Searching 21-cm Absorption Systems in Chinese Radio Telescopes

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Abstract Neutral hydrogen clouds are known to exist in the Universe, however their spatial distributions and physical properties are poorly understood. Such missing information can be studied by the Chinese new generation radio telescopes by a blind searching of 21-cm absorption systems. We forecast the abilities of surveys of 21-cm absorption systems by two representative radio telescopes in China – Five-hundred-meter Aperture Spherical radio Telescope (FAST) and Tianlai. The result shows that, in a few of years term, these telescopes with either high sensitivity (FAST) or wide field of view (Tianlai) can discover orders of magnitudes more 21-cm absorption systems, than the cumulative discoveries in the past 50 years.

Key words:

1 INTRODUCTION

Neutral hydrogen (H I) clouds are known to exist in the Universe, however only few of them are discovered in the past half a century, and we poorly understand their spatial distribution and physical properties (Wolfe et al. 2005). In damped Lyman-α absorption (DLA) systems, the radio spectrum is also substantially absorbed by the H I hyperfine structure, whose rest frame wavelength is approximately 21 cm ($\sim$1420 MHz in frequency). These systems are defined to have at least 2×10^{20} cm^{-2} H I column density, thus being able to house cold 21-cm absorbing gas in the cold neutral medium (CNM).

The 21-cm absorption systems are important in the study of the distribution, location, temperature and structure of neutral gas, and the evolution of neutral gas systems and galaxies over cosmic time scale. Due to the narrow intrinsic line width, the 21-cm absorption systems are proposed to be used to directly measure the cosmic acceleration (Darling 2012; Yu et al. 2014), via the Sandage-Loeb (SL) effect (Sandage 1962; Loeb 1998). The uncertainties are from the poorly understood neutral hydrogen clouds. Path finder surveys, taking less than a year, are needed to improve our understandings of spatial distribution and physical properties of neutral hydrogen clouds. This can be done by the Chinese new generation radio telescopes – Five-hundred-meter Aperture Spherical radio Telescope (FAST) (Li & Pan 2016) and Tianlai (Chen 2012). In the current and near future, these are the two symbolic modern radio telescopes in China. The single-dish FAST, like Arecibo[1], uses its gigantic single dish to achieve ultimate sensitivity, whereas Tianlai, designed like CHIME[2], has ultra wide field of view (FoV) per day, by using its cylindrical reflectors and arrays of receivers to scan the northern hemisphere of the sky as the Earth turns.

According to their different design and observing strategies, we forecast their abilities of blind searching of 21-cm absorption systems. In section 2 we show the sensitivity estimation and all the aspects needed to be taken into account, and according to the configurations of FAST and Tianlai, we show their forecast in section 3 and section 4 respectively. Conclusions are made in section 5.

2 SENSITIVITY

To find possible 21-cm absorption systems, radio telescopes could be devised to scan the radio sources in NRAO VLA Sky Survey (NVSS)[3]. If we assume the distributions of radio sources n_R and H I clouds $n_{\rm H\,I}$ are uniform over the sky, then the redshift distribution of the 21-cm absorption systems $n_{\rm system}$ would be

$$n_{\rm system}(z) = n_{\rm H\,I}(z)\int_z^{\infty} n_R(z')\mathrm{d}z' \qquad (1)$$

regardless of the observation sensitivity, where $n_R(z)$ is given by equation (26) of de Zotti et al. (2010). Spacial distribution of H I is poorly understood and is to be studied in upcoming surveys. Recent studies show that the number density of absorbers to be $\mathrm{d}n_{\rm H\,I}/\mathrm{d}z \sim 0.045$ per line of sight (Wolfe et al. 2005; Zwaan et al. 2007), so we apply this value in the following forcast.

Observation sensitivity depends on the background fluxes and foreground absorptions (current section), as well as telescope configurations and observation strategies (section 3,4).

NVSS contains 2 million sources (with declination $\delta > -40°$, cover 82% of the sky) stronger than 2.5 mJy at ν =1.4 GHz (Condon et al. 1998) and their flux distribution $n_R(F)$ is given by Condon (1984). Redshifted H I clouds absorb lower frequency bands where the radio sources are typically brighter by $\nu^{-0.7}$ (Condon et al. 1998), or $(1 + z_{\rm H\,I})^{0.7}$. The error of the measurement ΔF is given by

$$\Delta F = \mathrm{SEFD}/\sqrt{n_{\rm pol}\Delta\nu\Delta t}, \qquad (2)$$

where SEFD is the system equivalent flux density, $n_{\rm pol}$ is the number of polarizations, $\Delta\nu$ is the line width and Δt is the integration time. $\Delta\nu = (u_{\rm width}/c)\nu_{\rm obs}$, where $u_{\rm width}$ is the equivalent line width of the H I absorber. The properties of 21-cm absorbers are primarily derived from followup studies of optical absorbers. The discovery rate from the cross correlation is a lower bound on the expect number of absorbers, since high column density systems in the CNM may systematically obscure potential background optical sources (Yu et al. 2014). There are only 3 blind radio detections, and a survey may discover more systems which are optically obscured. They would likely be cold and at high column density. For sensitivity purposes, we treat all sources as $u_{\rm width} = 2~\mathrm{km\,s^{-1}}$ (Wolfe et al. 1982, 2005). $\nu_{\rm obs}$ is the observation frequency. For redshifted 21-cm absorption systems, $\nu_{\rm obs} = 1420~\mathrm{MHz}/(1 + z_{\rm H\,I})$. The integration time $\Delta t = (n_{\rm obs} \times 24~\mathrm{h})\tau$, where $n_{\rm obs}$ is the number of days an object is scanned, and $\tau = \lambda/2\pi D\cos\delta$ is the fractional time the object transits the FoV ($\lambda_{\rm obs} \ll D$ or $\delta \nrightarrow \pi/2$). For 21-cm absorption systems $\lambda_{\rm obs} = 21~\mathrm{cm} \times (1 + z_{\rm obs})$.

In the forecast we count $> 10\sigma$ detections, i.e., the absorption line depth is at least $10\Delta F$. The optical depth of H I absorbers are also poorly understood. Recent discoveries of 21-cm absorption systems have about $r = 20\%$ fractional depth (Allison et al. 2015; Zwaan et al. 2015), and we apply this value. Thus, all systems with $rF > 10\Delta F$ are counted.

[1] https://www.naic.edu
[2] http://chime.phas.ubc.ca
[3] http://www.cv.nrao.edu/nvss/

3 FAST ESTIMATION

Parameters:
Result: 90 per month.

4 TIANLAI ESTIMATION

Parameters:
Different declinations have different SEFD.
Result: 80 per year.

5 CONCLUSION

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