DARK MATTER MINI HALOS FROM PRIMORDIAL MAGNETIC FIELDS

Phys. Rev. Lett. 131, 231002

Pranjal Ralegankar

Postdoctoral scientist, SISSA

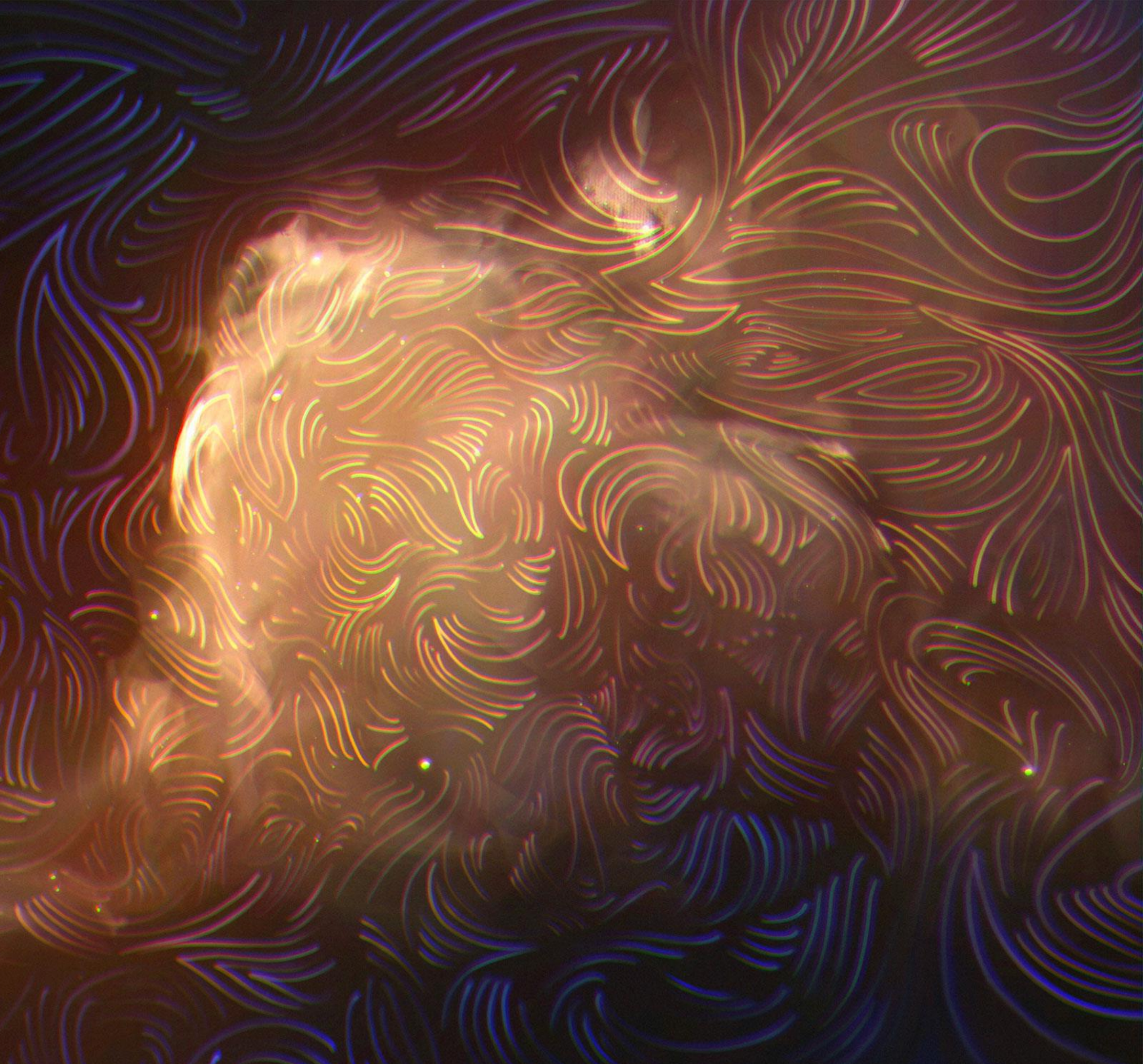

Image source: Pauline Voß for Quanta Magazine

PRIMORDIAL MAGNETIC FIELDS ENHANCE DENSITY PERTURBATIONS

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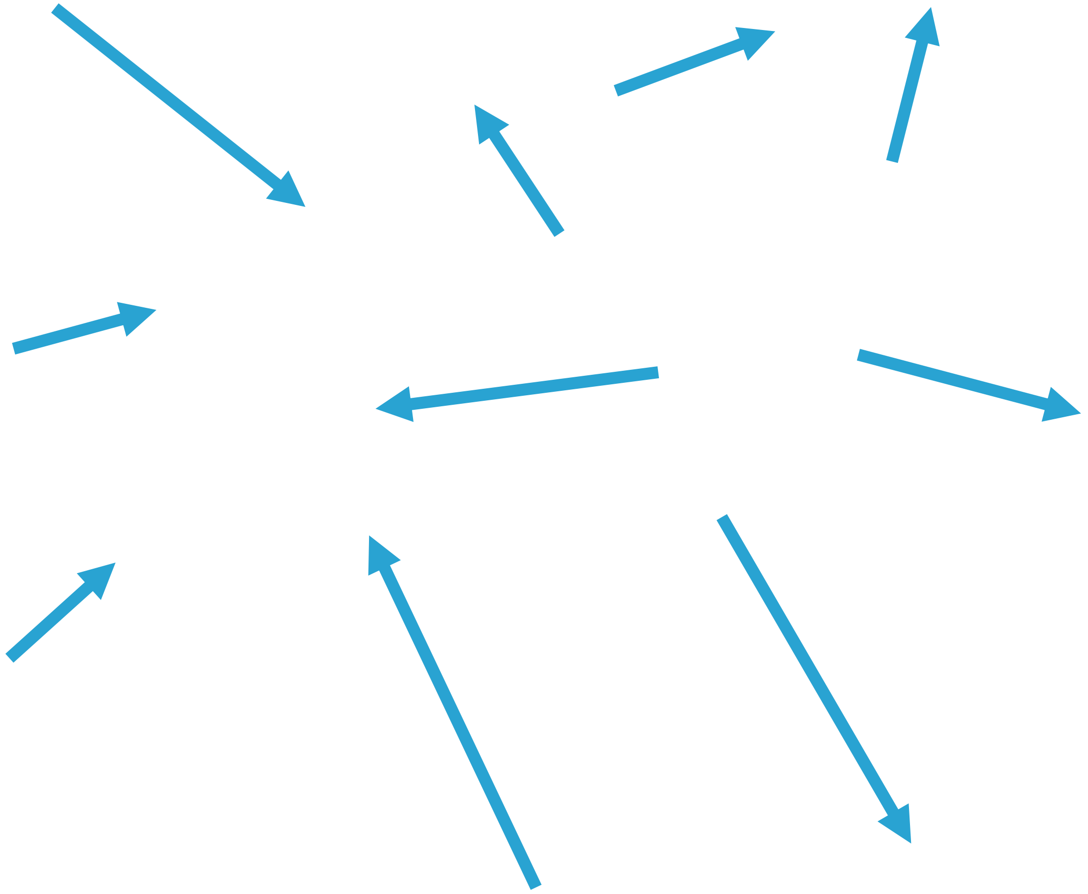
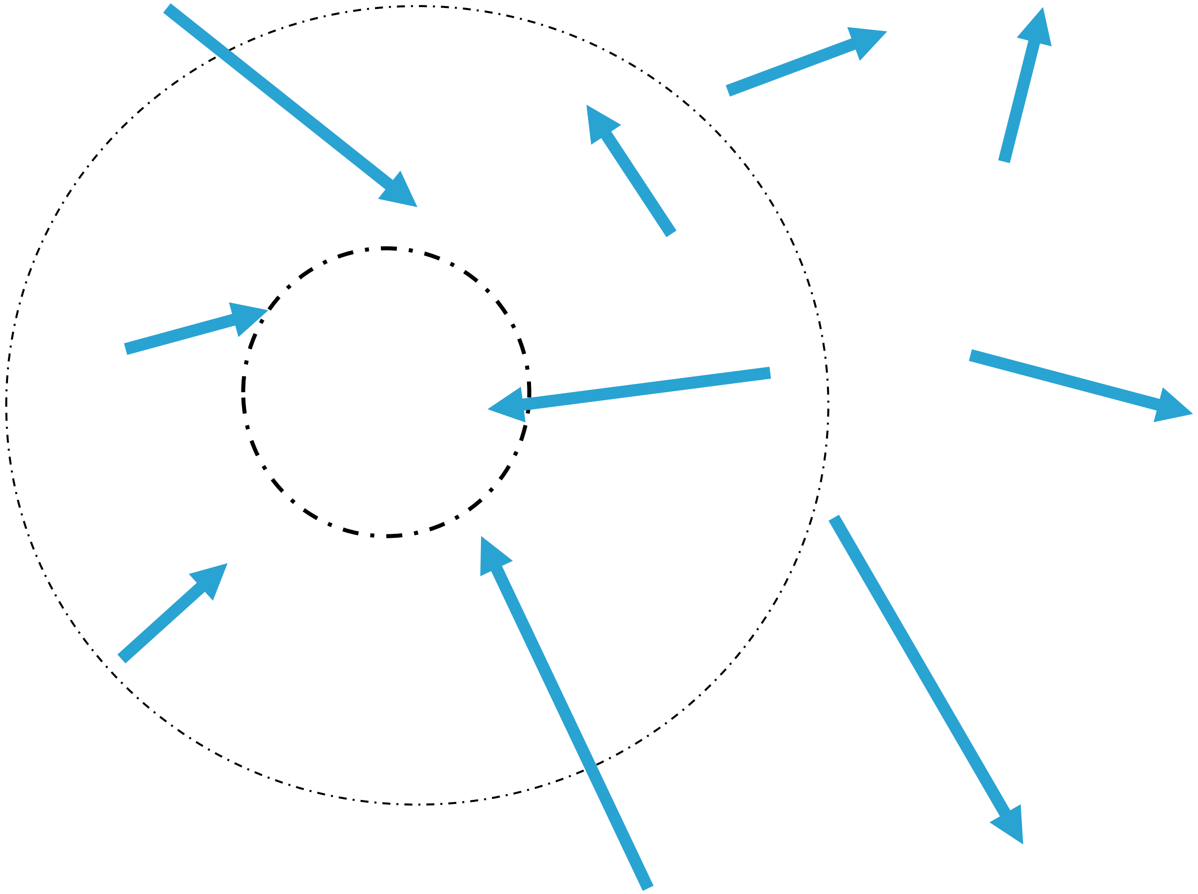
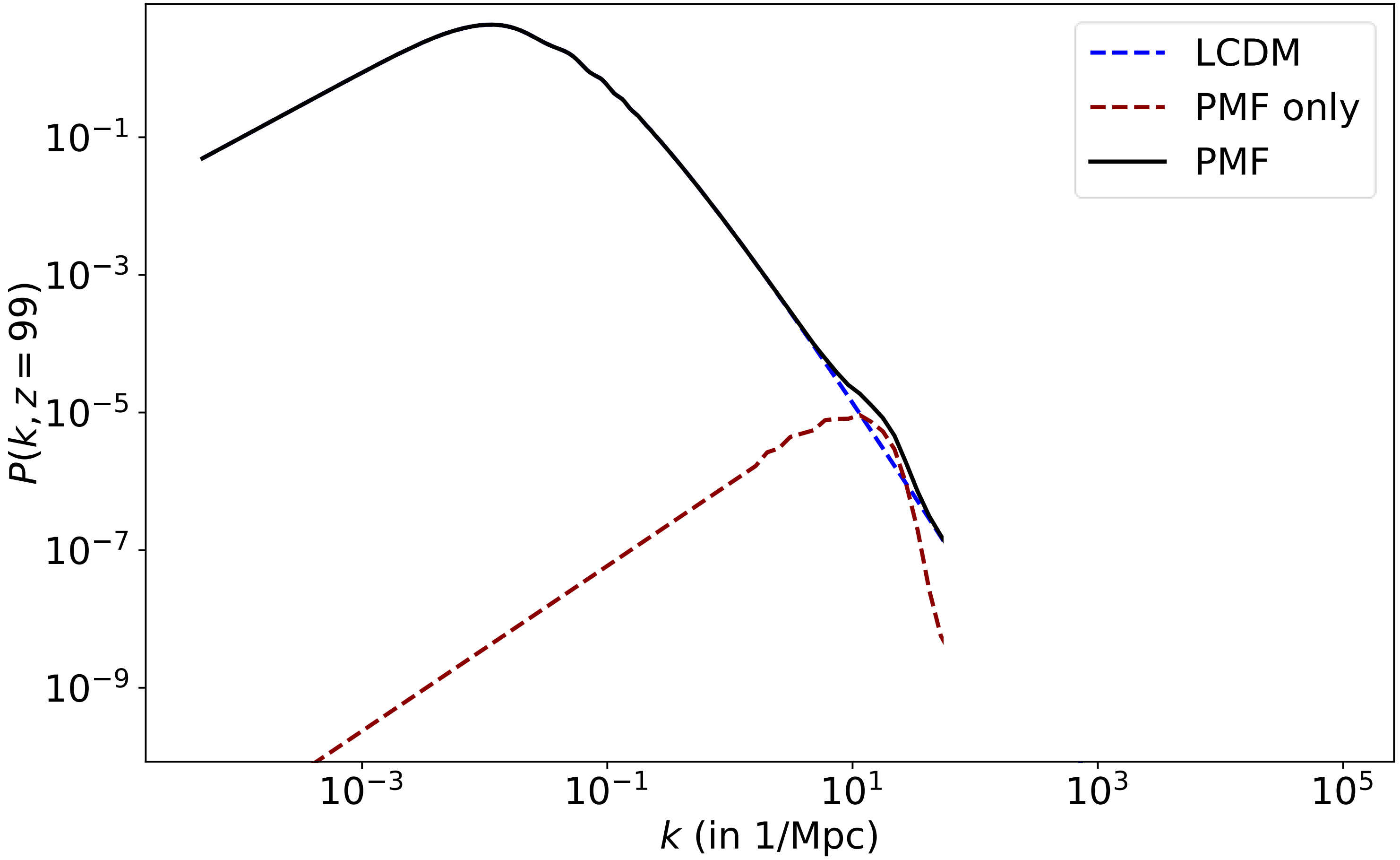


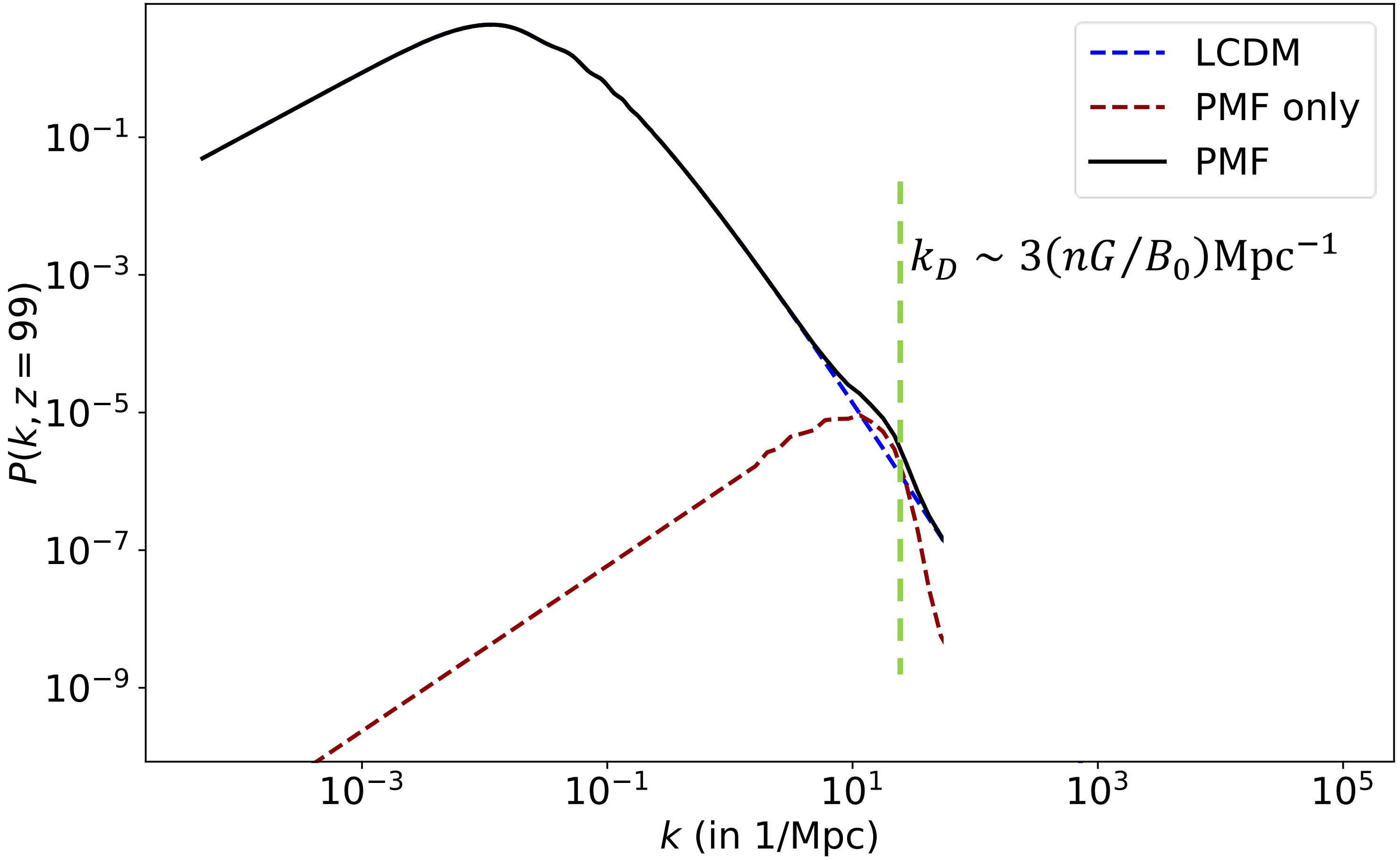
PRIMORDIAL MAGNETIC FIELDS ENHANCE DENSITY PERTURBATIONS



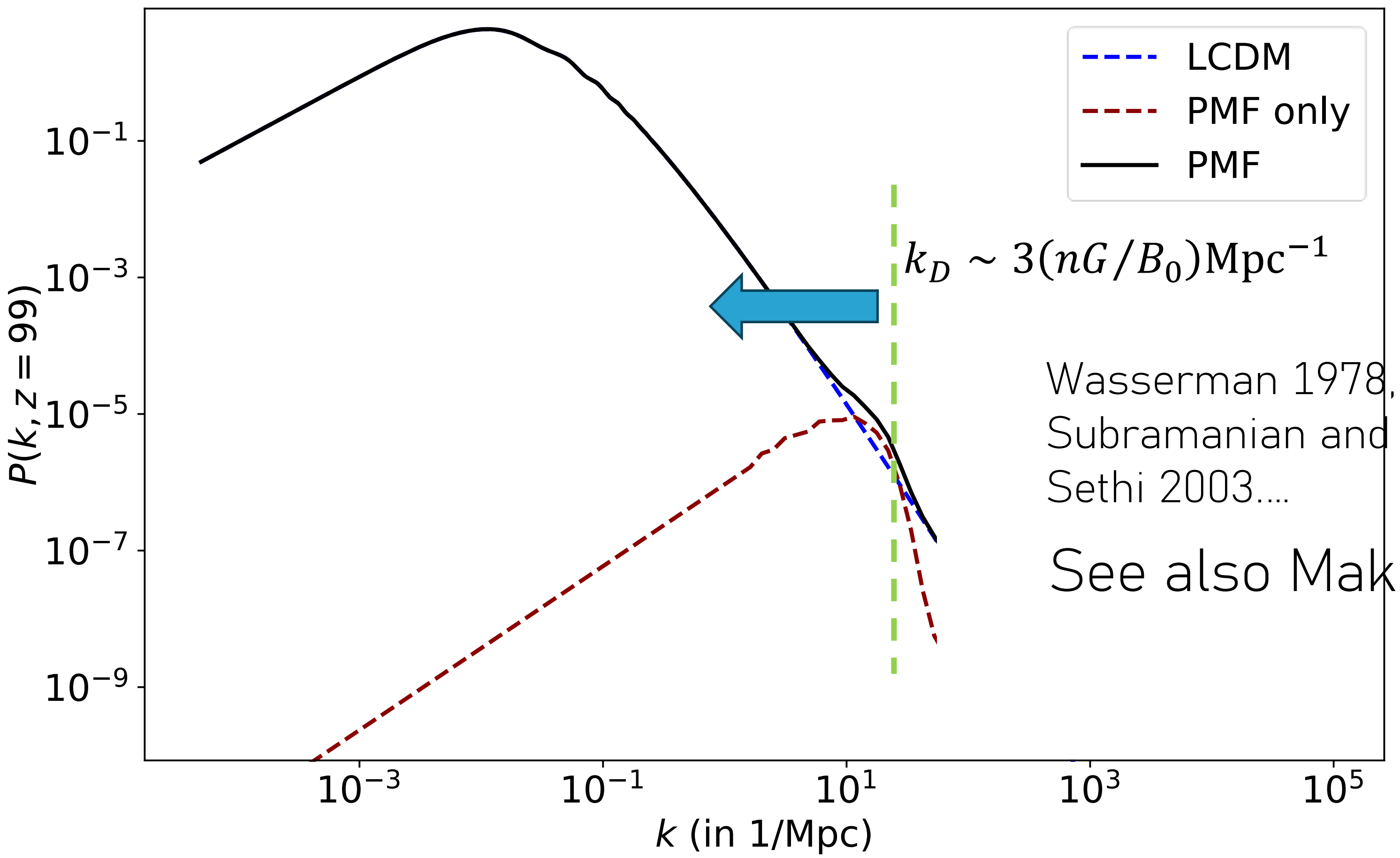
PRIMORDIAL MAGNETIC FIELDS ENHANCE POWER SPECTRUM ON SMALL SCALES



BACKREACTION FROM BARYONS SUPPRESSES BARYON DENSITY PERTURBATIONS BELOW MAGNETIC DAMPING (JEANS) SCALE



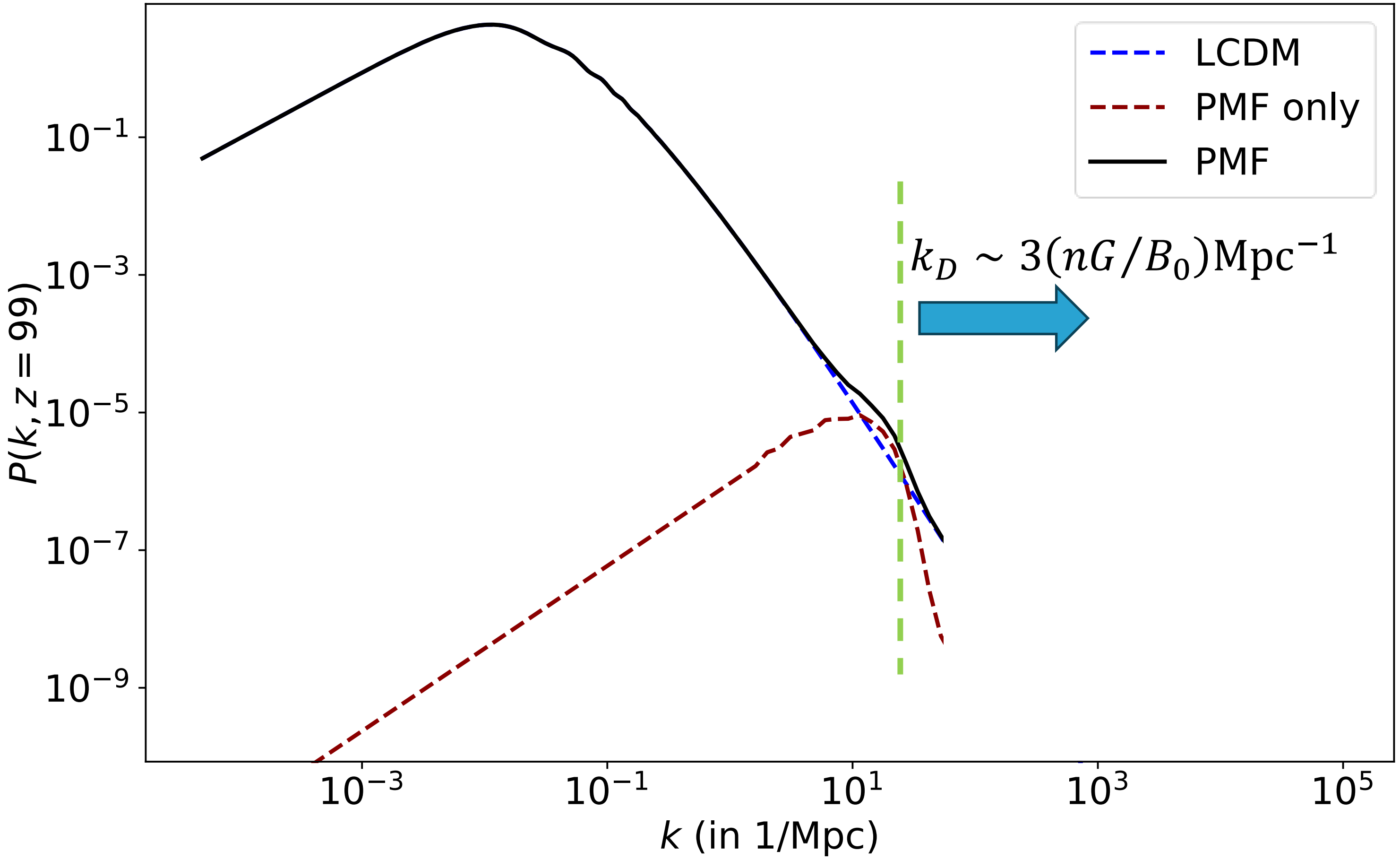
EARLIER WORKS FOCUSED ON SCALES BELOW MAGNETIC DAMPING (JEANS) SCALE



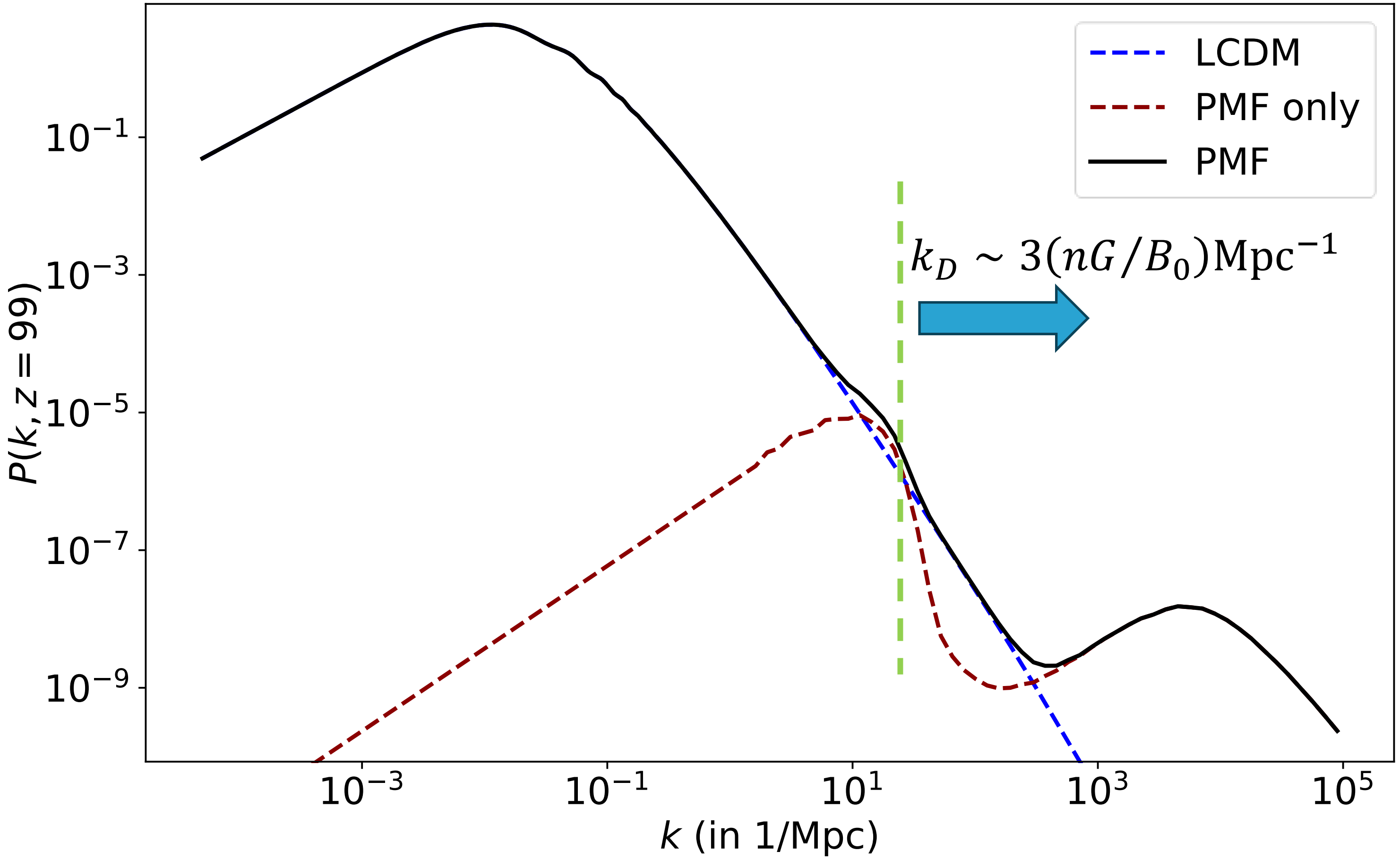
Wasserman 1978, Kim et al 1996, Subramanian and Barrow 1997, Gopal and Sethi 2003....

See also Mak's talk later

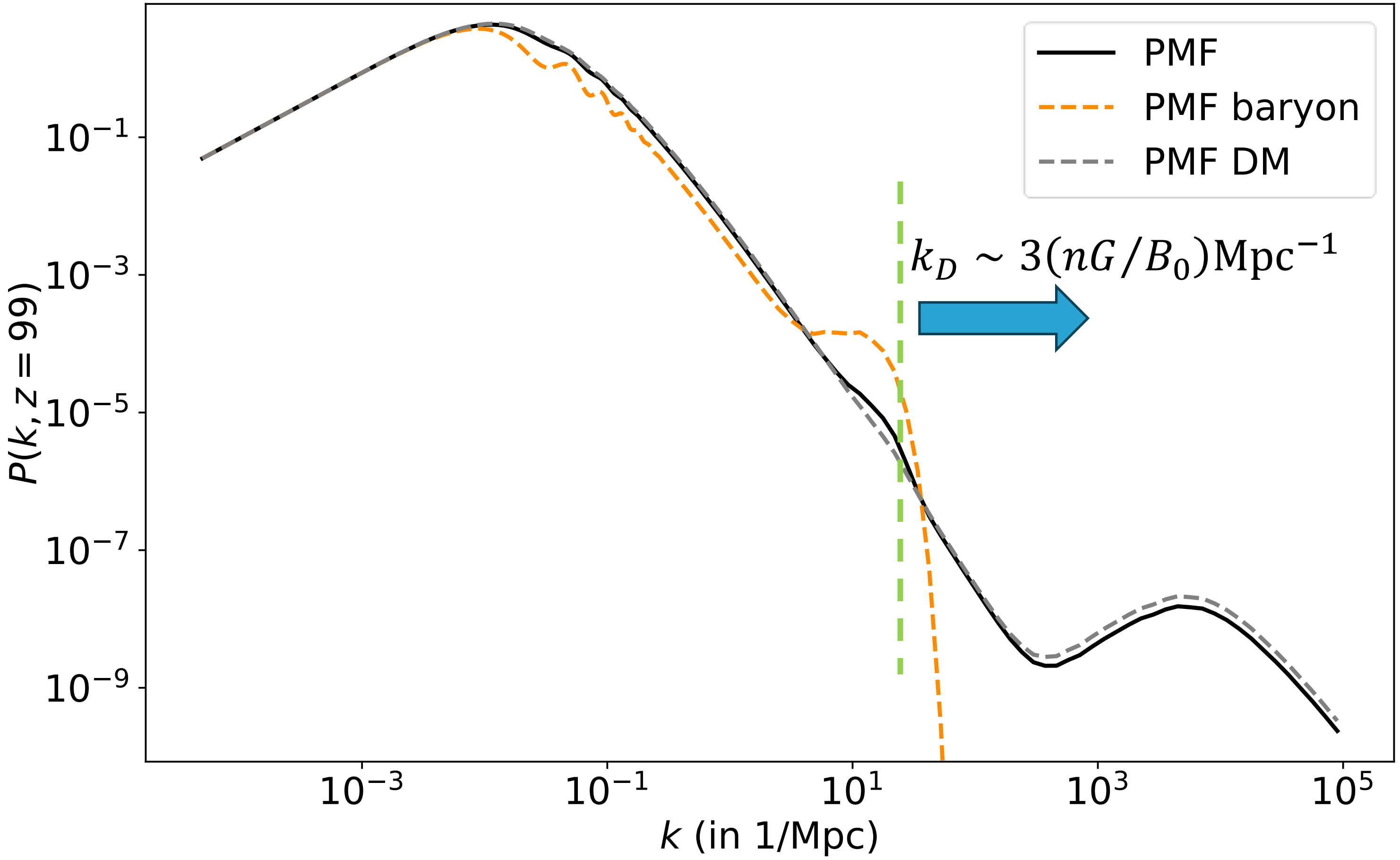
MY STUDY FOCUSES ON SCALES BELOW MAGNETIC DAMPING (JEANS) SCALE



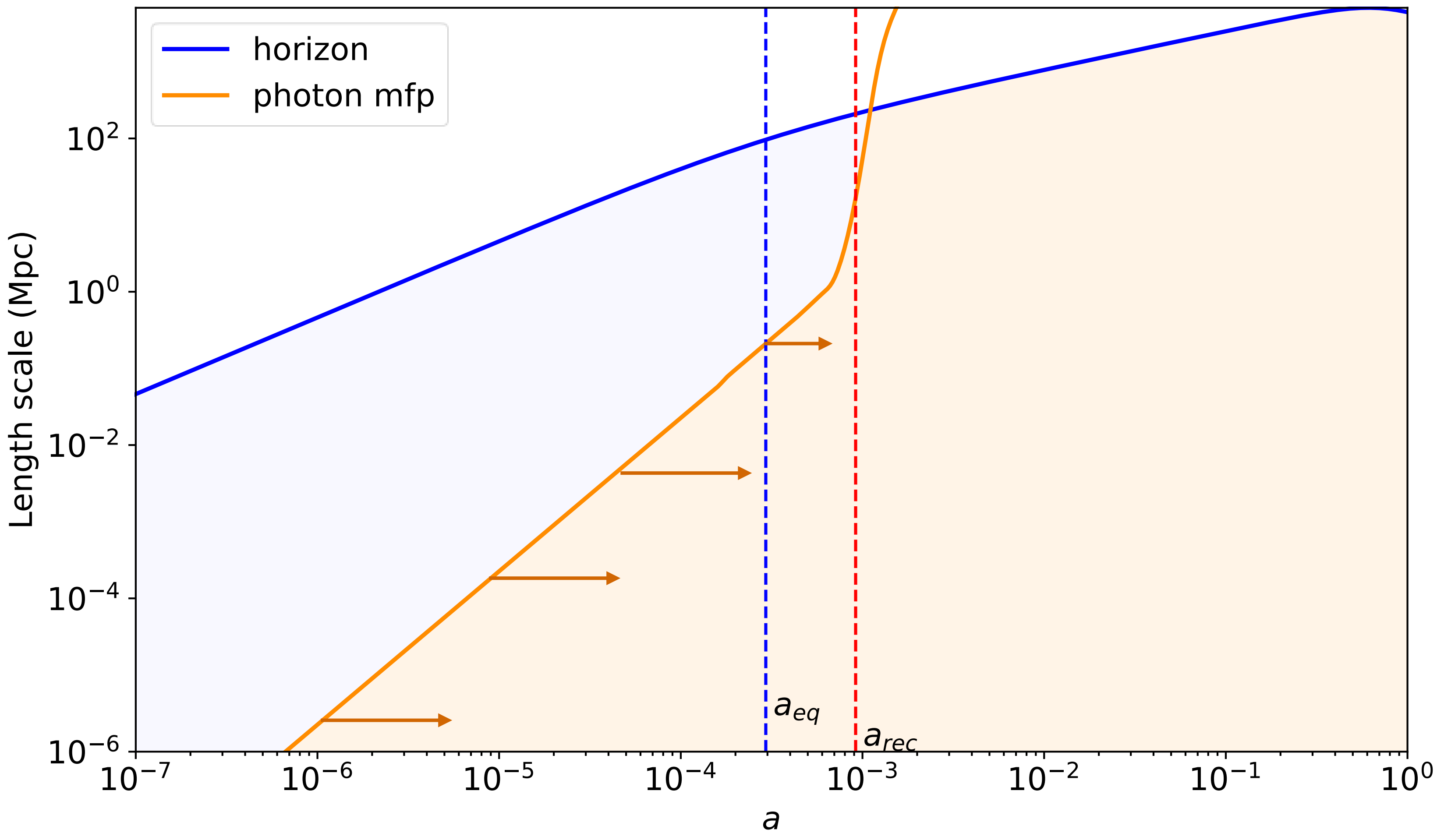
FINDING: HIGHLY ENHANCED POWER SPECTRUM BELOW JEANS SCALE



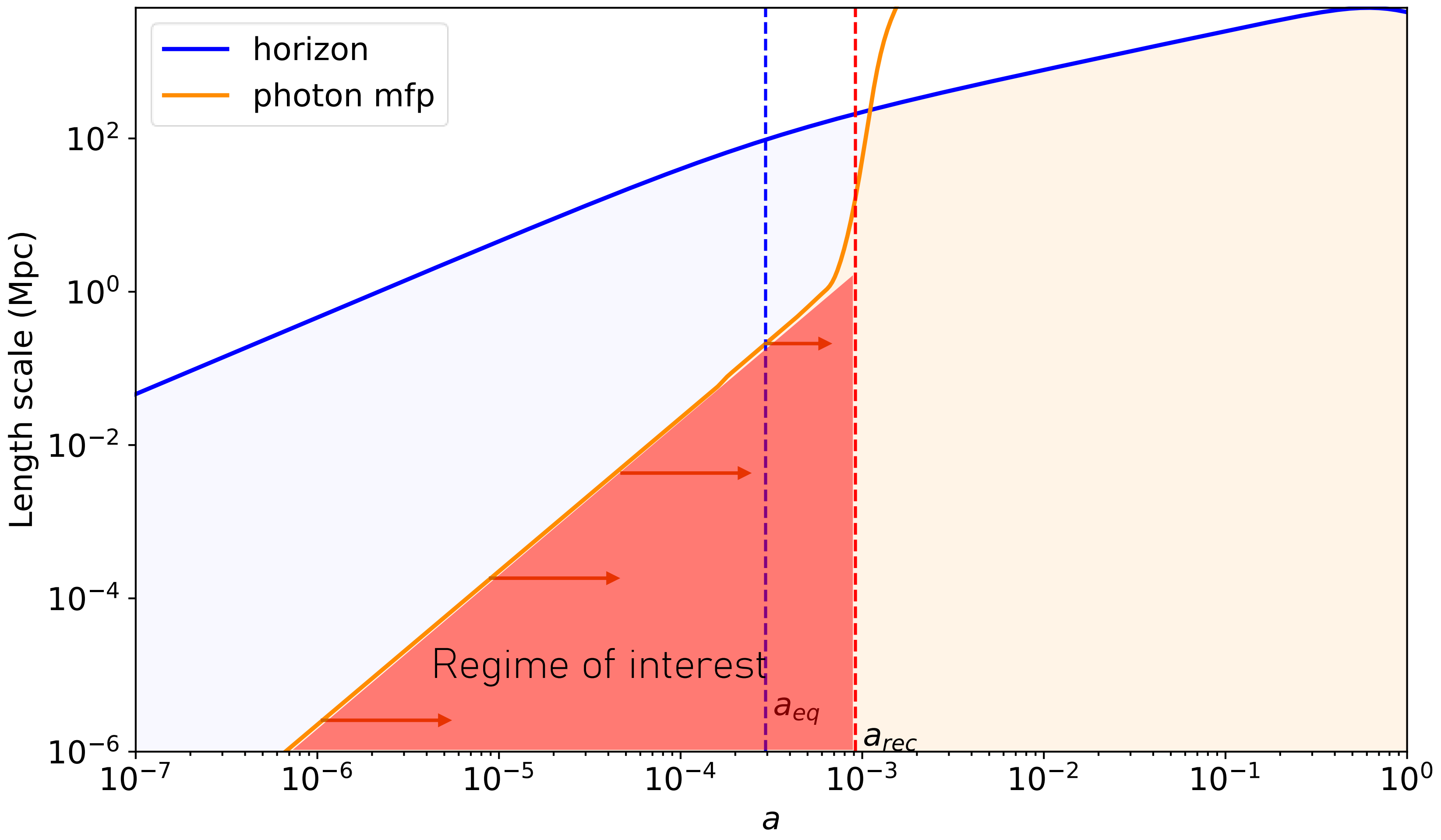
FINDING: BARYON PERTURBATION SUPPRESSED BELOW JEANS SCALE BUT NOT DARK MATTER!



SCALES OF INTEREST: PRE-RECOMBINATION AND SCALES SMALLER THAN PHOTON MFP



SCALES OF INTEREST: PRE-RECOMBINATION AND SCALES SMALLER THAN PHOTON MFP



IDEAL MHD IN PHOTON DRAG REGIME:

IDEAL MHD IN PHOTON DRAG REGIME: LAMINAR FLOW IN BARYONS

$$\frac{\partial \vec{v}_b}{\partial t} + (H + \alpha)\vec{v}_b + \frac{(\vec{v}_b.\nabla)\vec{v}_b}{a} = \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi a \rho_b} - \frac{\mathrm{c}_\mathrm{b}^2 \nabla \delta_b}{a} - \frac{\nabla \phi}{a}$$

IDEAL MHD IN PHOTON DRAG REGIME: LAMINAR FLOW IN BARYONS

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Abel and Jedamzik 2010,
Campanelli 2013,
Jedamzik and Saveliev 2018

IDEAL MHD IN PHOTON DRAG REGIME: KEY FORCES

$$\frac{\partial \vec{v}_b}{\partial t} + (H + \alpha)\vec{v}_b = \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi a \rho_b} - \frac{\mathrm{c}_\mathrm{b}^2 \nabla \delta_b}{a} - \frac{\nabla \phi}{a}$$

Lorentz force

Thermal pressure

Gravity

IDEAL MHD IN PHOTON DRAG REGIME: LARGE LORENTZ FORCE LIMIT

$$(H+\alpha)\vec{v}_b \approx \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi a \rho_b}$$

IDEAL MHD IN PHOTON DRAG REGIME: LARGE LORENTZ FORCE LIMIT

$$(H + \alpha)\vec{v}_b \approx \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi a \rho_b}$$

$$\frac{\partial\ (a^2\vec{B})}{\partial t} = \frac{\nabla \times (\vec{v}_b \times a^2\vec{B})}{a}$$

IDEAL MHD IN PHOTON DRAG REGIME: MAGNETIC DAMPING SCALE

$$(H+\alpha)\vec{v}_b \approx \frac{\left(\nabla\times\vec{B}\right)\times\vec{B}}{4\pi a\rho_b}$$

$$\frac{\partial\,(a^2\vec{B})}{\partial t} = \frac{\nabla\times(\vec{v}_b\times a^2\vec{B})}{a}$$

$$P_B(k,t) = P_B(k,t_I)e^{-\frac{k^2}{k_D^2}}$$

$$k_D^{-1}(a) \sim \tau v_b$$

Campanelli 2013

IDEAL MHD IN PHOTON DRAG REGIME: MAGNETIC DAMPING SCALE

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$$k_D^{-1}(a) \sim \tau v_b$$

Campanelli 2013

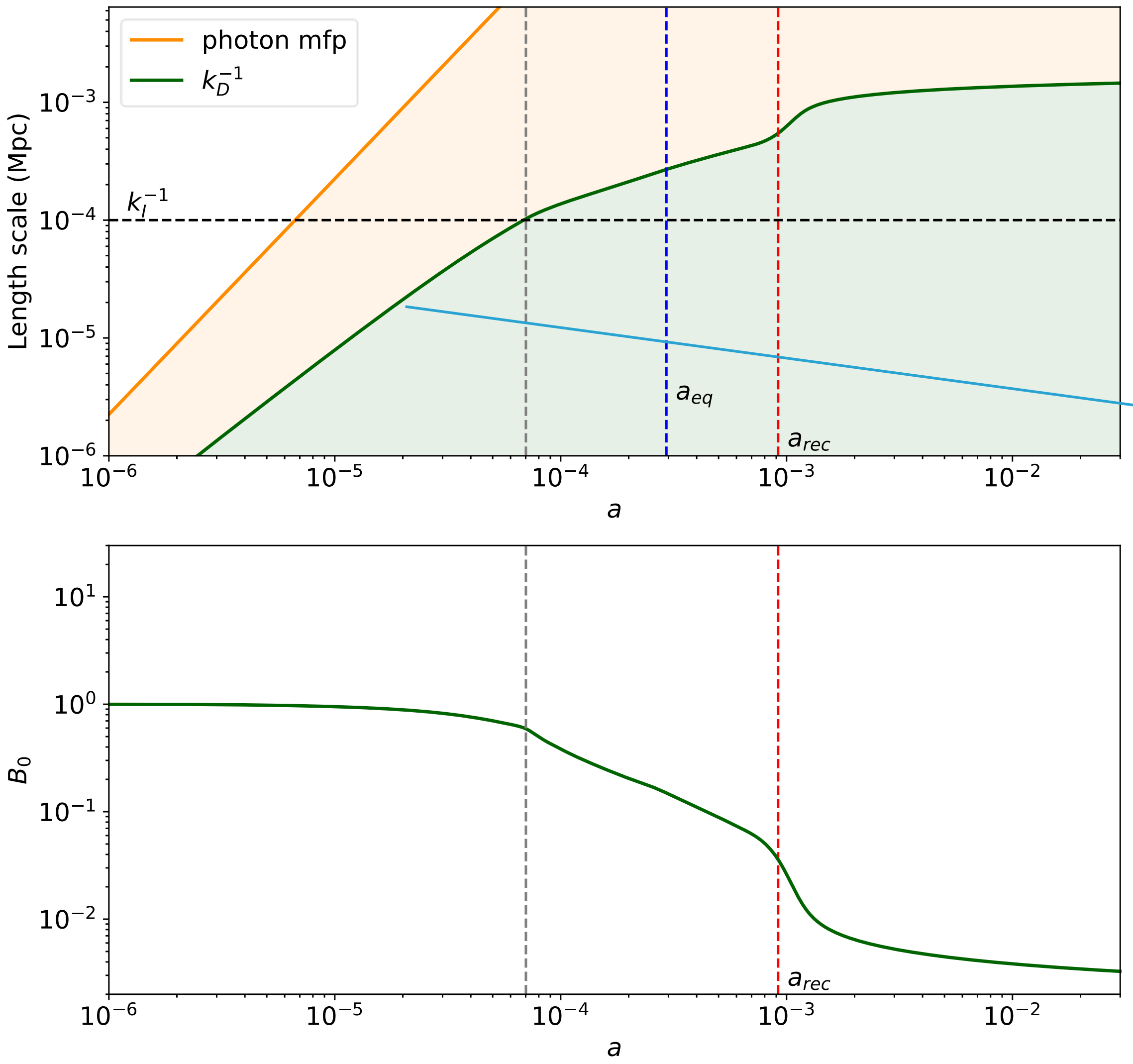
<u>ASSUMED</u>

B_0 Gaussian

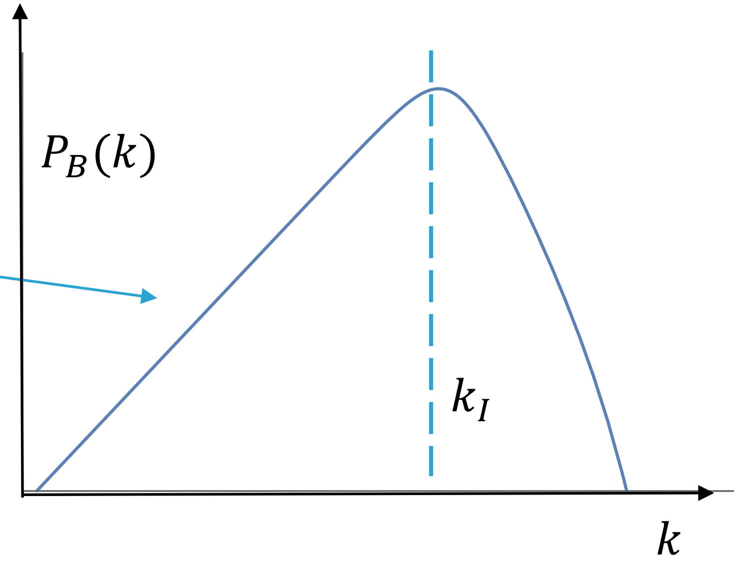
IDEAL MHD IN PHOTON DRAG REGIME: DAMPING SCALE GROWS WITH TIME

$$(H+\alpha)\vec{v}_b \approx \frac{(\nabla \times \vec{B}\ldots}{4\pi\ldots}$$

$$\frac{\partial\,(a^2\vec{B})}{\partial t} = \frac{\nabla \times (\vec{v}_b \times \ldots}{a}$$



$$k_D^{-1}(a) \sim \tau v_A$$



IDEAL MHD IN PHOTON DRAG REGIME: DAMPING SCALE GROWS WITH TIME

$$(H+\alpha)\vec{v}_b \approx \frac{(\nabla \times \vec{B} \ldots}{4\pi \ldots}$$

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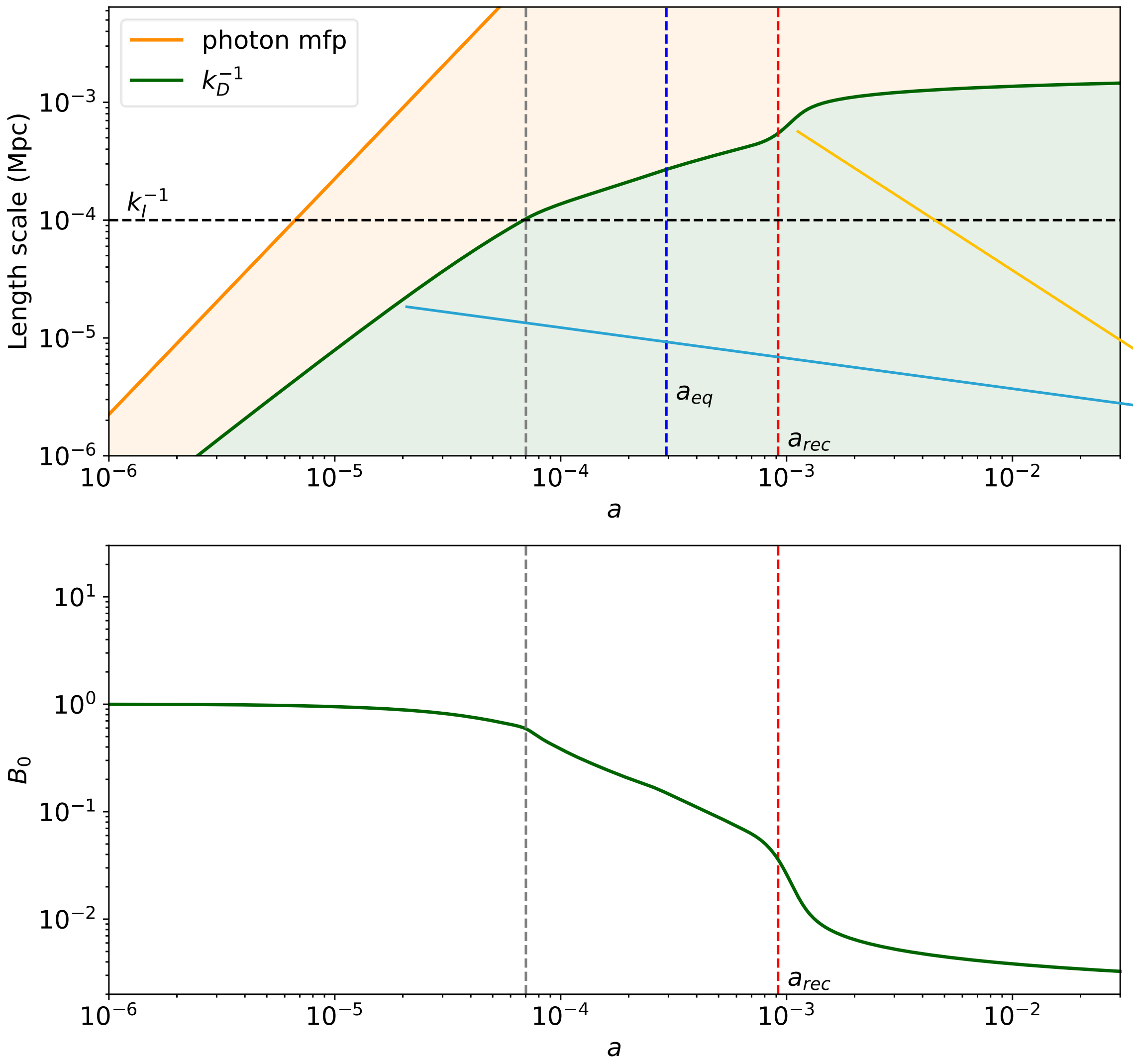

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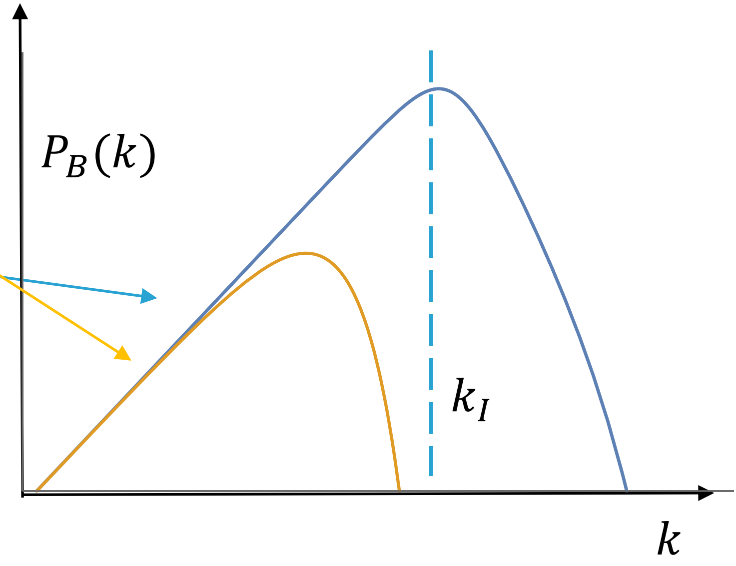

SOLVING DENSITY PERTURBATION EQUATIONS

$$L_B = \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi a \rho_b}$$

$$\frac{\partial \vec{v}_b}{\partial t} + (H + \alpha)\vec{v}_b = L_B - \frac{\mathrm{c}_\mathrm{b}^2 \nabla \delta_b}{a} - \frac{\nabla \phi}{a}$$

$$\frac{\partial \delta_b}{\partial t} = -\frac{\nabla . \vec{v}_b}{a}$$

$$\nabla^2 \phi = \frac{a^2}{2M_{Pl}^2}(\rho_b \delta_b + \rho_{DM} \delta_{DM})$$

$$\frac{\partial^2 \delta_{DM}}{\partial a^2} + \left[\frac{\partial \ln(a^2 H)}{\partial \ln a} + 1\right] \frac{\partial \delta_{DM}}{a \partial a} = \frac{\nabla^2 \phi}{(a^2 H)^2}$$

SOLVING DENSITY PERTURBATION EQU...NS

$$L_B = \frac{\left(\nabla \times \vec{B}\right) \times \vec{B}}{4\pi a \rho_b}$$

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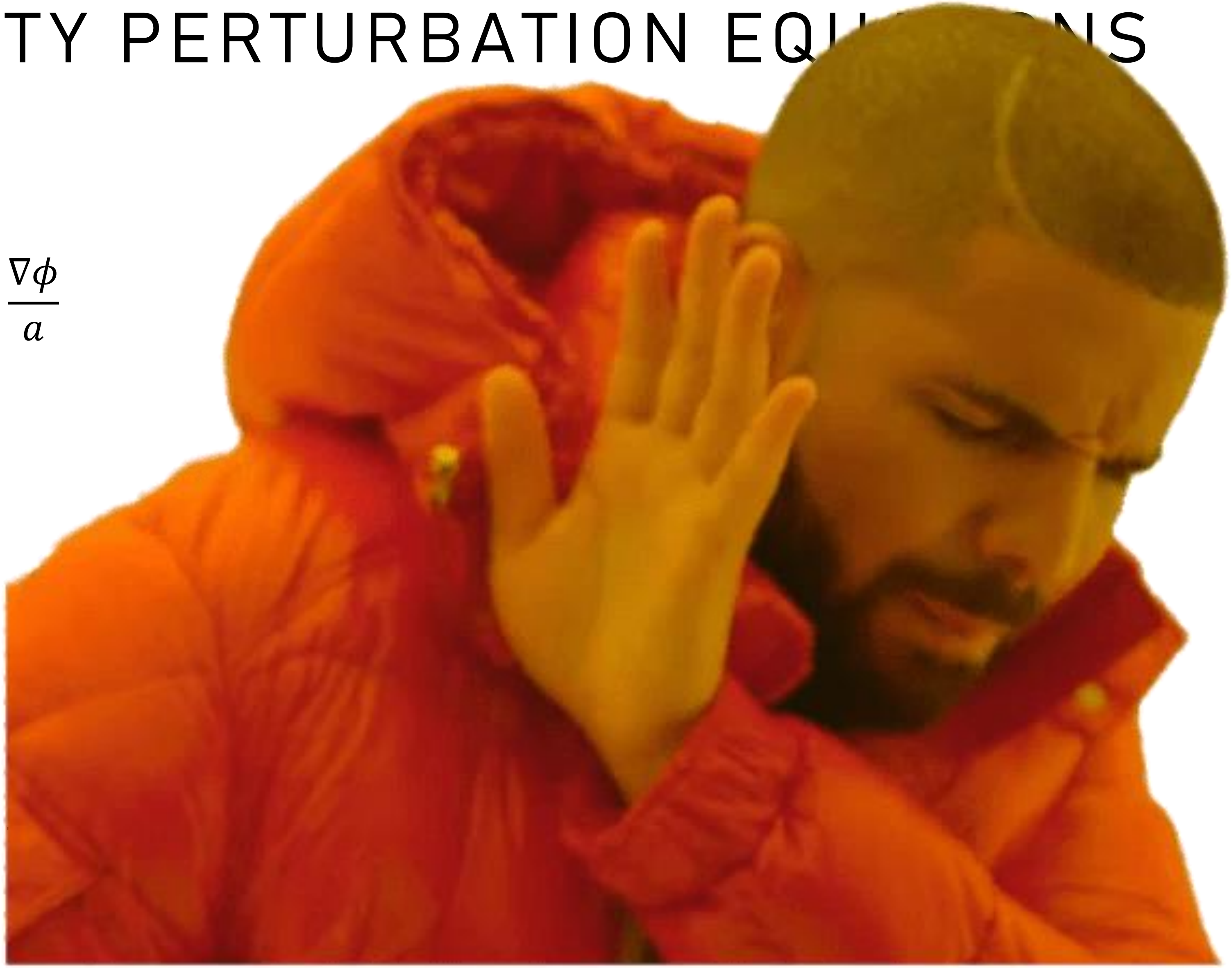
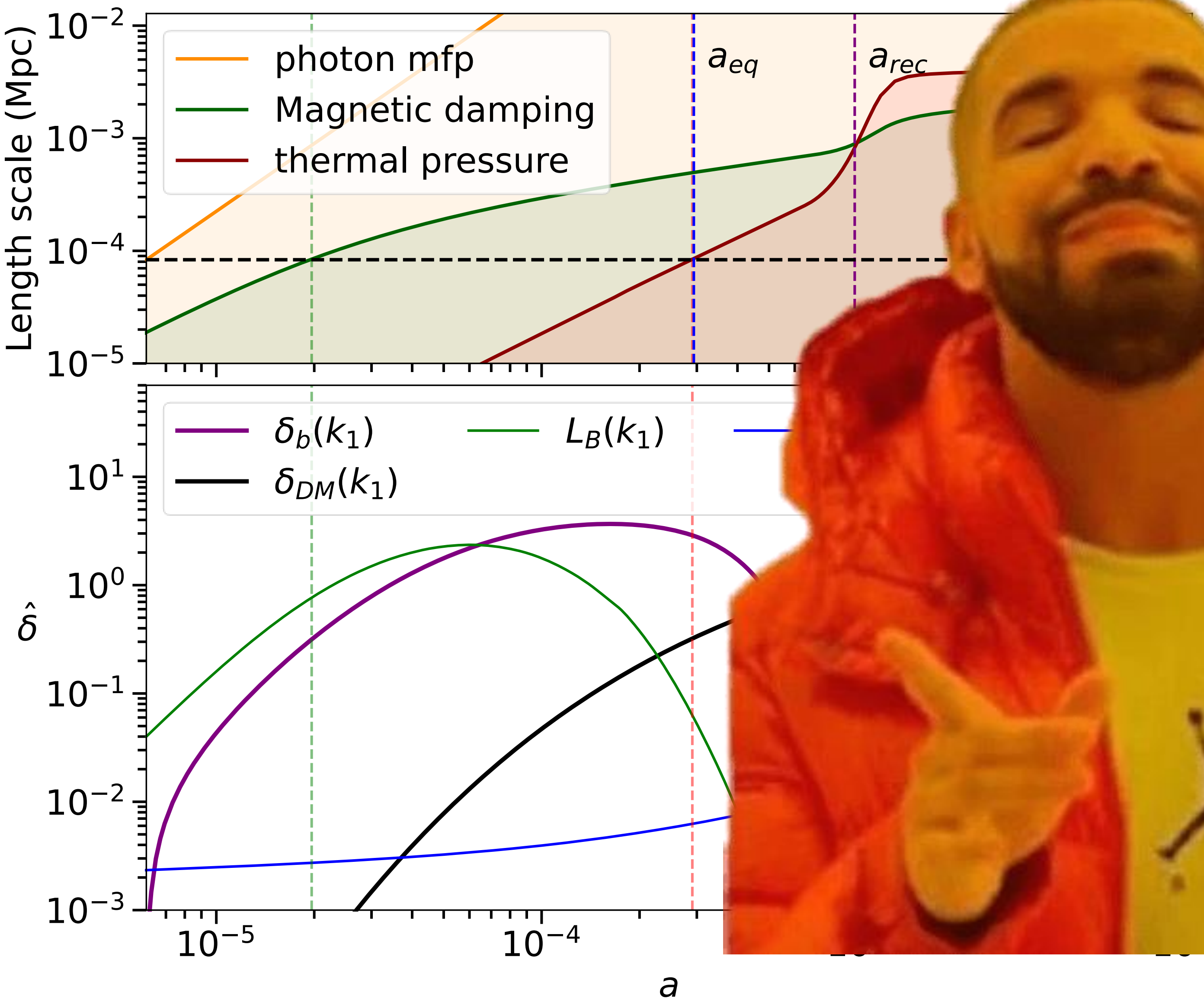
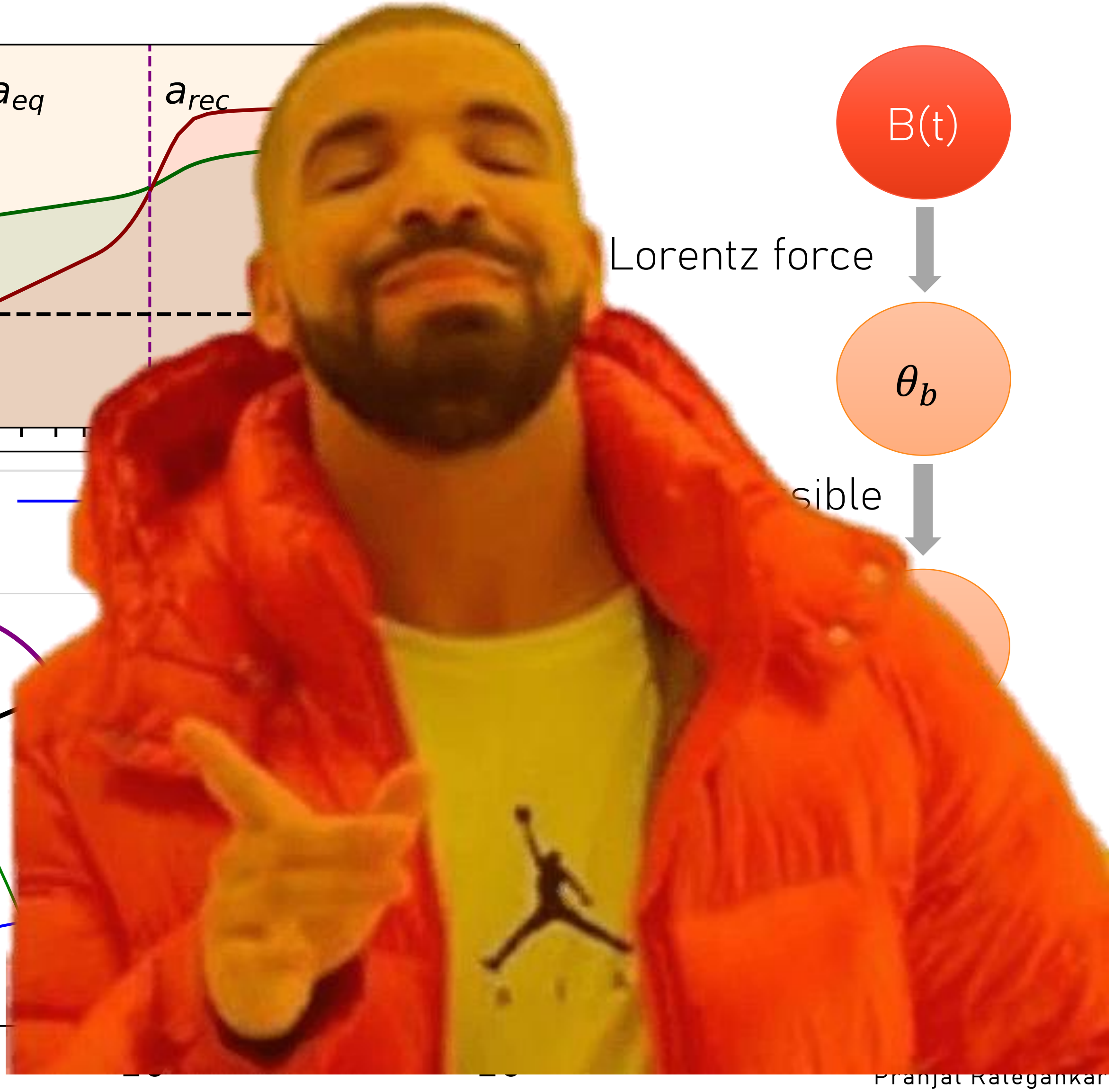
$$\frac{\partial^2 \delta_{DM}}{\partial a^2} + \left[\frac{\partial \ln(a^2 H)}{\partial \ln a} + 1\right]\frac{\partial \delta_{DM}}{a \partial a} =$$



PERTURBATION EVOLUTION PLOT

$B_I = 5$ nG





PERTURBATION EVOLUTION PLOT

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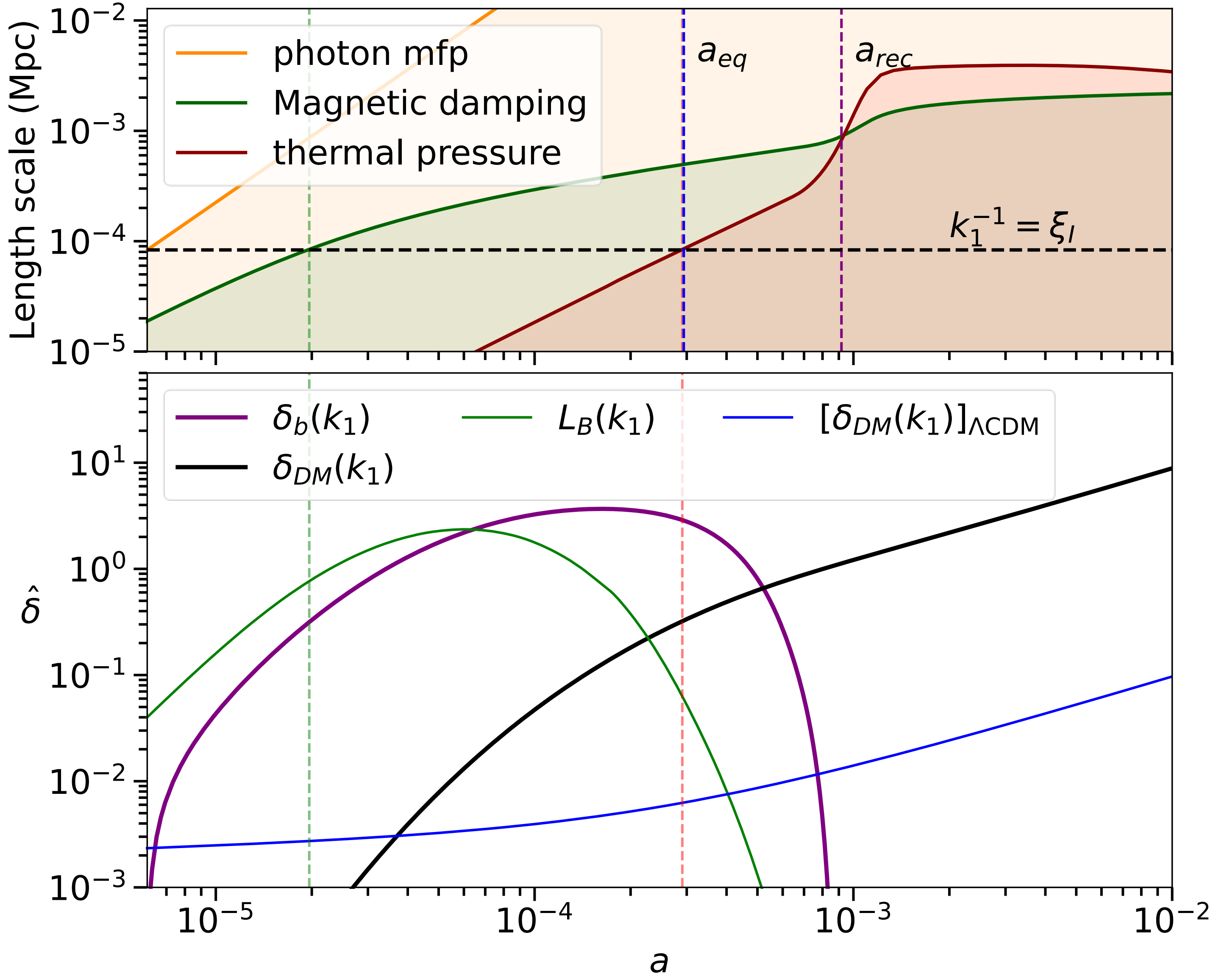
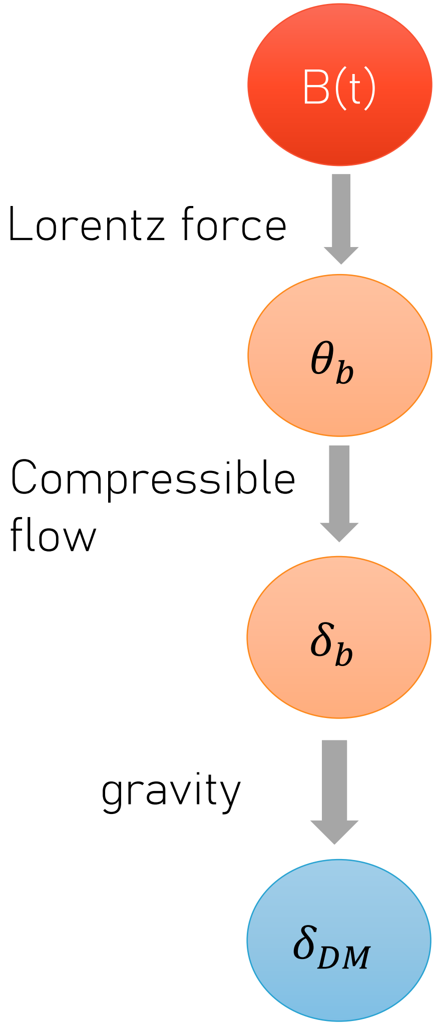
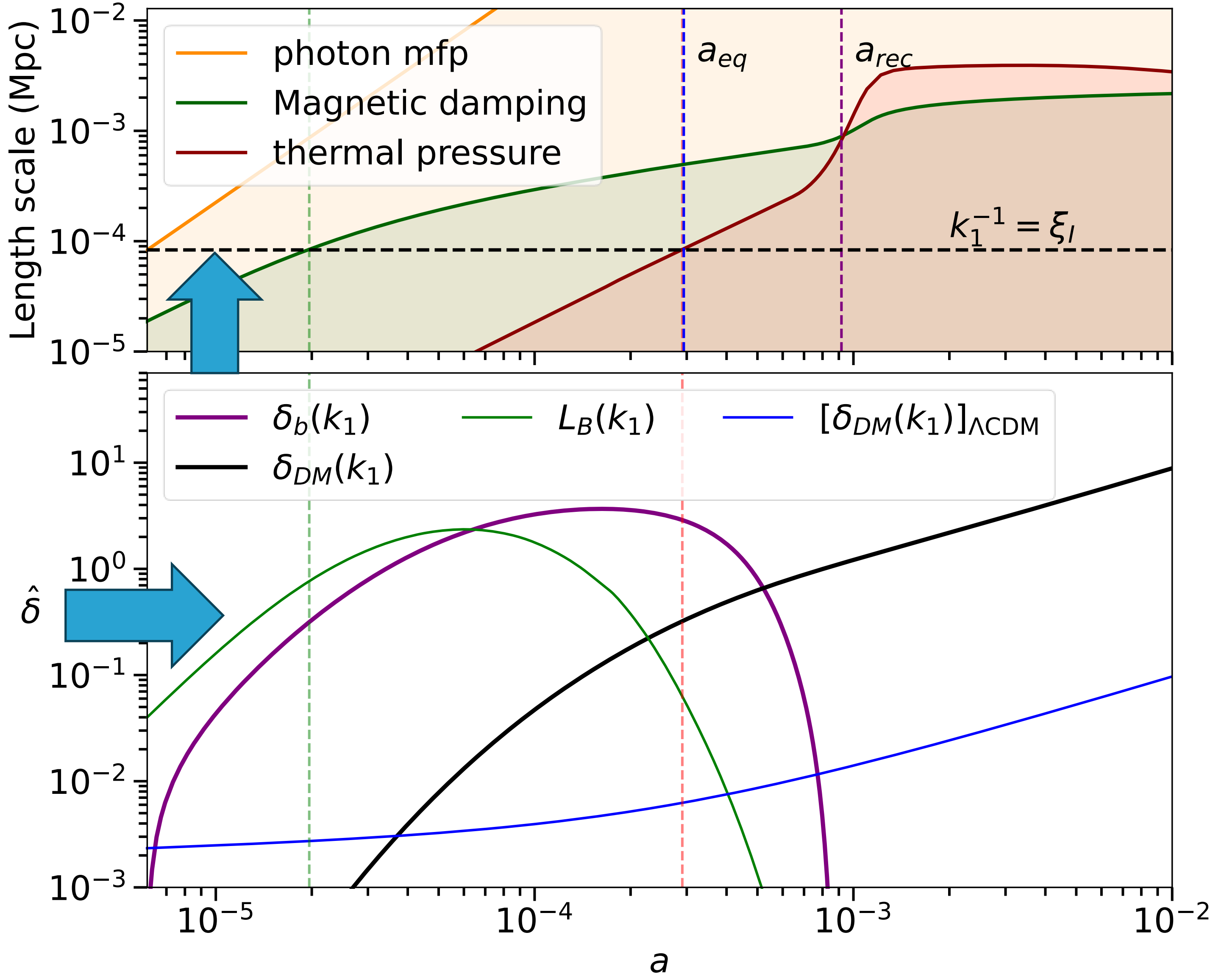
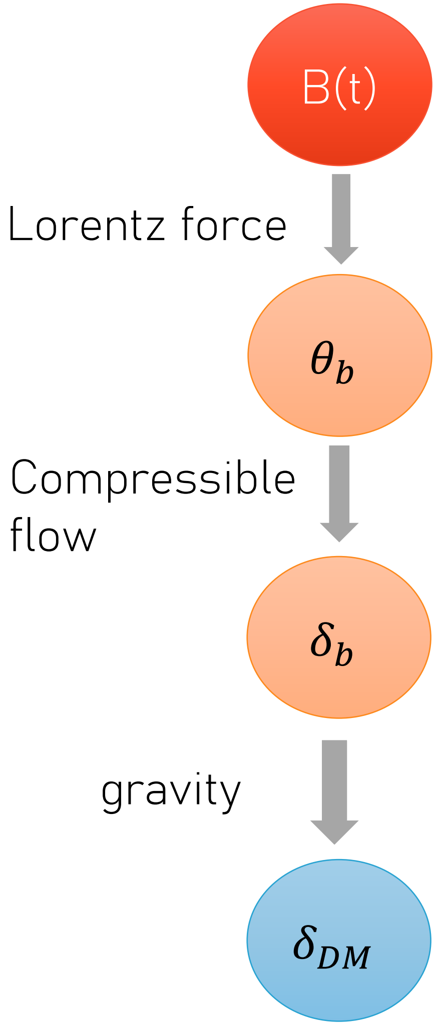




LORENTZ FORCE ENHANCES BARYON PERTURBATIONS FOR MODES OUTSIDE k_D^{-1}

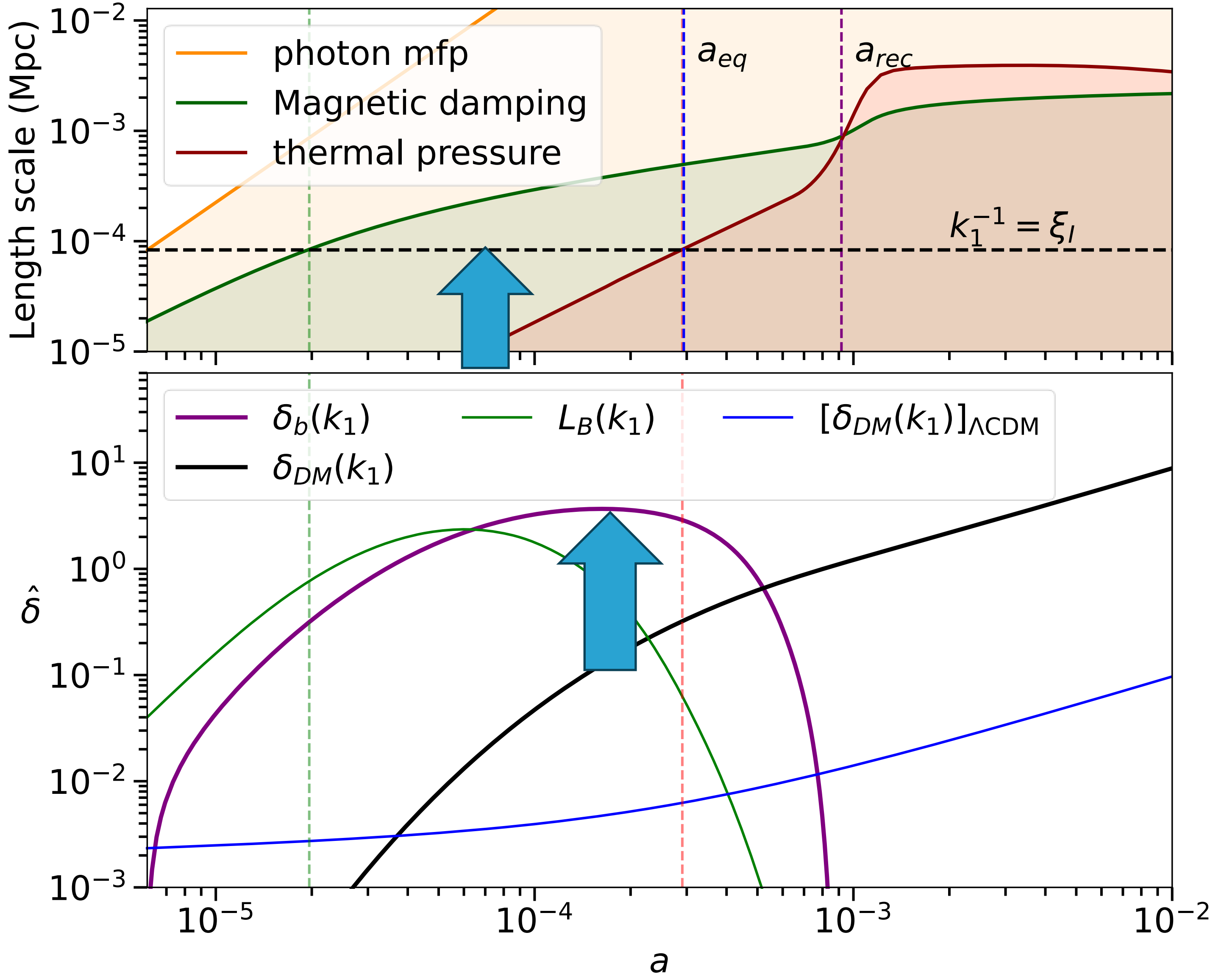
$B_I = 5$ nG

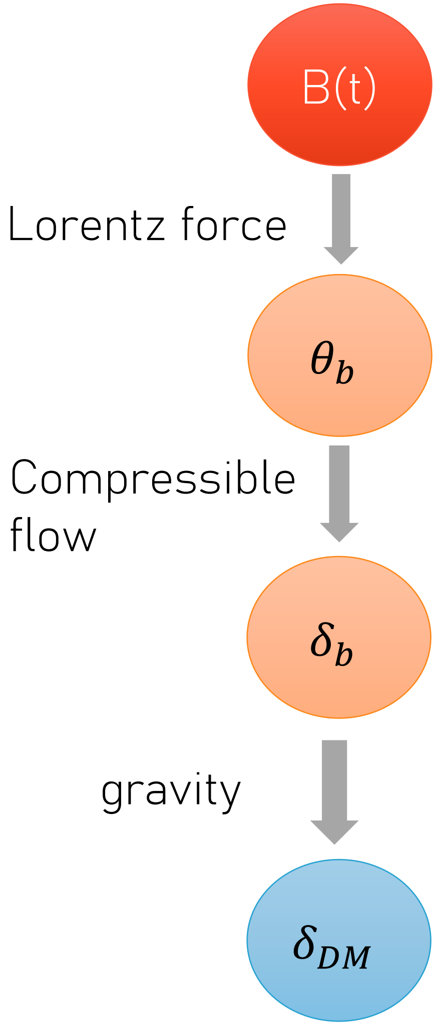




BARYON PERTURBATIONS ASYMPTOTE ONCE MODE ENTERS k_D^{-1}

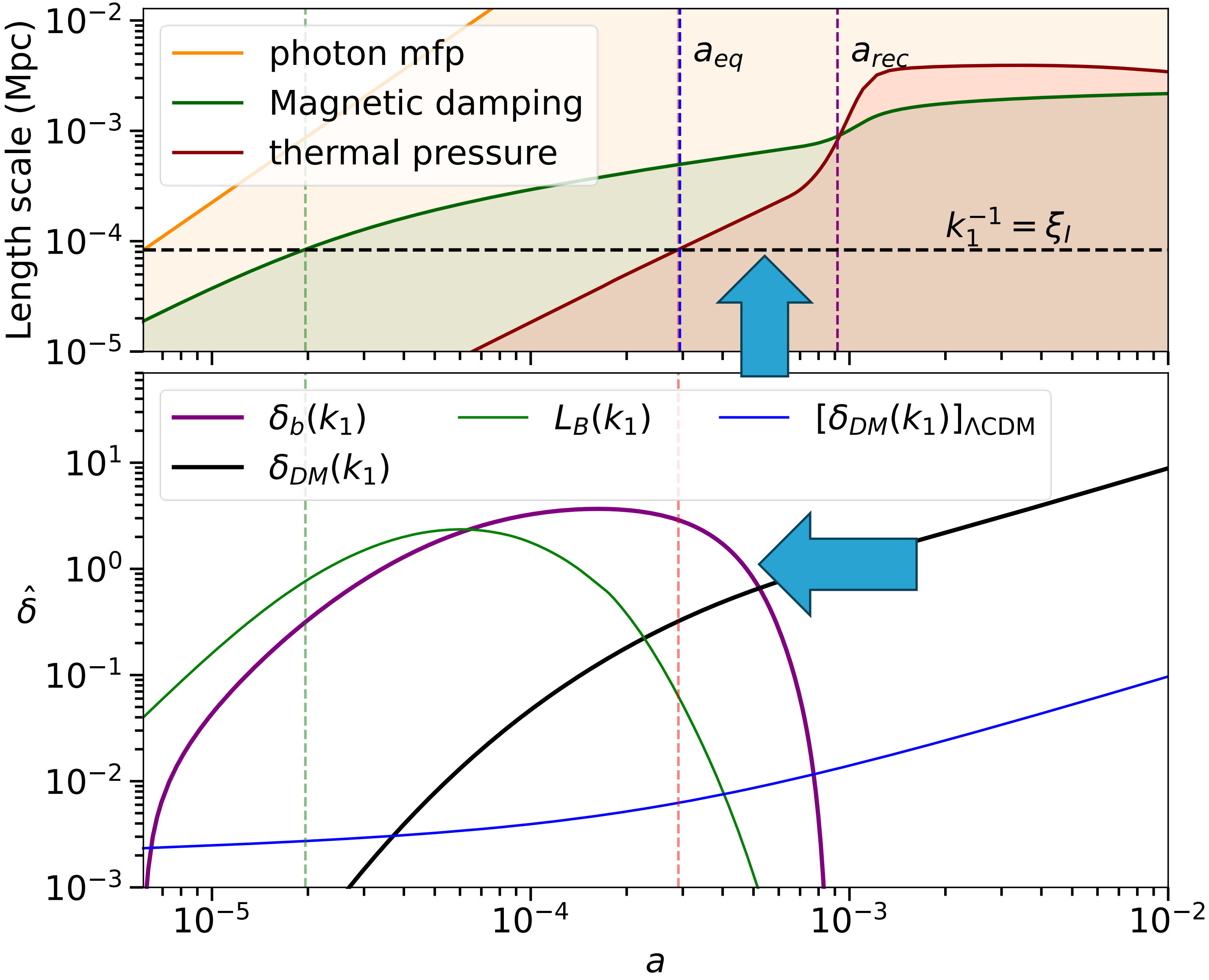
$B_I = 5$ nG

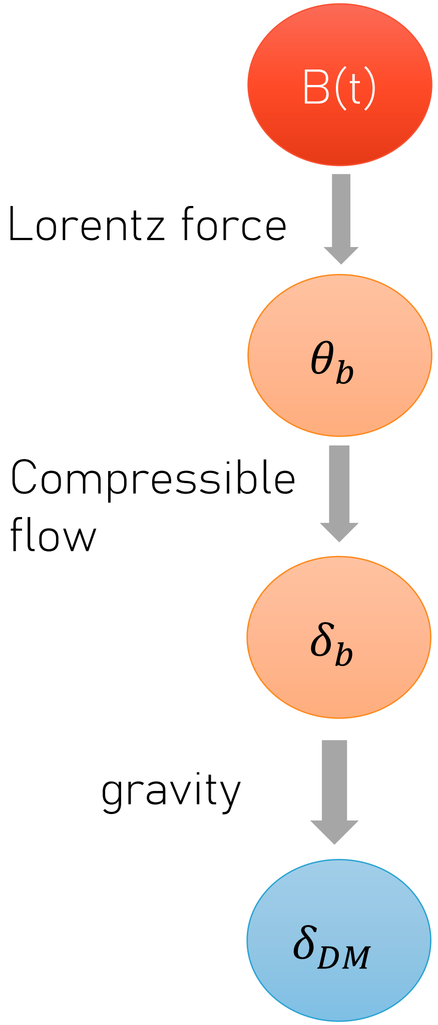




BARYON PERTURBATIONS DAMPED BY THERMAL PRESSURE

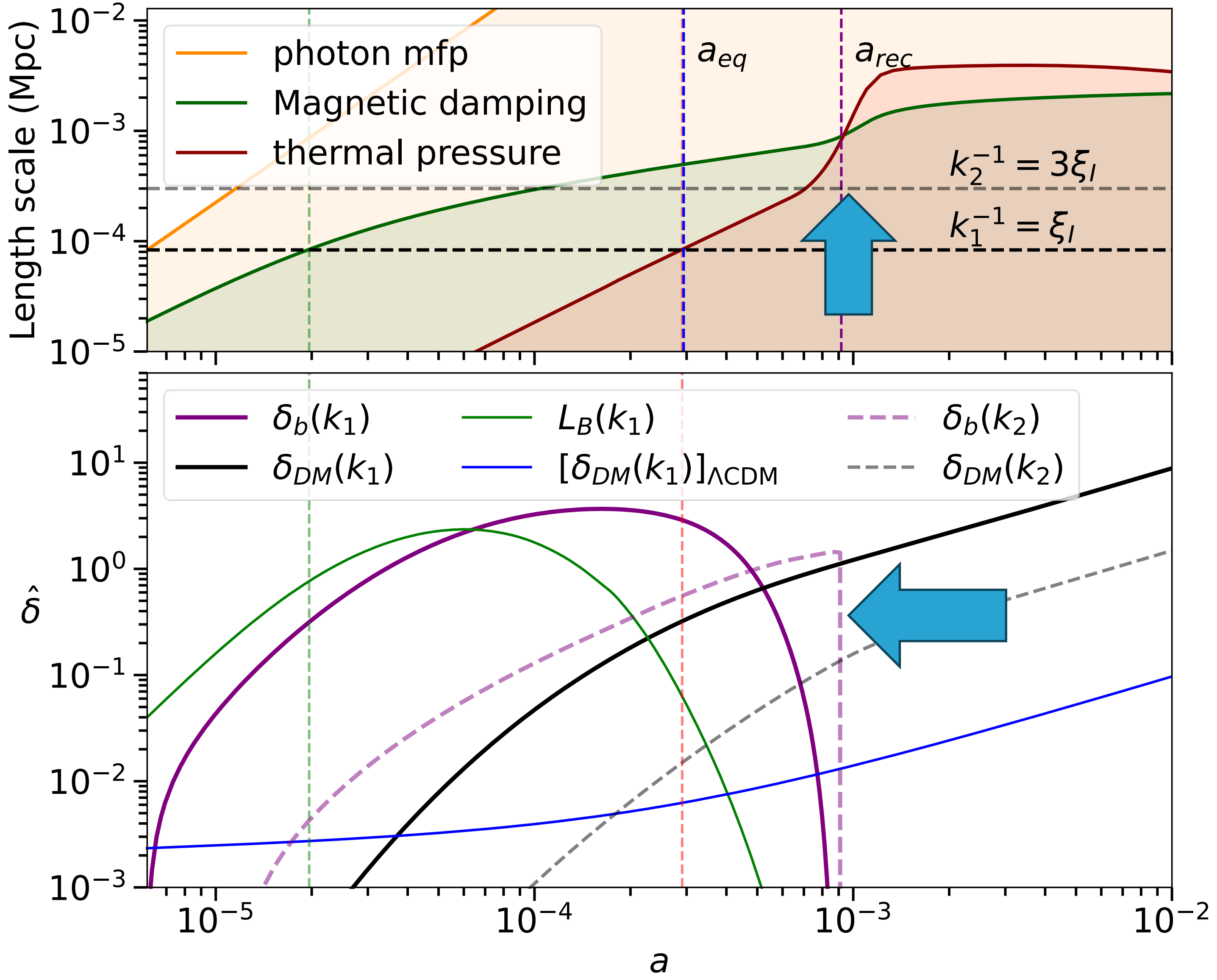
$B_I = 5$ nG

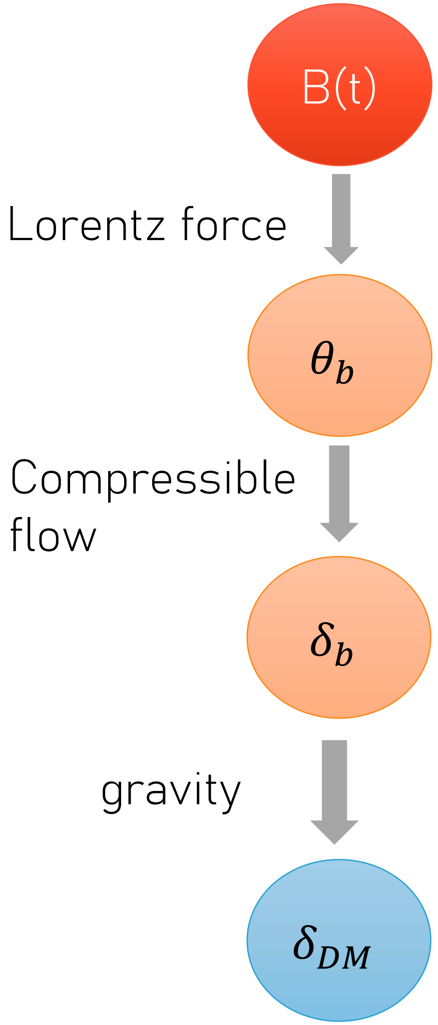




BARYON PERTURBATIONS DAMPED BY TURBULENCE AT RECOMBINATION

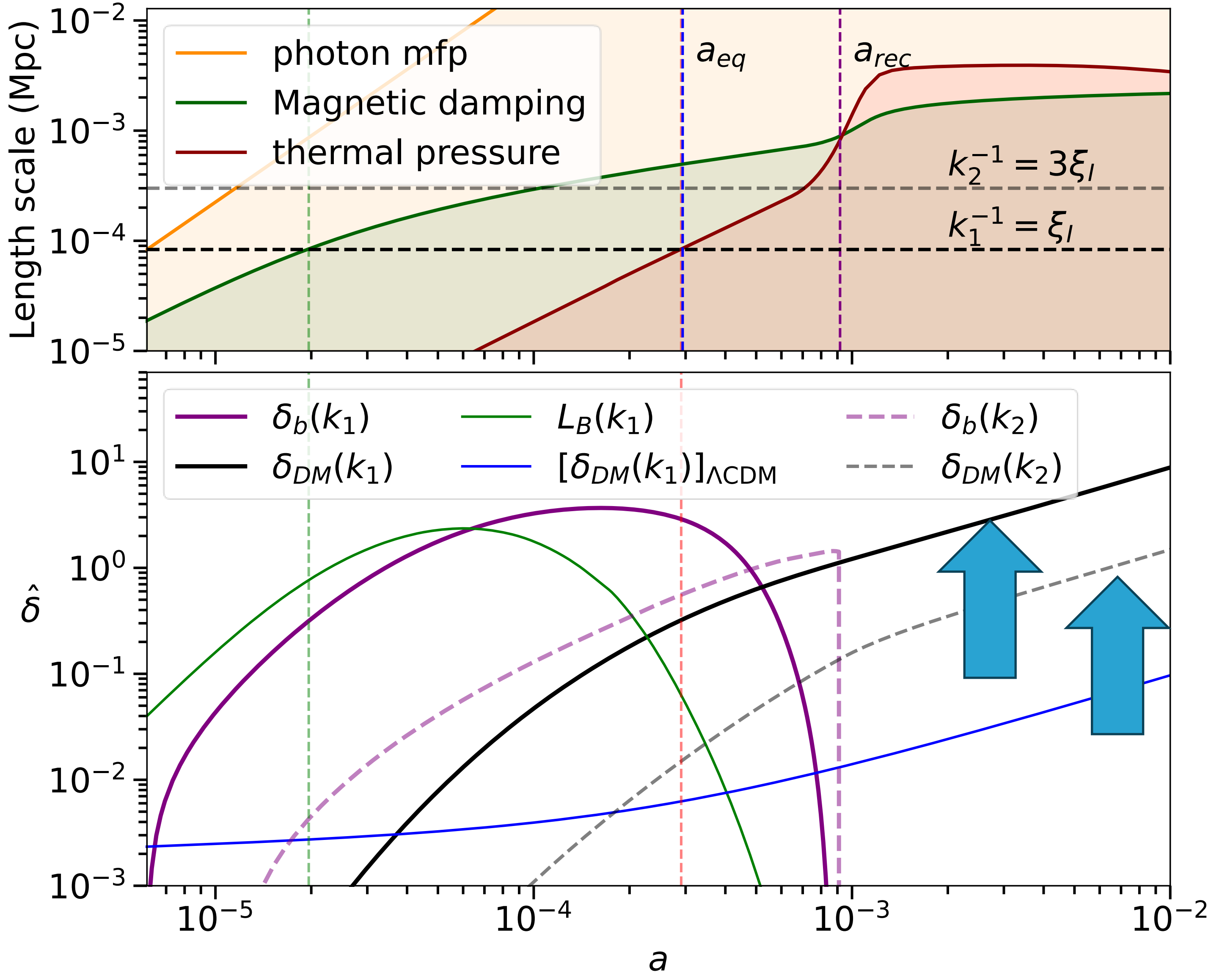
$B_I = 5$ nG

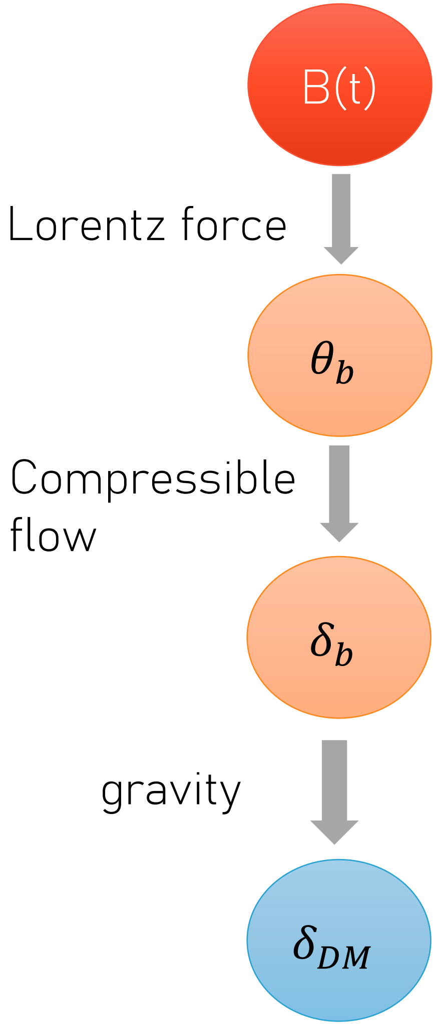




DARK MATTER PERTURBATIONS CONTINUES TO GROW!

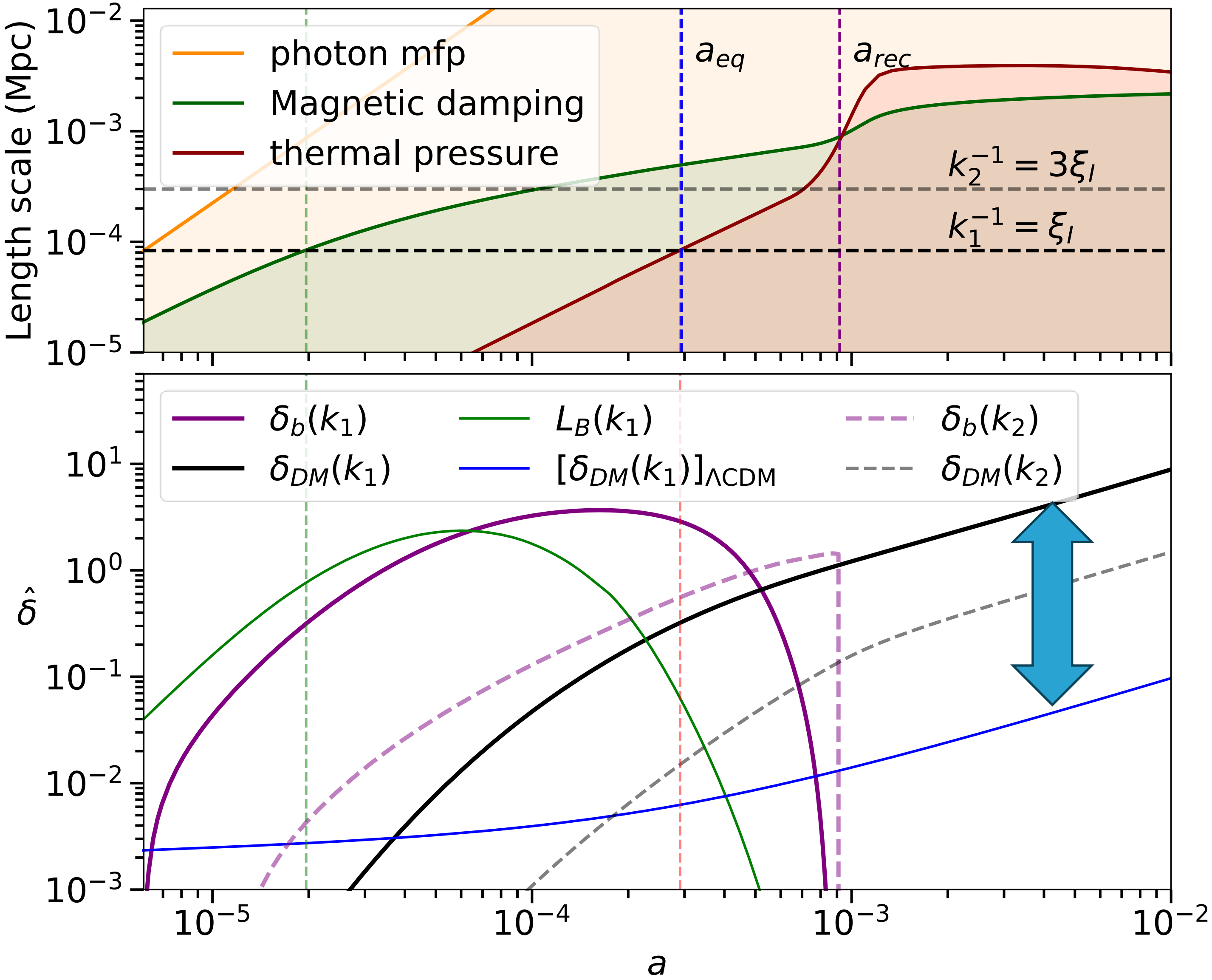
$B_I = 5$ nG

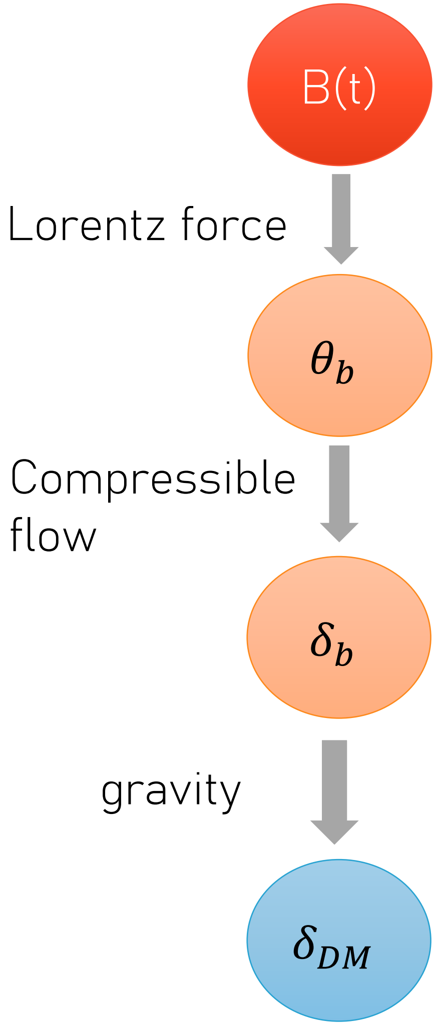




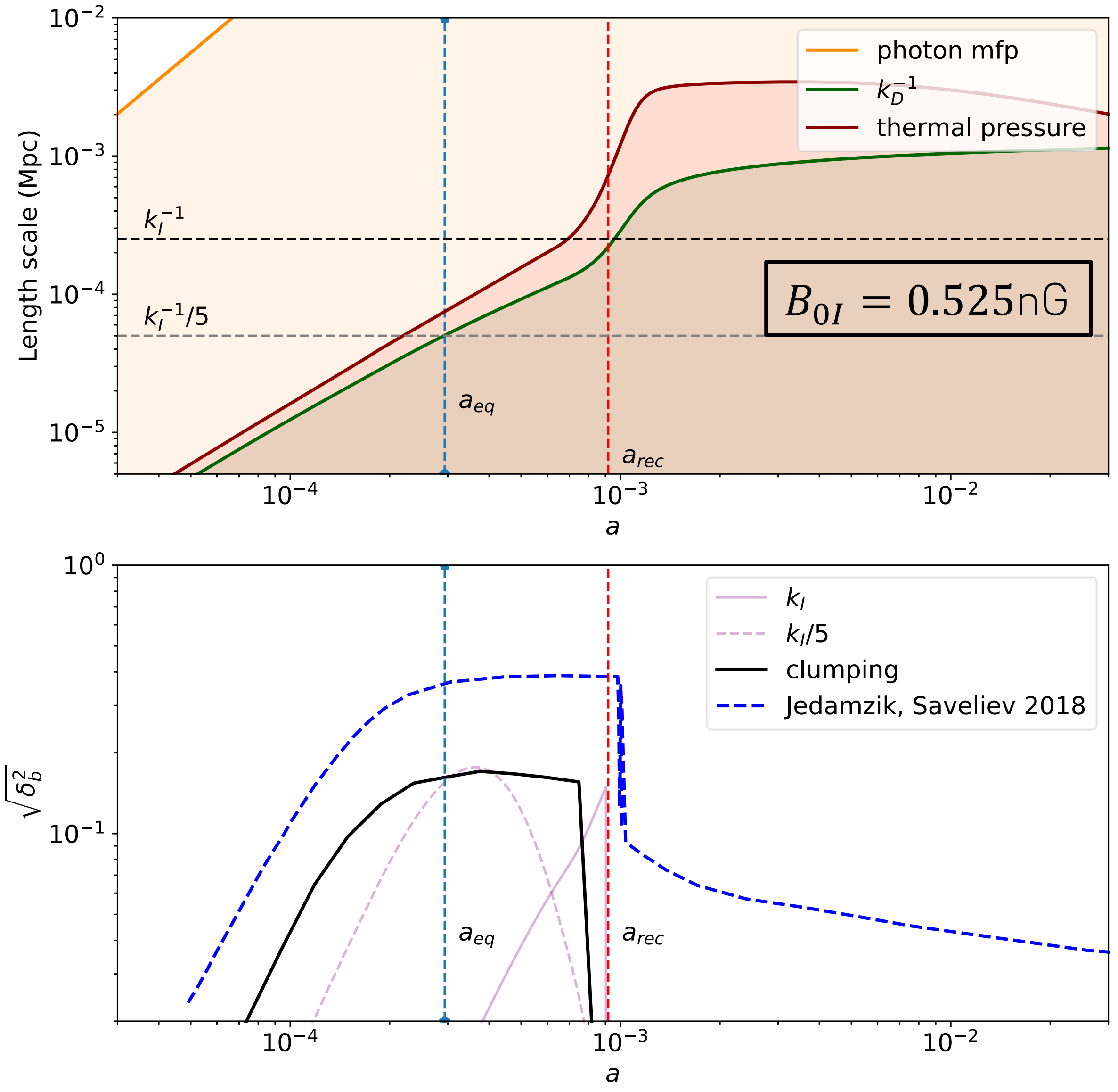
DARK MATTER PERTURBATIONS ENHANCED BY ORDERS OF MAGNITUDE COMPARED TO ΛCDM

$B_I = 5$ nG



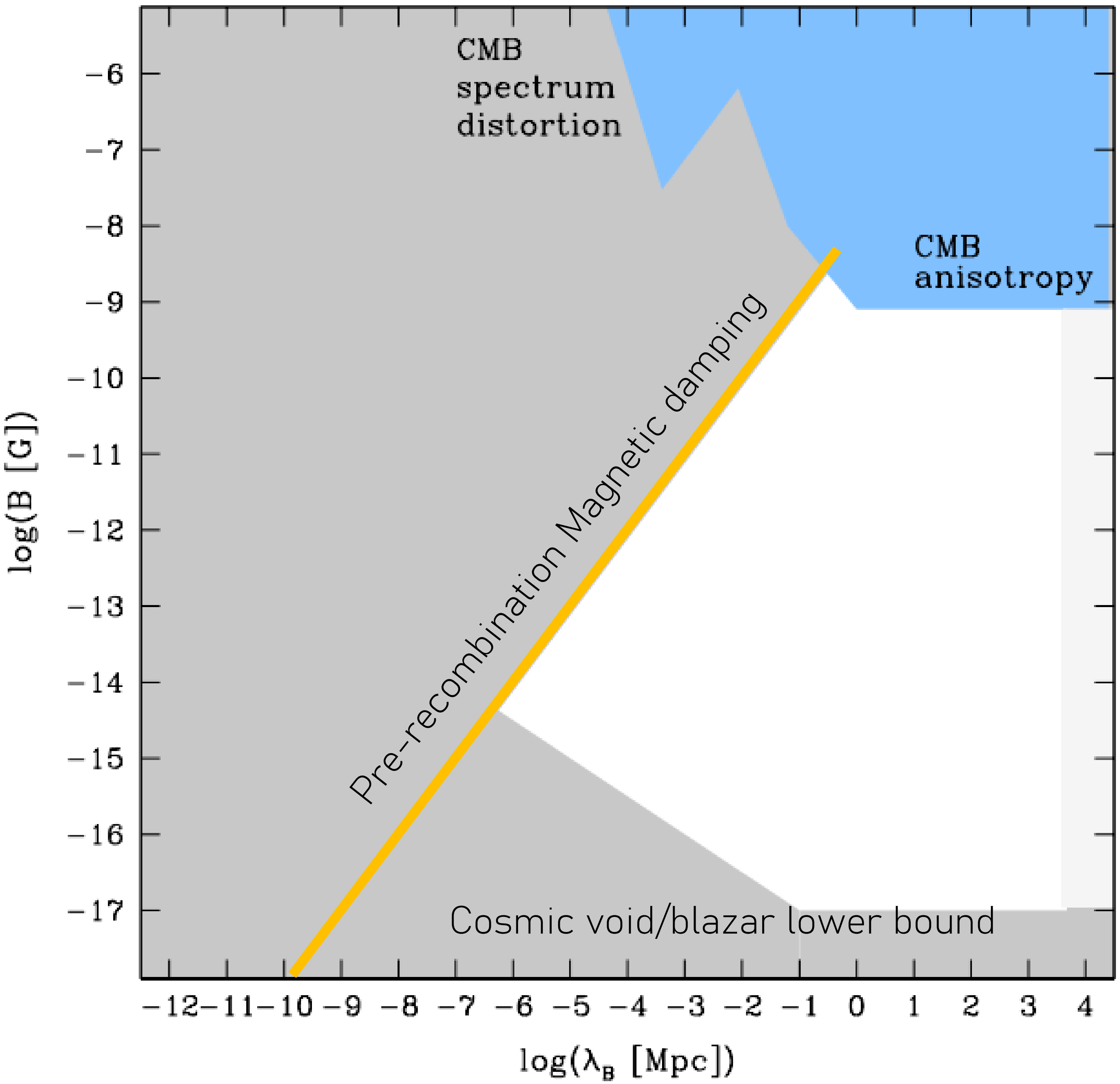


COMPARING WITH SIMULATIONS: ANALYTICAL NOT THAT BAD

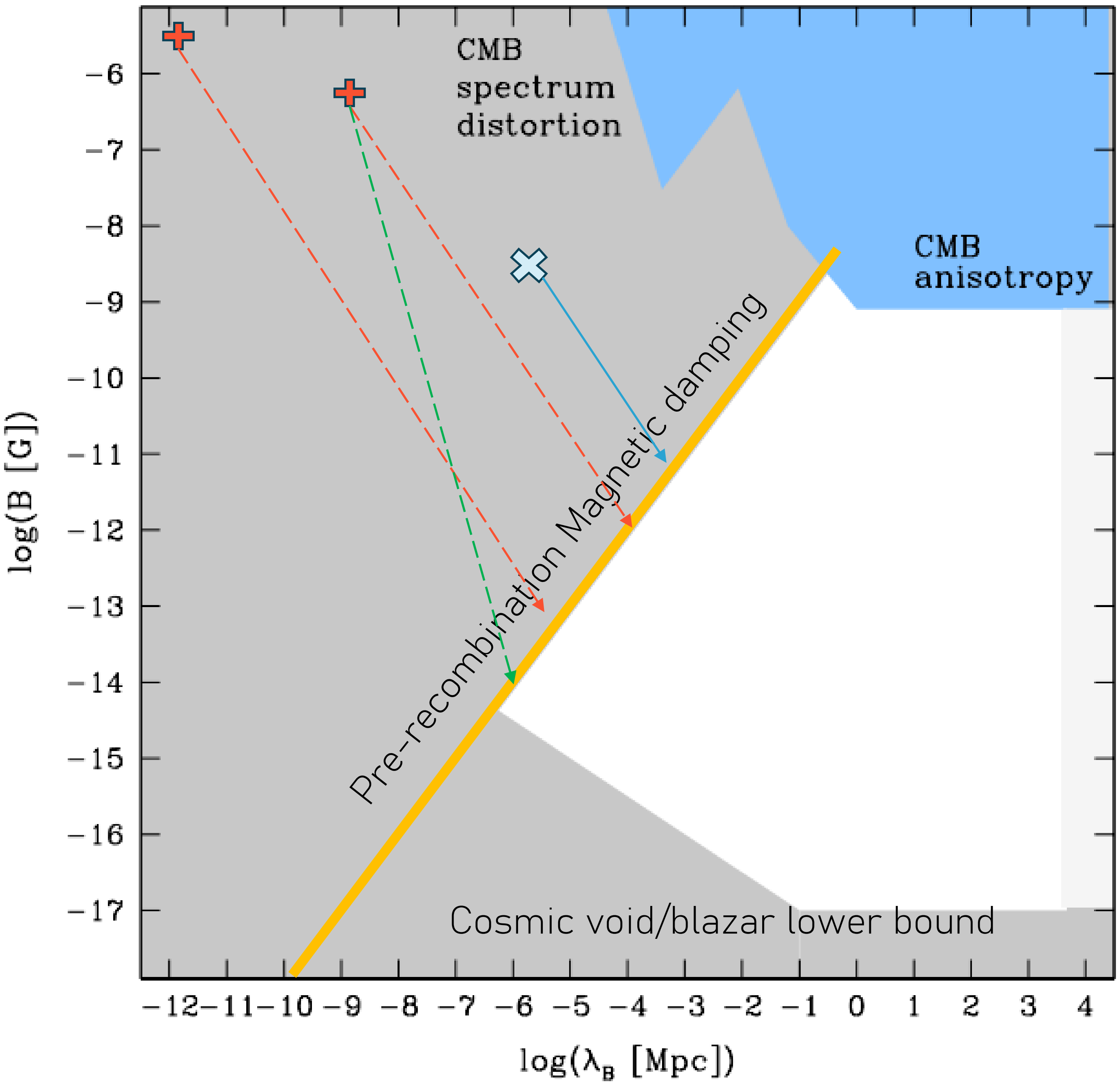


CONSTRAINTS ON PMF

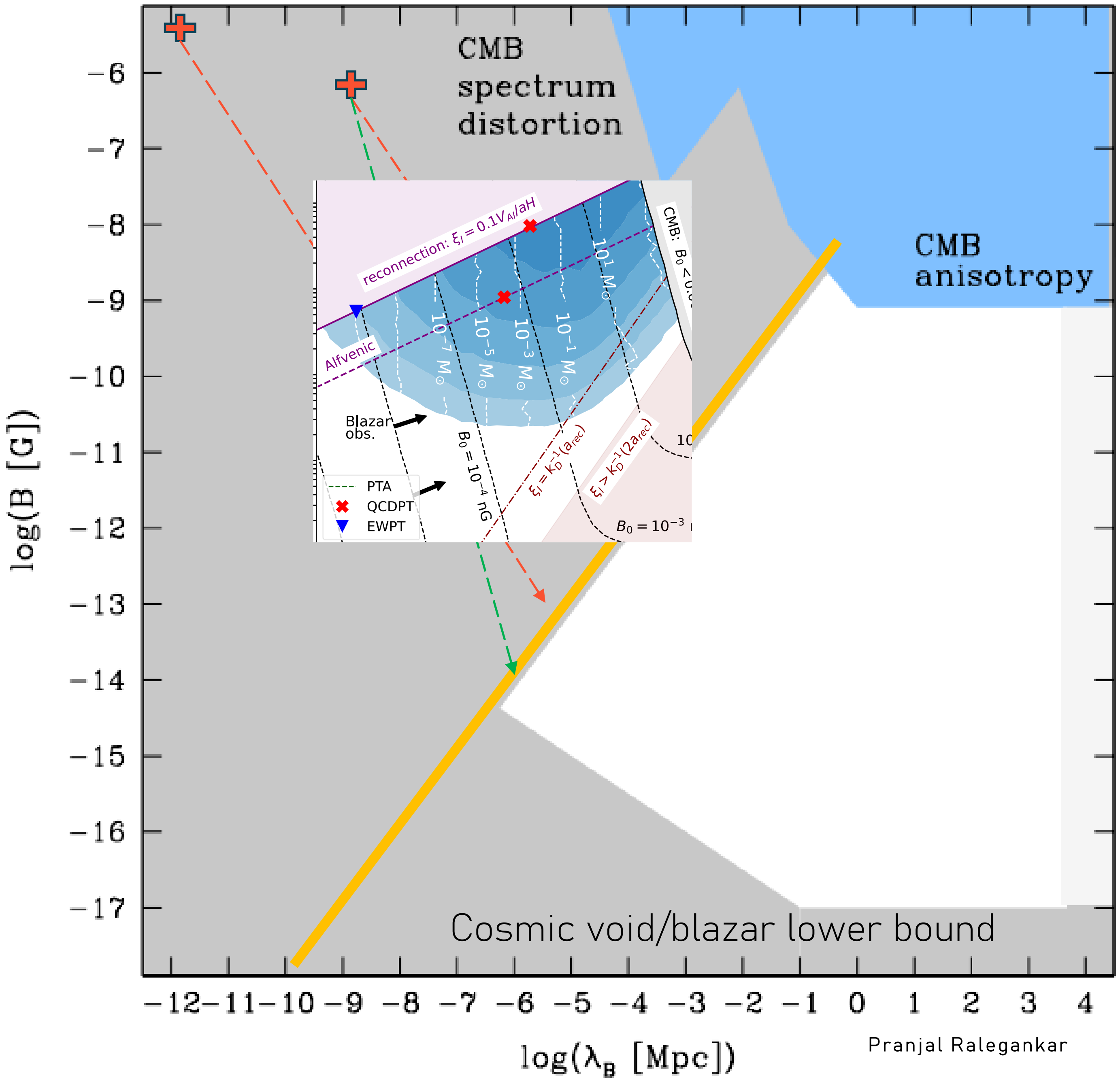
Durrer and Neronov 2013



EVOLUTION OF EARLY UNIVERSE PMFS

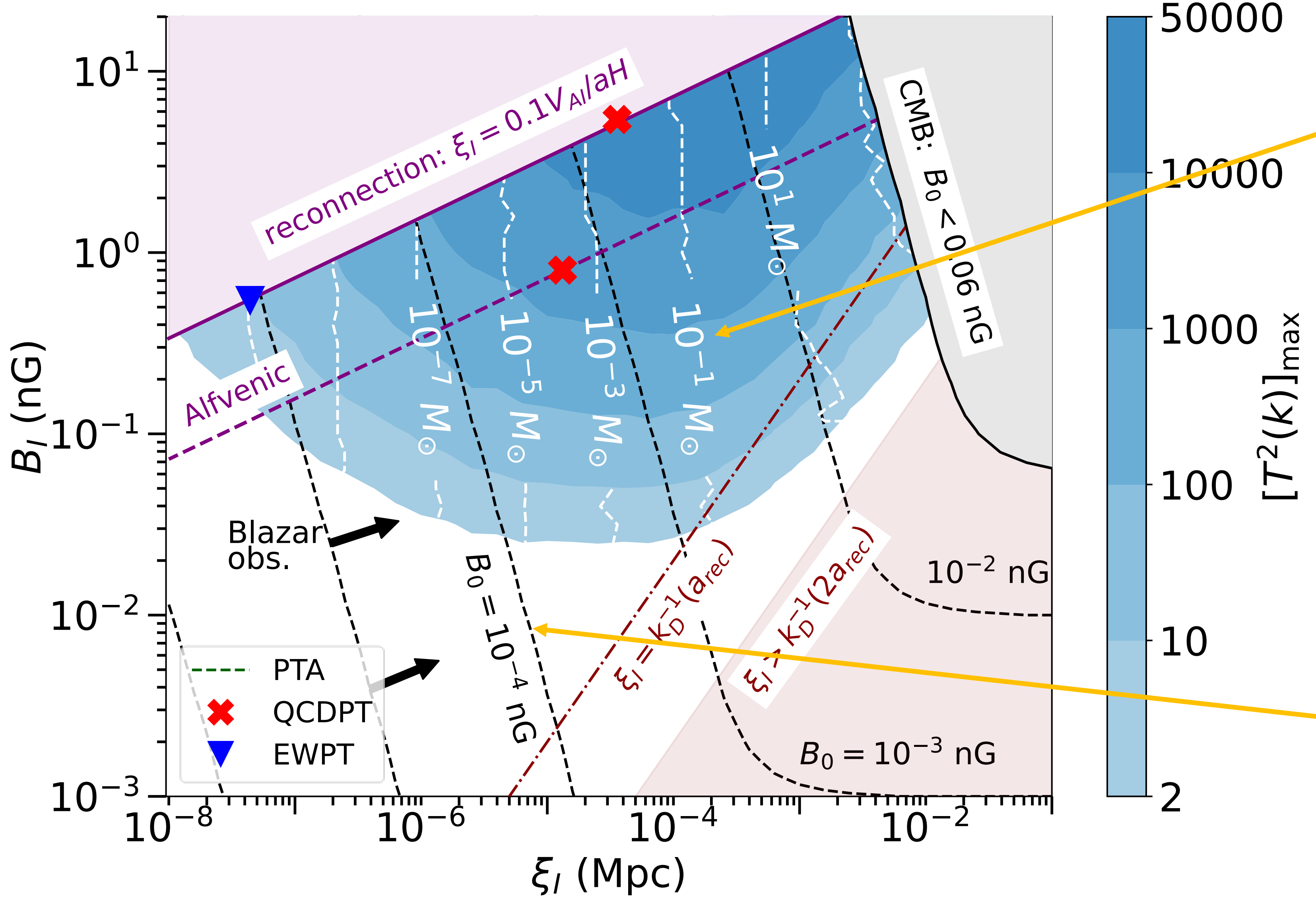


RELEVANCE OF DARK MATTER MINIHALO GENERATION



PARAMETER SPACE WITH ENHANCED POWER ON SMALL SCALES

Subscript I refers to the time at the beginning of laminar flow regime



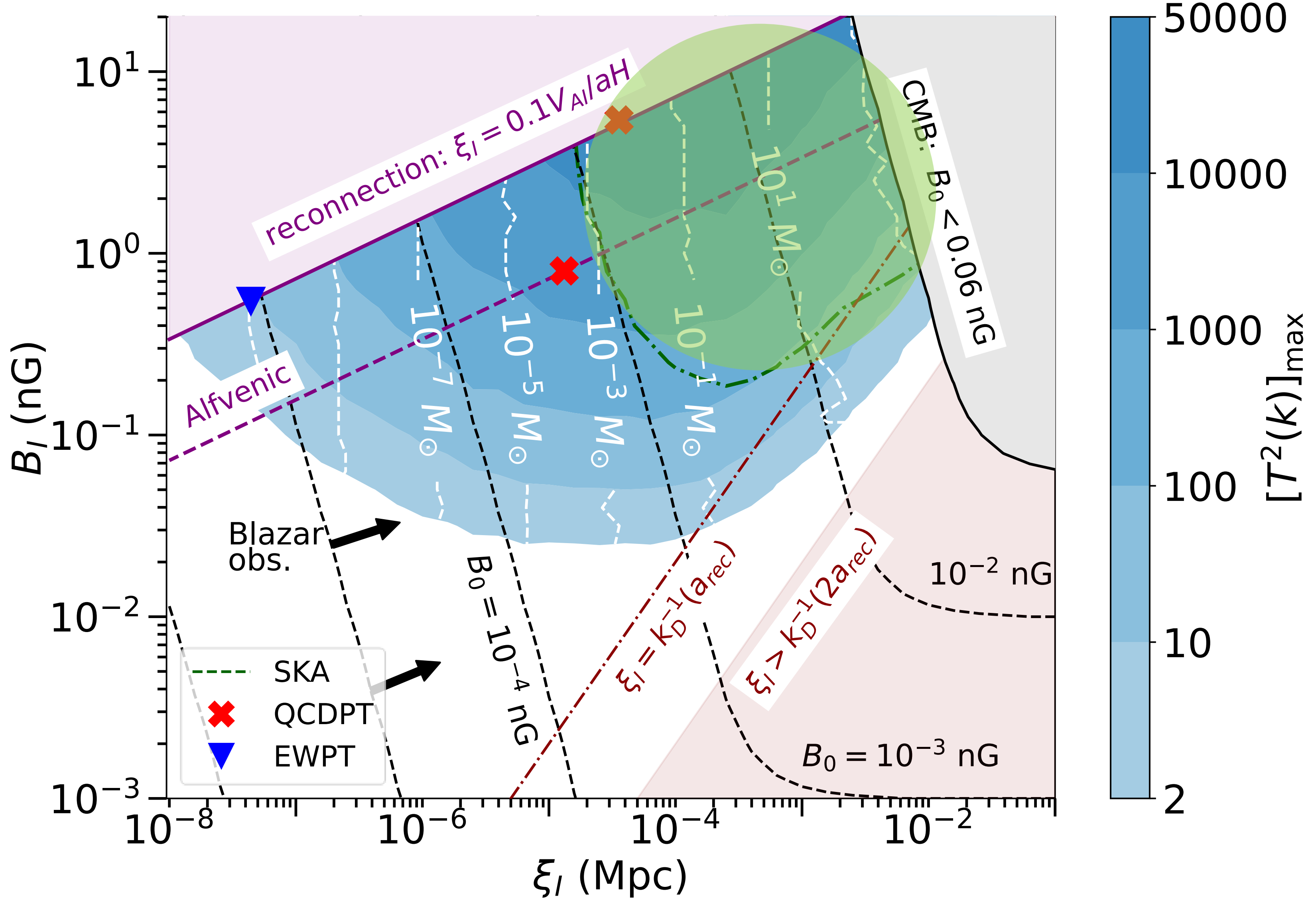
$= \frac{P(k)}{P_{\Lambda CDM}(k)}$

DM minihalo mass

Present-day magnetic field strength

PARAMETER SPACE WITH ENHANCED POWER ON SMALL SCALES: THEIA SKA SENSITIVITY

Subscript I refers to the time at the beginning of laminar flow regime



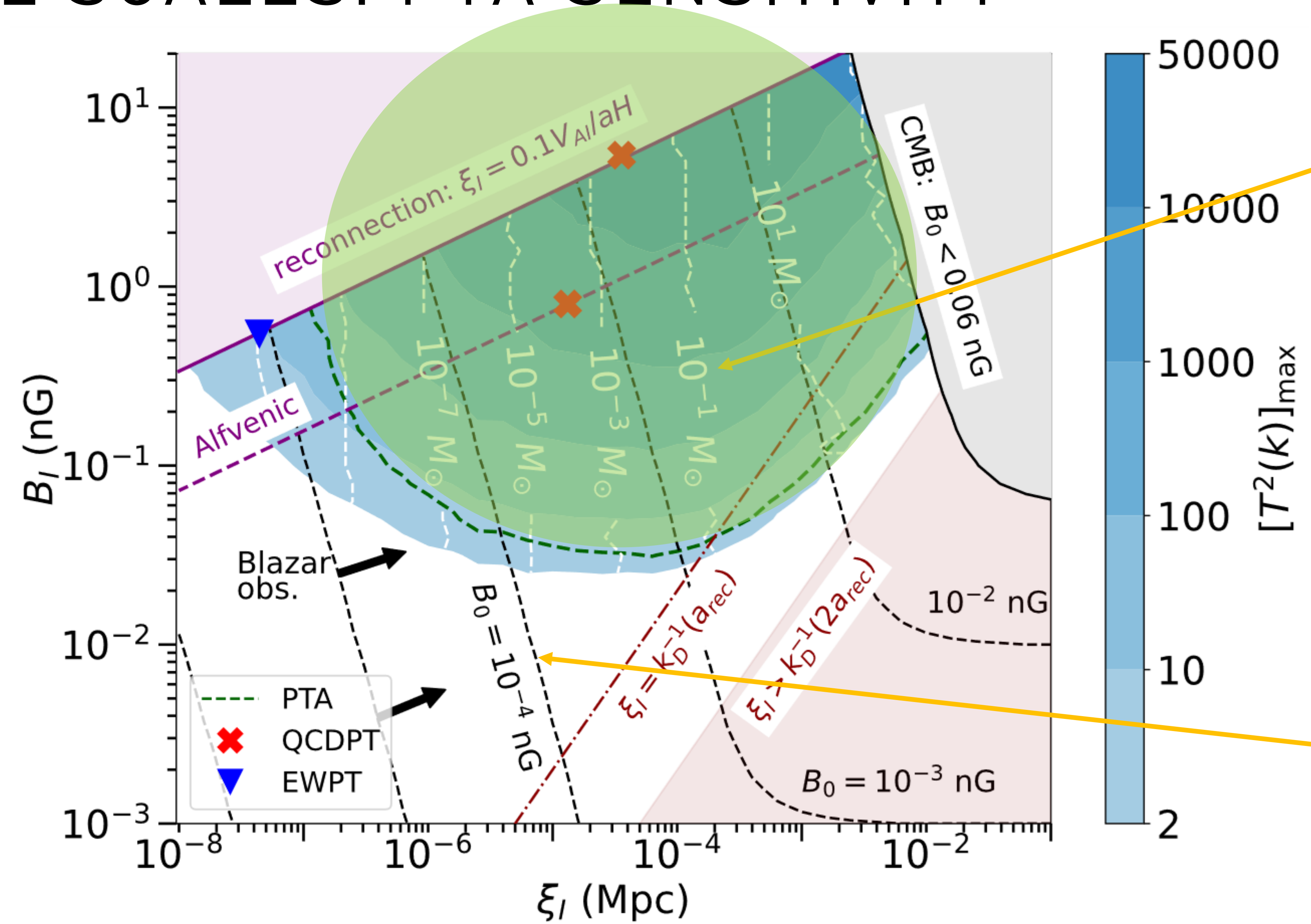
$= \frac{P(k)}{P_{\Lambda CDM}(k)}$

DM minihalo mass

Present-day magnetic field strength

PARAMETER SPACE WITH ENHANCED POWER ON SMALL SCALES: PTA SENSITIVITY

Subscript I refers to the time at the beginning of laminar flow regime

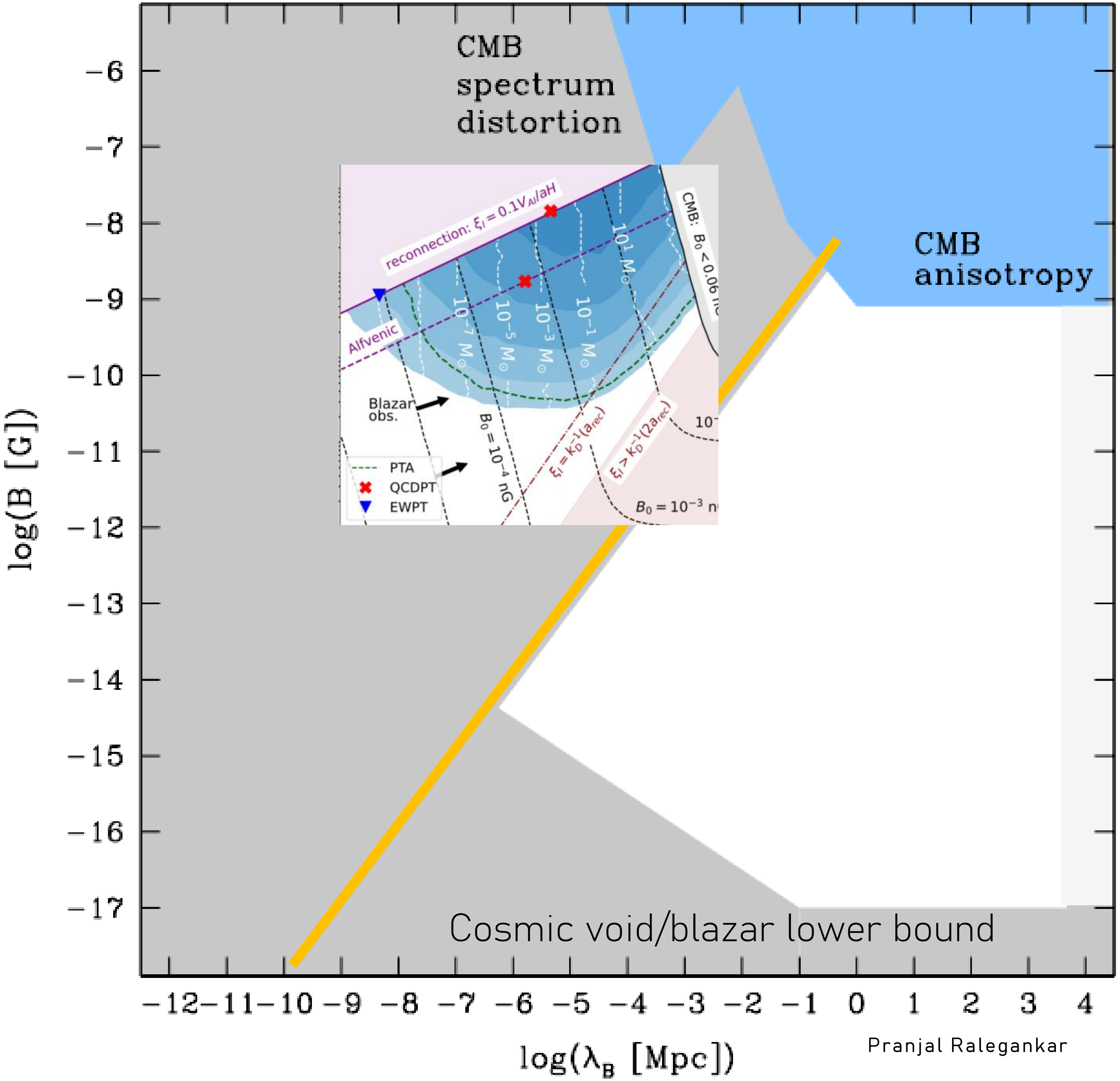


$$= \frac{P(k)}{P_{\Lambda CDM}(k)}$$

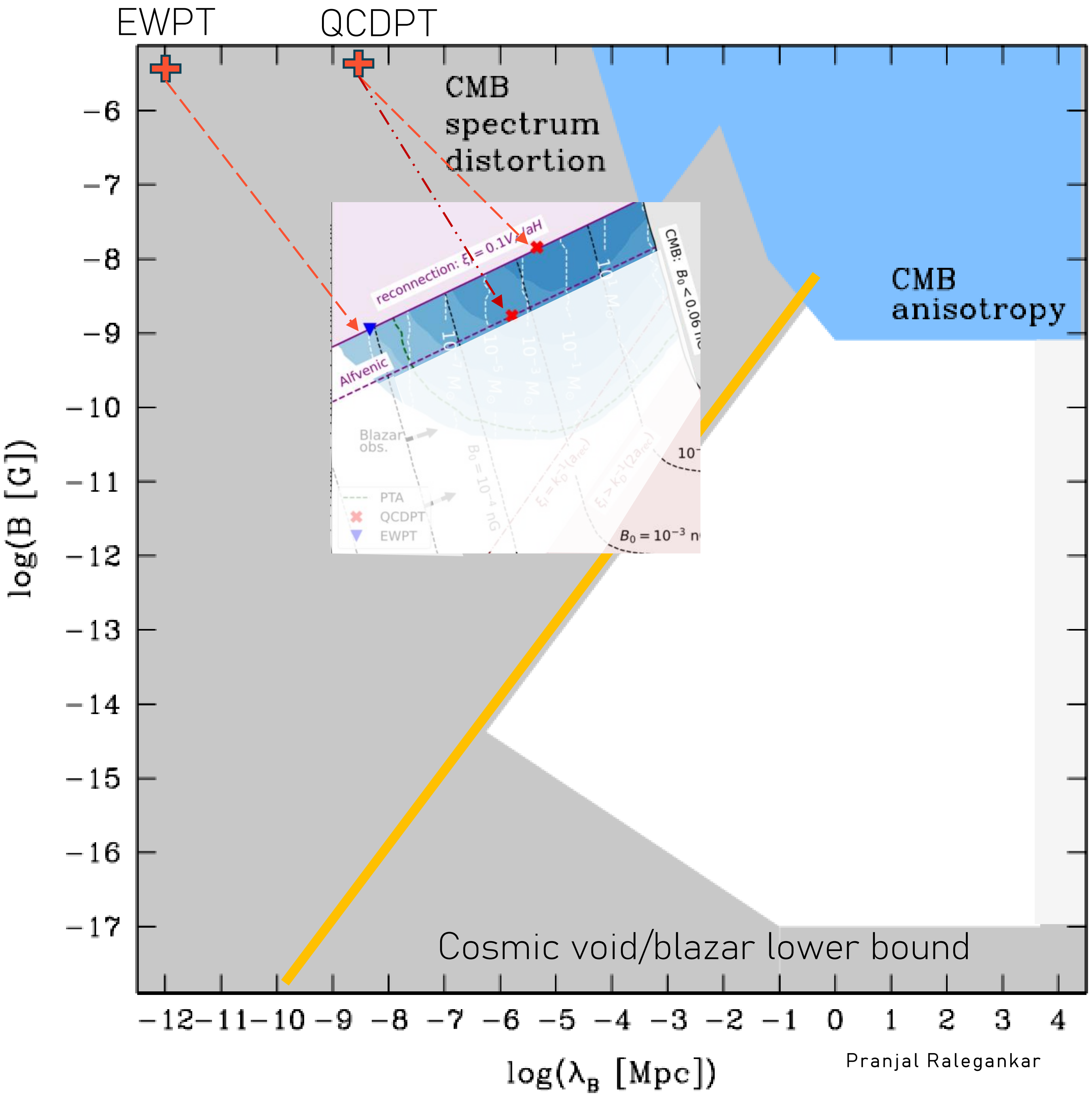
DM minihalo mass

Present-day magnetic field strength

MINIHALOS FROM CAUSALLY GENERATED PMFS

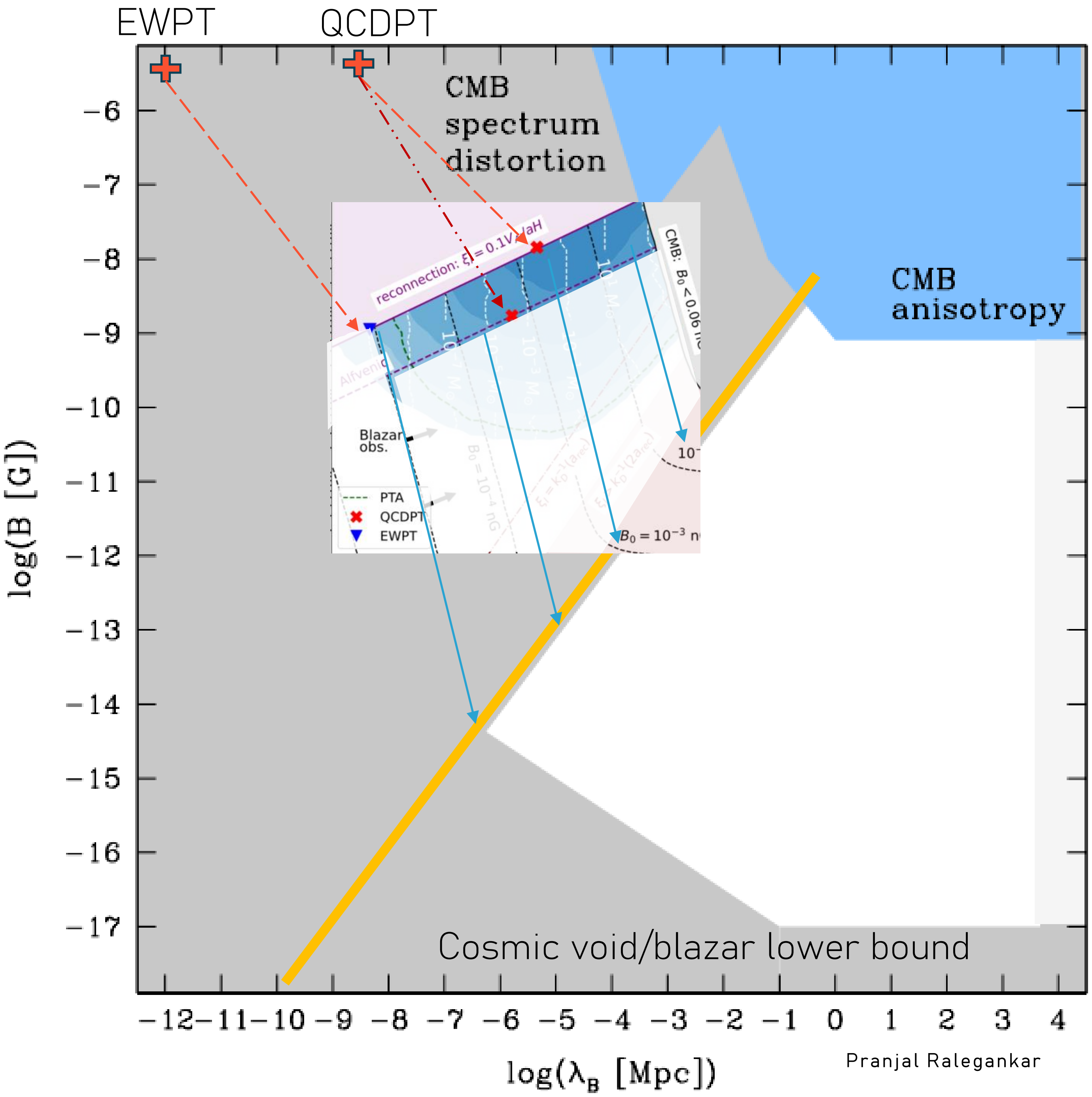


MINIHALOS FROM CAUSALLY GENERATED PMFS

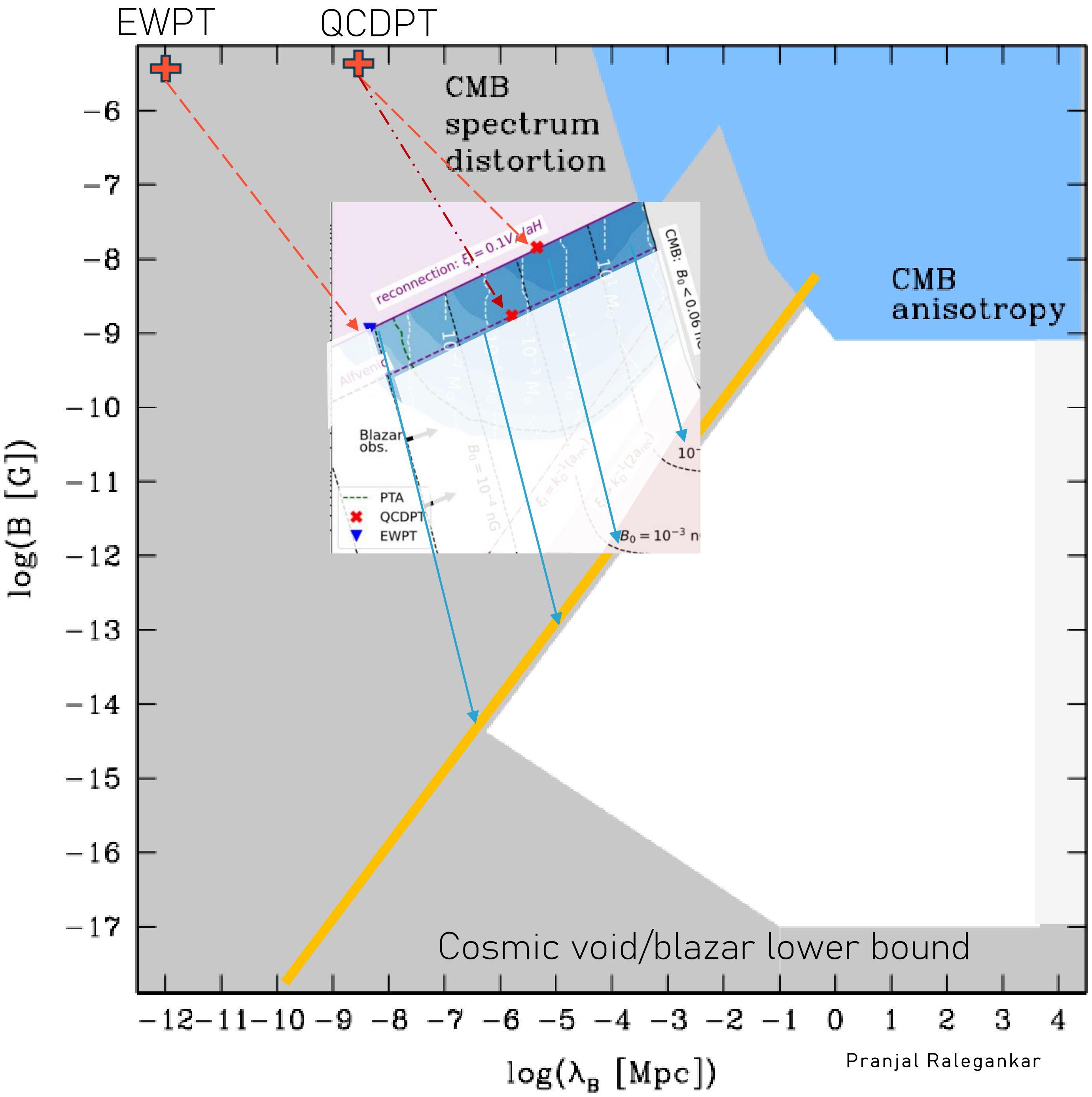


PMFS TO EXPLAIN COSMIC VOID OBSERVATIONS

Assuming Batchelor spectrum!



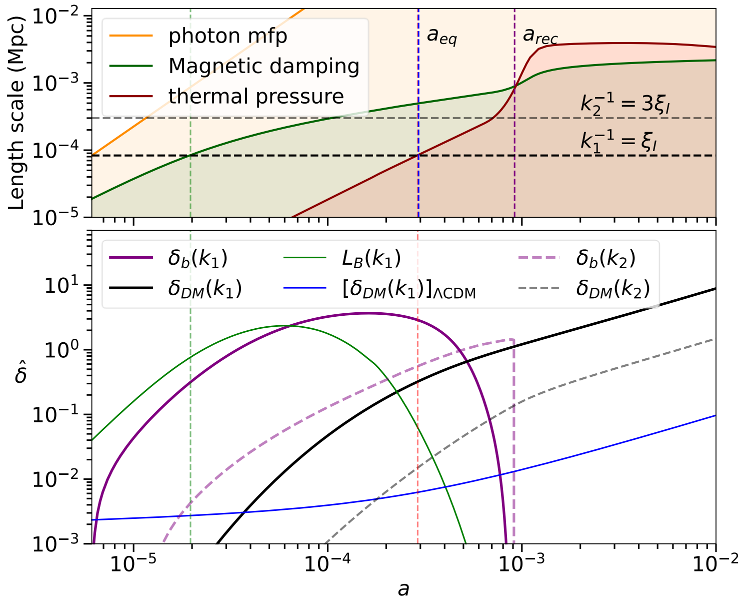
UNIVERSE MAYBE FILLED WITH DARK MATTER MINIHALOS!!

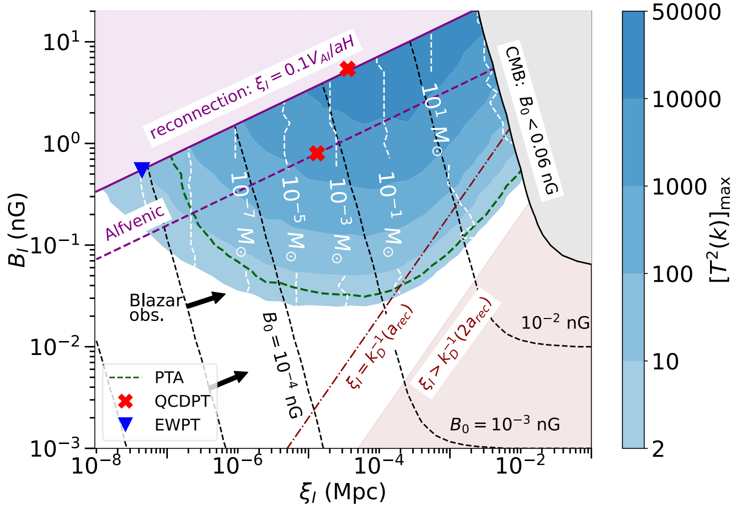


Assuming Batchelor spectrum!

SUMMARY AND CONCLUDING REMARKS

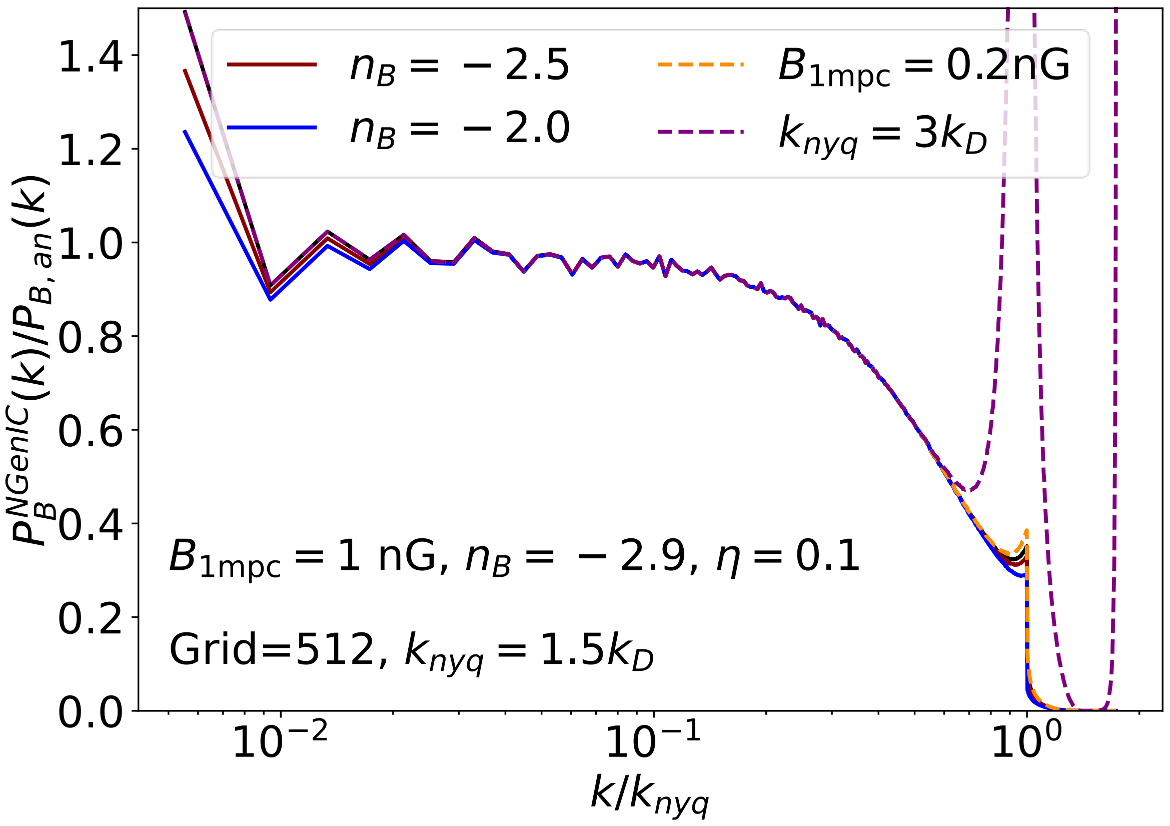
- Magnetic fields can enhance power dark matter power spectrum below magnetic Jeans scale.
- PTA/GAIA detection of DM minihalos can provide best probe of primordial magnetic fields
- Results are qualitative: Need MHD simulations to get accurate quantitative answers.
- Ironic: how invisible dark matter can help look for visible entity: magnetic fields

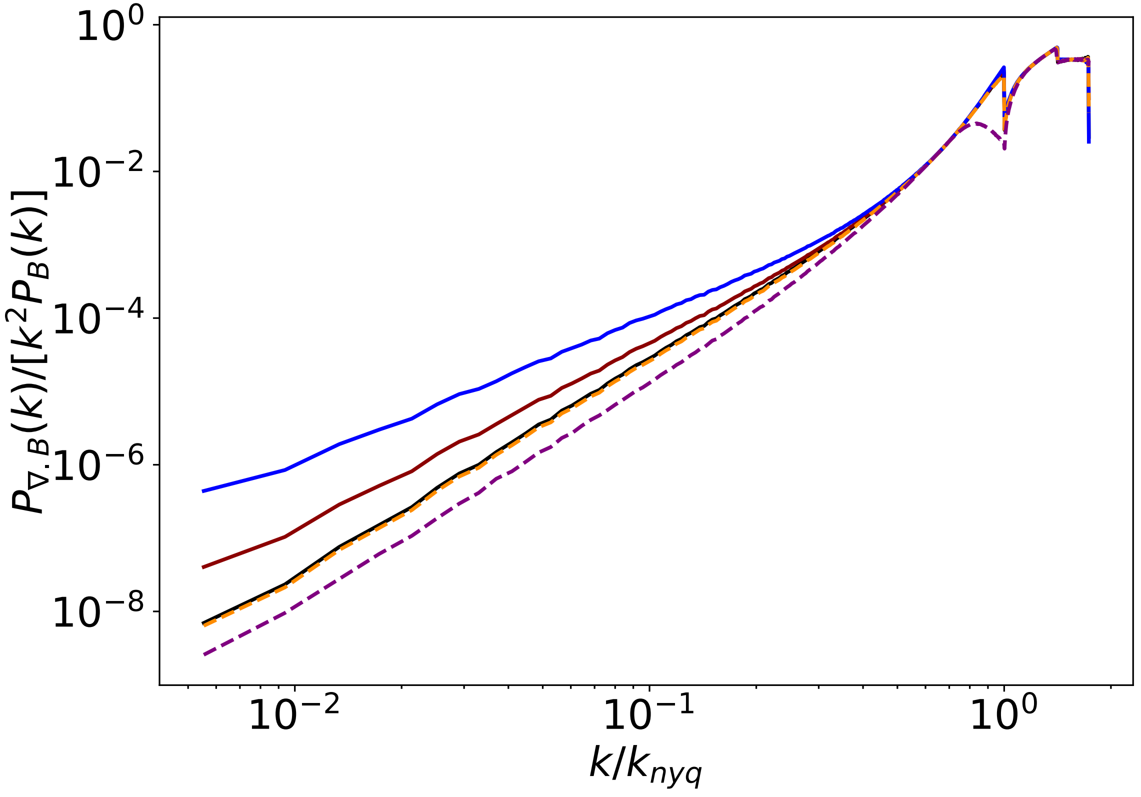




PROBLEM WITH LORENTZ FORCE IN MY LATTICE

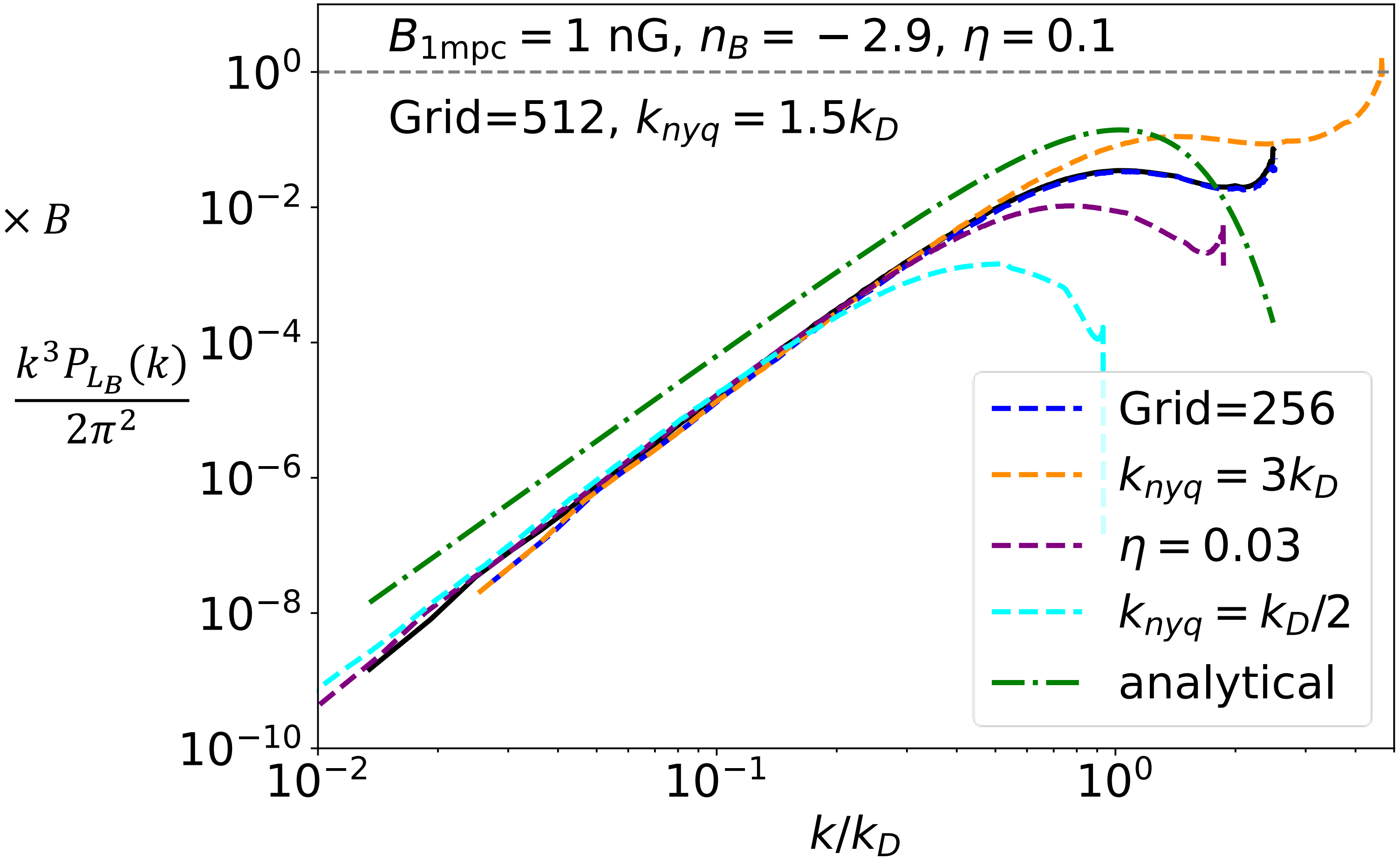
INITIALIZING STOCHASTIC PMFS ON LATTICE



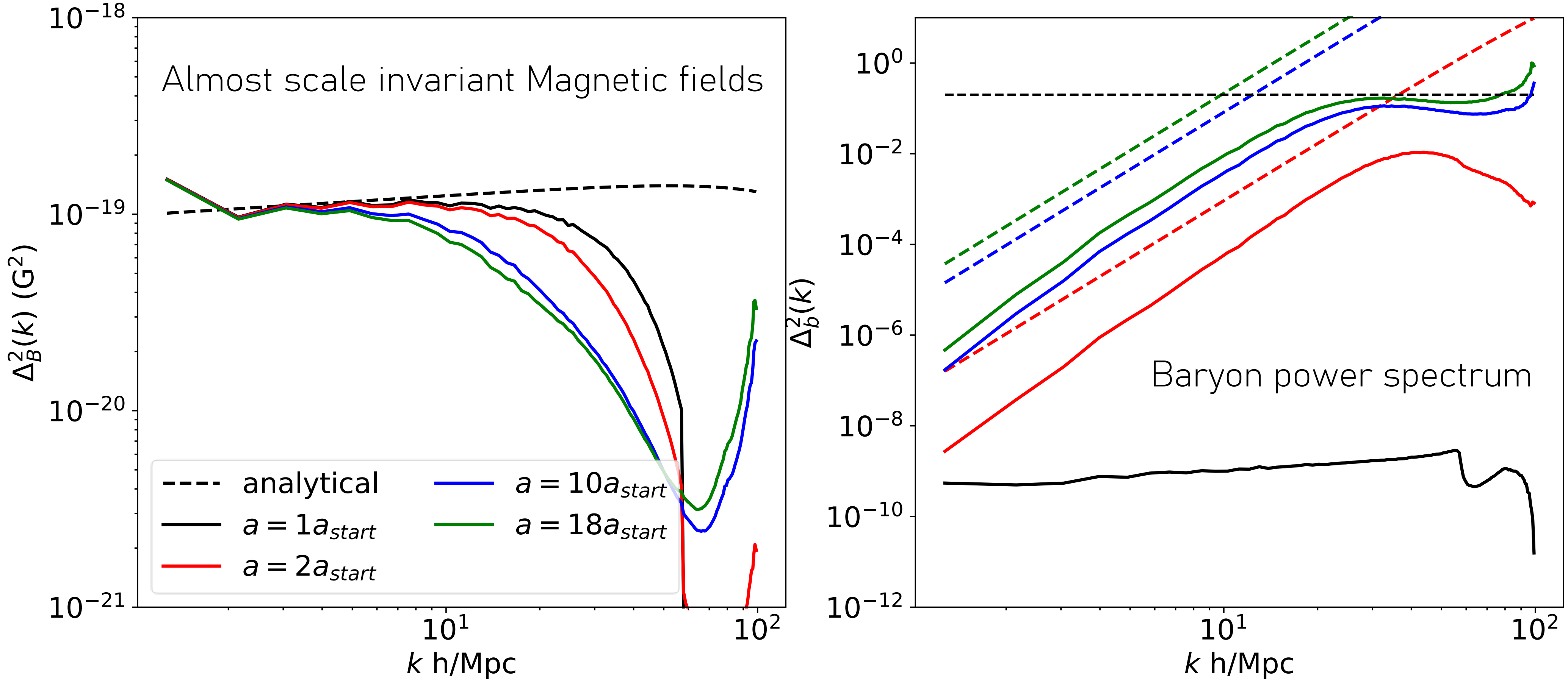


LORENTZ FORCE POWER SPECTRUM DOESN'T AGREE WITH THEORY

$L_B \propto \nabla.(\nabla \times B) \times B$



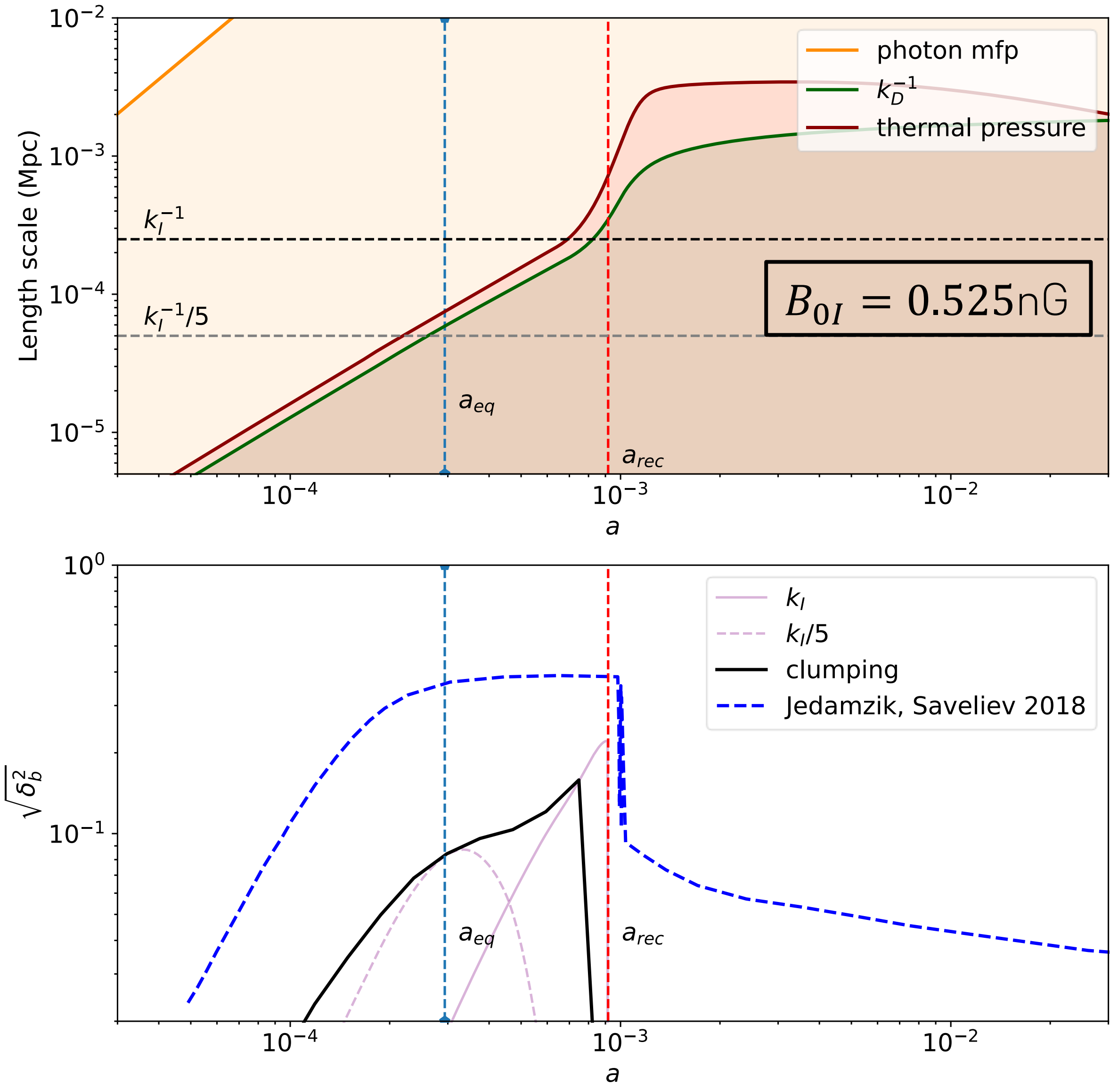
THE SUPPRESSION OF POWER IS ALSO SEEN IN AREPO (PRELIMINARY!!)



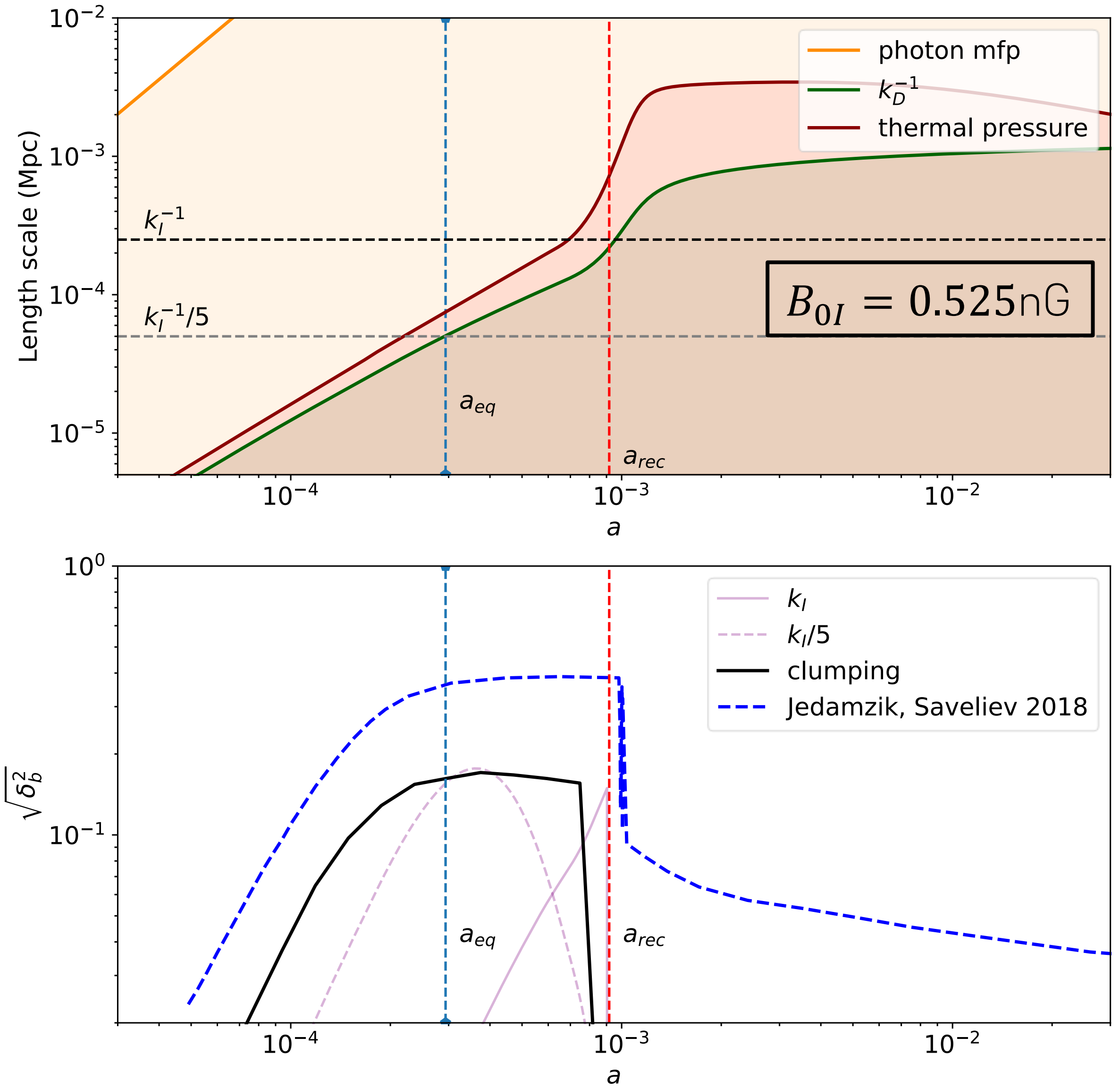
BACKUP SLIDES

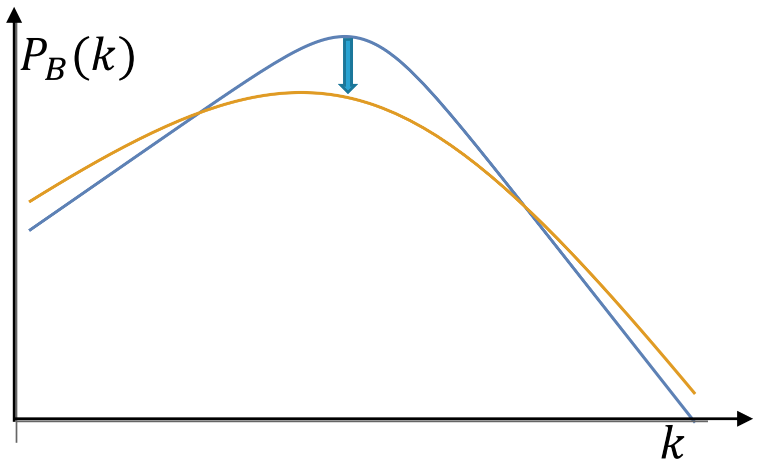
COMPARING WITH FULL MHD SIMULATIONS

COMPARING WITH SIMULATIONS: SENSITIVE TO INITIAL POWER SPECTRUM

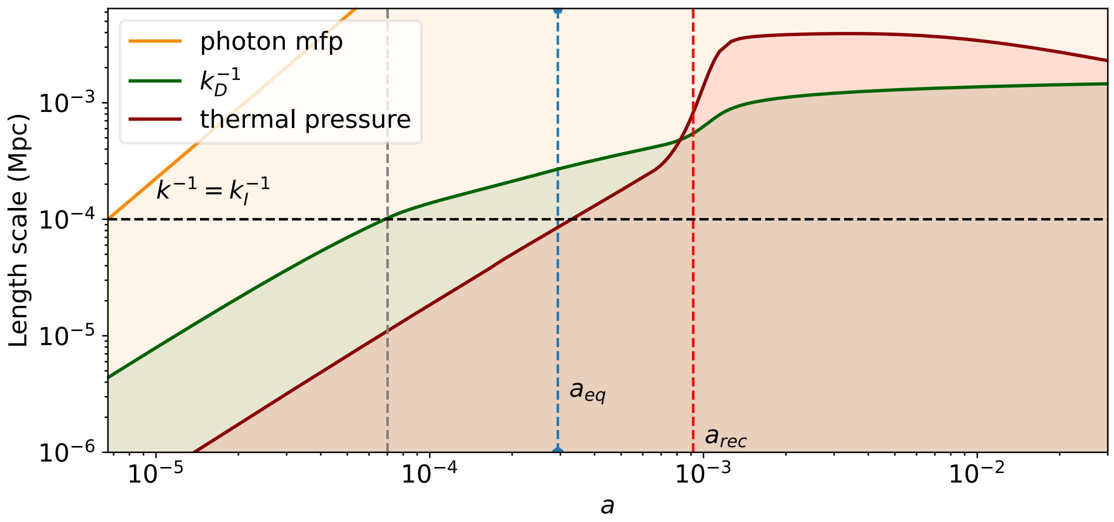


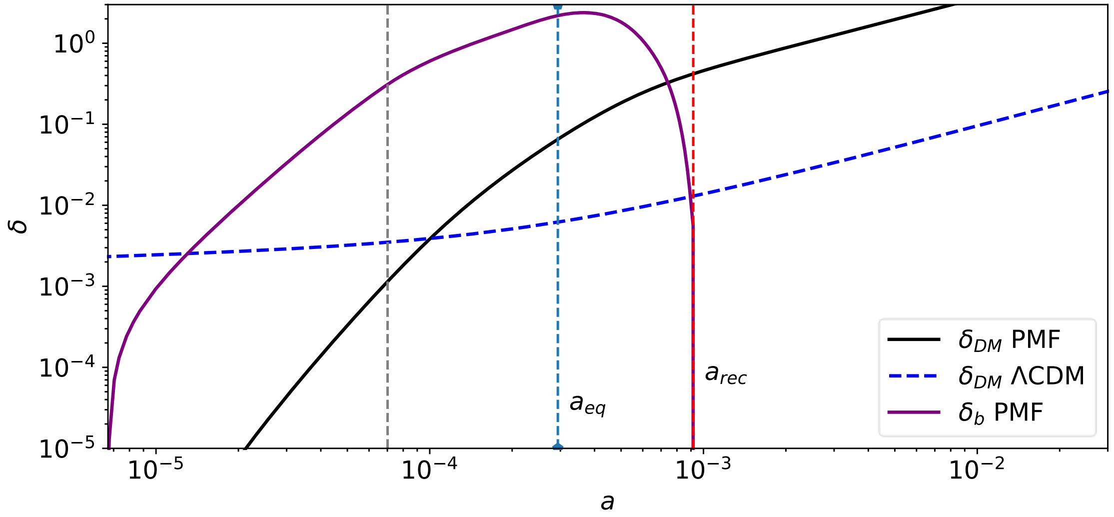
COMPARING WITH SIMULATIONS: SENSITIVE TO INITIAL POWER SPECTRUM



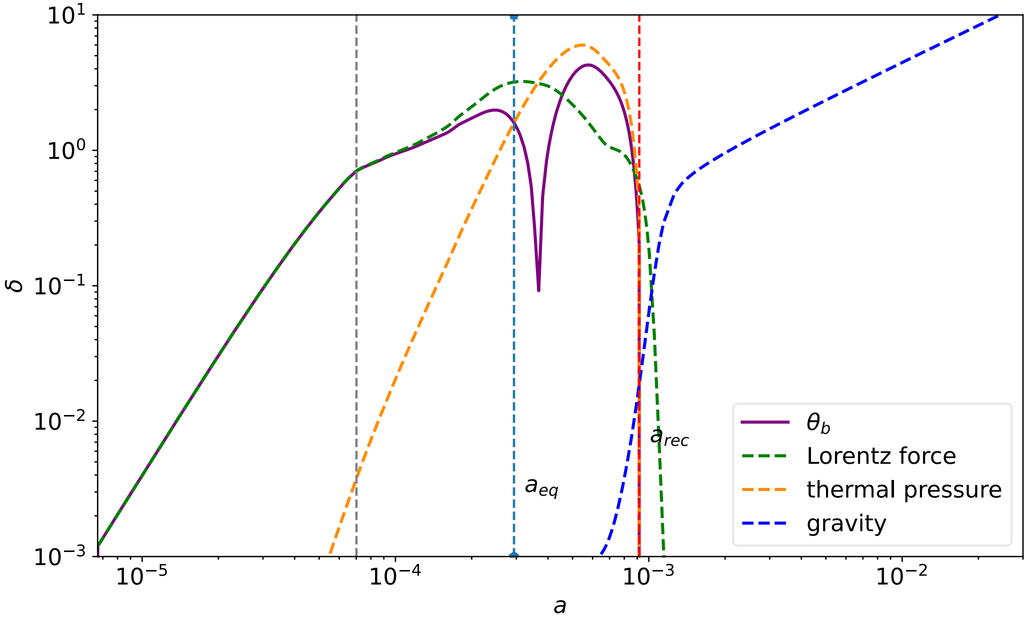


MORE PERTURBATION PLOTS

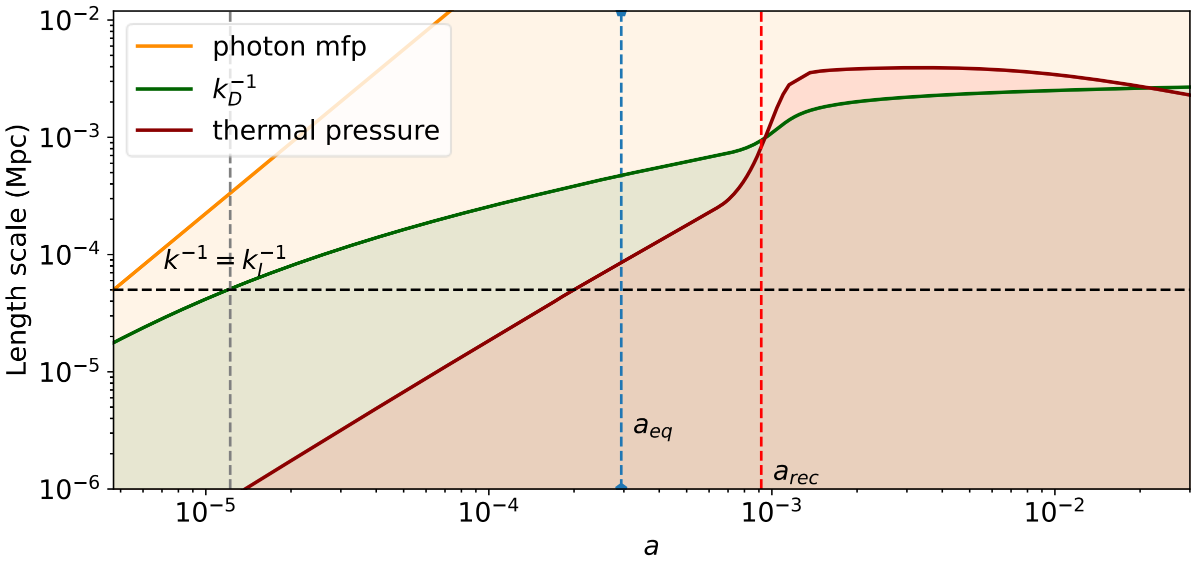


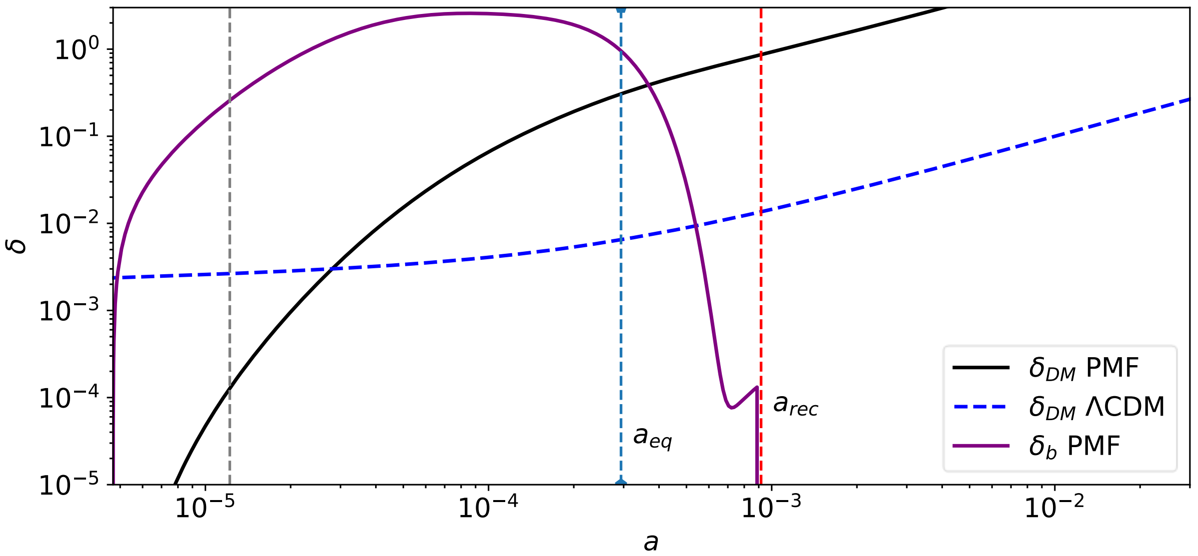


$$B_0 = 1\text{nG}$$
$$k_I = 10^4\ Mpc^{-1}$$



MORE PERTURBATION PLOTS





$B_0 = 8\text{nG}$
$k_I = 10^4\ Mpc^{-1}$