Self Introduction

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Affiliation:
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(Japan SKA consortium)

Research interest:
21-cm cosmology, Cosmic magnetic fields, CMB,
Structure formation in Dark Ages, …

Hobbies: Movies, Cooking, Running, Comics

Staying: 3-13th. March for discussion with Dr. Shintaro Yoshiura.

My research

Studies so far:

- thermal SZ effect from primordial magnetic fields (arXiv:1705.10054)
- constraint on primordial magnetic fields from 21-cm global signal (arXiv:1812.00730)

Now working:

- constraint on primordial magnetic fields from small-scale CMB anisotropy
- constraint on ultra-compact minihalos

My research

Studies so far:

- thermal SZ effect from primordial magnetic fields (arXiv:1705.10054)
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I show this work today

Now working:

- constraint on primordial magnetic fields from small-scale CMB anisotropy
- constraint on ultra-compact minihalos

Introduction

Magnetic fields exist with various astronomical objects
(e.g., galactic magnetic fields are ~10 micro G)

"When and How are these magnetic fields created?"

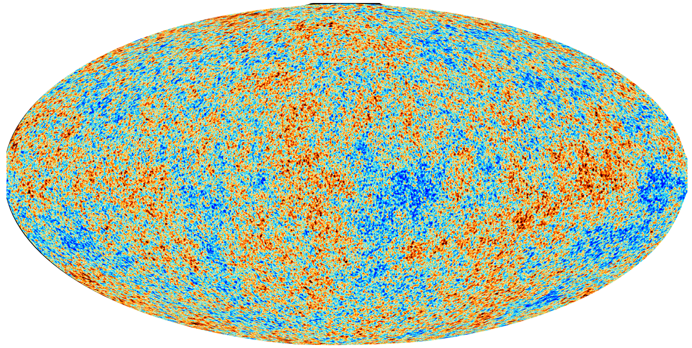
One possibility is
"Primordial Magnetic Fields" (PMFs)
(generated by inflation, phase transition, topological defects, Harrison mechanism, ...)

Consistent with observational results?
 -> Constraint from observational data.

CMB observation

CMB temperature anisotropy

- almost isotropic with T~2.7 K
- small anisotropy due to the metric perturbation caused by inflation



Einstein equation:

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

metric fluctuation

matter (energy)

If PMFs exist, magnetic energy-momentum tensor can also create the curvature perturbation.

$$\langle \mathbf{B}_i(\mathbf{k}) \mathbf{B}_j(\mathbf{k}') \rangle = \frac{(2\pi)^3}{2} \delta_D(\mathbf{k} - \mathbf{k}')(\delta_{ij} - \hat{k}_i \hat{k}_j) P_B(k)$$

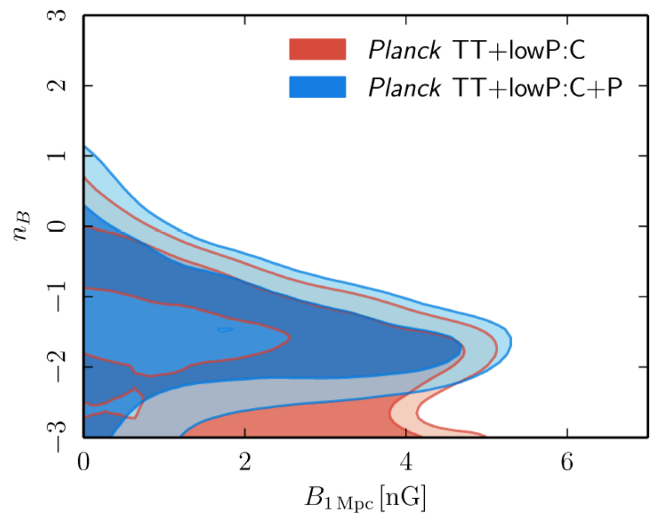
$$P_B(k) \propto B_{1\mathrm{Mpc}} k^{n_B}$$

Planck **2015 constraint**

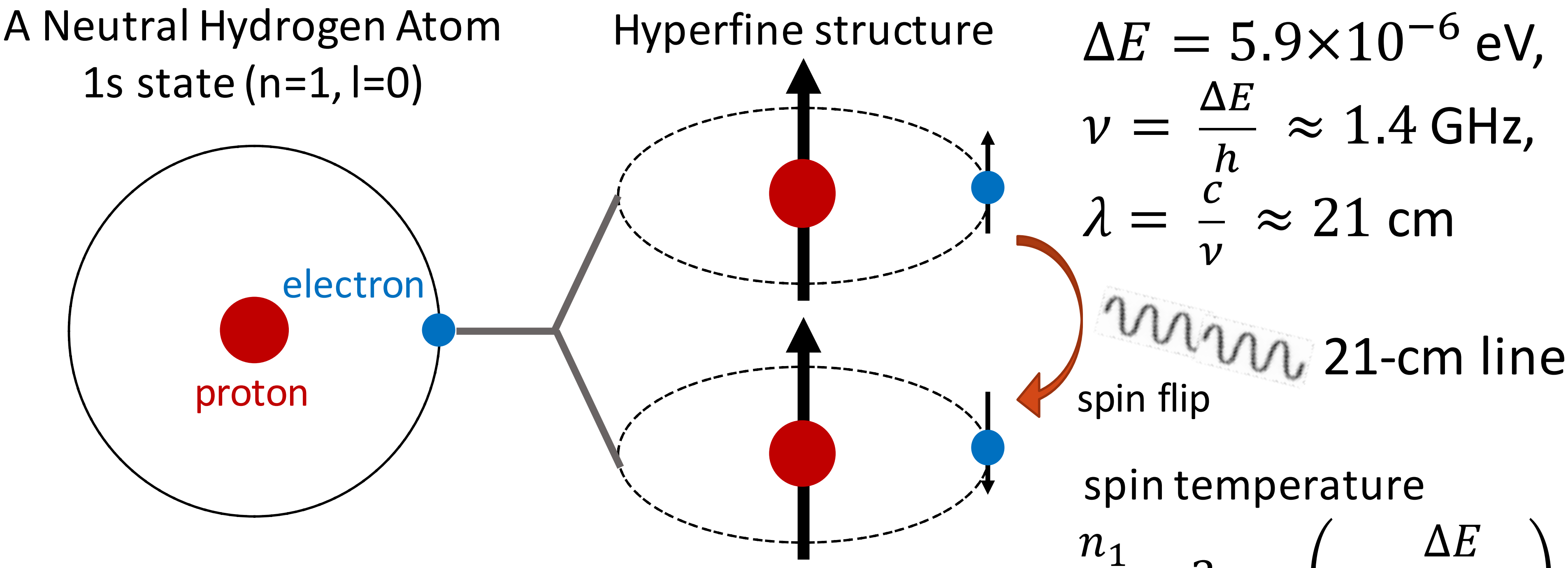
$$B_{1\mathrm{Mpc}} \lesssim 4.4\mathrm{nG}$$

(co-moving value at recombination)

Ade et al. (1502.01594)



21-cm global signal



$$\Delta E = 5.9\times10^{-6}\ \text{eV},$$

$$\nu = \frac{\Delta E}{h} \approx 1.4\ \text{GHz},$$

$$\lambda = \frac{c}{\nu} \approx 21\ \text{cm}$$

spin temperature

$$\frac{n_1}{n_0} = 3\exp\left(-\frac{\Delta E}{k_B T_{spin}}\right)$$

the distribution of neutral hydrogen atoms in high redshifts

=> matter density field, IGM thermal history, EoR process, …

21-cm global signal

In 2018, EDGES claimed that they detected the 21-cm absorption signal around 78MHz~1.4GHz/(1+17)

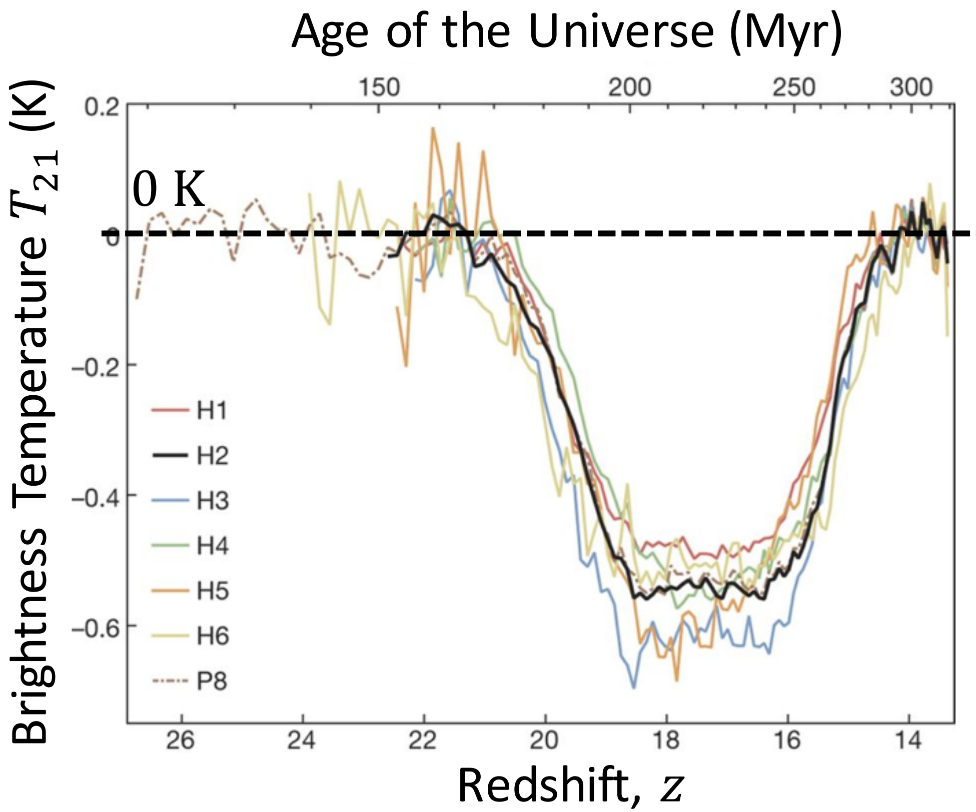
$$T_{21} \propto (T_{\rm spin} - T_{\rm CMB})$$

The global signal should be emission when

$$T_{\rm K} \geq T_{\rm spin} \geq T_{\rm CMB}$$

and absorption when

$$T_{\rm K} \leq T_{\rm spin} \leq T_{\rm CMB}$$



*(Bowman et al. 2018, Nature 555, 67)

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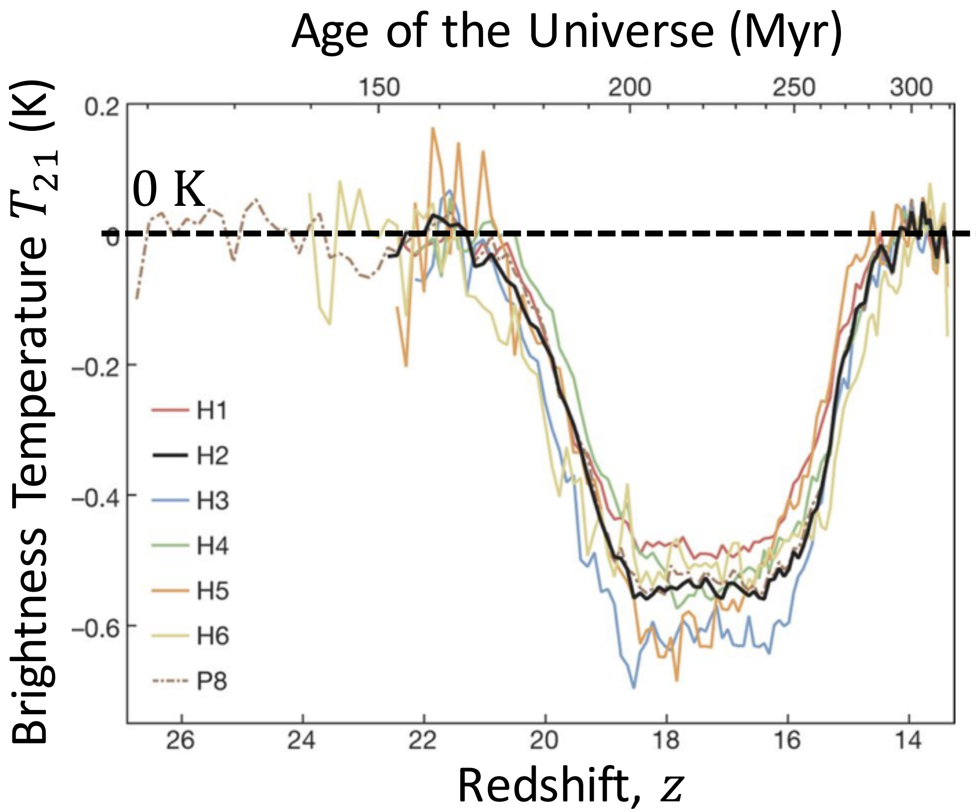
<u>We focus on the absorption at the dark age (z~17)</u>



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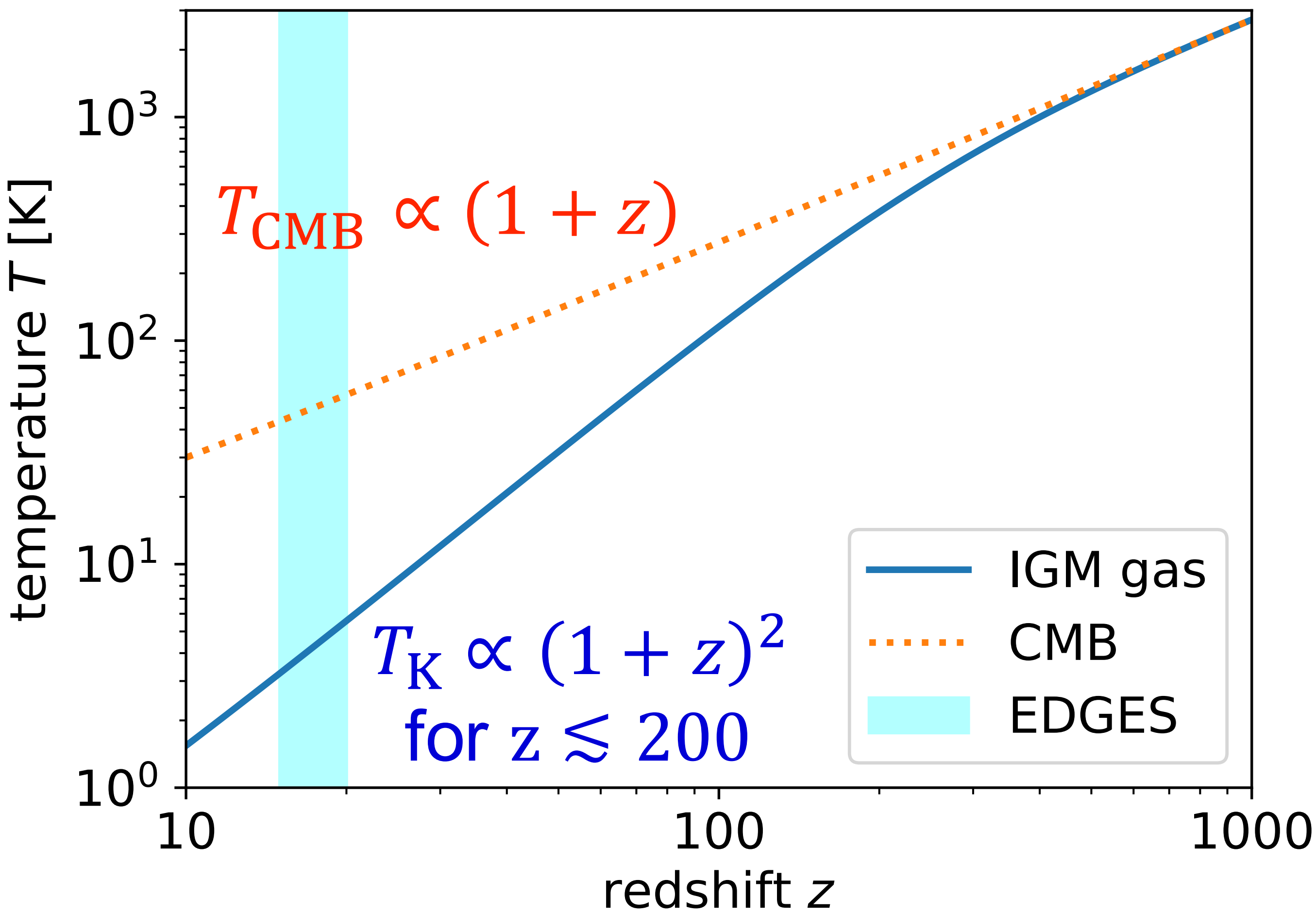
IGM thermal history

standard case (w/o astrophysical heating sources):

$T_K < T_{CMB}$ around z~17 (absorption)



IGM heating from PMFs

$$P_B(k) \propto B_{1\mathrm{Mpc}} k^{n_B}$$

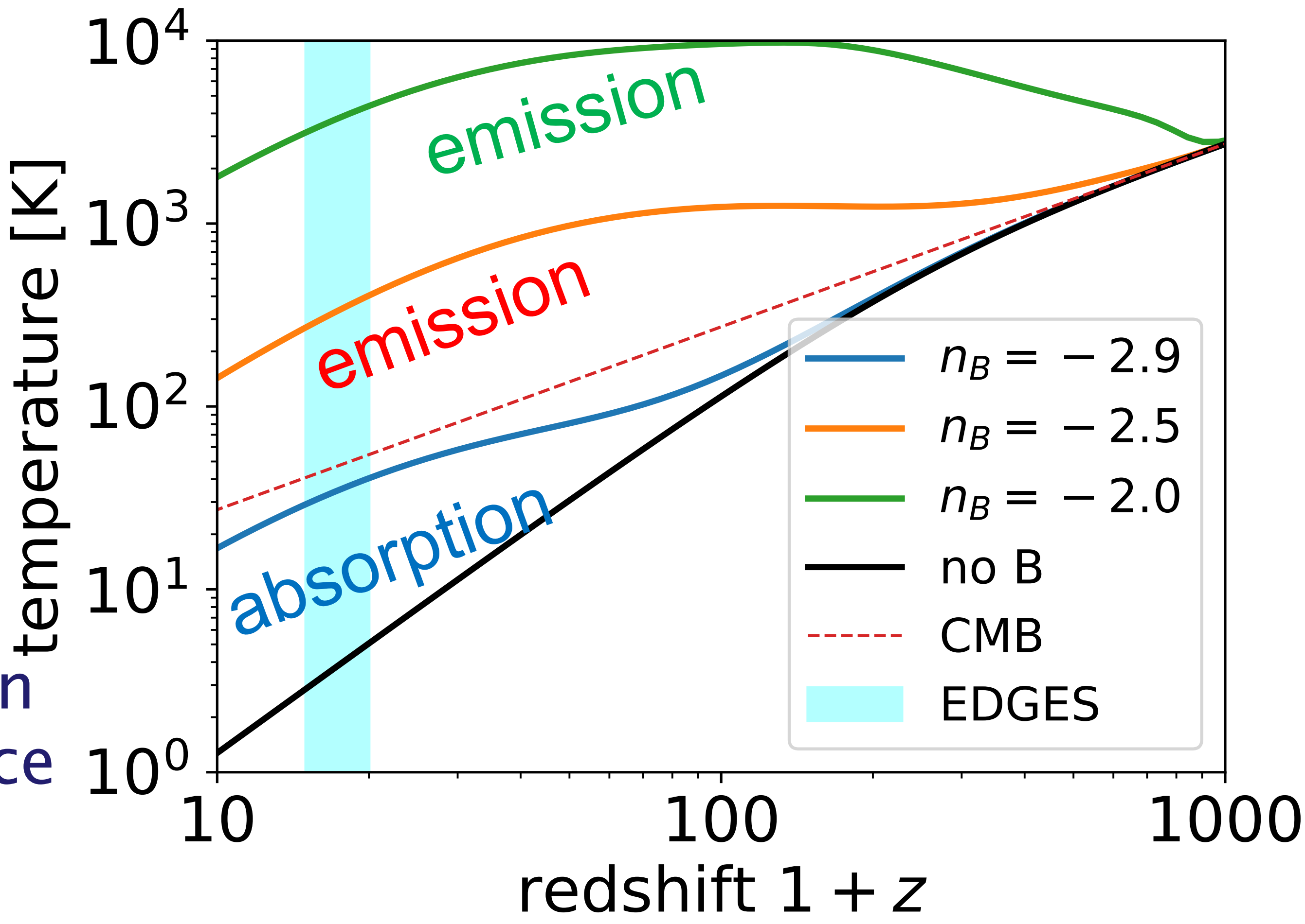
$$B_{1\mathrm{Mpc}} = 0.1\mathrm{nG}$$

Calculation:

- gas temperature
- ionization fraction
- magnetic energy density

PMF heating effects:

- ambipolar diffusion
- decaying turbulence



Results

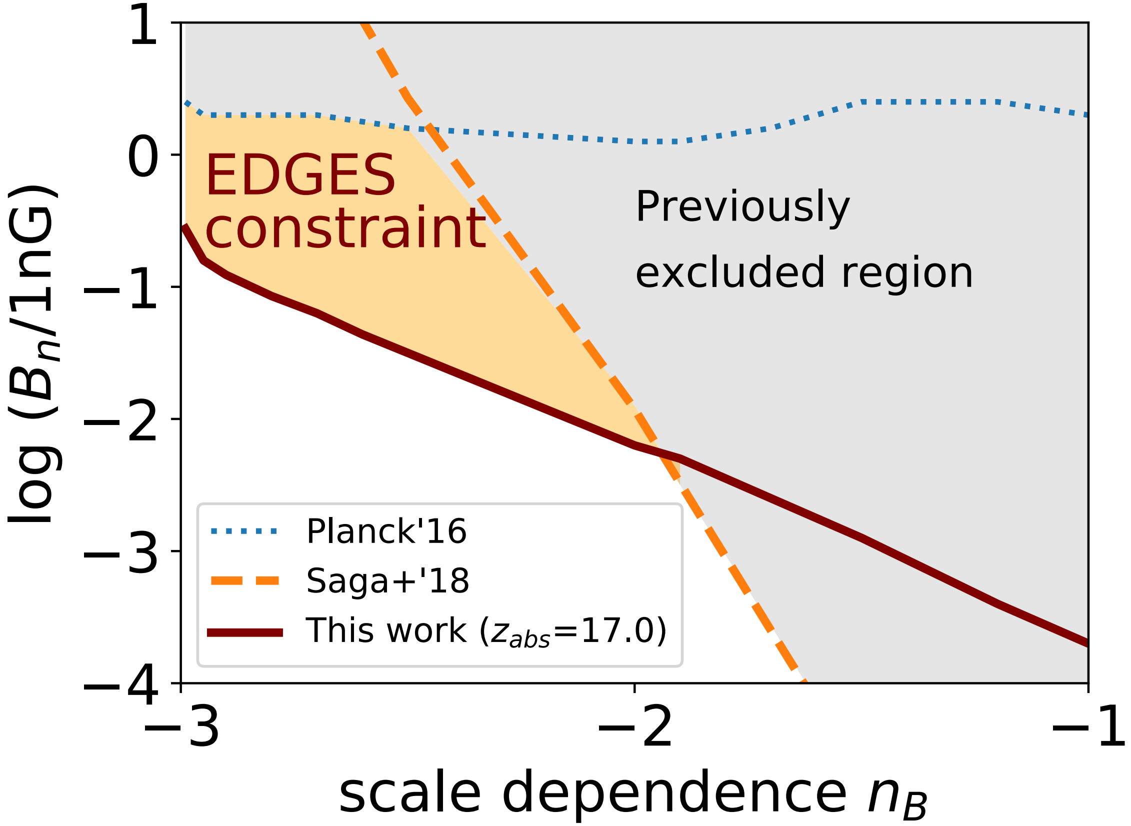
Calculate T_K with various PMF model parameters ($B_{1\ \mathrm{Mpc}}$, n_B)

With 21-cm absorption condition as $T_K < T_{CMB}$ (for $z \sim 17$),

Put the upper limit of PMFs.

=> $B_{1\ \mathrm{Mpc}} < 0.1$ nG

<u>A stringent constraint for $-3 < n_B < -2$</u>




Thank you for listening!
I'm staying on 3rd floor until 13th,
so please feel free about discussion.

Ambipolar Diffusion

For weakly ionized plasma, charged particles feel

$$\boldsymbol{F}_{\mathrm{Lorentz}} = \frac{(\nabla\times\boldsymbol{B})\times\boldsymbol{B}}{4\pi}, \text{ and } \boldsymbol{F}_{\mathrm{drag}} = \xi\,\rho_{\mathrm{n}}\rho_{\mathrm{i}}\,(\boldsymbol{v}_{\mathrm{n}} - \boldsymbol{v}_{\mathrm{i}})$$

$\xi = \frac{\sigma|\boldsymbol{v}_{\mathrm{n}}-\boldsymbol{v}_{\mathrm{i}}|}{m_n+m_i}$: drag coefficient [cm³/g/s]

By assuming total force to be zero, $\boldsymbol{F}_{\mathrm{Lorentz}} + \boldsymbol{F}_{\mathrm{drag}} = 0$,

$$\boldsymbol{v}_{\mathrm{i}} - \boldsymbol{v}_{\mathrm{n}} = \frac{\boldsymbol{F}_{\mathrm{Lorentz}}}{\xi\rho_{\mathrm{n}}\rho_{\mathrm{i}}} = \frac{\boldsymbol{F}_{\mathrm{Lorentz}}}{\xi\rho_{\mathrm{b}}^2}\frac{1}{x_e(1-x_e)}$$

x_e : ionization fraction

Heating rate for ambipolar diffusion is

$$\dot{Q}_{\mathrm{AD}} = \boldsymbol{F}_{\mathrm{drag}}\cdot(\boldsymbol{v}_{\mathrm{i}} - \boldsymbol{v}_{\mathrm{n}}) = \frac{|(\nabla\times\boldsymbol{B})\times\boldsymbol{B}|^2}{16\pi^2\xi\rho_{\mathrm{b}}^2}\frac{1-x_e}{x_e}$$

(Shu 1992, “Gas Dynamics”)

Decaying Turbulence

In flat-space, the scaling-law of the magnetic energy is

$$\tilde{E}_B = \tilde{E}_{B,\mathrm{init}} \left(1 + \frac{\tilde{t}}{\tilde{t}_\mathrm{d}}\right)^{-w_B}$$

$$w_B = \frac{2(n_B + 3)}{n_B + 5}$$

$$\tilde{E}_B = E_B a^4$$
$$d\tilde{t} = a^{3/2} dt$$

physical variables in matter-dominated era

$$E_B a^4 = E_{B,\mathrm{init}}\, a_\mathrm{init}{}^4 \left[\frac{\ln(1 + t_\mathrm{d}/t_\mathrm{init})}{\ln(1 + t_\mathrm{d}/t_\mathrm{init}) + \ln(t/t_\mathrm{init})}\right]^{w_B}$$

$$\frac{d}{dt}(E_B a^4) = E_{B,\mathrm{init}}\, a_\mathrm{init}{}^4 \frac{[\ln(1 + t_\mathrm{d}/t_\mathrm{init})]^{w_B}}{[\ln(1 + t_\mathrm{d}/t_\mathrm{init}) + \ln(t/t_\mathrm{init})]^{w_B+1}} \cdot \left(-\frac{w_B}{t}\right)$$

The heating rate for decaying turbulence is

$$\dot{Q}_\mathrm{DT} = \frac{3w_B}{2} H \frac{|\boldsymbol{B}|^2}{8\pi} \frac{1}{\ln(1 + t_\mathrm{d}/t_\mathrm{init}) + \ln(t/t_\mathrm{init})}$$

$$t_\mathrm{d} = \frac{1}{k_\mathrm{cut} V_\mathrm{A}}$$

Olesen (astro-ph/9610154); Sethi and Subramanian (astro-ph/0405413)

Evolutionary Equations

- Kinetic temperature of IGM gas

$$\frac{dT_{\rm K}}{dt} = -2HT_{\rm K} + \frac{x_e}{1+x_e}\frac{8\rho_{\rm CMB}\sigma_{\rm T}}{3m_e c}(T_{\rm CMB} - T_{\rm K}) + \frac{\dot{Q}_{\rm AD} + \dot{Q}_{\rm DT}}{1.5k_{\rm B}n_{\rm b}}$$

- Ionization fraction of IGM gas

$$\frac{dx_e}{dt} = \gamma_e n_{\rm b} x_e + \left[-\alpha_e n_{\rm b} x_e^2 + \beta_e (1-x_e) \exp\left(-\frac{3E_{\rm ion}}{4k_{\rm B}T_{\rm CMB}}\right)\right] \times \frac{1 + K_\alpha \Lambda n_{\rm b}(1-x_e)}{1 + K_\alpha(\Lambda + \beta_e)\, n_{\rm b}(1-x_e)}$$

- Energy density of the PMFs

$$\frac{d}{dt}\left(\frac{|\boldsymbol{B}|^2}{8\pi}\right) = -4H\frac{|\boldsymbol{B}|^2}{8\pi} - (\dot{Q}_{\rm AD} + \dot{Q}_{\rm DT})$$

RECFAST code (astro-ph/9909275, astro-ph/9912182, 1503.04827)