Statistical distribution of HI 21cm absorbers as potential cosmic acceleration probes

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ABSTRACT

Damped Lyman-α Absorber (DLA) or HI 21cm absorber, is an important probe to directly measure the acceleration of spectroscopic velocity $v_S$ via the Sandage-Loeb (SL) effect. Confined by the shortage of actual DLAs samples and the coarse background radio sources assignment, the detectable amount of Damped Lyman-α Absorption System (DLASs) is ambiguous in most cases. After differencing the unmeasurable, global and physical $a$ from the observed and local $\dot{v}_S$, we make a statistical investigation of the components of DLASs. We use Kernel Density Estimation (KDE) to depict a general redshift distribution of background radio sources via three radio deep survey datasets, CENSORS, LBDS-Hercules and CoNFIG-4, and provide a multi-Gaussian expression. Testing the generation process of DLA redshift number density in literature, we try to make a modified power law fitting of low-redshift ($z \lesssim 1.65$) DLA preselected by MgII absorption and analysis its defects. Finally, we present a simple DLASs number estimation of FAST, ASKAP and SKA-Mid when considering a blind HI absorption survey with our derived radio number density and the previous DLA one in literature. For comparability, our FAST prediction gives a practical amount of 100, and an optimistic amount of 470, while our latter amount and previous predictions are within an order of magnitude.

Keywords: Interstellar medium (xxx) — Observational cosmology (xxx) — Quasar absorption line spectroscopy (xxx)

1. INTRODUCTION

An accelerating expansion process is happening in our universe, whose acceleration has not been convincingly measured up to now. An unprecedentedly precise observational determination will provide more clues to the fundamental modeling of the expanding mechanism, such as the most recognized dark energy with many candidates of Equation of State (EoS).

Common cosmological probes can detect a round-about acceleration of scale factor, $\ddot{a}$, while the stringently defined spectroscopic velocity drifts of objects faithfully tracing the Hubble flow in real time are still beyond our reach. Proposed by Sandage (1962) and improved by Loeb (1998), the redshift drift, namely the SL effect now is a model-independent probe of cosmic acceleration and free of cosmic geometry, used to distinguish cosmological models (Codur & Marinoni 2021; Mishra 2022) and explore the inhomogeneity and anisotropy of the universe (Buchert et al. 2022; Heinesen & Macpherson 2022). Moresco et al. (2022) recorded more details of redshift drift, and Melia (2022) discussed the significance of a zero or non-zero redshift drift.

Direct measurement of redshift drift most depends on Damped Lyman-α Absorbers (DLAs) or Damped Lyman-α Absorption Systems (DLASs). DLAs contain abundant dense HI gas (column density $N_{HI} \geq 2 \times 10^{20}$ cm$^{-2}$) which absorbs Lyman-α photons (optical) and most 21cm radiation (radio) from HI hyperfine spin-turning in the local rest frame.

The first feasible Lyman-α forests (LFs) approach was carefully searched by Liske et al. (2008) for the next generation instrument ESO-ELT, and is currently renewed by Dong et al. (2022). Optical DLAs are often discovered in intergalactic environment. With abundant potential Lyman-α absorption in line forests, the
LFs approach gathers much attention like the Cosmic Accelerometer project (Eikenberry et al. 2019), the ACCELERATION programme (Cooke 2020), ESPRESSO and NEID spectrographs (Chakrabarti et al. 2022). Interestingly, Esteves et al. (2021) concluded that measuring redshift drift and constraining cosmological parameters is a dilemma. However, confined by the earth’s ionosphere, ground-based observation can only receive LFs photons at \( z \gtrsim 1.7 \), which corresponds to the decelerating expansion and jerk era. As for the lower redshift drift and most of the lookback time, only space-borne experiments could cover up.

The second HI 21cm Absorbers or HI 21cm Absorption Systems approach was first conducted by Darling (2012), in which it gave the best constraint (until now) on redshift drift of three magnitudes larger than theoretical prediction. Radio DLAs usually originate in the active parts (star-forming or nuclei) of galaxies at low redshift. Long-term stabilities in frequency were also established in GBT and used DLAs. Due to the tiny energy temperature difference which theoretically gives HI atoms in the ground state a steady distribution, DLAs’ 21cm lines are less affected in the cold neutral medium (CNM) and have a narrow width, while the inner-galactic origination of DLAs may cause prominent frequency shifts (namely velocity uncertainty) and disturb the connected results. Jiao et al. (2020) made an HI 21cm absorption spectral observation in PARKES, advocating the necessity of consecutive high-resolution spectral observations against the high-velocity uncertainty. Lu et al. (2022) made a high-accuracy HI 21cm spectral observations against the high-velocity uncertainty (namely velocity uncertainty) and disturbances between today and the past(redshift \( z \)).

In this paper, the defined difference between the measured radial velocity change and the homogeneous realistic cosmic acceleration is stressed again in sec 2. We conduct comparative research on the number density of radio sources (sec 3.1) and DLAs (sec 3.2) based on several databases, and predict the possible detection amount of DLASs for FAST and SKA (sec 3.3). Our discussion and conclusion are given in sec 4 and 5, respectively. All the calculation in this paper is based on a fiducial Planck18 ΛCDM model (Planck Collaboration 2020) \((Ω_{k0} = Ω_{r0} = 0, Ω_{m0} = 0.315, H_0 = 67.4 \text{ km s}^{-1} \text{ Mpc}^{-1})\).

2. COSMIC ACCELERATION

For many papers contain the necessary formulae and their derivations, we would give a brief description with a standard ΛCDM model:

\[
E^2(z) = Ω_{k0}(1 + z)^4 + Ω_{m0}(1 + z)^3 + Ω_{l0}.
\]

The redshift drift of the tracers in Hubble flow is:

\[
\Delta z = H_0[1 + z - E(z)]\Delta t_0 = \frac{a_0 - \dot{a}(z)}{a(z)}\Delta t_0, \quad (2)
\]

and the change of its spectroscopic radial velocity in low redshift approximation \((v_S \approx cz)\) is:

\[
\Delta v_S = \frac{c}{1 + z} \Delta z = cH_0[1 - \frac{E(z)}{1 + z}]\Delta t_0 = c[a_0 - \dot{a}(z)]\Delta t_0. \quad (3)
\]

In this case, the velocity drift is an indicator of \( \dot{a} \) differences between today and the past(redshift \( z \)).

However, when we explain the cosmic expansion strictly with general relativity (GR), the recession velocity (Davis & Lineweaver 2001) is:

\[
v_G = \dot{a}(z)D_C(z) = \frac{c}{H_0} \dot{a}(z) \int_0^z \frac{dz'}{E(z')} \quad (4)
\]

where \( D_C(z) = c \int_0^z \frac{dz'}{H(z')} \) is the comoving distance. The time derivative of \( v_G \) (Jiao et al. 2020) is:

\[
\dot{v}_G = \ddot{a}(z)D_C(z) + \dot{a}(z)\dot{D}_C(z) = \dot{a}(z)D_C(z) + \dot{a}(z)\frac{dD_C(z)}{dz} \frac{dz}{dt_0}. \quad (5)
\]
According to \( q(z) \), we could write down \( \ddot{a}(z) \):
\[
q(z) = \frac{1 + z}{2E^2(z)} \frac{dE^2(z)}{dz} - 1, \quad (6)
\]
\[
\ddot{a}(z) = -H_0^2 q(z) a(z) E^2(z). \quad (7)
\]

With the above quantities shown in Figure 1, we can notice that the zero-points of \( \ddot{a} \) and \( \dot{z} \) (or low-redshift approximated \( \dot{v}_S \)) are very different, where the former \( (z_{a0} \approx 0.65) \) relies on \( q(z) \) and the latter \( (z_{a0} \approx 1.9) \) depends on \( 1 + z - E(z) \).

It is worthy of attention that only dynamical \( \ddot{a} \) can depict the physical process of actual deceleration or acceleration of the universe expansion physically, and has consistent value at any point from any distance in the same moment.

However, the observed \( \dot{z} \) or \( \dot{v}_S \) is related to comparison within a pair of locations (present observer and some past receding spot). For a fixed spot, its \( \dot{z} \) value would change with the reference (the observer position) selection. Thus it is just a relative quantity to measure the apparent velocity changes for a local observer. Although we measure it, it does not represent the real acceleration of the universe’s expansion. Considering the secular observing time in the magnitude of a decade, what we actually measure is a time-averaged drift.

**Figure 1.** Several quantities versus redshift. In the upper panel, the green dashed-dotted line is the redshift drift. In the middle panel, the red and blue dashed lines are the low-redshift approximated and GR recession velocities. In the bottom panel, we show their corresponding velocity drifts. The pale green block in three panels covers the redshift range of FAST(0 \( \sim \) 0.352).

From the upper panel in Figure 1, only when \( z < z_{a0} \), the \( \ddot{a} \) is positive and the universe undergoes an accelerating expansion. And the universe expanded in deceleration at \( z > z_{a0} \). The \( z_{a0} \) cannot distinguish between the two states. Combined with the eq. 3, the difference is further illustrated in Figure 2. When \( z < z_{a0} \), \( a_0 \) is always larger than \( \dot{a}_z \) and the observed \( \dot{v}_S \propto (a_0 - \dot{a}_z) \) is always positive, but it does not mean the universe expanding acceleratingly through redshift from 2 to 0.

The other difference between \( \ddot{a} \) and \( \dot{z} \) (or \( \dot{v}_S \)) is, that the former is not directly measurable, while the latter could come from spectra conveniently.

From the lower two panels in Figure 1, it can be seen that, if the universe is genuinely dominated by a \( \Lambda \) CDM model, we could use FAST safely to research spectroscopic velocity with good approximation at low redshift.

### 3. EXPECTATION OF DLASS

The redshift number density of DLASs (or HI 21cm absorption systems) in every square degree of the sky could be expressed as
\[
n_{21}(z) = n_{DLA}(z) \int_{F_{min}}^\infty \int_2^\infty n_R(z', F')dz'dF', \quad (8)
\]
where \( n_{DLA}(z) \) is the averaged number density of DLAs (or HI 21cm absorbers) in some certain line of sight directing toward a background radio source, and \( n_R(z', F') \) is the number density of background radio source per square degree related with its redshift and observed flux density.

#### 3.1. Prediction of Radio Source

The commonly quoted redshift distribution of radio source in the calculation of \( n_{21}(z) \) is given by de Zotti et al. (2010):
\[
n_R(z) = 1.29 + 32.37z - 32.89z^2 + 11.13z^3 - 1.25z^4, \quad (9)
\]
which comes from a polynomial fitting of the CENSORS data (Brookes et al. 2008). The Combined EIS-NVSS Survey of Radio Sources (CENSORS) was conducted at 1.4GHz, targeting the ESO Imaging Survey (EIS) Patch D covering a $3 \times 2\text{deg}^2$ field of view and 150 sources selected from NRAO VLA Sky Survey (NVSS). Rigby et al. (2011) finally presented a subset of 135 in CENSORS with a received flux density completeness of 7.2mJy. We notice that the CENSORS data contains redshift and flux density at the same time, useful to limit the background radio source. And in the following paper, we would use Rigby’s dataset to represent the CENSORS.

3.1.1. Comparing the Radio-source Description

Marcos-Caballero et al. (2013) made a gamma fitting for the redshift-binned count of CENSORS. When comparing the galaxy angular power spectrum via the Bayesian evidence test, the gamma fitting outperformed the polynomial description. However, the two ways both overemphasize the ability to fit the peak bin (for the rigid shape, the gamma fitting even cannot fit the second small peak at high redshift), seem to lack the complexity and understanding of the actual redshift distribution.

Here we introduce the Kernel Density Estimation (KDE) to depict the CENSORS dataset. As a mature non-parametric method, KDE is an expert in estimating the probability density of a random variable without any prior knowledge. Particularly when using the Gaussian kernel, the accurate expression of the final distribution can be reached by multi-Gaussian fitting.

We use a 0.1-length redshift bin to count the CENSORS data (133 sources at redshift $z < 4.0$), and make 4-order polynomial and gamma fitting. Then two different KDE functions, \texttt{scipy.stats.gaussian\_kde} and \texttt{skelearn.neighbors.KernelDensity}, are separately considered. The former (grid-KDE), fed by 2-dimension data, is easy to apply without assigning more prior parameters, while the latter (pure-KDE) needs to carefully test the bandwidth parameter. We present our fitting comparison in Figure 3, in which the KDE methods both behave excellently, but the bandwidth 0.2 and lower values (not given) pure-KDEs show severe over-fitting. The bandwidth 0.3 pure-KDE is a comparable result to the grid-KDE. However, regarding the effort to check the bandwidth for every dataset, it is more convenient and impersonal for us to adapt the grid-KDE as the default way in the following data analysis.

3.1.2. Enlarging the Radio Dataset

The CENSORS data does provide a comprehensive insight to research the global redshift revolution of radio sources. Nonetheless, whether a 6deg$^2$ survey could be an ideal representative of the whole sky situation? Although the cosmological principle should guarantee, it is still worth verifying this point.

For the comparison with the CENSORS, other radio-source deep surveys with the information of redshift and 1.4GHz flux density are needed, and the Leiden-Berkeley Deep Survey (LBDS) Hercules (Waddington et al. 2001) and CoNFIG-4 (Gendre et al. 2010) covering the different sky satisfy the important requirement.

The Leiden-Berkeley Deep Survey (LBDS) Hercules sampled 2deg$^2$ sky and 64 radio sources with $S_{1.4\text{GHz}} > 2\text{mJy}$, and the Combined NVSS-FIRST Galaxies-4 (CoNFIG-4) sample observed 52deg$^2$ sky and 185 radio sources with $S_{1.4\text{GHz}} > 50\text{mJy}$. With the introduction of the two datasets, our analysis is greatly improved.

To unify the comparison standard and eliminate several outliers, we choose radio sources with redshift between 0.01 and 4, and flux density $s < 400\text{mJy}$. There needs special attention that only 86 of 184 sources from CoNFIG-4 have the redshift record. Therefore when considering the sky coverage of CoNFIG-4, we make a direct proportion to counteract the lost information, regarding it as $86/184 \times 52 \approx 24.3\text{deg}^2$. The flux density and redshift distribution of the three datasets are plotted in Figure 4.

For the lower limit of flux density, 50mJy, of the CoNFIG-4, we can only evaluate the radio-source redshift distribution above this value first. Given rare samples from CENSORS and Hercules in this flux density region, CoNFIG-4 could make a considerable contribution to complement the number-lacking. According to the observation of HI 21cm absorption (Gerbé et al. 2015), 32 systems are observed, and only 3 background radio sources show 1.4GHz flux density lower than 50mJy (but larger than 35mJy). Thus 50mJy can be a proper lower limit for the present observation ability. Here we use grid-KDE to extract the redshift distribution per degree square from three datasets, and make a number-weighted average of the former three as the final result of 50mJy, showing the above four cases in Figure 5. However, toward the next generation of great radio telescope and HI 21cm absorption blind survey project, we make further research with a lower limit 10mJy in CENSORS and Hercules data, and add their number-weighted average in Figure 6. In the end, we list our final 3-Gaussian fitting parameters for the two cases in Table 1.

3.2. Forecasting of DLAs

The recent research of the DLAs statistical distribution at large redshift region ($0 \lesssim z \lesssim 5$) was advanced by Rao et al. (2017)(thereby RTS17). They provided
Figure 3. The fitting comparison for CENSORS data. The green square line is 4-order polynomial fitting, the yellow pentagon line is gamma fitting, and the blue left-triangle and cyan right-triangle lines are pure-KDE with bandwidths of 0.2 and 0.3, respectively. The red cross and red plus lines are grid-KDE and its 3-Gaussian components fitting. The black dot and gray bar are the redshift binned count, where the error bars are the 68% confident interval of the Poisson distribution (Marcos-Caballero et al. 2013).

Figure 4. The flux density and redshift distribution of the three sets. The blue triangles from CENSORS, green squares from Hercules, and red circles from CoNFIG-4 represent our selected background sources. The amounts of every dataset are shown in the legend block.

Figure 5. The redshift distribution of radio sources of 3 datasets with a flux lower limit 50mJy. The blue line is the grid-KDE result, the red circle line is the redshift count of 0.1 bin, and the red dashed line is the 4-order polynomial fitting of the redshift count. The number in the subtitle shows the gross count in per square degree.

Considering their result at the same time, we are more concentrated on the low-redshift scenario for radio telescope detection. So we use their original data and obtain a more detailed local low-redshift description, where 72 DLAs from 369 MgII absorbers are extracted. The general number approximately matches the RTS17 case (70/369), and the details of some sub-datasets vary slightly.

We select DLAs with their lower estimation of column density \( N_{\text{HI}} < 2 \times 10^{20} \text{cm}^{-2} \), the equality is not enough here to make sure the rough consistency to Rao’s result. And then we will show two main differences in sub-datasets. The paper of Rao et al. (2006)
presented 41 DLAs from 197 MgII absorbers, but we find 46 DLAs with their rest-frame equivalent widths $W_0^\lambda 2796 > 0.6\AA$. And they selected 26 DLAs from 96 MgII absorbers(labeled as A and B) in the paper of Turnshek et al. (2015), while we extract 23 DLAs from the same MgII absorbers.

At first, we make a statistic of the DLAs incident rate in every 0.1-redshift bin as the yellow star dotted line in Figure 7(the lines referred in this paragraph are all listed in Figure 7), showing a fluctuating ascending trend. Therefore we decide to fit it with an easy power law as the yellow circle dotted line. Then, we construct the MgII redshift number density via grid KDE as the green square dashed line. The DLA number density is derived from the product of DLA incidence and MgII number density at corresponding redshifts, $n_{DLA}(z) = n_{DLA}^H n_{MgII}(z)$. Fitting the DLA number density with a power law(the magenta cross line) and a 3-Gaussian profile(the blue up-triangle line), we also plot the RTS17's result as the red pentagon line together.

Besides, we also compare the DLA number densities from RTS17 and Curran et al. (2016); Curran (2021), which provided 88 associated(A-type) and 56 intervening(I-type) DLAs, in Figure 8. According to the comparison, we conclude that the DLA number density directly derived by us from RTS17 may have some severe bias around the $z \geq 0$ to lower the detection rate and cannot fix itself. Therefore, considering the similarity between our original power law and RTS17 at the low redshift region(0.1~0.5), we manually use the estimation $n_{DLA}(z = 0) = 0.026 \pm 0.003$ (Braun 2012) to replace the first element in the $n_{DLA}$, and re-fit a final modified power law(the cyan plus line in Figure 7):

$$n_{DLA2}(z) = 0.03381 z^{0.41206} + 0.02545. \quad (11)$$

Our result given here is rough and experimental. We will simply discuss it with the RTS17 result(eq. 10) later, but the latter is our main reference in the later calculations. As for why we do not appreciate our result, we would explain it in the discussion.

### 3.3. Anticipation of DLASs

Two estimations of radio-source redshift number density per square degree, $n_{z50}(z)$ and more extended $n_{z10}(z)$ are exhibited in Table 1 at the end of section 3.1.2. Two predictions of DLA number density in the sightline toward every background radio source are presented in equation 10(global RTS17’s, $n_{dgl}(z)$) and 11(local ours, $n_{dloc}(z)$). We plot the four functions of redshift in Figure 9.

According to the eq. 9, we combine the four distributions to derive the redshift distribution of DLASs(or HI 21cm absorption systems), $n_{z21}(z)$, where the upper limit of integrated redshift for radio source is replaced by 5 instead of $\infty$. In the upper panel of Figure 10 we show the four kinds of redshift number density $n_{z21}(z)$, and give the corresponding redshift number integration $N_{z21}(z)$ in the lower panel of Figure 10.

Now it is easy to use our result to anticipate the possible total detected numbers of a HI absorption blind survey. We use the $n_{z50}(z)$&$n_{dgl}(z)$ as a practical(harsh), and $n_{z10}(z)$&$n_{dloc}(z)$ as an extended(optimistic) one.

FAST covers about 24000 square degrees of the sky and the redshift of 0 to 0.352(1050-1450MHz)(Li et al. 2018), gives a practical amount of 100 and an extended amount of 470.

ASKAP covers 33000 square degrees of the sky and the redshift of 0.4 to 1.0(711.5-999.5MHz)(Allison et al. 2022), gives a practical amount of 290 and an extended amount of 1480.

As for the most remarkable instrument, the full SKA(now the SKA1-mid) will cover about 30000 square degrees with a flux lower limit 10mJy. The symbols are the same as Figure 5.

**Figure 6.** The redshift distribution of radio sources of 2 datasets with a flux lower limit 10mJy. The symbols are the same as Figure 5.

**Table 1.** The number-weighted average of 3-Gauss fitting of two cases. The every basic component of two cases($n_{z50}(z)$ and $n_{z10}(z)$) is $f(z) = \frac{a}{\sqrt{2\pi}\sigma} \exp \left(\frac{(z-\mu)^2}{2\sigma^2}\right)$.

| case | component | $a$  | $\mu$  | $\sigma$ |
|------|-----------|------|--------|---------|
| 50mJy| 1         | 0.03490 | 1.94418 | 0.78346 |
|      | 2         | 0.08259 | 1.32178 | 0.58973 |
|      | 3         | 0.23736 | 0.51484 | 0.43653 |
| 10mJy| 1         | 0.17191 | 2.49829 | 0.67762 |
|      | 2         | 0.58973 | 1.32355 | 0.41893 |
|      | 3         | 0.78615 | 0.51247 | 0.45345 |
Figure 7. The statistics of RTS17 data of DLAs. The yellow circle dotted line is a power law fitting of the DLA incidence (the yellow star dotted line) from the redshift bin statistics. The green square dashed line is MgII absorbers number density. The magenta cross and blue up-triangle lines are the fitted power law and 3-Gaussian profile respectively. The red pentagon line is the DLA number density predicted by Rao et al. (2017). The cyan plus line is our final modified DLA number density.

Figure 8. The redshift number density of two datasets of DLAs. The green line is from the RTS17, the others are from Curran’s work (Curran et al. 2016; Curran 2021). The red dashed line is the A-type DLAs, the blue dashed-dotted line is the I-type DLAs, and the gray star line (total2) is their sum, while the black dotted line (total1) is the independent KDE curve estimated from the total number distribution.

Figure 9. The redshift number density of radio sources and DLAs. For radio sources, the green dashed line is from the 50mJy lower limit, the red dotted line is from the 10mJy one, and their unit is per square degree. For DLAs, the yellow line is from RTS17, the blue dashed-dotted line is from our modified power law, and this count is conducted along a sightline toward a background radio source.

4. DISCUSSION

We examine how much the different binning methods would affect our fitting. The result presented in Figure 11 shows that they have little impact on fitting, and are negligible in smaller bins, confirming the feasibility.

Considering the three radio source datasets we use, CENSORS, LBDS-Hercules and CoNFIG-4, the most samples of them are AGNs, and the classification we apply just stops here. A more detailed classification must help us to better grip the redshift distribution and radio luminosity function of different types of radio sources. But confined to the extremely limited data amount, it is still beyond our present reach.

The RTS17 dataset does provide the most abundant DLA research at low-redshift ($z \lesssim 1.65$) where the ground-based optical telescope could not directly receive the Lyman-α photons due to the truncation effect of the Earth’s ionosphere. However their MgII absorption preselection is likely to have luminosity and dust-extinction bias, having the risk of omitting some MgII absorbers or maybe a few DLAs not related to the...
MgII absorption. Dutta et al. (2017); Dutta (2019) advanced an absorption-blind or galaxy-selected approach, where one selects a galaxy visually close to a background quasar (Quasar-Galaxy Pair, QGP). Without the prior of any absorption toward the quasar, their method is not biased by dust as MgII preselection, and gives a more direct DLAs redshift distribution without the integration in eq. 8. We hope their project would provide more QGPs data and distribution information of radio DLAs.

Although we give a statistical description of DLAs redshift distribution, the key challenge to identify a DLA as qualified cosmic acceleration probe is its inner state of the absorbers inside or near the host galaxy. Moreover, the local environment of DLAs, according to Dutta et al. (2017), is very complicated. It is possible that not all of them faithfully trace their local Hubble flow, and needs long-term observation to verify the frequency stability.

There is an intriguing phenomenon that the redshift number densities of A-type DLAs from Curran and Rao’s one have more similar profiles in the low-redshift region (in Figure 8) than I-type DLAs’. After checking the emission and absorption redshift and considering the MgII absorption preselection, however, Rao’s green curve should represent the I-type DLAs. The difference between the two I-type’s profiles may reflect the discrimination of detection methods. The RTS17’s result is purely from MgII preselection, while Curran’s result does not show the clear detection origin of every sample.

The difference in DLA number densities between our original power-law and RTS17’s global fitting is notable at a very low and high range of redshift \( z \) in (0, 1.65). At the very low region, our analysis of DLA number density is heavily impacted by its low detection rate of MgII absorbers (and no DLA is detected), and that’s why we introduce a zero-point prior value to modify the estimation. At the high redshift region, our prediction is descending for the actual local prediction (shorter bin and less MgII absorbers), while the RTS17 result is still rising for their global vision of the DLAs (longer bin and higher number density beyond the redshift 1.65). Therefore we regard RTS17’s prediction as a better statistical work and use their formula in our prediction. But the modified power law and the RTS17 one also raise the risk of overestimating the DLA number density at the very lower redshift with the introduction of \( n_{\text{DLA}}(z = 0) \) and its fitting, instead of the realistic and reachable low detection rate at the low redshift region (Darling et al. 2011). Furthermore, we should recall that the closer DLAs usually suffer more severe peculiar motion or acceleration, making them harder to serve as the probe.

Given a more stringent physical condition in a preliminary blind radio HI 21cm absorption in FAST, our practical prediction of the potential DLA amount (\(~ 100\)) is about 1-order magnitude smaller than the bulk of previous work, such as Zhang’s 1500 from a local luminosity function estimation (Zhang et al. 2021) and Jiao’s 2600 for a decade CRAFTS observation (Zhang et al. 2019) with a similar calculation (Jiao et al. 2020). However, ours can agree with the magnitude of 100 from the estimation from Wu et al. (2015). Considering our extended amount (\(~ 470\)), it is at most one-third of them. Additionally, Zhang’s result from the estimated amount of AGNs probably omitted that only 10% AGNs are radio-loud. And if adding the factor of 10%, their result would be very close to our prediction as well. Our result is convenient (harsh) and possible (optimistic) detectable numbers for the blind survey considering the background. When adding more proper limitations, it is quite natural that the anticipation would continue to decrease. And there is no doubt that we might ignore some existing but undetectable DLAs with very faint absorption.

5. CONCLUSION

In this paper, we make a small but important distinction between the physical \( \ddot{a} \) and the observed \( \ddot{v}_S \) at first, and emphasize that only the \( \ddot{a} \) can express an actual expansion state for the whole universe at one certain time, but it cannot be measured straightforwardly.

Subsequently, we separately explore the redshift number density of radio source via three datasets of radio deep survey containing the information of redshift and 1.4GHz received flux density, and explore the redshift number density of DLAs (or HI 21cm absorbers) through a low-redshift (\( z \lesssim 1.65 \)) MgII-absorption preselected dataset. (1) Introducing the KDE method, we fresh the traditional polynomial description of the radio-source redshift number density, with a more flexible and comprehensive form that can be fitted by multi-Gaussian
profiles. (2) After checking the procedure of generating DLA number density from RTS17 data solely and giving a modified power law expression, we finally use their global fitting. (3) With the re-estimated distributions, we predict a new total number for a HI 21cm absorption blind survey with more detailed condition settings. For a conservative evaluation, FAST covers 100 DLAs totally, and SKA-Mid covers 420. But for a prospective and optimistic survey (running for a long time with high sensitivity), FAST will cover 470 DLAs, and SKA-Mid can cover 2030 of DLAs.

The lack of samples from radio deep surveys (better with their morphology) and low-redshift DLAs now is one of the crucial obstructions to further study. Nevertheless, with more potential DLASs (HI 21cm absorption systems) discovered in the future, it is a good chance to research the physical essences and environments of DLAs, as well as to revise the background radio sources from a new aspect. And all this progress could propel our knowledge of the universe, and help us to comprehend its expansion and the underlying drivers.

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