21 cm line signal from magnetic modes

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Abstract. The Lorentz term raises the linear matter power on small scale which leads to interesting signatures in the 21 cm signal. Numerical simulations of the resulting nonlinear density field, the distribution of ionized hydrogen and the 21 cm signal at different values of redshift are presented for magnetic fields with field strength $B = 5 \text{nG}$, and spectral indices $n_B = -2.9, -2.2$ and $-1.5$ together with the adiabatic mode for the best fit data of Planck13+WP. Prospects of constraining the magnetic field parameters with SKA1-LOW of the Square Kilometre Array (SKA) as well as the Hydrogen Epoch of Reionization Array (HERA) are discussed.

Keywords: cosmic magnetic fields theory, cosmological simulations, primordial magnetic fields, reionization

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1 Introduction

Magnetic fields come in different shapes and sizes in the universe. Observed magnetic fields range from those associated with stars and planets up to cluster and super cluster scales (cf., e.g., [1–3]). Observations of the energy spectra of a number of blazars in the GeV range with Fermi/LAT and in the TeV range with telescopes such as H.E.S.S., MAGIC or VERITAS have been interpreted as evidence for the existence of truly cosmological magnetic fields. These are not associated with virialized structures but rather permeate the universe. Limits on the field strengths of these void magnetic fields are of the order $10^{-25}$–$10^{-15}$ G (e.g., [4–6]) which is considerably below those of galactic magnetic fields which are of the order of $10^{-6}$ G (e.g., [7]).

Cosmological magnetic fields present from before decoupling influence the cosmic plasma in different ways. Before recombination photons are strongly coupled to the baryon fluid via Thomson scattering off the electrons. As the observed high degree of isotropy on large scales limits the magnitude of a homogeneous magnetic field a putative, primordial magnetic field is modelled as a gaussian, random field. As such it actively contributes to the total energy density perturbations as well as to the anisotropic stress perturbation. Furthermore the Lorentz term changes the baryon velocity. This has important implications for the linear matter power spectrum which will be the focus of this work. The linear matter power spectrum provides the initial distribution of the density field from which nonlinear structure evolves. It determines implicitly the distribution of neutral hydrogen in the post recombination universe during the cosmic dark ages and later on ionized hydrogen. Cosmic dawn starts with the formation of the first star forming galaxies within dark matter halos. These are sources of high energetic UV photons and at later epochs X-ray photons from quasars that ionize and heat matter. These high energetic photons can redshift down to the corresponding Lyman α wave length which can be absorbed by an hydrogen atom and emitted spontaneously allowing for the atom to change from, say, the hyperfine singlet to the triplet state which is the Wouthuyzen-Field mechanism coupling the spin and gas temperature (e.g. [8]). At some point the Lyα coupling saturates. Upto this moment fluctuations in the Lyα flux could significantly influence the final 21 cm signal. The 21 cm line signal is the change in the brightness temperature of the CMB as seen by an observer today. It is necessary for a non zero signal that the spin temperature which determines the equilibrium of the ratio of the occupation numbers in the ground state hyperfine states of neutral hydrogen and the CMB temperature are different. At large redshifts the gas is still cold. Thus the 21 cm line
signal is seen in absorption. Once the heating of the gas due to the high energetic photons in the UV and X-ray range becomes efficient the matter temperature is well above the CMB temperature and the 21 cm line signal is seen in emission. Moreover, in this case the change in brightness temperature will saturate. Magnetic fields can also influence the 21 cm line signal by additional heating of matter because of dissipative processes (cf. [9–11]). However, here the focus will be on the effects due to the change in the linear matter power spectrum.

The magnetic field is assumed to be a non helical, gaussian random field determined by its two point function in $k$-space,

$$\langle B_i^*(\vec{k})B_j(\vec{q})\rangle = (2\pi)^3\delta(\vec{k} - \vec{q})P_B(k)\left(\delta_{ij} - \frac{k_i k_j}{k^2}\right), \quad (1.1)$$

where the power spectrum, $P_B(k)$ is given by [12]

$$P_B(k, k_m, k_L) = A_B \left(\frac{k}{k_L}\right)^{n_B} W(k, k_m) \quad (1.2)$$

where $k_L$ is a pivot wave number chosen to be 1 Mpc$^{-1}$ and $W(k, k_m) = \pi^{-3/2}k_m^{-3}e^{-(k/k_m)^2}$ is a gaussian window function. $k_m$ corresponds to the largest scale damped due to radiative viscosity before decoupling [13, 14]. $k_m$ has its largest value at recombination $k_m = 299.66 \left(\frac{B}{nG}\right)^{-1}$ Mpc$^{-1}$ (1.3)

for the best fit parameters of Planck13+WP data [15, 16]. In the numerical solutions the best fit parameters of the Planck13+WP have been used where $\Omega_m h^2 = 0.12038$, $\sigma_8 = 0.8347$, $A_s = 2.215 \times 10^{-9}$, $n_s = 0.9619$, $H_0 = 67.04$ [16].

2 The linear matter power spectrum

At the epochs of interest here close to reionization the universe is matter dominated. The initial linear matter power spectrum is assumed to be given by the contributions from the primordial curvature mode as well as the magnetic mode. For modes inside the horizon the linear matter power spectrum of the adiabatic curvature mode is given by (cf., e.g., [17–19])

$$P_m^{(ad)}(k) = \frac{2\pi^2}{k^3} \left(\frac{k}{a_0 H_0}\right)^4 \frac{4}{25} A_s \left(\frac{k}{k_p}\right)^{n_s-1} T^2(k), \quad (2.1)$$

where the transfer function $T(k)$ is given by [20, 21]

$$T(k) = \frac{\ln(1 + 2.34 q)}{2.34 q} \left[1 + 3.89 q + (16.1 q)^2 + (5.46 q)^3 + (6.71 q)^4\right]^{-\frac{1}{2}} \quad (2.2)$$

where $q = \frac{k}{\Omega_m h^2 \text{Mpc}^{-1}}$.

For the magnetic mode the matter power spectrum is found to be [19]

$$P_m^{(B)}(k) = \frac{2\pi^2}{k^3} \left(\frac{k}{a_0 H_0}\right)^4 \frac{4}{225} (1 + z_{\text{dec}})^2 \left(\frac{\Omega_{\gamma,0}}{\Omega_{m,0}}\right)^2 P_L(k), \quad (2.3)$$
where \( P_L(k) \) is the dimensionless power spectrum determining the two point function of the Lorentz term \( \langle L^*(k)L(k') \rangle = \frac{2 \pi^2}{k^3} P_L(k) \) given by [12]

\[
P_L(k) = \frac{9}{\Gamma \left( \frac{n_B+3}{2} \right)} \left( \frac{\rho_{B,0}}{\rho_{\gamma,0}} \right)^2 \left( \frac{k}{k_m} \right)^{2(n_B+3)} e^{-\left( \frac{k}{k_m} \right)^2} \times \int_0^{\infty} dz z^{n_B+2} e^{-2 \left( \frac{1}{m} \right)^2 z^2} \int_{-1}^{1} dx x^2 \left( \frac{1}{m} \right)^2 z x \left( 1 - 2zx + z^2 \right)^{n_B-2} \times \left[ 1 + 2z^2 + (1 - 4z^2)x^2 - 4zx^3 + 4z^2x^4 \right], \tag{2.4}
\]

and \( x \equiv \frac{kq}{k_m} \) and \( z \equiv \frac{q}{k} \) where \( q \) is the wave number over which the resulting convolution integral is calculated.

The resulting linear matter power spectrum for the magnetic plus adiabatic mode is shown in figure 1. A detailed analysis of the behaviour of the matter power spectrum close to the magnetic Jeans length has been done in [22] where it was found that below the magnetic Jeans scale pressure supports against collapse and hence prevents any further growth of the density perturbation. This effect can be taken into account by imposing a sharp cut-off in the linear matter power spectrum induced by the magnetic mode. This cut-off is performed at a maximal wave number corresponding to the magnetic Jeans scale \( k_J \), [22, 23]

\[
\left( \frac{k_J}{\text{Mpc}^{-1}} \right) = \left[ 14.8 \left( \frac{\Omega_m}{0.3} \right)^{1/2} \left( \frac{h}{0.7} \right) \left( \frac{B}{10^{-9} \text{ G}} \right)^{-1} \left( \frac{k_L}{\text{Mpc}^{-1}} \right)^{n_B+3/2} \right]^{2/5} n_B+3. \tag{2.5}
\]

Imposing this cut-off results in the characteristic feature in the total linear power spectrum as reported in figure 1. The linear matter power spectrum is normalized to \( \sigma_8 \) of the best fit Planck13+WP parameters (cf. section 1) [16].

3 The 21 cm line signal

For the simulations the Simfast21\(^1\) code [24, 25] is adapted to allow for reading in the modified linear matter power spectra. Simfast21 calculates the change in the brightness

\(^1\)https://github.com/mariogrs/Simfast21.
temperature following a similar algorithm as the \texttt{21cmFAST}\(^2\) code \cite{26}. The initial Gaussian, random density field is determined by the linear matter power spectrum. The subsequent evolution in time leads to gravitational collapse and nonlinear structure and formation of dark matter halos. The halo distribution is found by using the excursion formalism whereby a given region is considered to undergo gravitational collapse if its mean overdensity is larger than a certain critical value \(\delta_c(M, z)\) depending on the halo mass \(M\) and redshift \(z\). As the halo positions are based on the linear density field these have to be corrected for the effects of the non linear dynamics. This is done using the Zel’dovich approximation. A source for reionization of matter in the universe are galaxies which form inside dark matter haloes. Thus the corrected halo distribution allows to determine the ionization regions. In the version of \texttt{Simfast21} \cite{25} used in this work the criterion to decide whether a given region is ionized is determined by the local ionization rate \(R_{\text{ion}}\) and the recombination rate \(R_{\text{rec}}\). These are implemented using a numerical fitting formula which was obtained from numerical simulations. In addition there is a free parameter which is the assumed escape fraction of ionizing photons from star forming regions \(f_{\text{esc}}\). A bubble cell is defined to be completely ionized if the condition

\[ f_{\text{esc}} R_{\text{ion}} \geq R_{\text{rec}} \tag{3.1} \]

is satisfied. In this work the value of the escape rate is set to \(f_{\text{esc}} = 0.06\). Once the evolution of the ionization field has been determined the 21 cm line signal can be calculated. In equilibrium the ratio of the populations of the two hyperfine states, the less energetic singlet state and the more energetic triplet state, of neutral hydrogen is determined by the spin temperature \(T_S\), e.g. \cite{27, 28},

\[ \frac{n_1}{n_0} = \left( \frac{g_1}{g_0} \right) \exp \left( -\frac{T_s}{T_S} \right), \tag{3.2} \]

where \(T_s = E_{10}/k_B = 68\) mK and the energy difference \(E_{10}\) corresponds to a wave length \(\lambda_{10} \sim 21\) cm. When CMB photons travel through a medium with neutral hydrogen some of them will be absorbed by hydrogen atoms in the singlet state exciting them to the triplet state. At the same time hydrogen in the triplet state might spontaneously relax to the singlet state emitting a photon. Therefore the observed brightness temperature of the CMB results in

\[ T_b(z) = T_{\text{CMB}}(z) e^{-\tau(z)} + \left(1 - e^{-\tau(z)}\right) T_S(z) \tag{3.3} \]

where \(T_{\text{CMB}}(z)\) is the brightness temperature of the CMB without absorption and \(\tau(z)\) is the corresponding optical depth along the ray through the medium. Thus the change in the brightness temperature of the CMB as measured by an observer today is given by, e.g. \cite{27, 28},

\[ \delta T_b = T_b - T_{\text{CMB}} = \frac{(1 - e^{-\tau(z)}) [T_S(z) - T_{\text{CMB}}(z)]}{1 + z}. \tag{3.4} \]

With the approximations \(\tau \ll 1\) and \(z \gg 1\), the 21 cm line signal is given by

\[ \delta T_b = 28 \text{ mK} \left( \frac{\Omega_{b,0} h}{0.03} \right) \left( \frac{\Omega_{m,0}}{0.3} \right)^{-\frac{3}{2}} \left( \frac{1 + z}{10} \right)^{\frac{1}{2}} \frac{T_S - T_{\text{CMB}}}{T_S} x_{\text{HI}}. \tag{3.5} \]

\(^2\)http://homepage.sns.it/mesinger/DexM__21cmFAST.html.
As can be seen from equation (3.5) there is only a signal if the spin temperature is different from the CMB radiation temperature. Otherwise the hydrogen spin state is in thermal equilibrium with the CMB and emission and absorption processes are compensated on average. The net emission or absorption result from a higher or lower, respectively, spin temperature than the CMB radiation temperature. There are several processes which can lead to the spin temperature being different from the CMB temperature such as the presence of radiation sources or heating of the gas. In addition there are two processes which can change the spin temperature of the neutral hydrogen gas. Firstly, collisional excitation and de-excitation of the spin states. Secondly the Wouthuysen-Field process which couples the two spin states. In the limit that the spin temperature $T_S$ is much higher than the temperature of the CMB photons $T_{\text{CMB}}$ the change in the brightness temperature $\delta T_b$ (cf. equation (3.5)) becomes saturated. This is the case for lower redshifts when UV photons from star forming galaxies heat the IGM. Apart from these astrophysical sources magnetic fields themselves provide a source of heating. Cosmic magnetic fields present before decoupling are tightly coupled to the completely ionized baryon-photon fluid. Thus they suffer damping by radiative viscosity similar to the photon diffusion damping of density perturbations. After decoupling radiative viscosity rapidly becomes suppressed allowing for magnetohydrodynamical (MHD) turbulence to develop. Nonlinear interactions between different scales lead to decay of MHD turbulence and energy dissipation. Yet another process of cosmological magnetic field dissipation is plasma drift (or ambipolar diffusion) which is important at lower redshifts but well before reionization. This is caused by the fact that matter is not completely neutral. This leads to different velocities in the ionized and neutral matter components resulting in a friction force and subsequent energy dissipation. These three channels of energy dissipation of cosmological magnetic fields lead to energy injection into the photons before recombination and heating of matter also after recombination. The changes in the thermal and ionization history of the universe lead to interesting observational implications such as spectral distortions of the CMB [23, 29, 30] as well as changes in the CMB temperature anisotropies and polarization [15, 31]. To obtain a more complete understanding one certainly has to take into account all these different heating sources. However, here we will focus on the effect of the additional feature in the linear matter power spectrum due to the presence of the magnetic mode. Thus it is assumed that matter is already heated well above the CMB temperature and that $T_S \gg T_{\text{CMB}}$. A similar approach has also been taken in other studies of the 21 cm line signal. This is the case, for example, in [32] where $T_S \gg T_{\text{CMB}}$ was assumed at all epochs. Moreover, there it was argued that, in addition to the complications added by more detailed models, generally thermal noise dominates the signal at the highest redshifts.

4 Results

Simulations were done for four different case, namely, no magnetic field and in the presence of a primordial, stochastic magnetic field with amplitude $B = 5 \text{nG}$ and spectral indices $n_B = -2.9$, $n_B = -2.2$ and $n_B = -1.5$. These values for the magnetic field are chosen as matter of examples. The amplitude of the magnetic field used here is of the same order of magnitude as the constraints, for example, imposed on the compensated magnetic mode by observations of the CMB temperature anisotropies, e.g., Planck 2015 which constrains $B = 4.4 \text{nG}$ [33]. It might be worth mentioning that negative spectral indices are typically obtained from generation mechanisms of primordial magnetic fields during inflation (for a review, e.g., [34]). Changing the magnetic field parameters is certainly important for a
Figure 2. The density field at $z = 0$ when linear evolution up to the present is assumed. From left to right: simulations for no magnetic field and in the presence of a magnetic field with $B_0 = 5 \text{nG}$ and spectral magnetic index $n_B = -2.9$ and the PDFs for all four cases ($B = 0$ and $B = 5 \text{nG}$ with $n_B = -2.9, -2.2, -1.5$).

systematic cosmological parameter estimation which is, however, beyond the scope of this article and will be treated in the future. In the numerical simulations the initial linear matter power spectrum is given by the total linear matter power spectrum as calculated in section 2. Whereas, for the first case ($B = 0$) this means that only the adiabatic, curvature mode contributes (cf. equation (2.1)), for the three cases with $B = 5 \text{nG}$ in addition also the magnetic mode contributes (cf., equation (2.3)). In figure 2 the density field at $z = 0$ is shown when a linear evolution is assumed. The differences between the standard ΛCDM model and one with a magnetic field are most prominent for $n_B = -2.9$ for our choice of spectral magnetic indices as can be appreciated from the simulation boxes, with each side corresponding to 100 Mpc, reported in figure 2. The last panel in figure 2 shows the corresponding probability density function (PDF) for all four cases manifesting the initially assumed Gaussian distribution. For the visualization the python code tocmaxfastpy$^3$ has been adapted.

The Simfast21 code uses the Zeldovich approximation to obtain the nonlinear density field from which the halo distribution is obtained. The simulation boxes of the nonlinear density fields are shown for the three magnetic mode models at redshift $z = 32$ in figure 3 together with a panel showing the corresponding PDFs of all four models (the three including the magnetic mode and the one without). The effect of the feature in the initial linear matter power spectrum manifests itself by an increase in structure and amplitude in the matter density field. In figure 4 the average ionization fraction is shown as a function of redshift. It was obtained from averaging over the simulation boxes of the distribution of ionized hydrogen regions at different values of redshift. Ionized gas forms bubbles of increasing size. This corresponds to the classic inside-out topology where the densest regions are ionized first which is the underlying assumption of the Simfast21 code. This is reflected in the evolution of the mean ionization fraction for the different models under consideration. As there is more power on small scales in models with decreasing magnetic spectral index the ionization fraction starts increasing at larger redshifts for the smallest index, $n_B = -2.9$. As can be appreciated from figure 4 reionization is completed at a redshift below $z < 10$. From figure 4 it is also interesting to note that models including magnetic fields with the smallest spectral index, $n_B = -2.9$, show the longest duration of the epoch of reionization. It starts at larger values of redshift than in the other cases but it still reaches completion only below redshifts $z < 10$.

$^3$J. Prichard, https://github.com/pritchardjr/toccmfastpy.
Figure 3. The nonlinear density field at $z = 32$ for $B = 5 \text{nG}$ with $n_B = -1.5$, $n_B = -2.2$ (upper panel left and right), $n_B = -2.9$ and the PDFs for all four cases ($B = 0$ and $B = 5 \text{nG}$ with $n_B = -2.9, -2.2, -1.5$) (lower panel left and right).

Figure 4. The average ionization fraction as a function of redshift obtained from the simulation boxes at a number of redshifts.
Figure 5. The 21 cm line signal at \( z = 32 \) for \( B = 5 \) nG with \( n_B = -1.5 \), \( n_B = -2.2 \) (upper panel left and right), \( n_B = -2.9 \) and the PDFs for all four cases (\( B = 0 \) and \( B = 5 \) nG with \( n_B = -2.9, -2.2, -1.5 \)) (lower panel left and right). At \( z = 32 \) the average fraction of ionized hydrogen \( \overline{x}_{\text{HII}} = 0 \) in all four models (cf. figure 4).

The evolution of the ionization fraction of hydrogen is a key ingredient to determine the 21 cm line signal. As can be seen in figure 4 at \( z = 32 \) hydrogen is neutral in all four models under consideration. In figure 5 the simulation boxes of the 21 cm line signal are shown at this redshift, \( z = 32 \), for the models including the magnetic mode together with the corresponding PDFs where also the one for the standard ΛCDM model is shown. At this epoch the 21 cm line signal is saturated and observed in emission, \( \delta T_b > 0 \). This is an effect of not taking into account the details of Lyα coupling but rather assuming that the spin temperature is much larger than the temperature of the CMB. The spatial distribution of \( \delta T_b \) traces the underlying matter density field. This can be appreciated when comparing figures 3 and 5 observing that the amplitude and structure increases with decreasing magnetic spectral index (top left, top right, bottom left).

In figure 6 the average 21 cm line signal is shown as a function of redshift together with the projected sensitivities of SKA1-LOW of the Square Kilometre Array (SKA) [35] as well as HERA-350Core of the Hydrogen Epoch Reionization Array (HERA) [36, 37]. These have been estimated by the uncertainty in interferometric observations \( \Delta T_N \) given by (e.g., [38]),

\[
\Delta T_N = \frac{D_{\text{max}}^2}{A_{\text{tot}}} \frac{T_{\text{sys}}}{\sqrt{\Delta \nu_{\text{int}}}},
\]  

(4.1)
where $D_{\text{max}}$ is the maximal baseline, $A_{\text{tot}}$ the total effective collecting area, $T_{\text{sys}}$ the system temperature of the array, $\Delta \nu$ the spectral channel bandwidth and $t_{\text{int}}$ the integration time of the observations. The baseline design of SKA1-LOW will cover a frequency range of 50–350 MHz. In calculating the sensitivity we assumed one beam of bandwidth 300 MHz and an integration time of 1000h and $D_{\text{max}} = 1 \text{ km}$. The system temperature is determined by $T_{\text{sys}} = 1.1 T_{\text{sky}} + 40 \text{ K}$ and $T_{\text{sky}} = 60(300 \text{ MHz}/\nu)^{2.55} \text{ K}$. The effective collecting area evolves as $(110 \text{ MHz}/\nu)^2$ above 110 MHz and is constant at lower frequencies (SKA-LOW baseline specification\(^4\)). The HERA-350Core configuration\(^5\) will contain 350 14 m parabolic dishes, with 320 in a dense core with a maximal baseline $D_{\text{max}} = 294 \text{ m}$. The frequency channel bandwidth is $\Delta \nu = 97.7 \text{ kHz}$ and $T_{\text{sys}} = (100 + 120 (\nu_{150 \text{ MHz}})^{-2.55}) \text{ K}$. It is assumed that the antenna collecting area is constant at lower frequencies corresponding to redshifts beyond $z = 10$ [36, 37, 39]. With these parameters the projected sensitivities for SKA1-LOW and HERA-350Core indicate that the interesting region for constraining models including a magnetic mode is located at observation frequencies above 120 MHz (cf. figure 6).

In figure 7 the power spectra of the change in the CMB brightness temperature $(k^3/2\pi^2) \cdot P_{21}(k)$ is shown for two different values of the average ionization fraction in all four models. For each of the four models under consideration simulations have been carried out using Simfast21. Simulation boxes for the different physical quantities, i.e., density field, distribution of HII regions and the 21 cm line signal, have been saved at a number of values of redshift $z$. Each of these boxes have been analyzed to obtain the corresponding average signal and, in the case of $\delta T_b$, the power spectrum as well. However, in order to compare the latter for the different models the amplitudes have to be compared at fixed ionization fraction since this is the physical determinant of the 21 cm signal. To obtain the curves of the power spectra of the 21 cm line signal in figures 7 and 8 interpolations have been used, namely a one dimensional spline for $\tilde{\tau}_{\text{HII}}(z)$ and a two dimensional spline for the power spectra $(k^3/2\pi^2)P_{21}(k,z)$. The relative amplitudes of the power spectra in figure 7 for the different models might be explained by the observation that a given value of $\tilde{\tau}_{\text{HII}}$ is reached at a larger redshift for smaller values of $n_B$ (cf. figure 4). This means there is less time for the nonlinear evolution

\(^4\)https://www.skatelescope.org/.
\(^5\)http://reionization.org/.
of the density field which is traced by the fluctuations in the 21 cm signal which explains the lower amplitudes for smaller magnetic spectral indices.

In figure 8 the power spectra of the change in the CMB brightness temperature \( (k^3/2\pi^2)P_{21}(k) \) is shown at different redshifts, together with the corresponding average value of the ionization fraction, for no magnetic field, \( B = 0 \) (left panel), and a magnetic field with \( B = 5 \) nG and magnetic spectral index \( n_B = -2.9 \) (right panel).

5 Conclusions

Primordial magnetic fields present since before recombination influence the physics of the universe in several ways. Due to their interactions with the cosmic plasma part of the magnetic energy is dissipated and heats matter. Thereby changing the thermal and ionization history of the universe. In addition the part of the magnetic field spectrum which is not
dissipated contributes at the perturbative level to the total energy density and anisotropic stress. Thus influencing the evolution of cosmological perturbations and sourcing scalar, vector and tensor modes which generate signals, e.g., in the angular power spectra of the CMB temperature anisotropies and polarization. Moreover, due to the presence of the Lorentz term baryon velocities are also affected. This is particularly important for the linear matter power spectrum leading to an increase in power on small scales. Taking into account the effective introduction of a cut-off at wave number corresponding to the magnetic Jeans scale leads to a feature in the linear matter power spectrum. Our interest here was solely the effect of this modified linear matter power spectrum on the 21 cm line signal. This was used as initial condition for the simulation of the 21 cm line signal. Its effect on the nonlinear density field can be seen as subsequent changes in the distribution of ionized hydrogen as well as the distribution of the 21 cm line signal. Simulations have been reported for magnetic fields of $B = 5 \, \text{nG}$ and different magnetic field indices, $n_B = -2.9$, $n_B = -2.2$ and $n_B = -1.5$ with the largest, visible effect for $n_B = -2.9$. Simulations have been run using the Simfast21 code. When comparing the average 21 cm line signal with the projected sensitivities of the planned radio telescope arrays SKA1-LOW and HERA-350Core indicates that in the particular models studied here, i.e. including solely the effect of the initial linear matter modified by the presence of the magnetic mode, only observations at frequencies above 120 MHz would be able to constrain parameters of a primordial magnetic fields. However, it should be noted that, firstly, the particular models studied here do not take into account the additional heating of matter due to the dissipation of magnetic fields. Secondly, the physical 21 cm signal is the result of many different effects in particular from astrophysical sources such as first generation of stars and quasars. Therefore, it might be difficult to obtain strong constraints on the magnetic field parameters from the 21 cm signal alone. However, the situation might improve considering cross correlations with other observations, e.g., the CMB.

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