Primordial magnetic field signals in the 21 cm background

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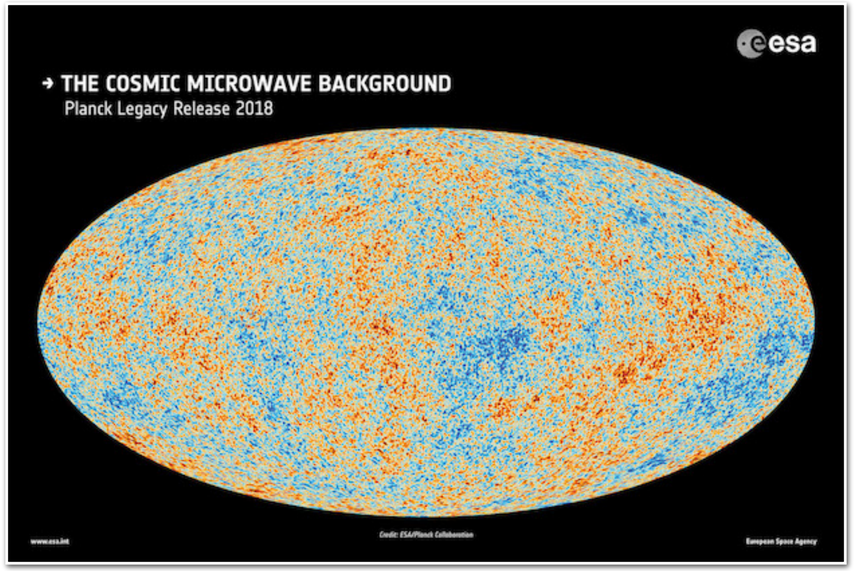
Overview

- Modelling cosmological magnetic fields and effects
- Effects on the matter power spectrum
- Simulations: modified matter density field induced 21 cm line signal
- Observations
- Conclusions

Modelling cosmological magnetic fields

- Global isotropy rules out significant homogeneous magnetic field.



Modelling cosmological magnetic fields

Assumptions

- Origin of magnetic fields in the very early universe
- Stochastic magnetic field

Most general form:
helical magnetic field

Consider only non helical magnetic field.

$$\langle B_i^*(\vec{k}) B_j(\vec{q}) \rangle = \delta_{\vec{k},\vec{q}} \mathcal{P}_S(k) \left(\delta_{ij} - \frac{k_i k_j}{k^2} \right) + \delta_{\vec{k}\vec{k}'} P_A(k) i \epsilon_{ijm} \hat{k}_m$$

where

$$\mathcal{P}_M(k, k_m, k_L) = A_M \left(\frac{k}{k_L} \right)^{n_M} W(k, k_m)$$

$$M = S, A$$

pivot scale

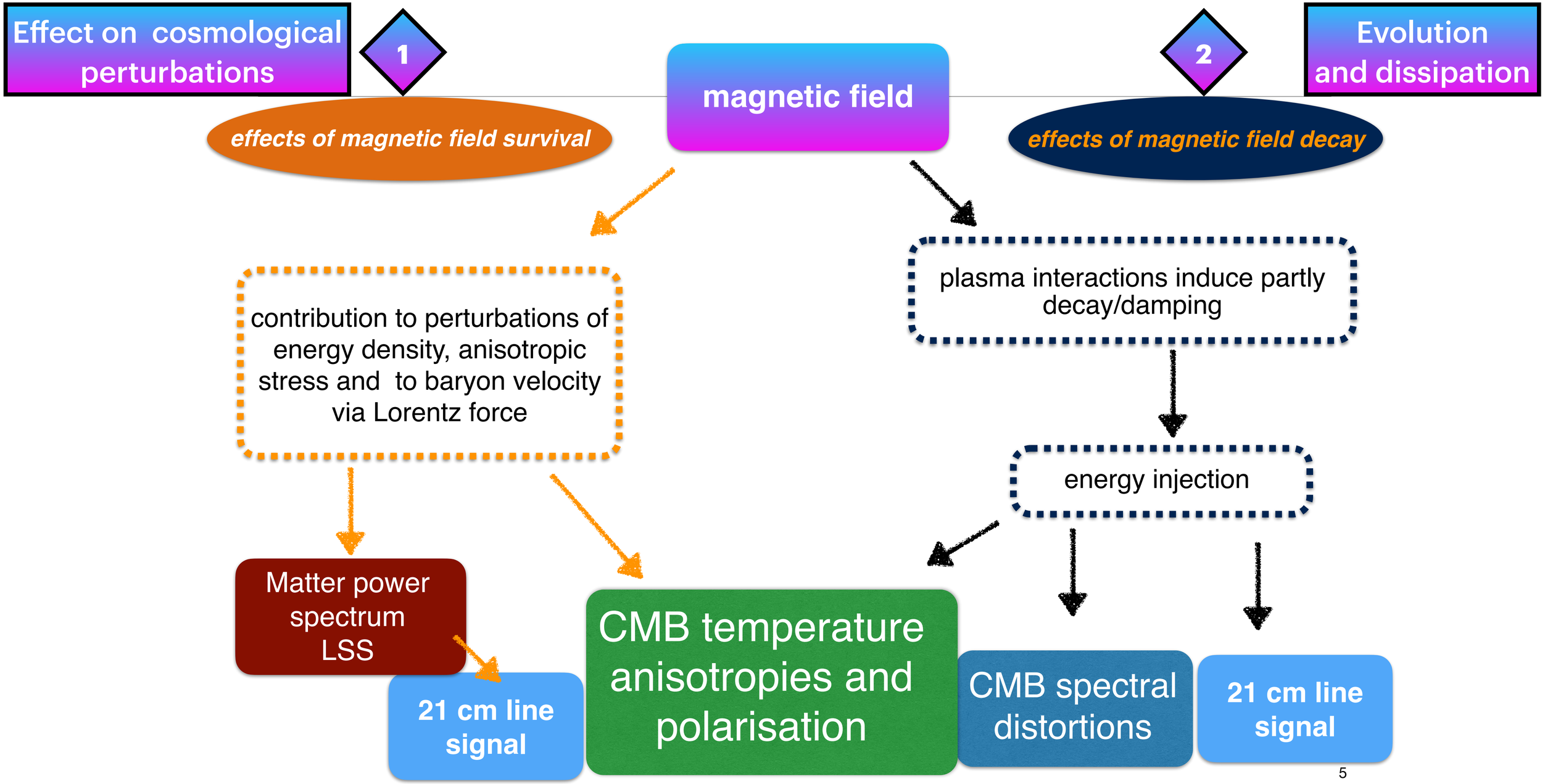
window function

$$W(k, k_m) = \pi^{-\frac{3}{2}} k_m^{-3} e^{-(k/k_m)^2}$$

damping scale

upper cut-off

Evolution and observational effects



Dissipation of cosmic magnetic fields: How and Where to

Damping of magnetic fields

There is also damping around neutrino decoupling at around z~ 10^{10} when a black body spectrum is always restored. (no spectral distortions)

- **Before decoupling of photons**
  - viscous damping
- **After decoupling of photons**
  - decaying MHD turbulence
  - ambipolar diffusion

energy injection

change in thermal and ionisation history

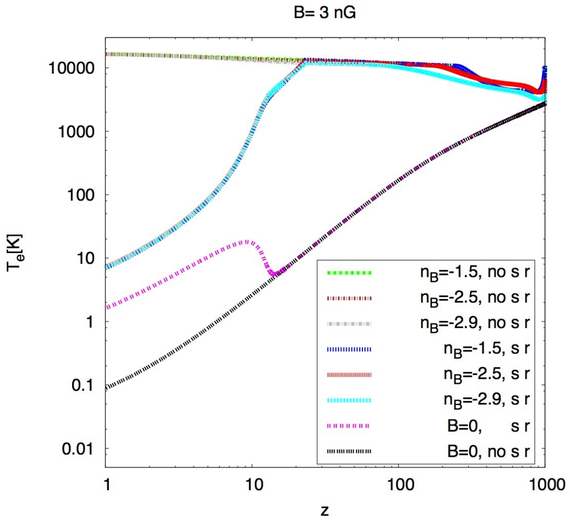
radiative viscosity $z > z_{dec}$

decaying MHD turbulence $z_{dec} > z > 100$

ambipolar diffusion $z < 100$

Evolution of electron temperature

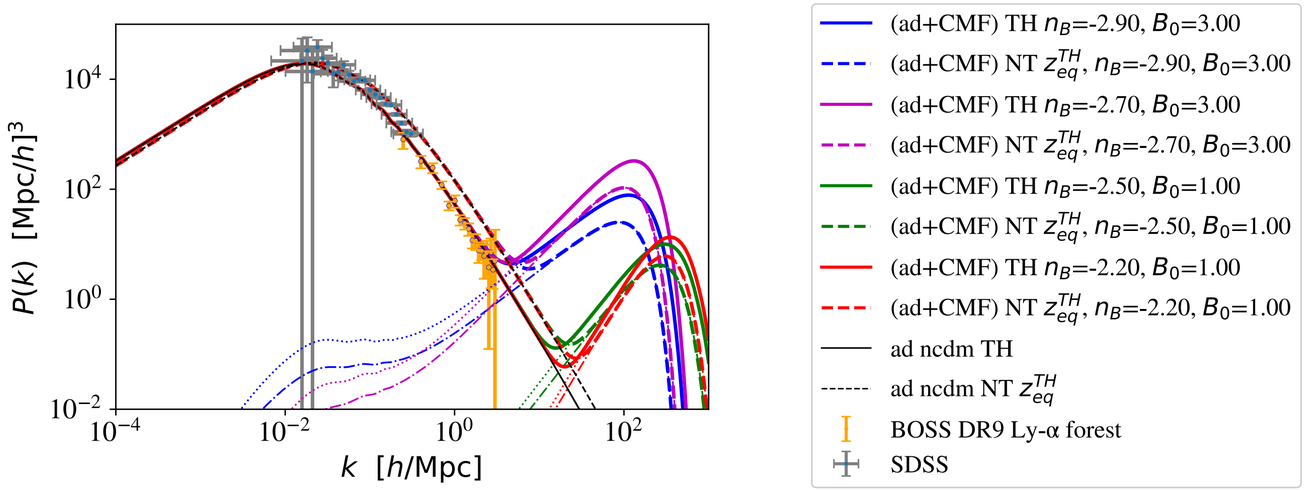
$$\dot{T}_e = -2\frac{\dot{a}}{a}T_e + \frac{x_e}{1+x_e}\frac{8\rho_\gamma \sigma_T}{3m_e c}(T_\gamma - T_e) + \frac{x_e \Gamma}{1.5 k_B n_e}$$



KK, Komatsu ‘15

Effect of magnetic mode on the linear matter power spectrum and 21cm line signal

- Total linear matter power spectrum: primordial curvature mode + magnetic mode



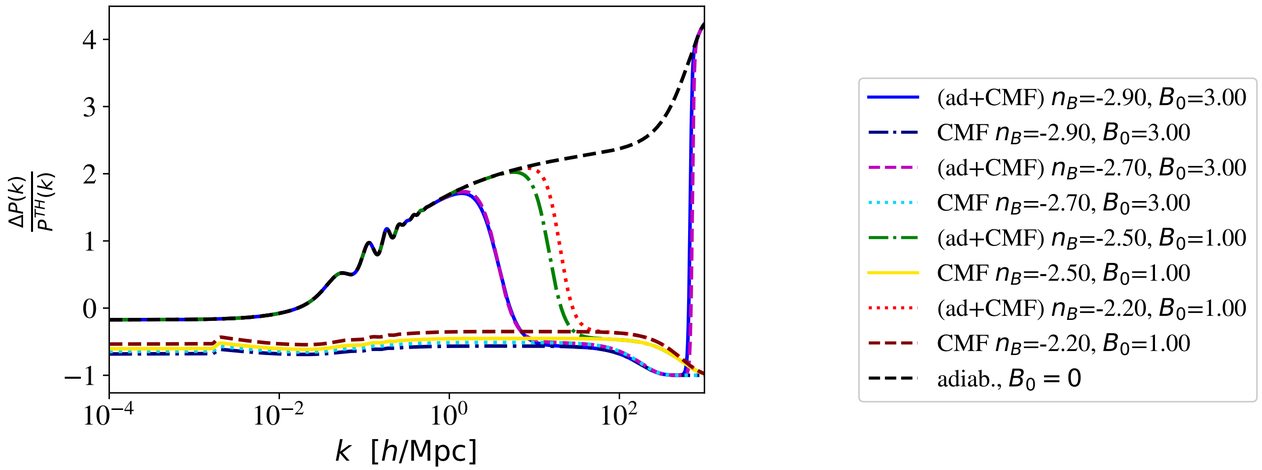


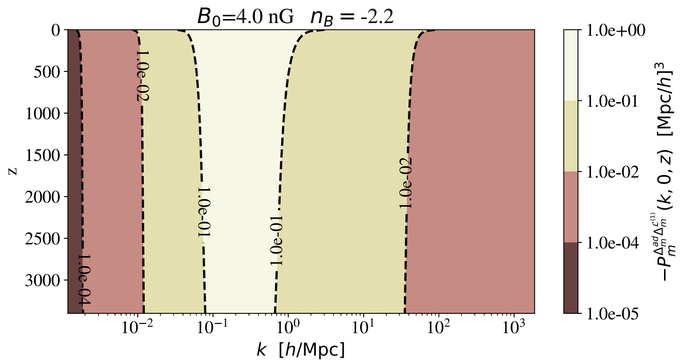
Figure 7. Linear matter power spectrum for three thermal neutrinos (TH) and three non-thermal neutrinos (NT, $z_{\rm eq}^{\rm TH}$) with distribution function (2.1) for different choices of the magnetic field parameters (B_0[nG], n_B). *Upper panel:* the total linear matter power spectrum of the adiabatic mode (ad) and the compensated magnetic mode (CMF) is shown together with data points from BOSS DR9 Ly-α forrest [42] and SDSS [43]. The light dotted and dashed-dottted lines indicate the three neutrino thermal magnetic mode and the three neutrino non-thermal pure magnetic mode solutions, respectively. $z_{\rm eq}^{\rm TH}$ denotes that the cosmological parameters have been adjusted so that the redshift of radiation-matter equality in the non-thermal model is the same as that in the non-thermal one (see details in the text). *Lower panel:* relative change of the linear matter power spectrum w.r.t. to the three thermal neutrino model (TH).

Effect of magnetic mode on the linear matter power spectrum and 21cm line signal

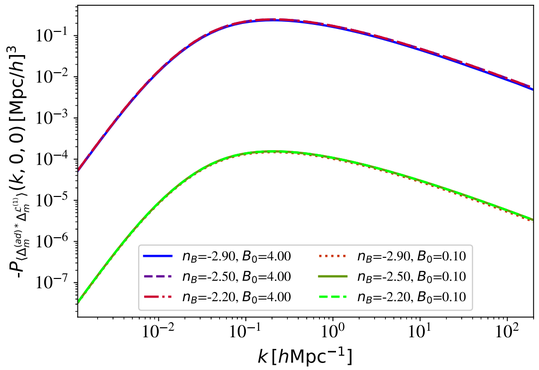
Beyond the frozen-in approximation of the comoving magnetic field

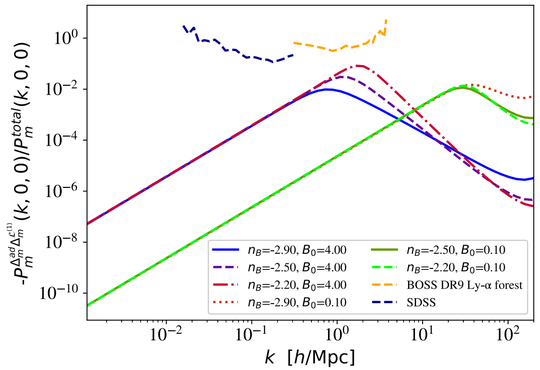
cross correlation between primordial curvature and magnetic mode induced matter density perturbations

Unequal time (redshift) cross correlation spectral functions at present

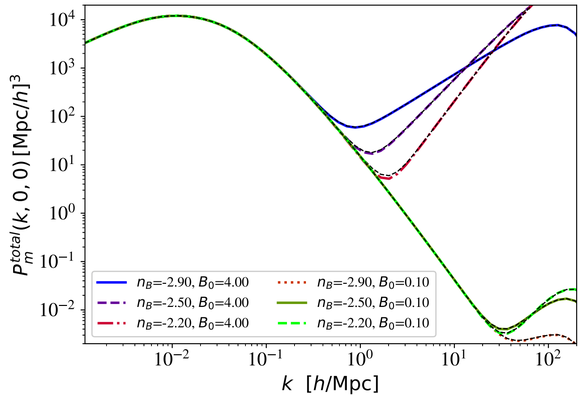


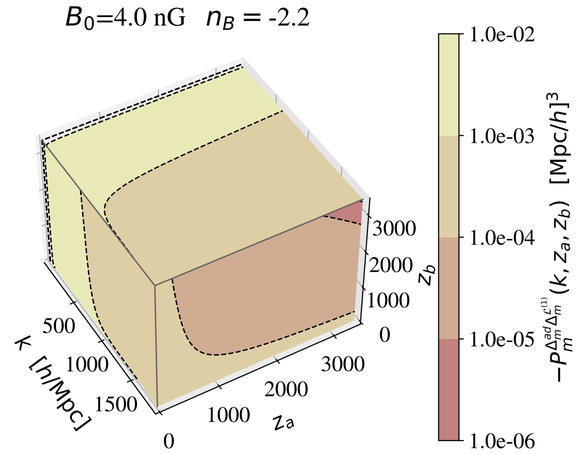
Equal time cross correlation spectral functions at present





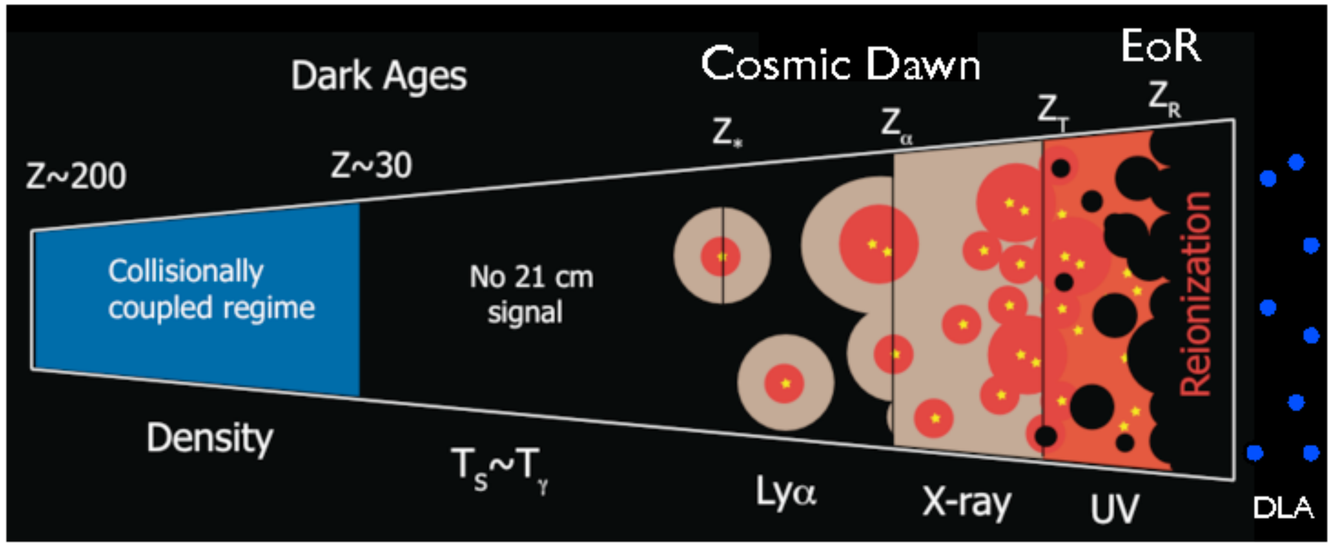
Total matter power spectrum including cross correlation at present





Effect of magnetic mode on the linear matter power spectrum and 21cm line signal

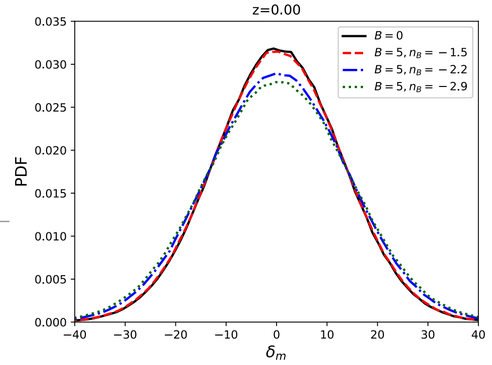
21 cm line signal: change in brightness temperature of CMB due to hyperfine transition in neutral hydrogen atoms along line of sight



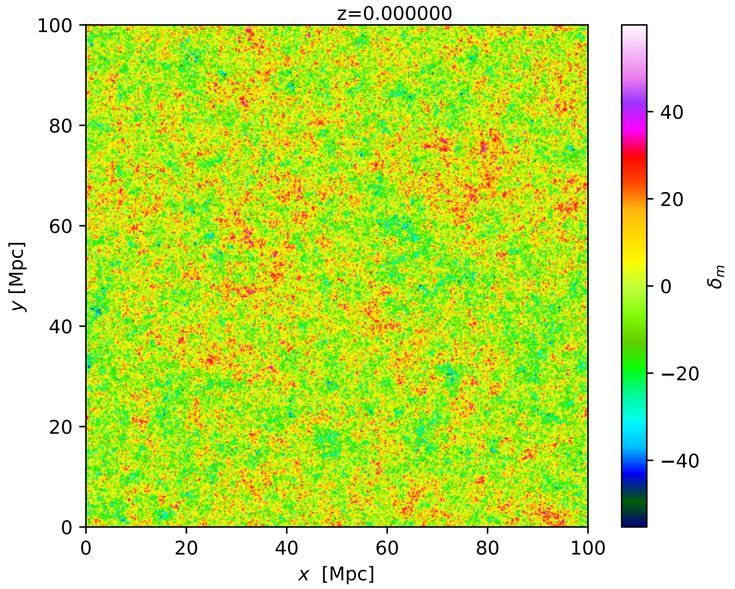
Pritchard, Loeb (2012)

Simulations: matter density field

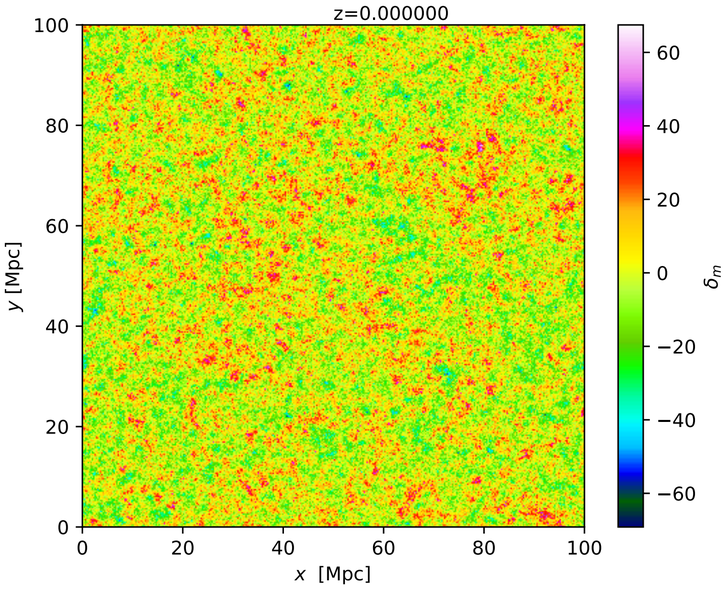
- Linear density matter field



B=0

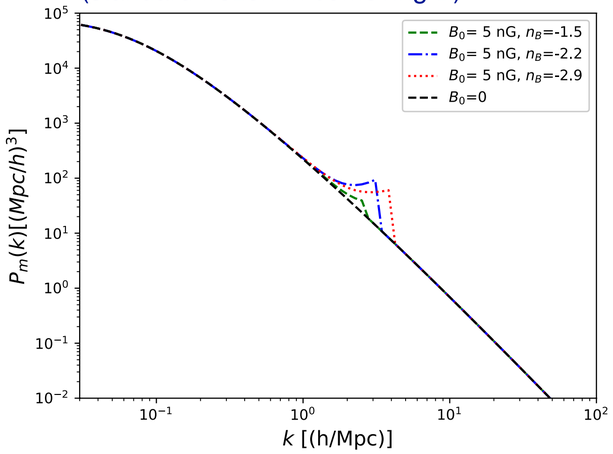


B=5 nG, nB=-2.9



Initial total linear matter power spectrum: primordial curvature mode + magnetic mode

(standard frozen-in comoving B)



Simulations with modified version of Simfast21 (Santos et al.)

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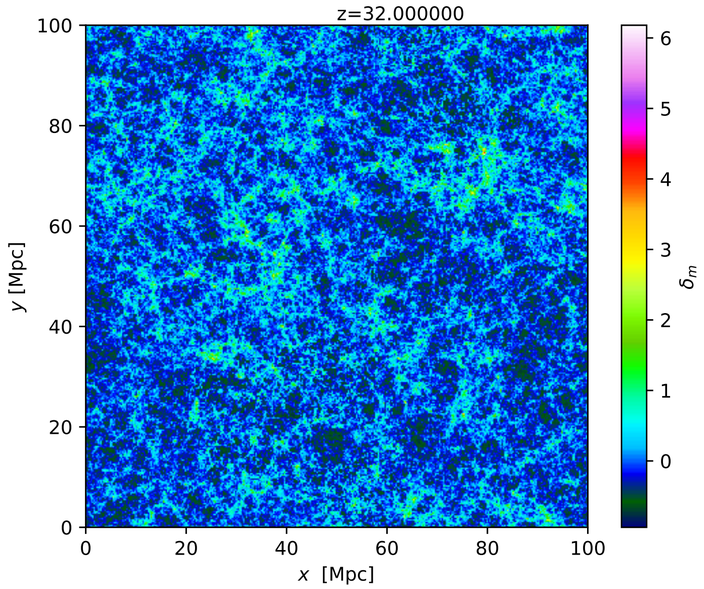
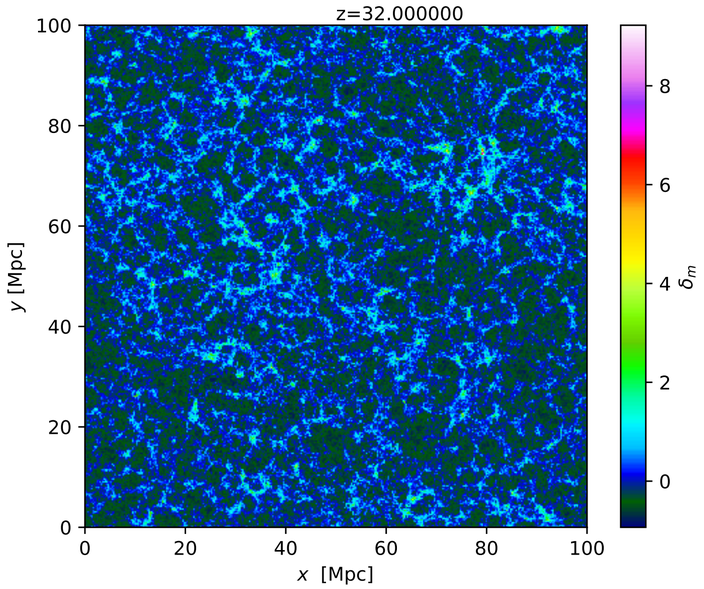
Simulations: matter density field

- non linear density matter field **z=32**

B=5 nG, nB=-1.5



B=5 nG, nB=-2.2



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Simulations: matter density field

- non linear density matter field **z=32**

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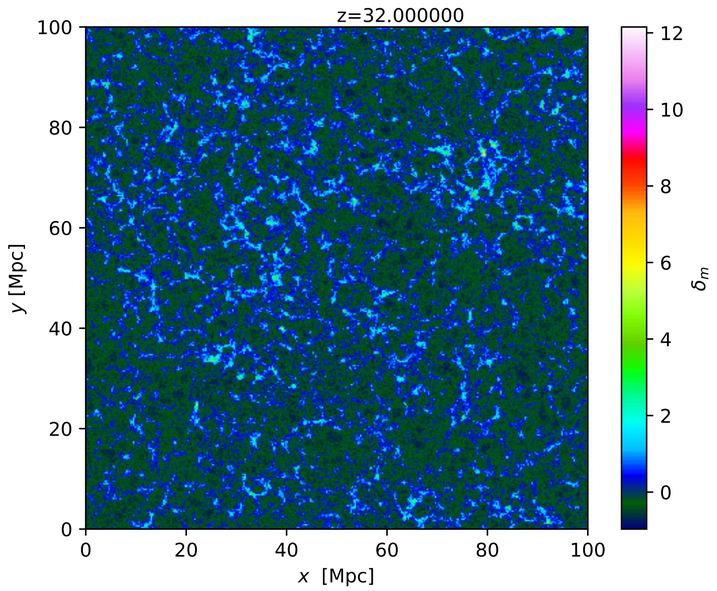

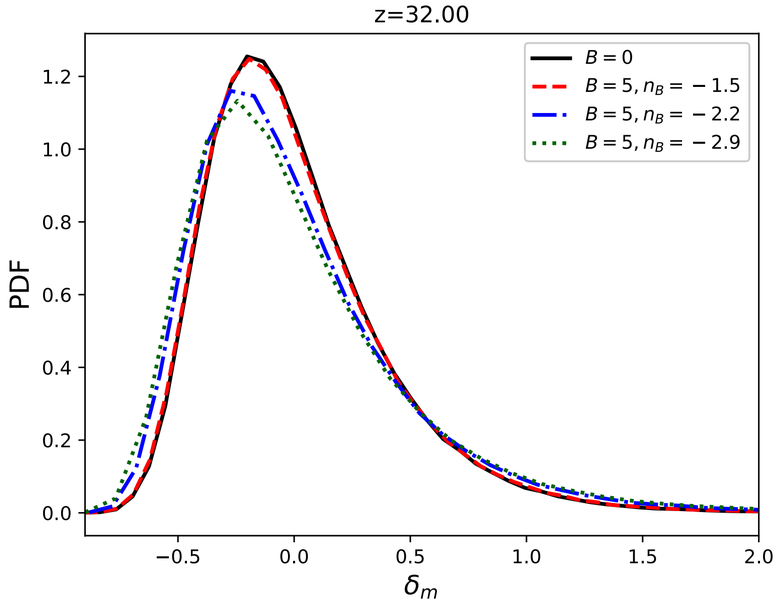

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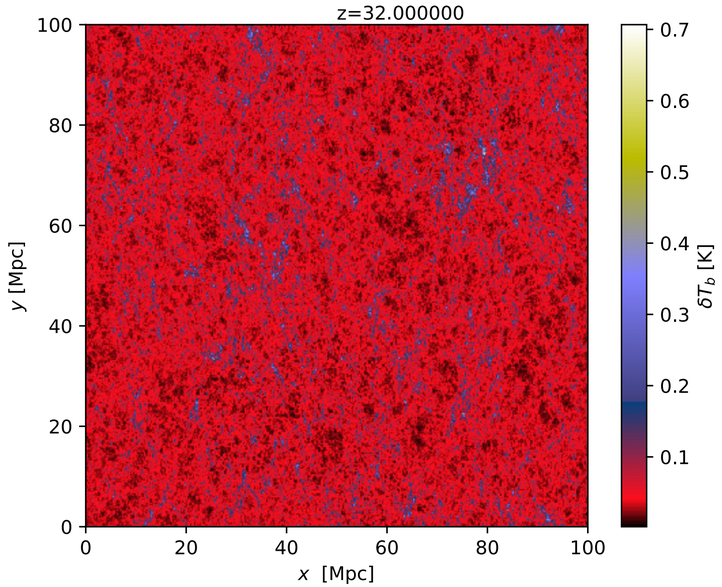
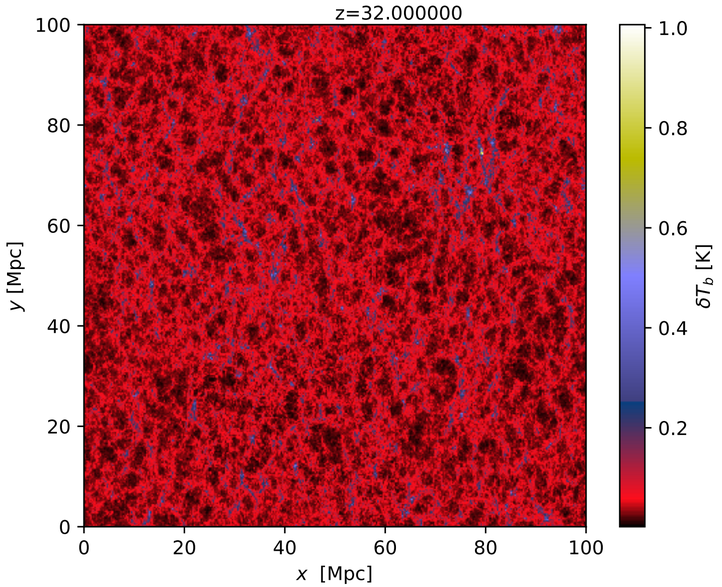
Simulations: 21cm line signal

z=32

B=5 nG, nB=-1.5



B=5 nG, nB=-2.2



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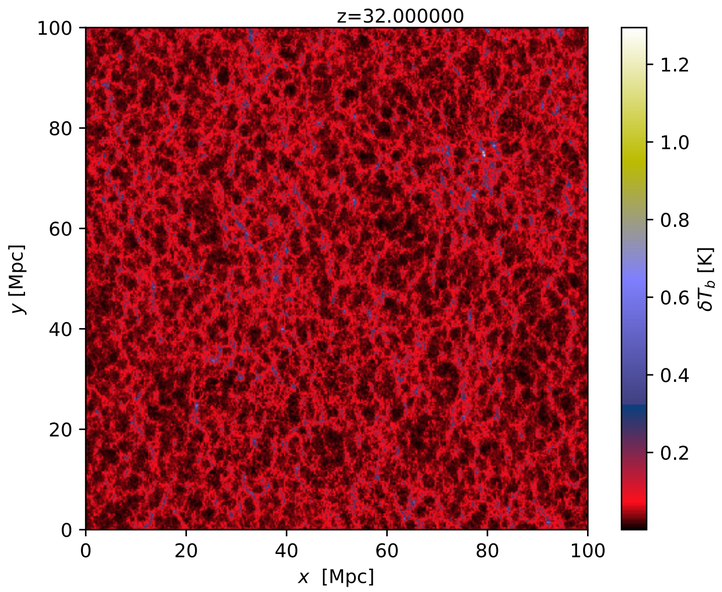

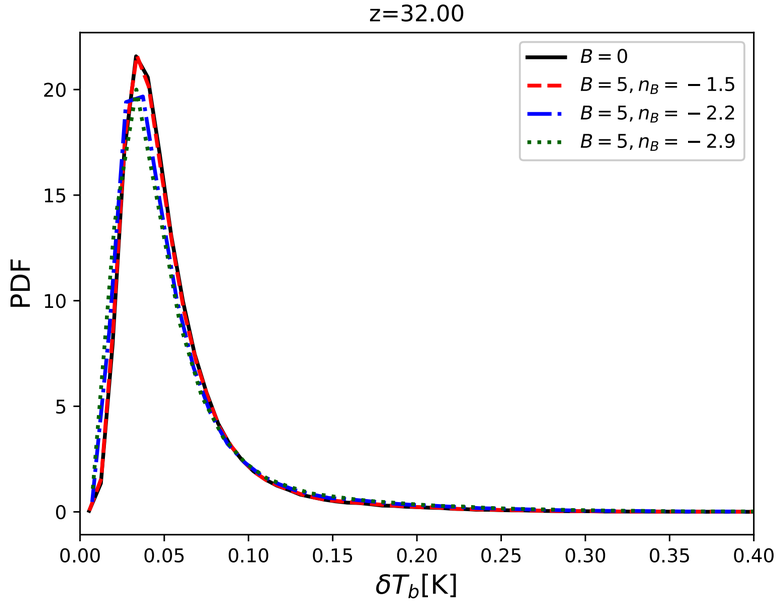

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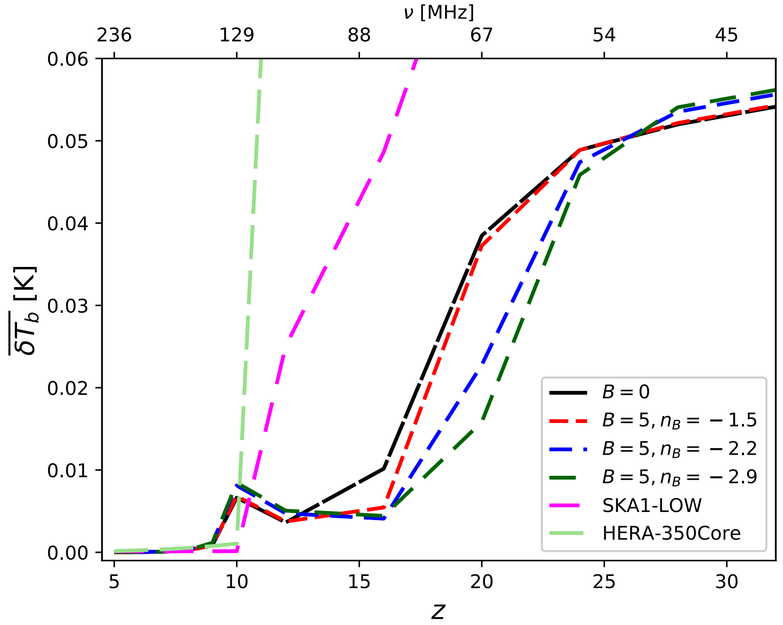
Observations

- Average 21 cm line signal



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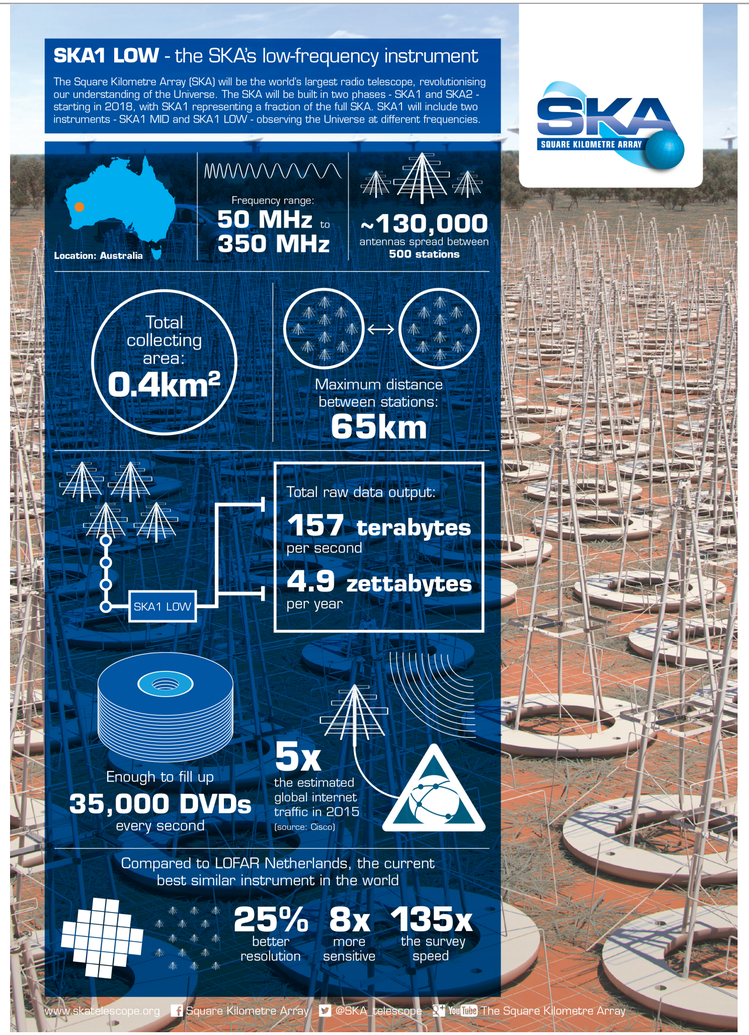
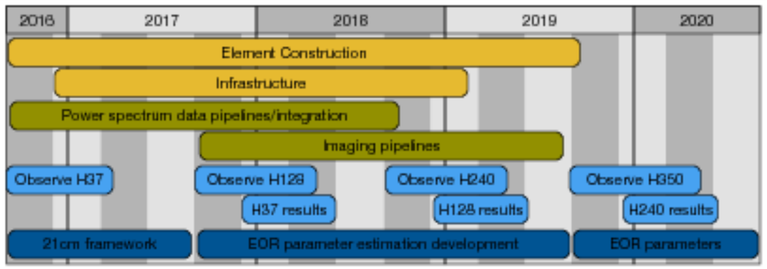


Observations

- Average 21 cm line signal

Hydrogen Epoch of Reionization Array (HERA)



DeBoer et al. PASP 2017

Table 1
Predicted S/N of 21 cm Experiments for an EoR Model with 50% Ionization at $z = 9.5$, with 1080 hr Observation, Integrated over a Δz of 0.8

Instrument	Collecting Area (m^2)	Foreground Avoidance	Foreground Modeling
PAPER	1,188	0.77σ	3.04σ
MWA	3,584	0.31σ	1.63σ
LOFAR NL Core	35,762	0.38σ	5.36σ
HERA-350	**53,878**	**23.34σ**	**90.97σ**
SKA1 Low Core	416,595	13.4σ	109.90σ

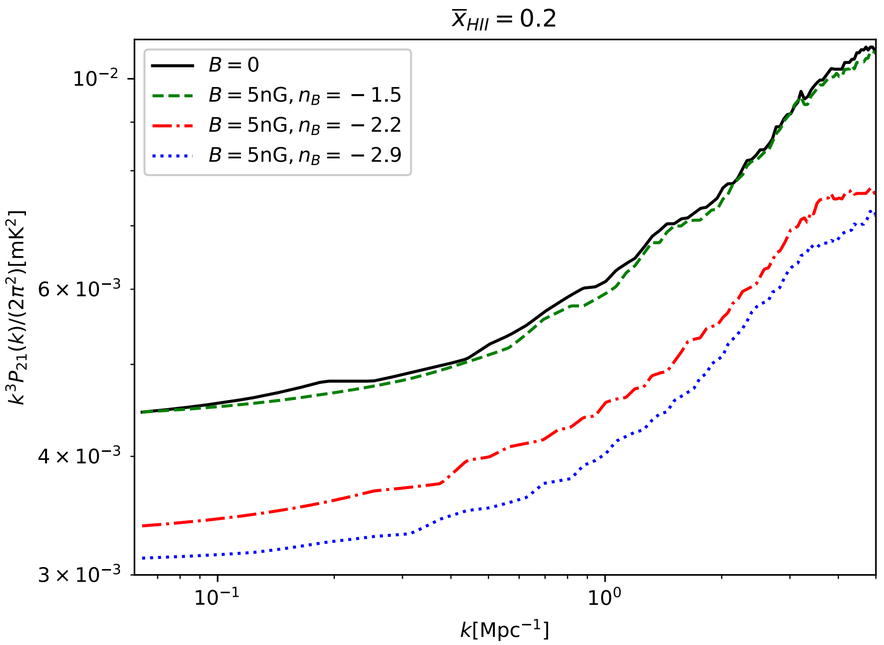
Table 2
HERA-350 Design Parameters and their Observational Consequences

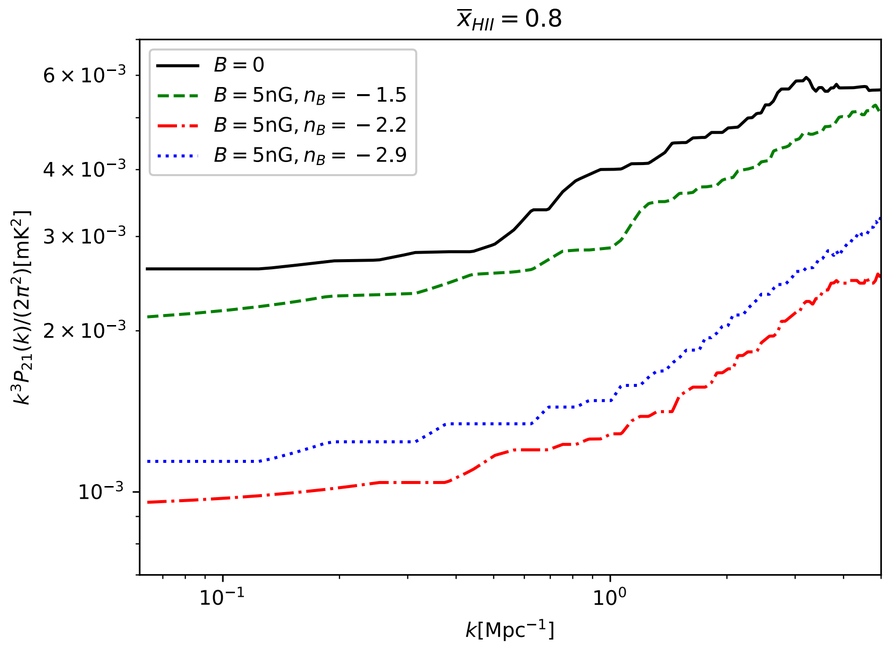
Instrument Design Specification	Observational Performance
Element Diameter: 14 m	Field of View: 9°
Minimum Baseline: 14.6 m	Largest Scale: 7?8
Maximum Core Baseline: 292 m	Core Synthesized Beam: 25′
Maximum Outrigger Baseline: 876 m	Outrigger Synthesized Beam: 11′
EOR Frequency Band: 100–200 MHz	Redshift Range: $6.1 < z < 13.2$
Extended Frequency Range: 50–250 MHz	Redshift Range: $4.7 < z < 27.4$
Frequency Resolution: 97.8 kHz	LoS Comoving Resolution: 1.7 Mpc (at $z = 8.5$)
Survey Area: ~1440 deg^2	Comoving Survey Volume: ~150 Gpc^3
T_{sys}: $100 + 120(\nu/150\,\mathrm{MHz})^{-2.55}$ K	Sensitivity after 100 hr: 50 μJy $beam^{-1}$

Note. Angular scales computed at 150 MHz.

HERA currently observing in the band 100–200 MHz in the **Karoo Radio Quiet Preserve in South Africa** [DeBoer et al., 2017] at a latitude of –30.73○.

Estimated power spectrum





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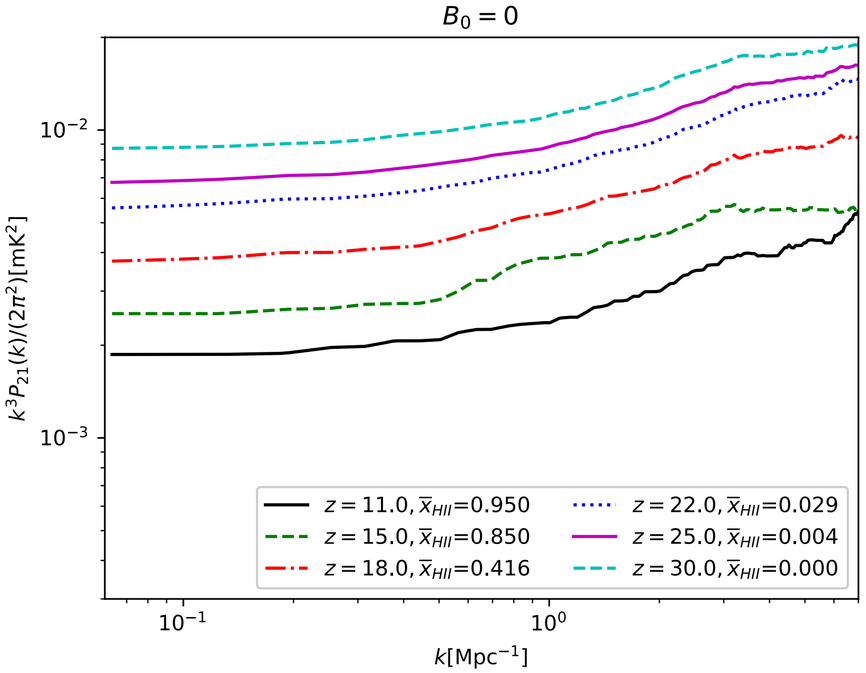
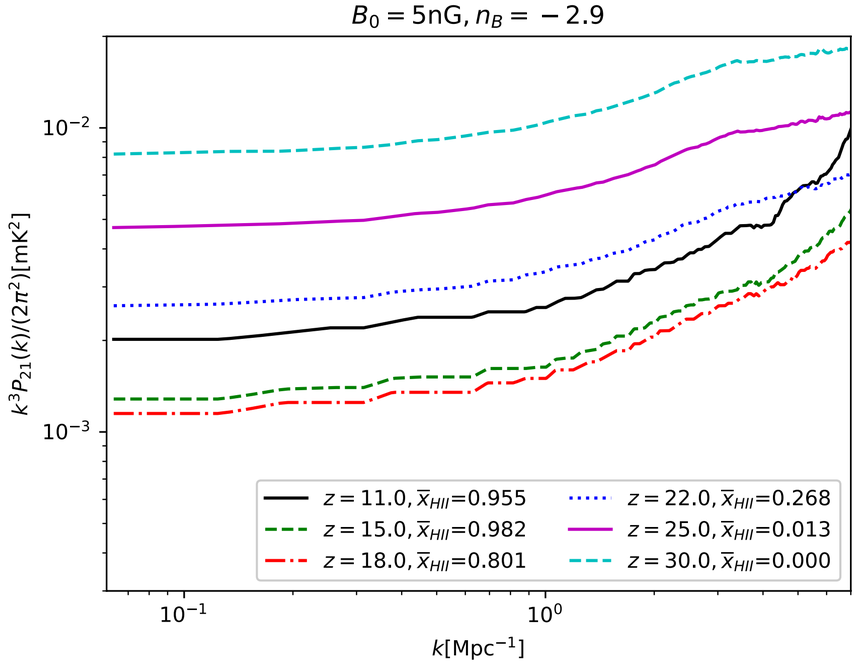
Estimated power spectrum



B=0



B=5 nG, nB=-2.9

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Conclusions

- 21 cm line observations seem to provide a new interesting possibility to constrain primordial magnetic fields.

- 21cm line tomography might be used to constrain magnetic field evolution.