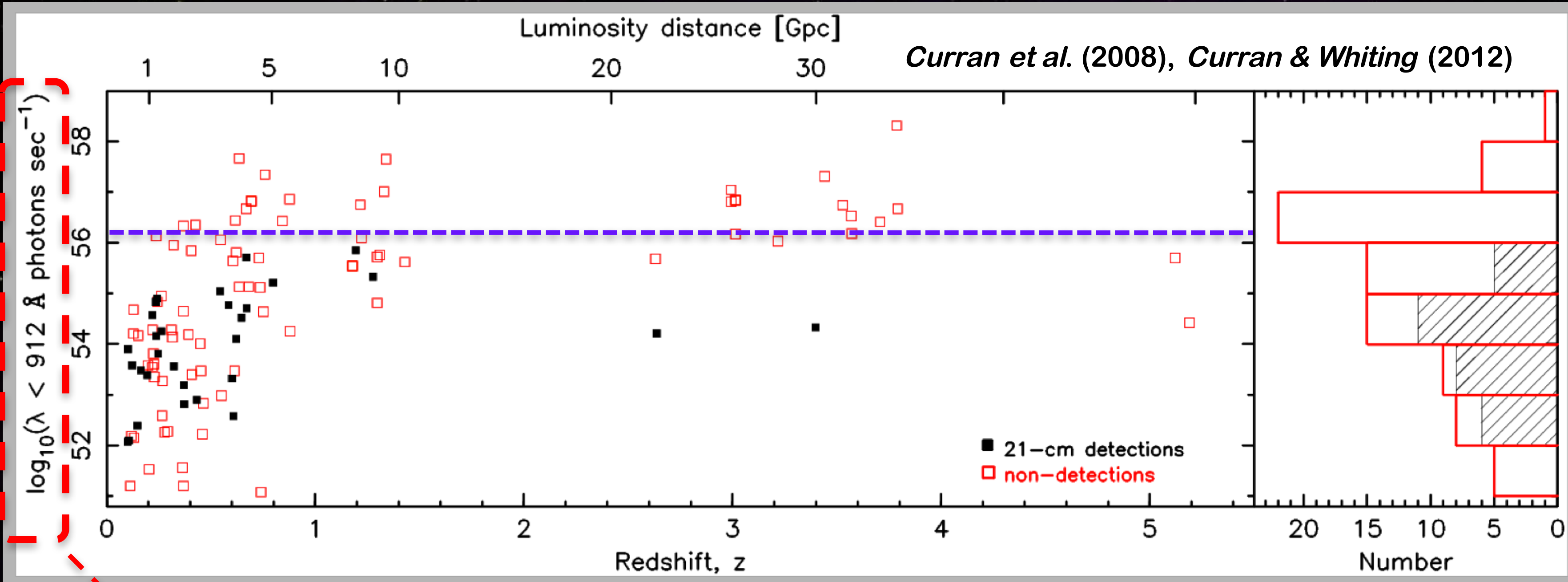


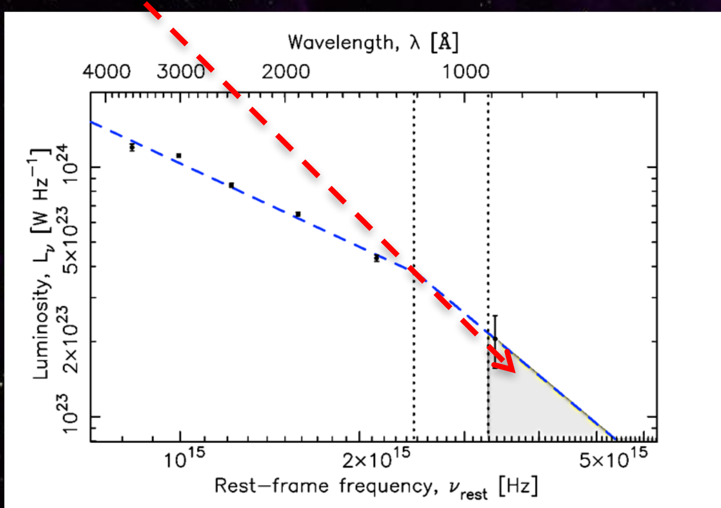
Surveys for associated HI 21-cm absorption



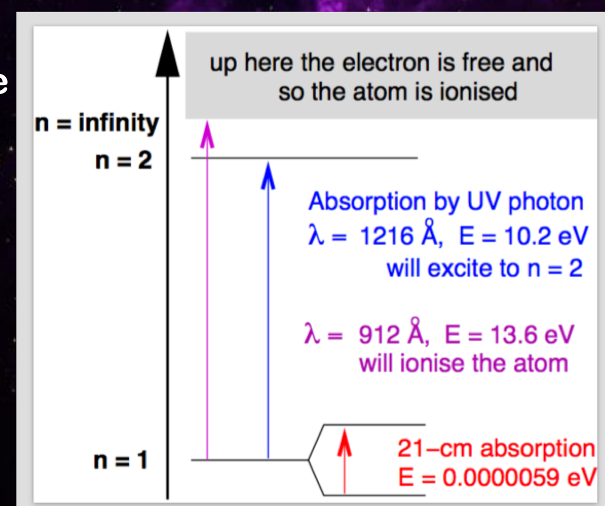


UV luminosities of new targets





High redshifts are the most distant and so bias towards most UV luminous objects (accretion around supermassive BHs) → gas is ionised to beyond detection



However…

- Why is there a <u>critical</u> luminosity at all?
- Why is this $\approx 10^{56}$ ionising photons sec^{-1} ($L_{UV} \approx 10^{23}$ W Hz^{-1})?
- Searches are generally limited to column densities of $N_{HI} \approx 10^{18}$ (T_{spin}/f) cm^{-2}. So is the neutral hydrogen ionised to just below the sensitivity thresholds of current large radio telescopes?

That is, could the *Square Kilometre Array* readily detect the reservoir for star currently missing in high redshift radio galaxies and quasars?

Applying the equation of photo-ionisation equilibrium to an exponential gas disk, we find the observed critical ~10^{56} ionising photons sec^{-1} just sufficient to ionise all of the gas in a large galaxy…

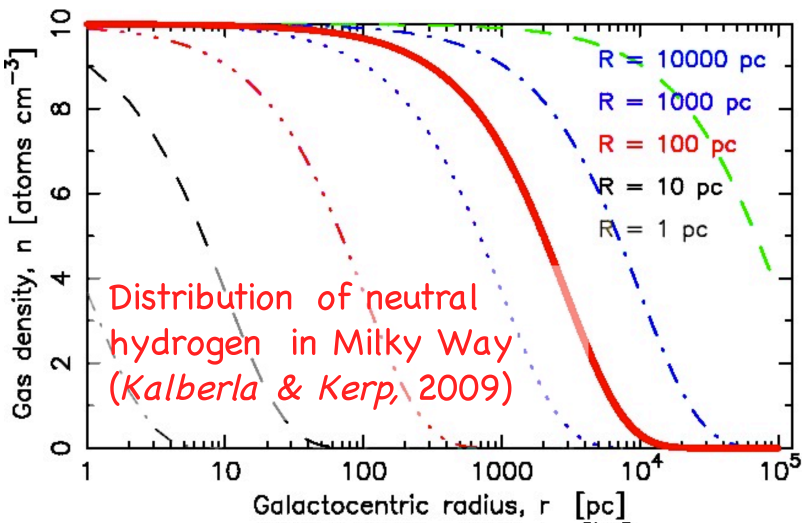
$$\int_{\nu}^{\infty} \frac{L_\nu}{h\nu}\, d\nu = 4\pi \int_0^{r_{\rm ion}} n_{\rm p}\, n_{\rm e}\, \alpha_{A,B}\, r^2\, dr$$

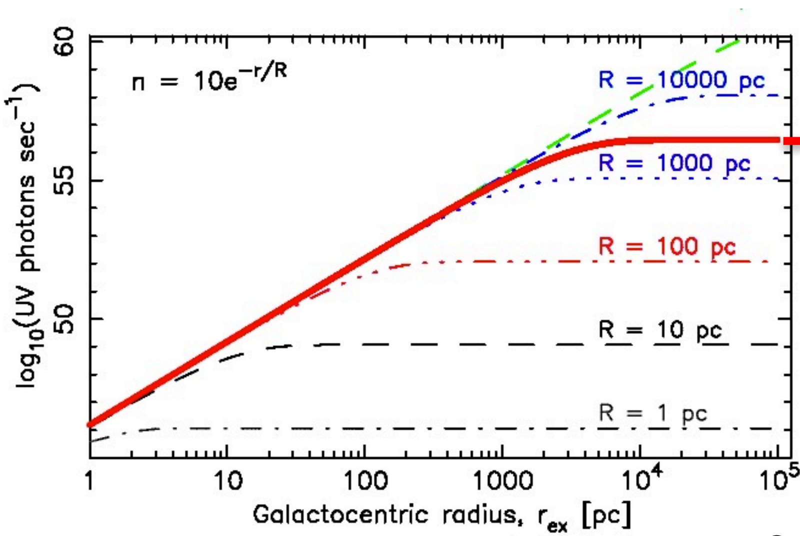
photo-ionisation — recombination of protons & electrons

For a neutral gas ($n_{\rm p} = n_{\rm e} = n$) with an exponentially decaying density distribution, $n = n_0\, e^{-r/R}$, where n_0 is the gas density at $r = 0$ and R is a scale-length describing the rate of decay of this with radius

$$4\pi \int_0^{r_{\rm ion}} n_{\rm p}\, n_{\rm e}\, \alpha\, r^2\, dr = 4\pi\, \alpha\, n_0^2 \int_0^{r_{\rm ion}} e^{-2r/R}\, r^2\, dr$$
$$= \pi\, \alpha\, n_0^2 \left[R^3 - R\, e^{-2r_{\rm ion}/R}\left(2\, r_{\rm ion}^2 + 2\, r_{\rm ion} R + R^2\right)\right].$$

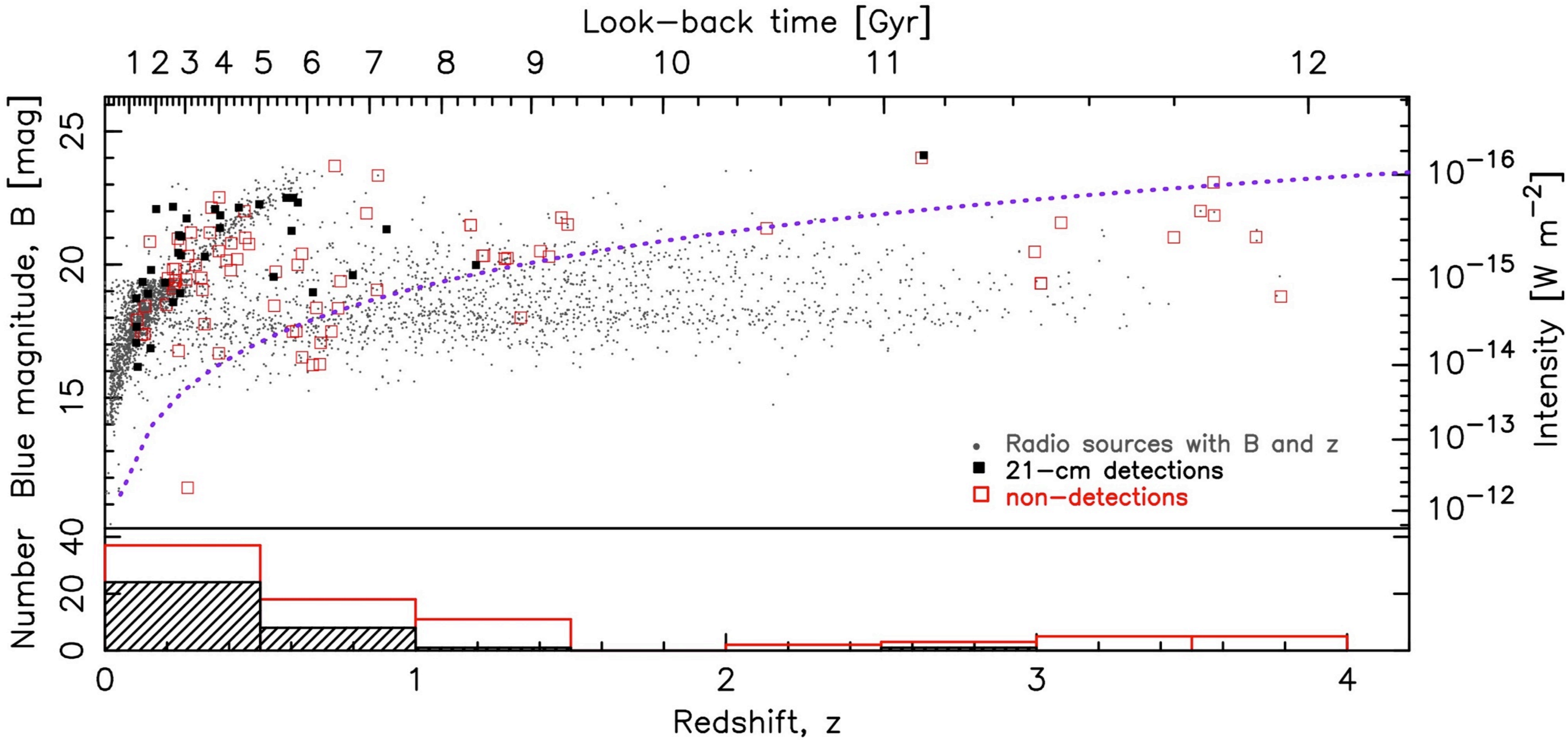
n_0 = 10 cm^{-3}, α = 1.27 x 10^{-12} cm^3 s^{-1} [i.e. T = 2000 K]





Curran & Whiting (2012)

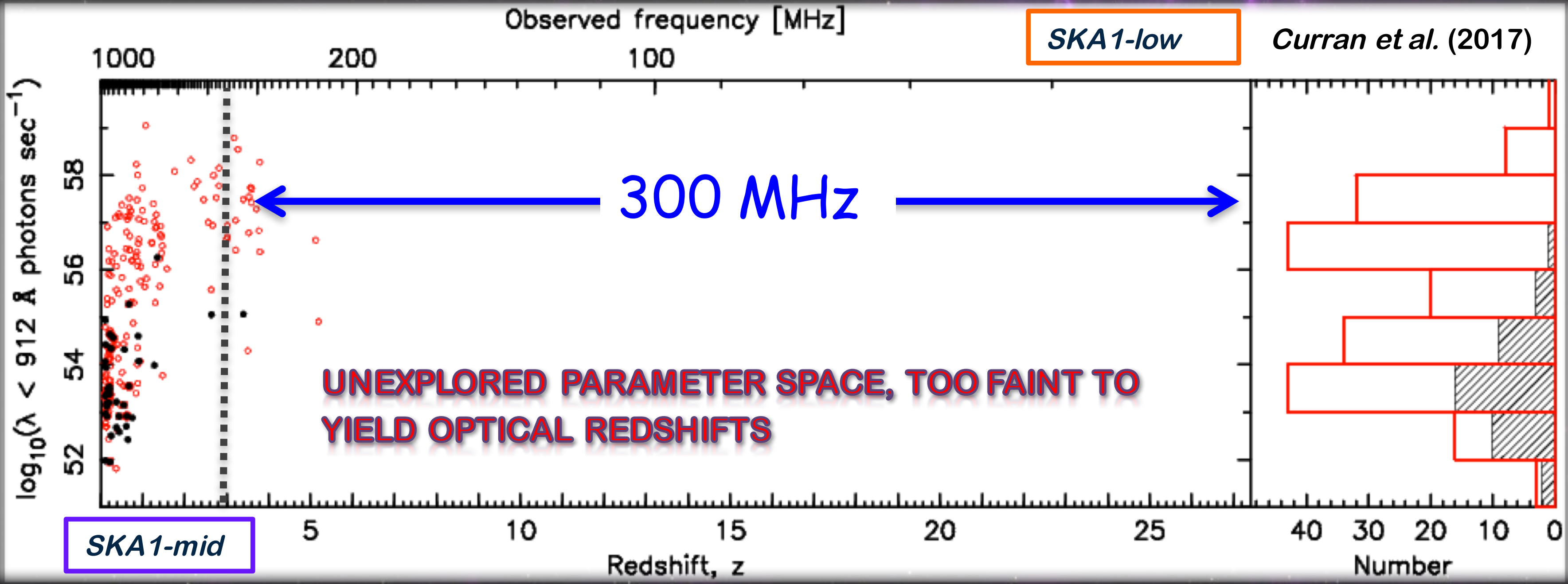
Traditional optical selection biases towards object in which gas is completely ionised even faint objects ($B \approx 23$) at z > 3 yields objects extremely UV luminous in the rest-frame ($L_{UV} \approx 10^{23}$ W Hz^{-1}) → target optically faint, radio-loud, sources at high-z. However…

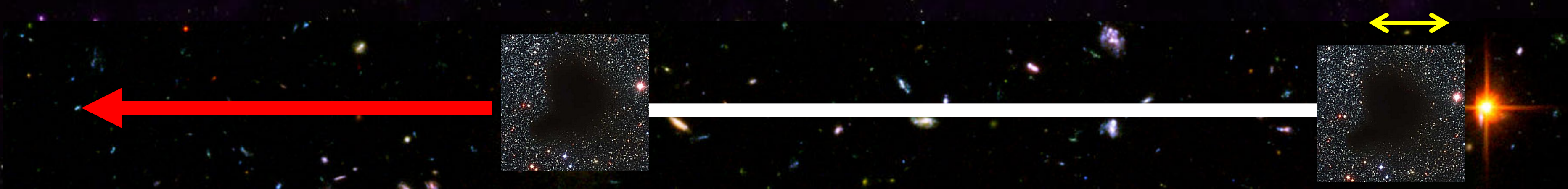


Since gas completely ionised (*Curran & Whiting*, 2012) even SKA won't be able to detect 21-cm absorption in z > 3 radio sources of known (optical) redshift!

To find the missing gas in the distant Universe need to dispense with traditional optical selection of targets. However, current radio telescopes have narrow RFI-free instantaneous bandwidths.

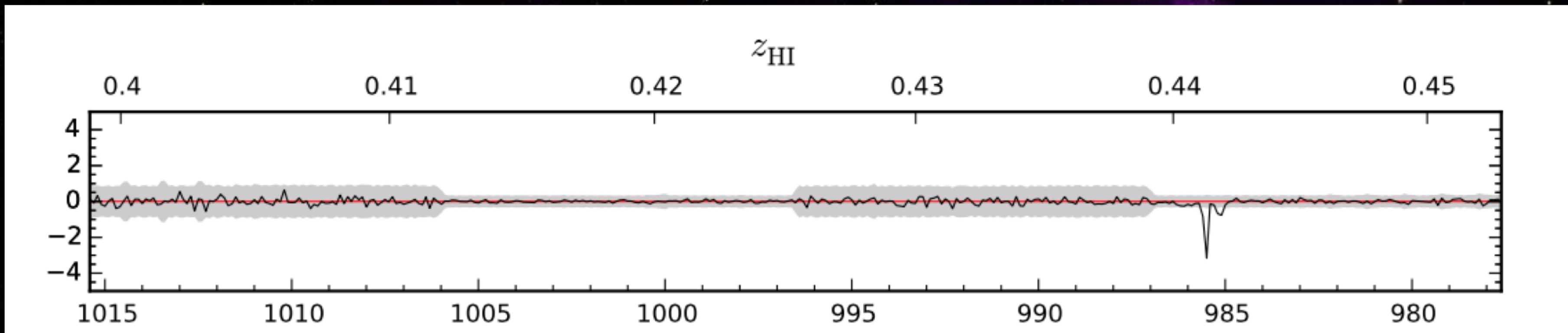
With the *Square Kilometre Array,* however…

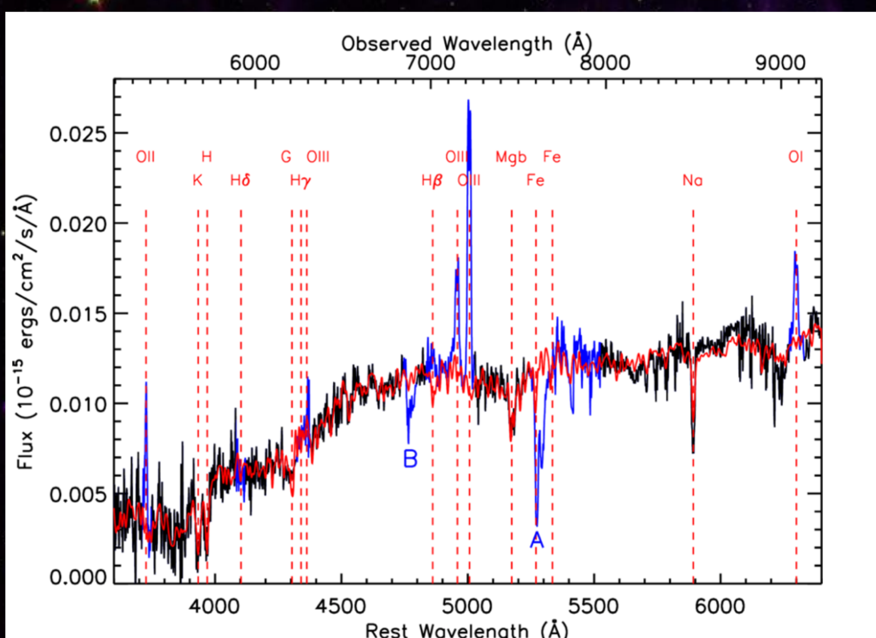




No optical spectrum - could be anywhere at $z_{abs} \geqq z_{QSO}$ → ***SPECTRAL SCAN***

For example, for a 1015 – 710 MHz (z = 0.4 – 1.0) scan with the *Boolardy Engineering Test Array* of the *Australian Square Kilometre Array Pathfinder* (ASKAP, *Allison et al.*, 2015)





No previous spectroscopy of PKS B1740−517 and photometric redshifts range z = 0.347 – 0.63, which corresponds to a difference of 2 Gyr in look-back time!

1.5 hours of Director's Discretionary Time *on Gemini-South* confirms that absorption is associated with $z_{\rm opt}$ = 0.44230 ± 0.00022 cf. $z_{\rm HI}$ = 0.44129230 ± 0.00000040

This is one line-of-sight with a six-antenna prototype. The full *First Large Absorption Survey in HI* (FLASH) on ASKAP will search 150,000 sight-lines with 36 antennas!

To summarise…

- Non-detection of associated HI 21-cm at high-z explained by UV luminosities of $L_{UV} > 10^{23}$ W Hz^{-1} ($Q_{HI} > 10^{56}$ sec^{-1}) either by ionisation or excitation of the neutral gas to below the detection limit of contemporary large radio telescopes.

- However, model of a quasar placed in an exponential has disk, suggests that this is *not* a sensitivity issue, but a consequence of *all of the gas being ionised.*

- So even the SKA is unlikely to detect 21-cm absorption in the currently known (optically selected) z > 3 radio galaxies and quasars.

- Spectral scans towards radio-loud, optically-faint objects are required in order to detect missing star-forming gas in high-z radio galaxies and quasars.

- With its wide instantaneous bandwidth (700 MHz for SKA1-mid & 250 MHz for SKA1-low) and high sensitivity, the SKA will be ideal in performing such scans for HI 21-cm out t ridiculously high redshifts!