# MAGNETIC FIELDS AND THE HELIUM CONTENT IN THE INTRACLUSTER MEDIUM

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3RD ICM THEORY AND COMPUTATION WORKSHOP

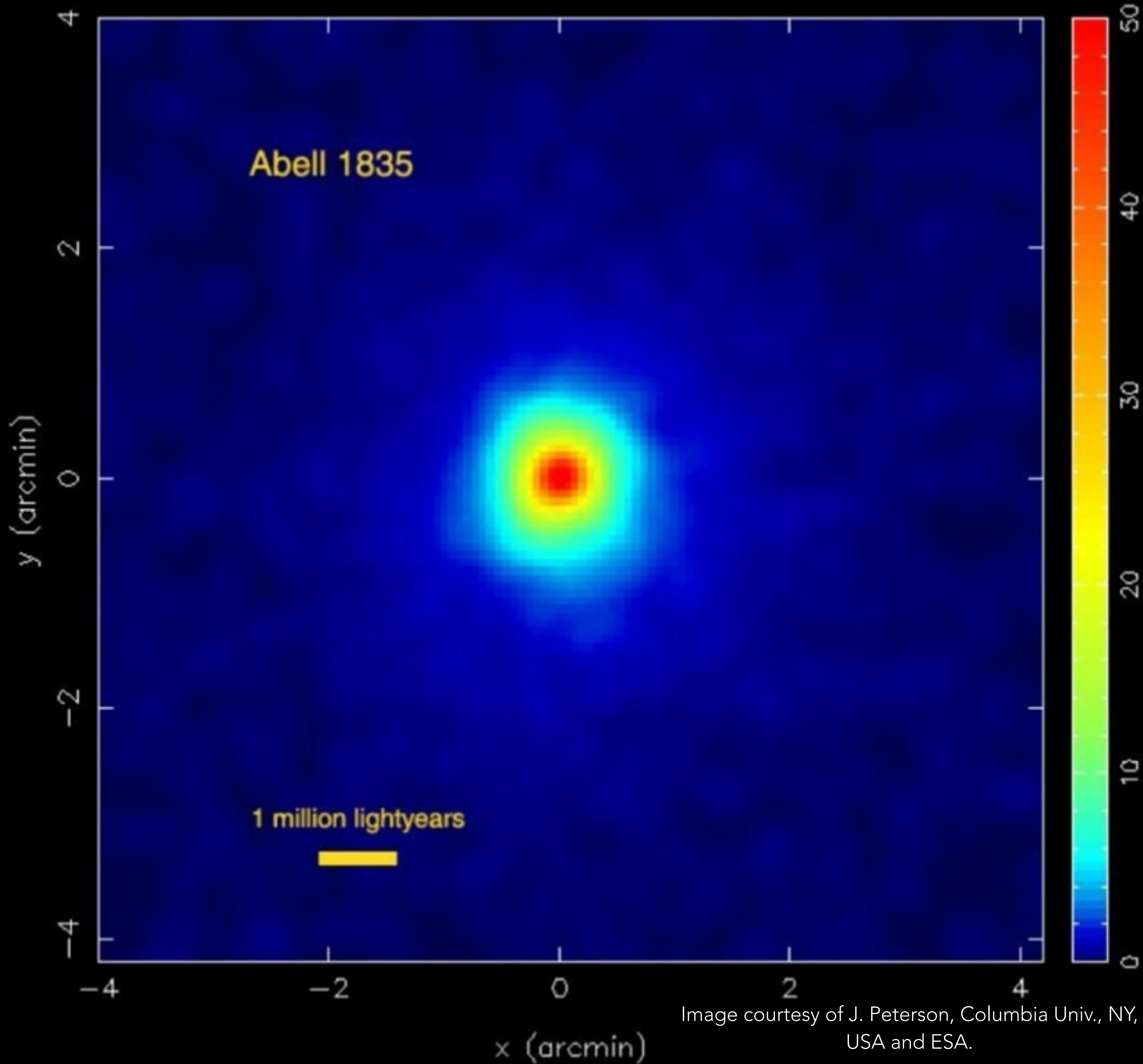
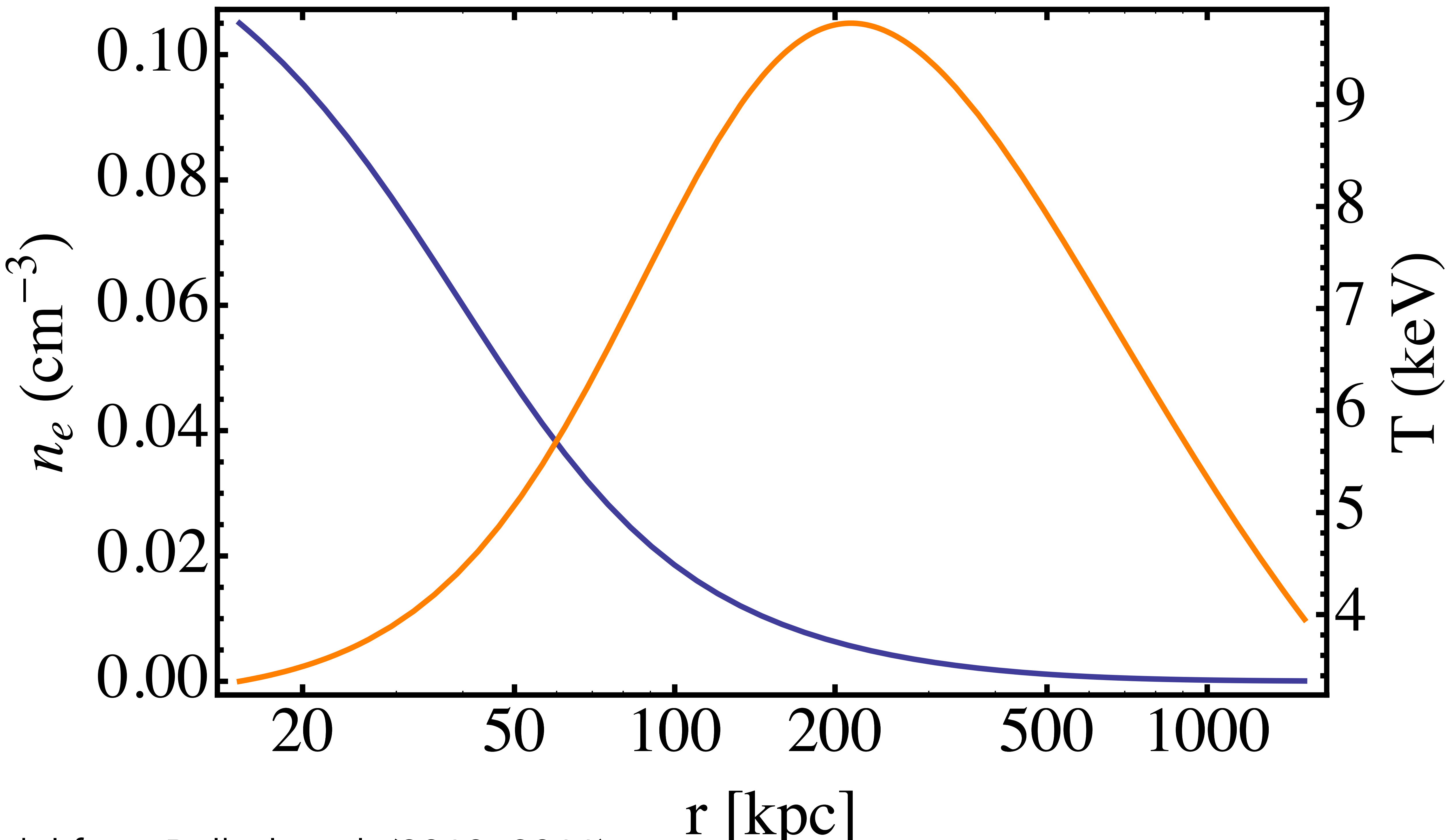



Image courtesy of J. Peterson, Columbia Univ., NY, USA and ESA.

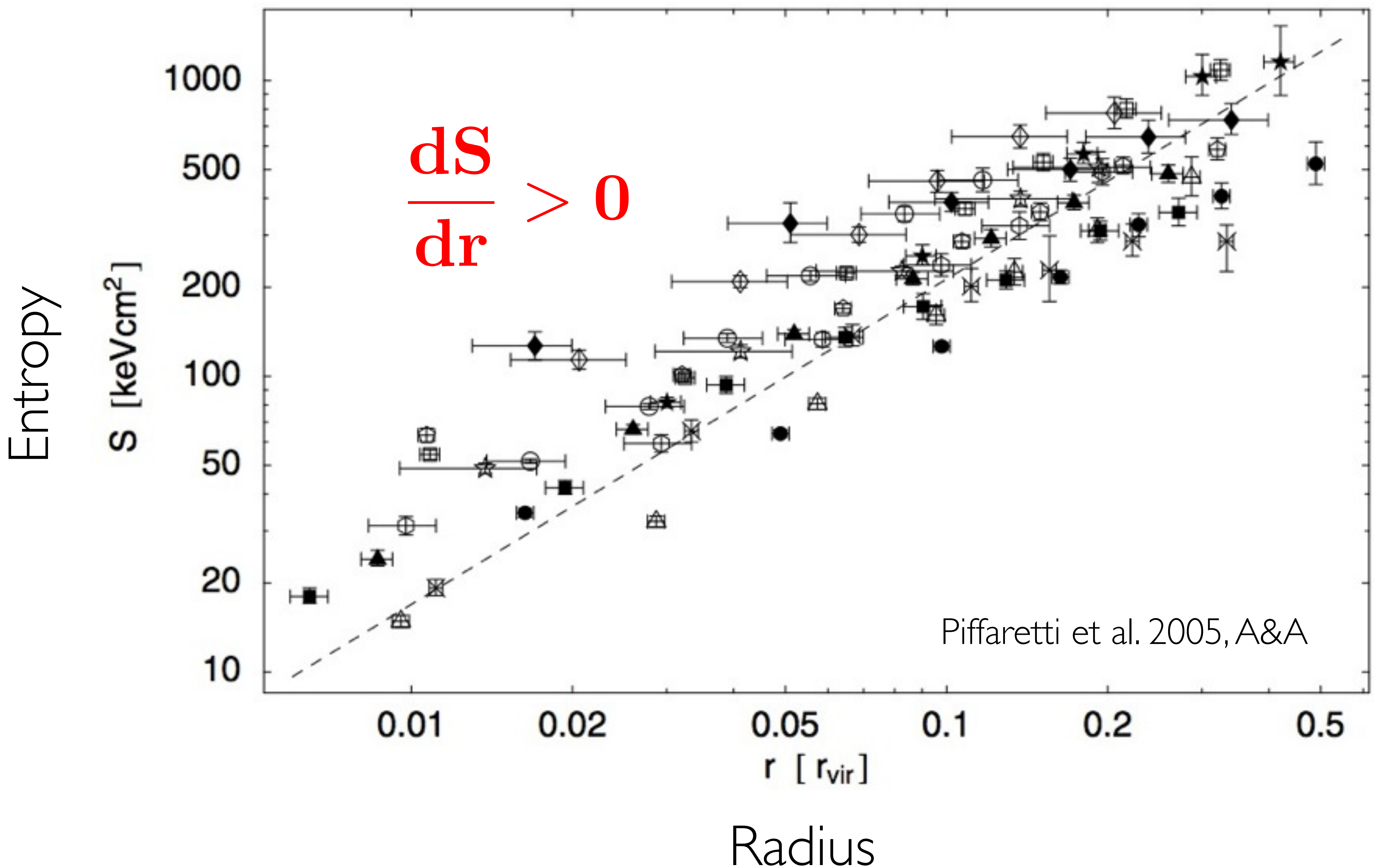
# THE TEMPERATURE AND DENSITY PROFILE



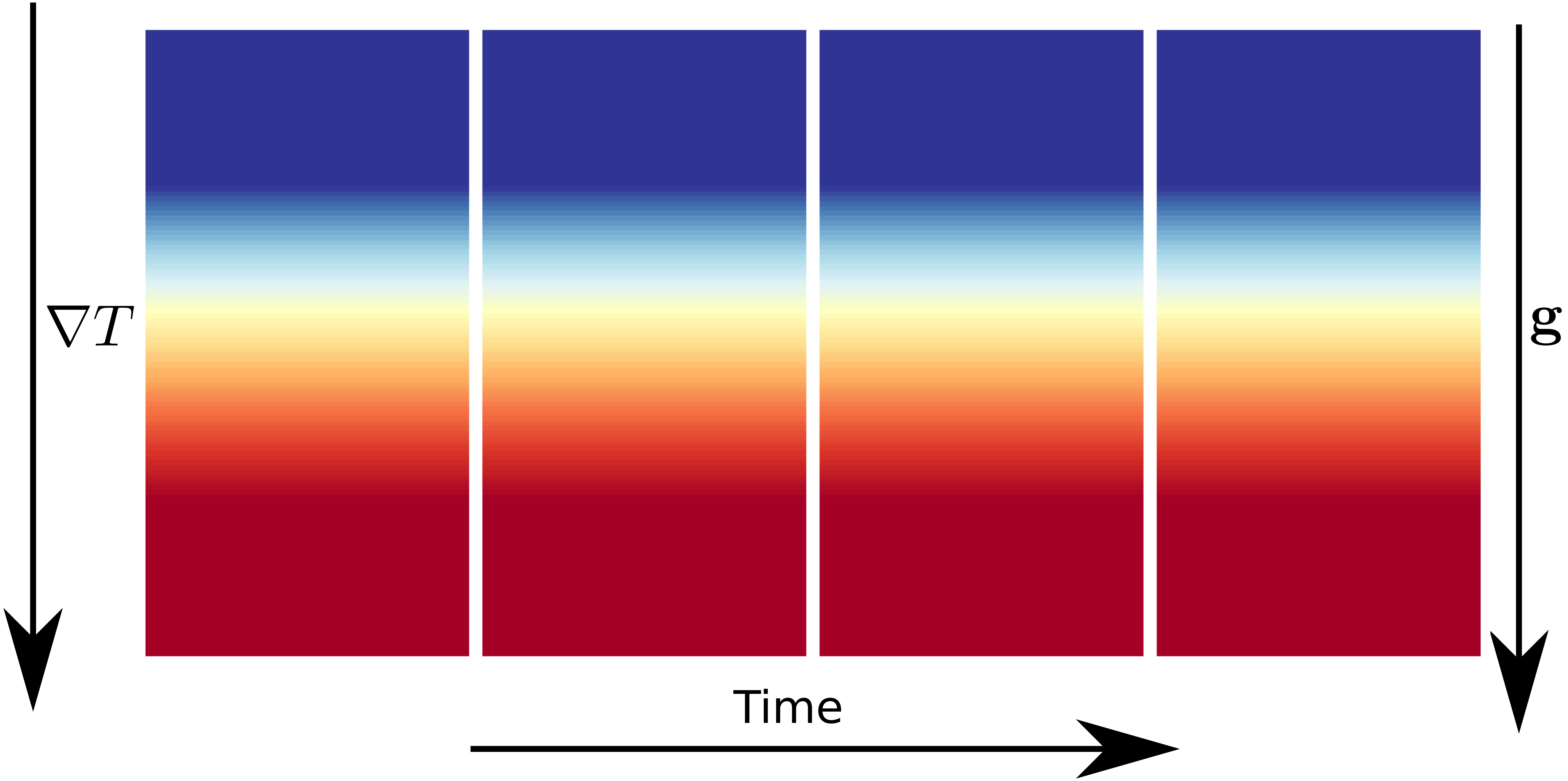

Model from Bulbul et al. (2010, 2011)

# ICM STABLE ACCORDING TO SCHWARZSCHILD

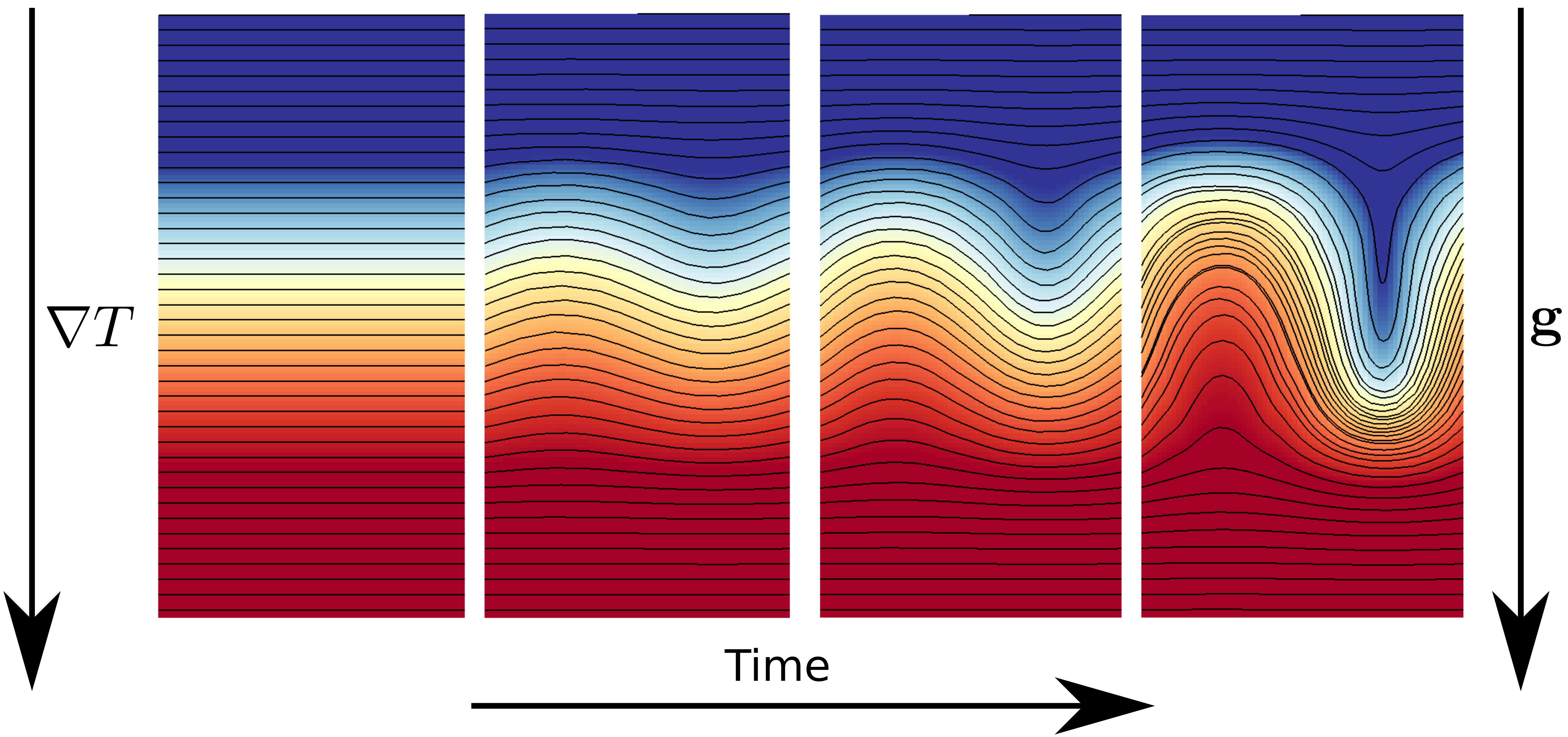
$$S \propto \ln p\rho^{-\gamma}$$



# STABLE ATMOSPHERE WITHOUT MAGNETIC FIELDS



# MAGNETIC FIELDS: ICM IS UNSTABLE!

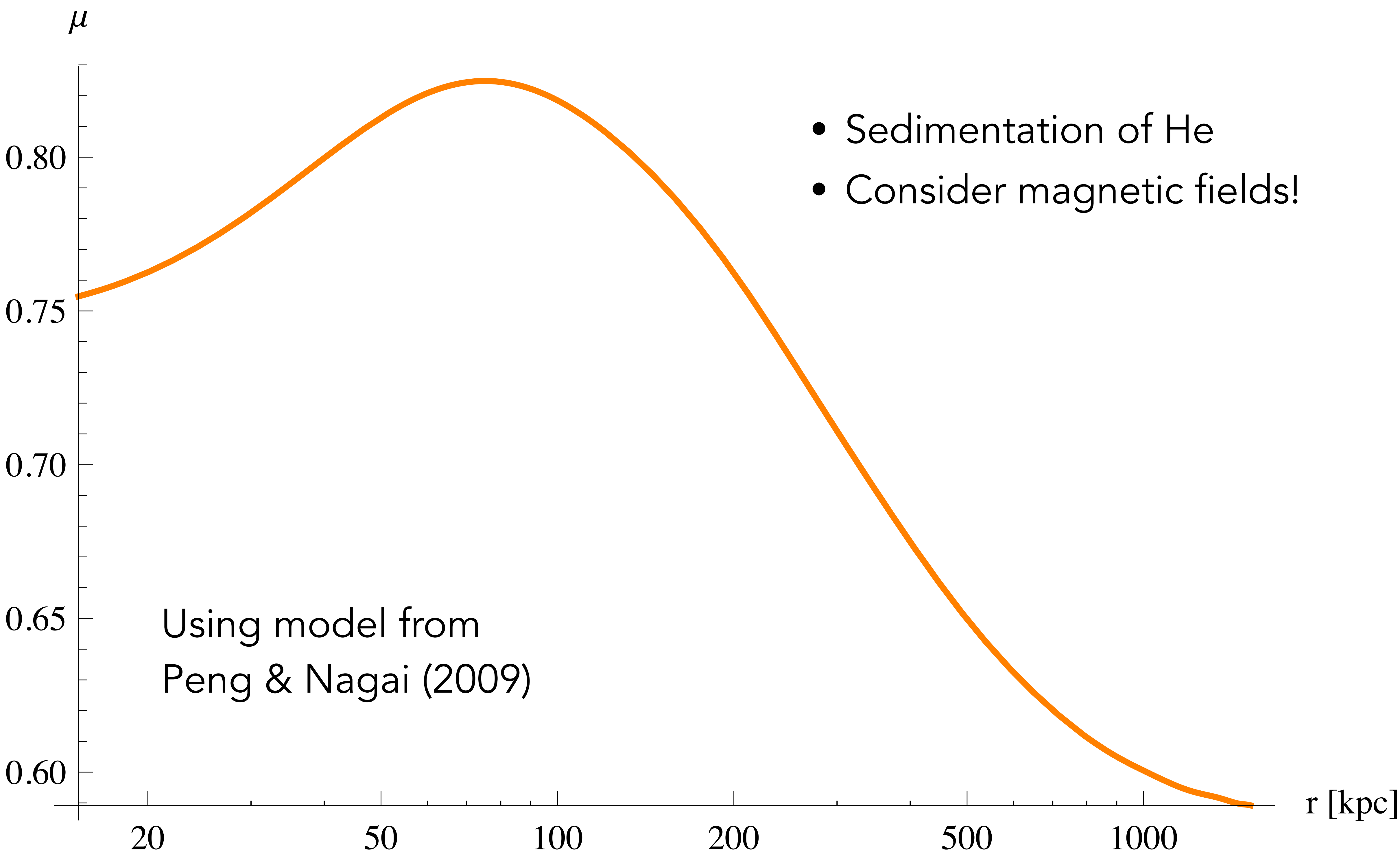


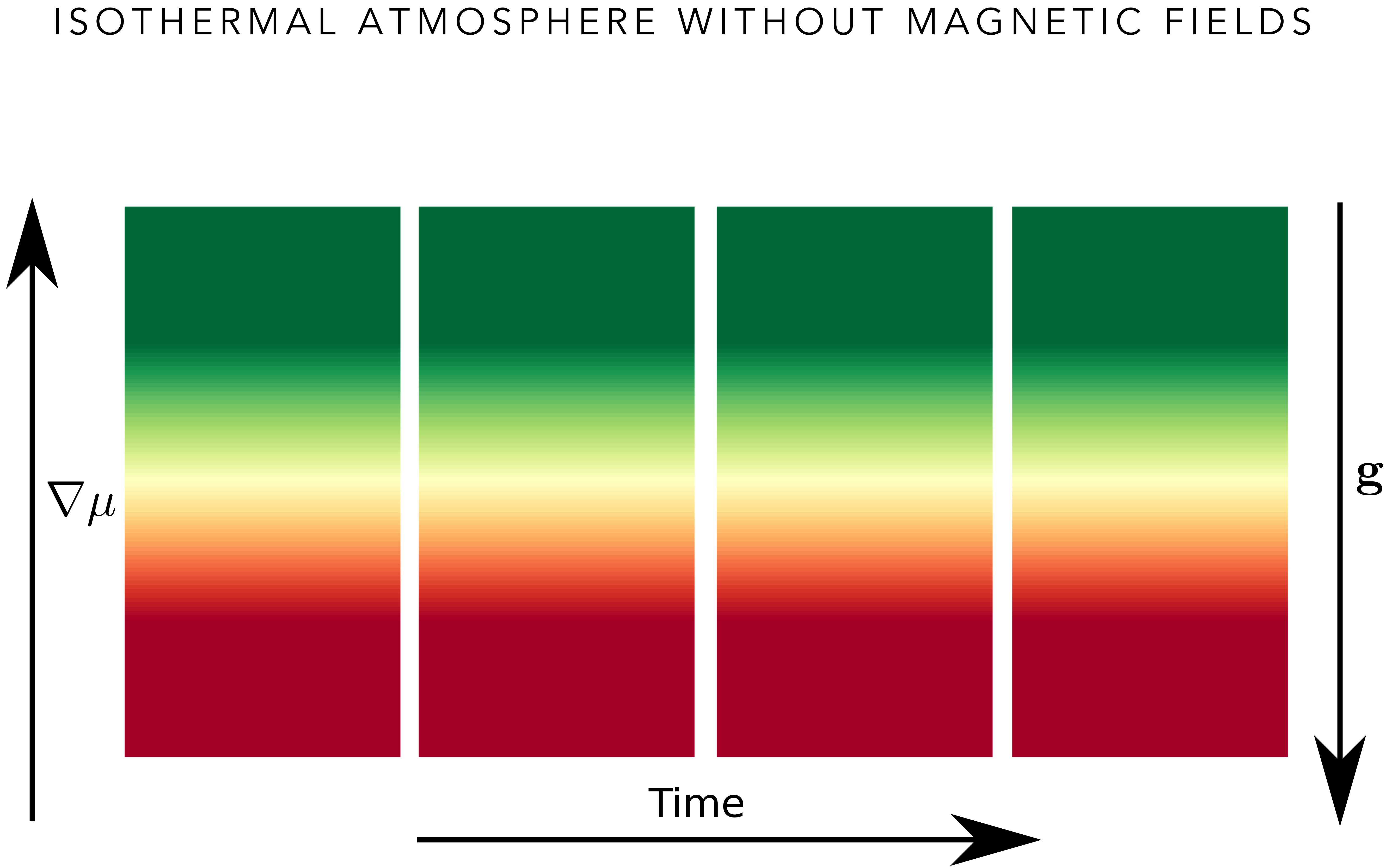

Balbus (2001)
Quataert (2008)

Parrish & Stone 2005
Parrish & Quataert 2008

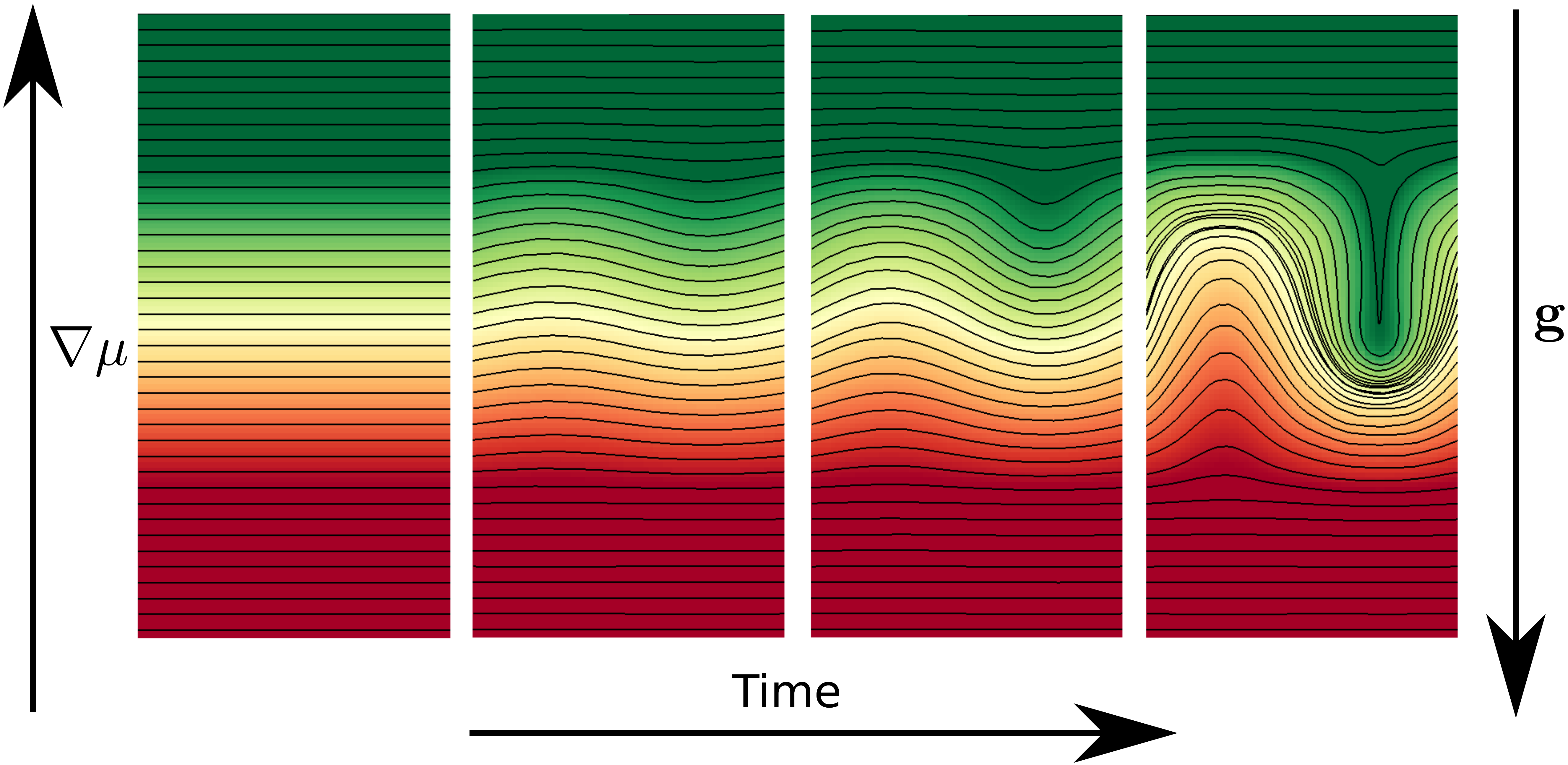
Kunz et. al 2012
and others

# BUT WHY SHOULD THE ICM BE HOMOGENEOUS?




ISOTHERMAL ATMOSPHERE WITHOUT MAGNETIC FIELDS
$\nabla\mu$
$\mathbf{g}$
Time

# UNSTABLE **ONLY** BECAUSE IT'S WEAKLY MAGNETIZED




Berlok & Pessah (in prep.)

# Anisotropic effects

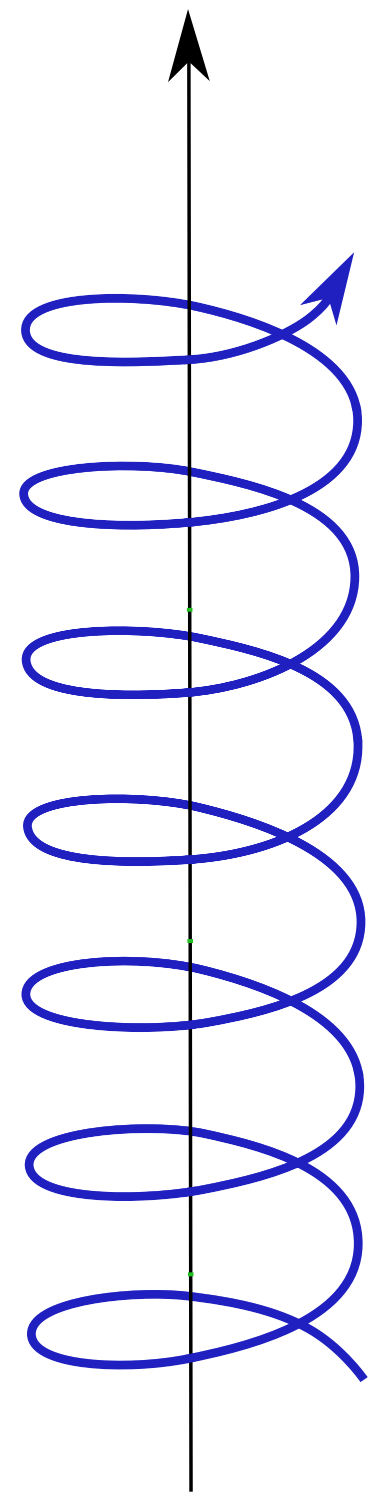
The ICM is magnetized

$$H \gg \lambda_{\mathrm{mfp}} \gg \rho$$

$H$ characteristic size.

$\lambda_{\mathrm{mfp}}$ mean free path

$\rho$ Larmor radius.



Heat conduction

$$\mathbf{Q_s} = -\chi \hat{\mathbf{b}}\hat{\mathbf{b}} \cdot \nabla \mathbf{T}$$

Diffusion of particles

$$\mathbf{Q_c} = -\mathbf{D}\hat{\mathbf{b}}\hat{\mathbf{b}} \cdot \nabla \mathbf{c}$$

Braginskii viscosity

# THE EQUATIONS OF KINETIC MHD WITH HELIUM

$$\frac{\partial \rho}{\partial t} + \boldsymbol{\nabla}\cdot(\rho \boldsymbol{v}) = 0\,,$$

$$\frac{\partial}{\partial t}(\rho \boldsymbol{v}) + \boldsymbol{\nabla}\cdot\left(\rho \boldsymbol{v}\boldsymbol{v} + \mathsf{P} + \frac{B^2}{8\pi}\mathsf{I} - \frac{B^2}{4\pi}\hat{\boldsymbol{b}}\hat{\boldsymbol{b}}\right) = \rho \boldsymbol{g}\,,$$

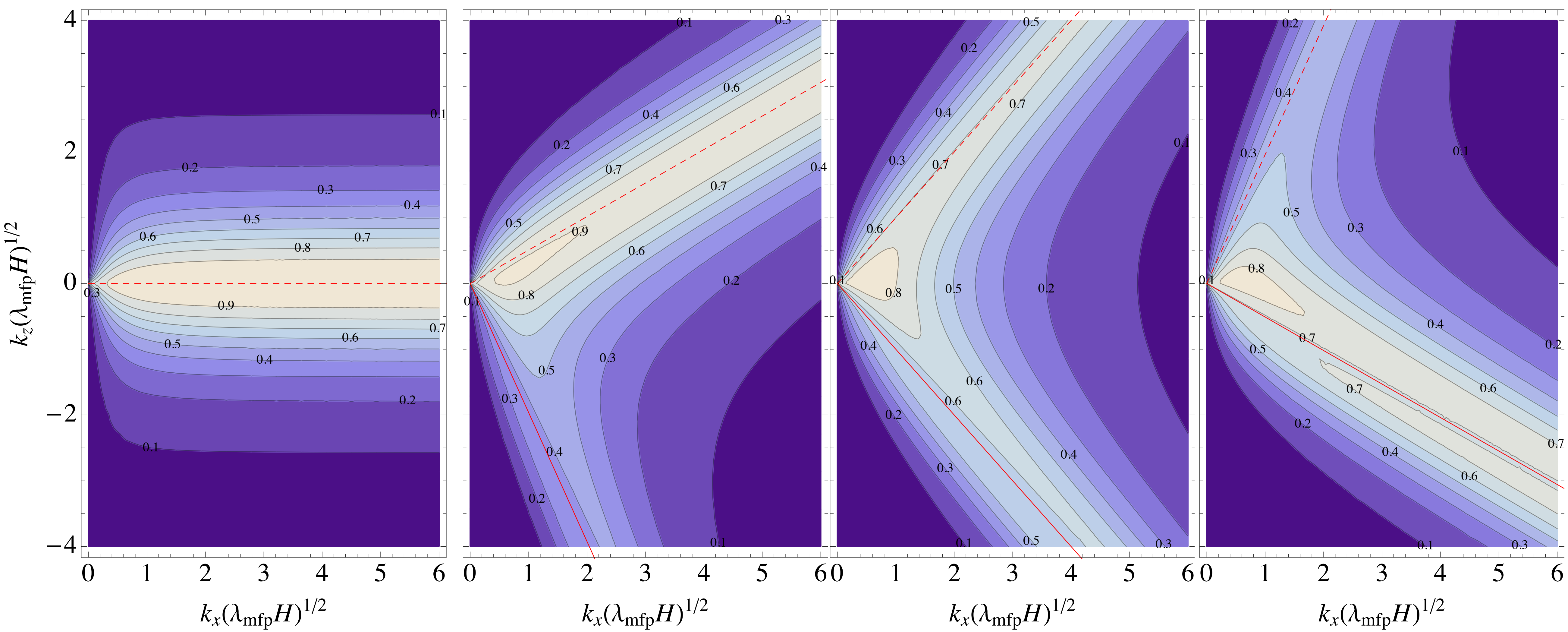
$$\frac{\partial \boldsymbol{B}}{\partial t} = \boldsymbol{\nabla}\times(\boldsymbol{v}\times\boldsymbol{B})\,,$$

$$\frac{P}{\gamma - 1}\frac{d}{dt}(\ln P\rho^{-\gamma}) = (p_\perp - p_\parallel)\frac{d}{dt}\ln\frac{B}{\rho^{2/3}} - \boldsymbol{\nabla}\cdot\boldsymbol{Q}_{\mathrm{s}}\,,$$

$$\frac{dc}{dt} = -\boldsymbol{\nabla}\cdot\boldsymbol{Q}_{\mathrm{c}}\,.$$

Pessah & Chakraborty 2013

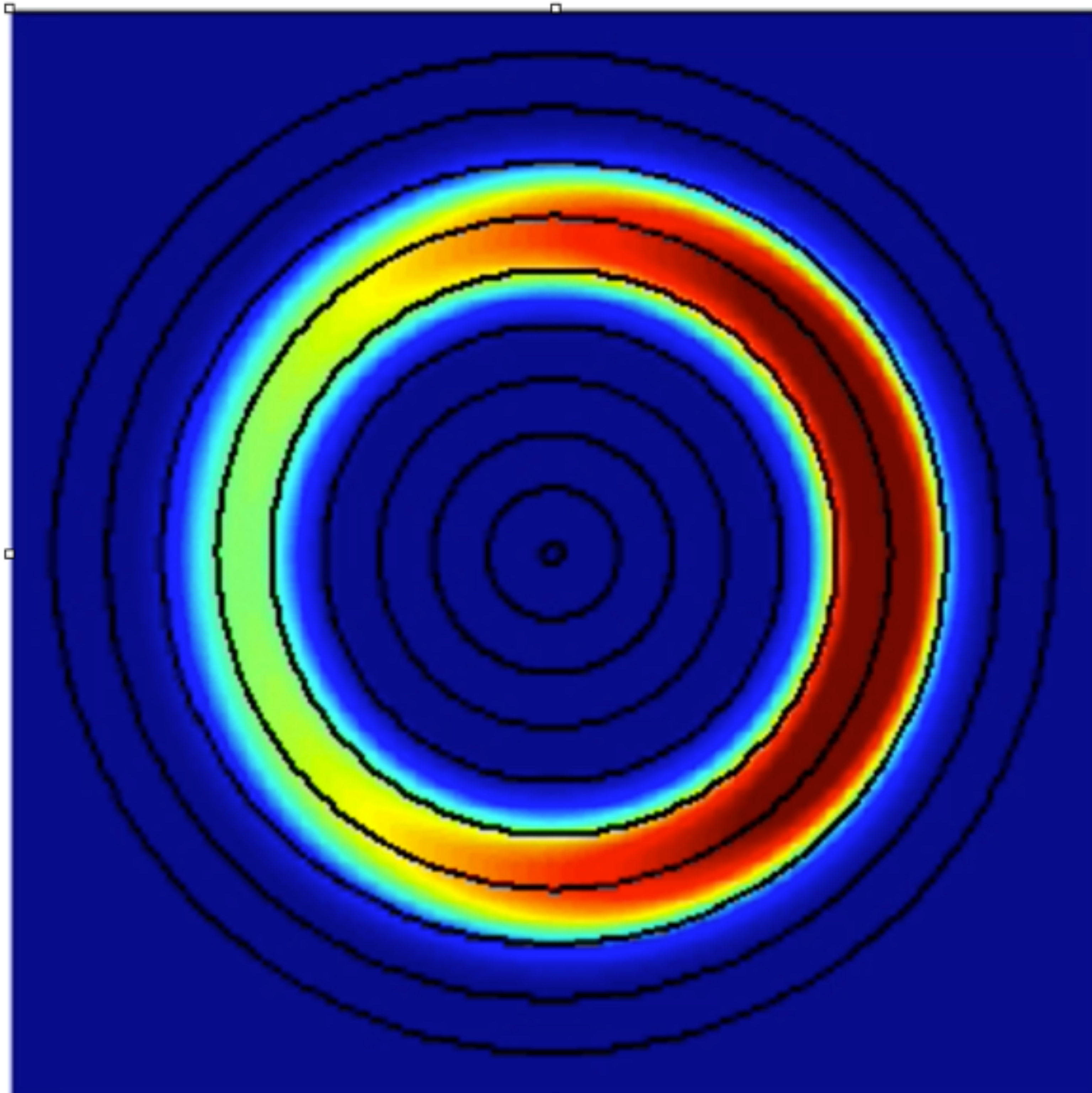
# VARYING THE MAGNETIC FIELD ANGLE FOR $\frac{d \ln \mu}{d \ln P} = -1$




Berlok & Pessah (in prep.)

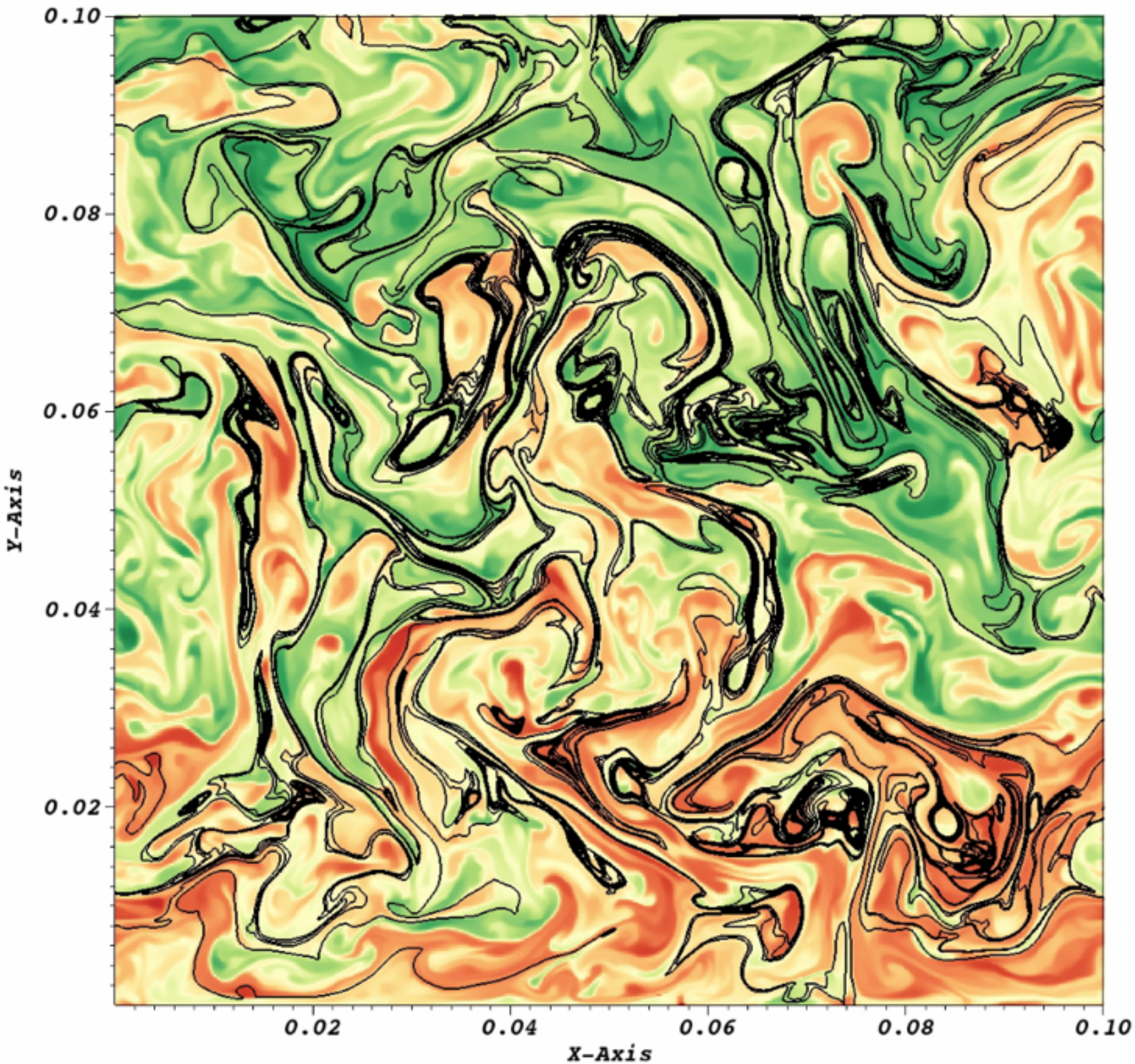
Analysis similar to Kunz 2011.

# ANISOTROPIC EFFECTS: AN EXAMPLE



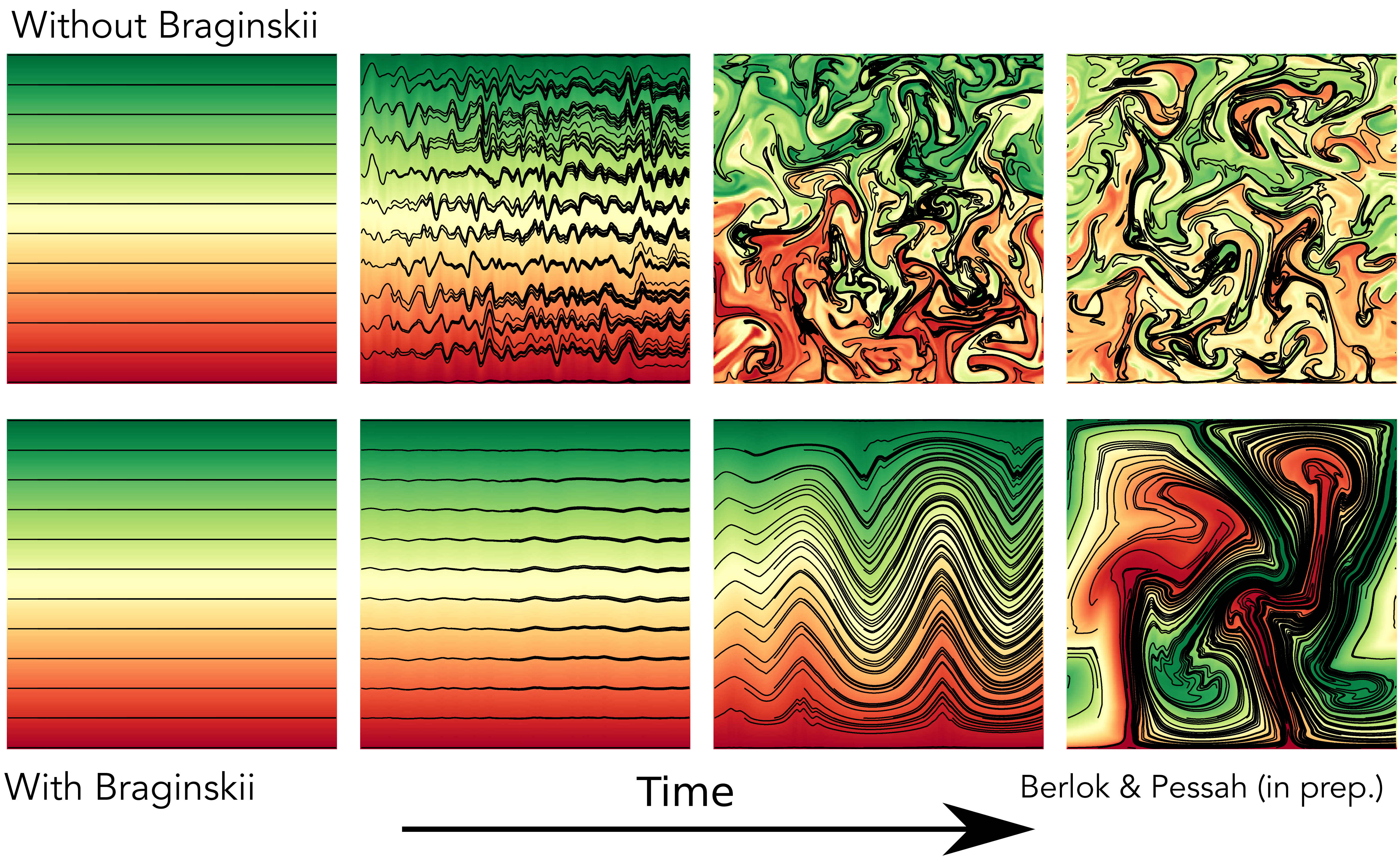
Modification to ATHENA (Stone et al. 2008)
Parrish & Stone 2005,   Sharma & Hammett 2007

# LOCAL MODELS: MIXING OF COMPOSITION



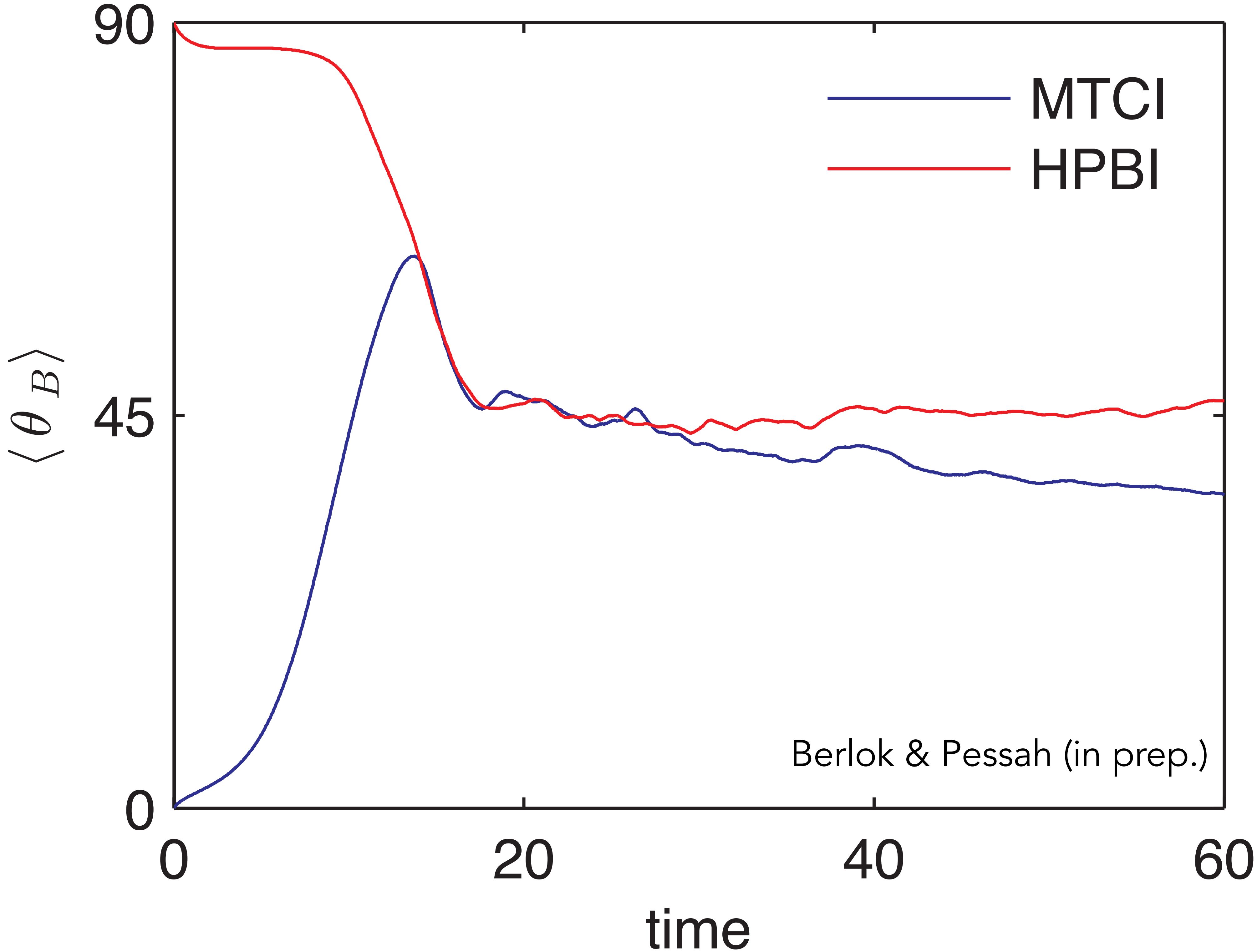

$0.1H_0$

# LOCAL MODELS: MIXING OF COMPOSITION




See Kunz et. al 2012 for details on Braginskii viscosity

# AVERAGE INCLINATION OF MAGNETIC FIELD

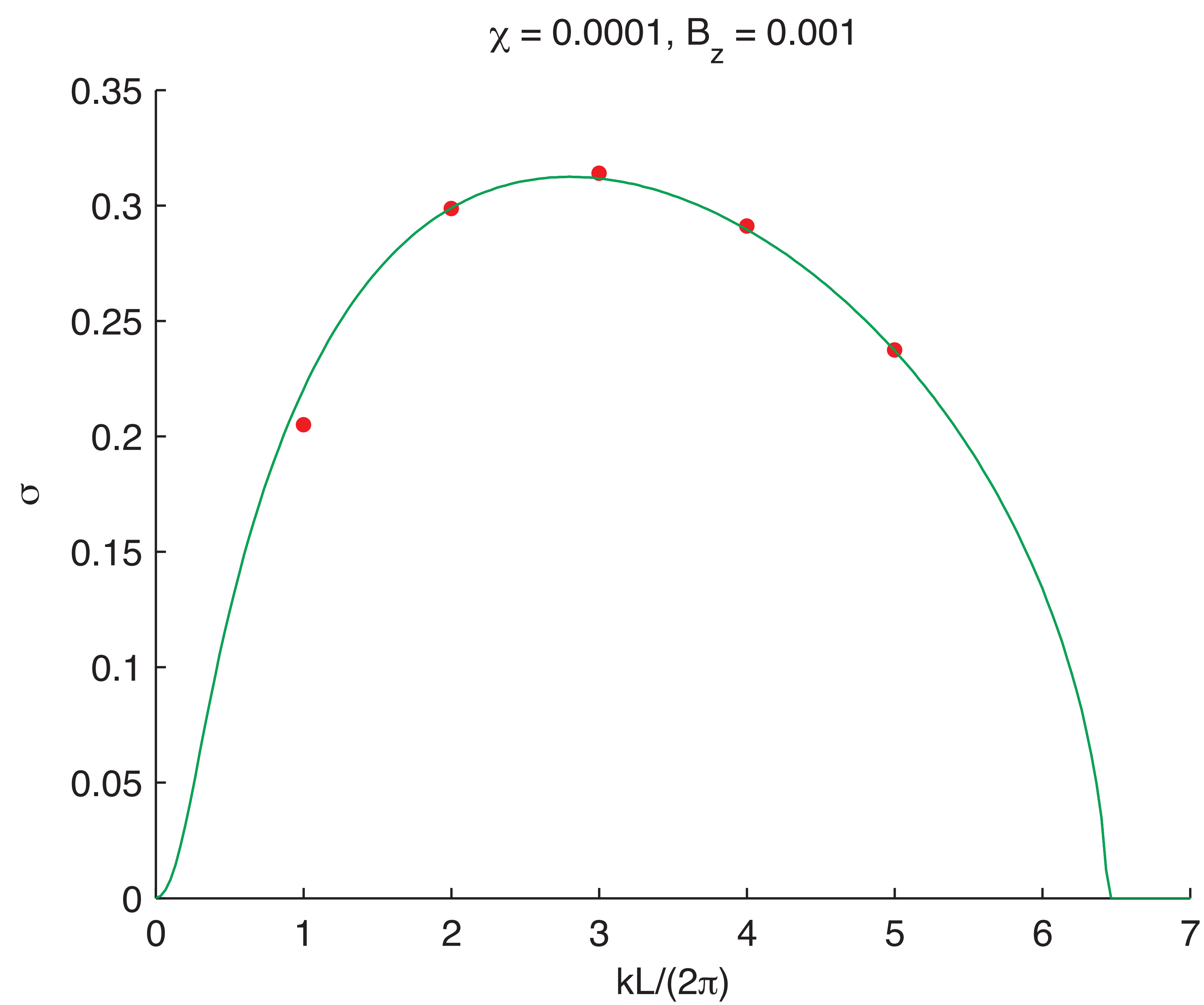



See also Parrish & Stone 2007 and Parrish & Quataert 2008 for the MTI and HBI.

# GROWTH RATES IN THE SIMULATIONS

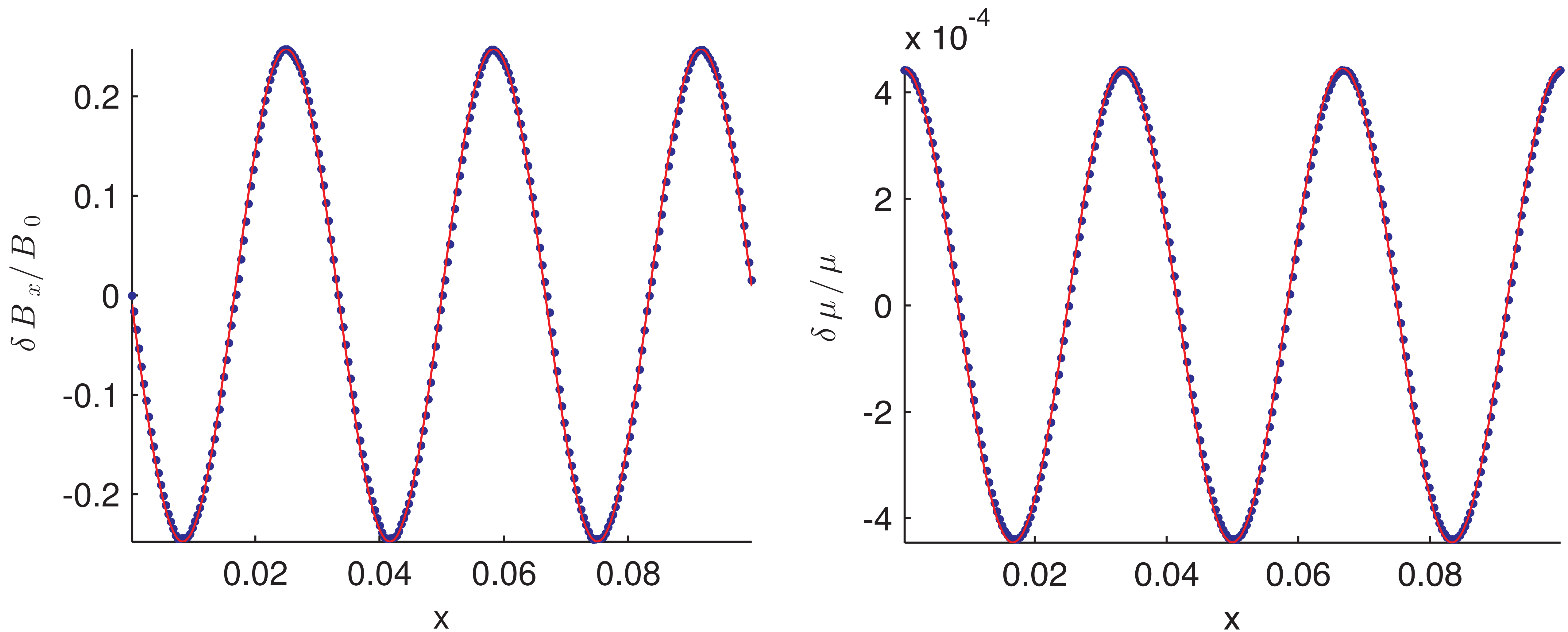
Conduction is faster on small scales

Magnetic tension stabilizes
small wave lengths

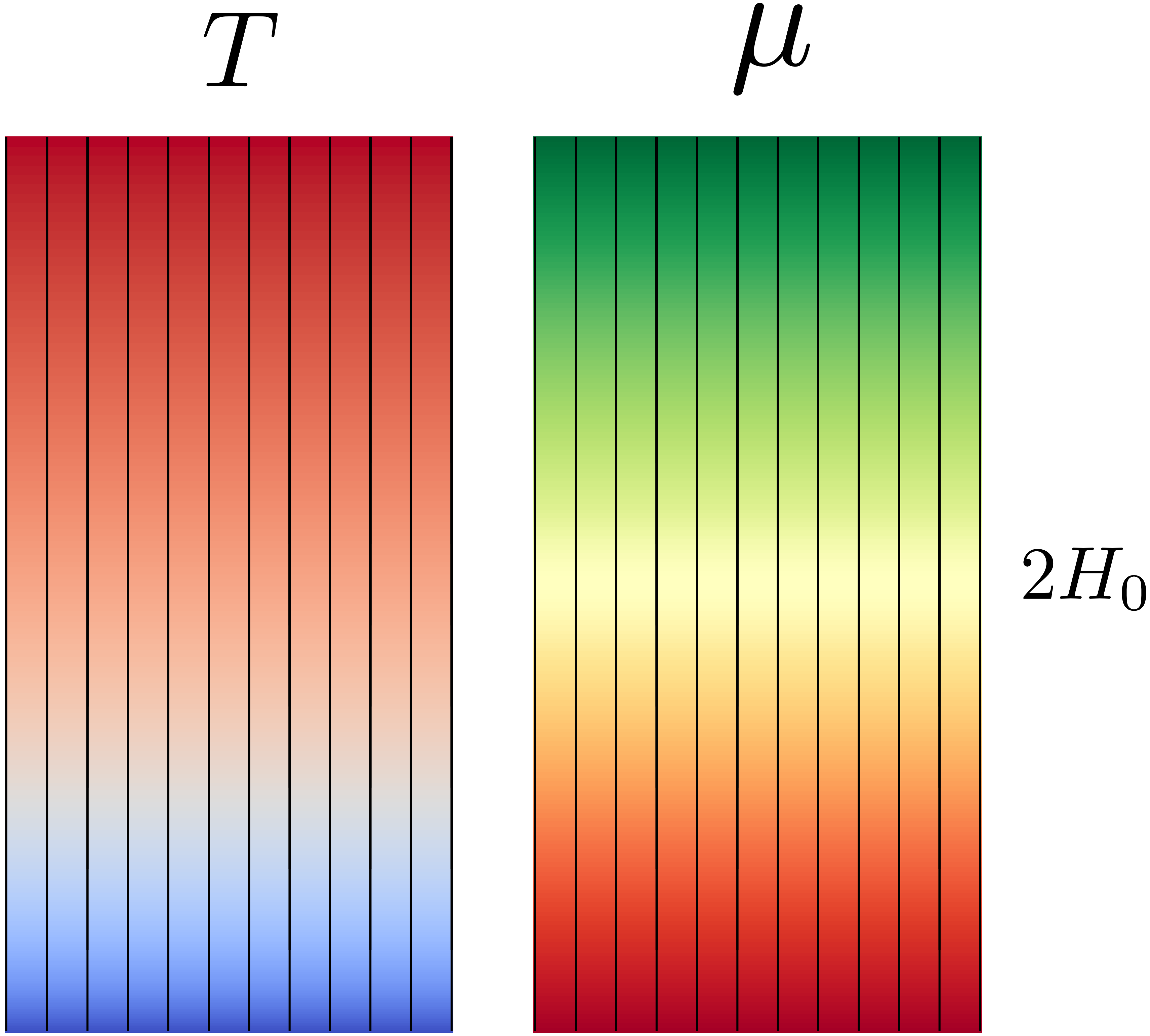



Berlok & Pessah (in prep.)

# EIGENMODES OF THE LINEARIZED SYSTEM AT t=6

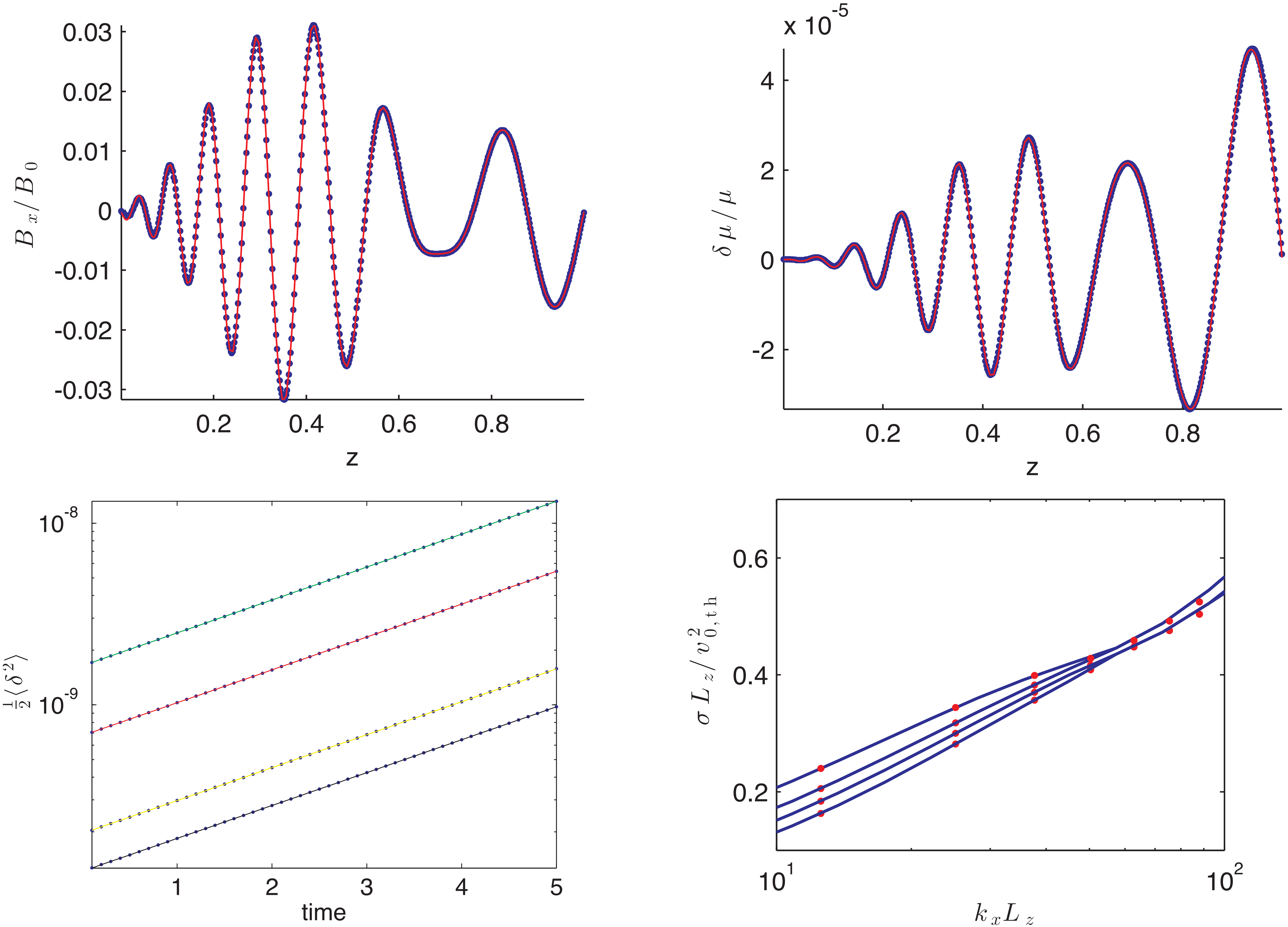


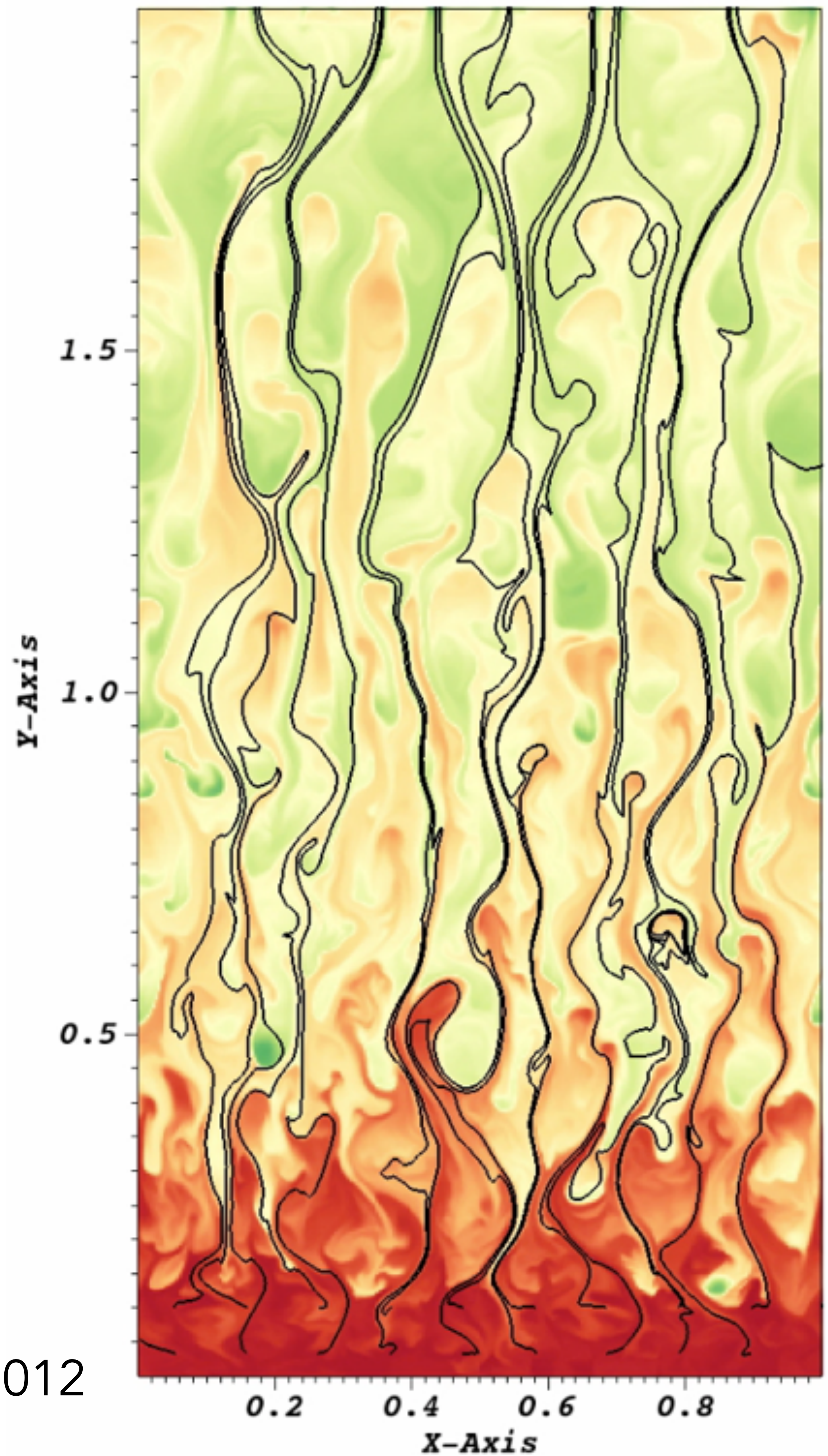
# QUASI-GLOBAL MODELS WITH $\frac{dT}{dz} > 0$ and $\frac{d\mu}{dz} > 0$




Thermal profile as in Latter & Kunz 2012 but including composition gradient

# QUASI-GLOBAL MODELS (AS IN LATTER & KUNZ 2012)

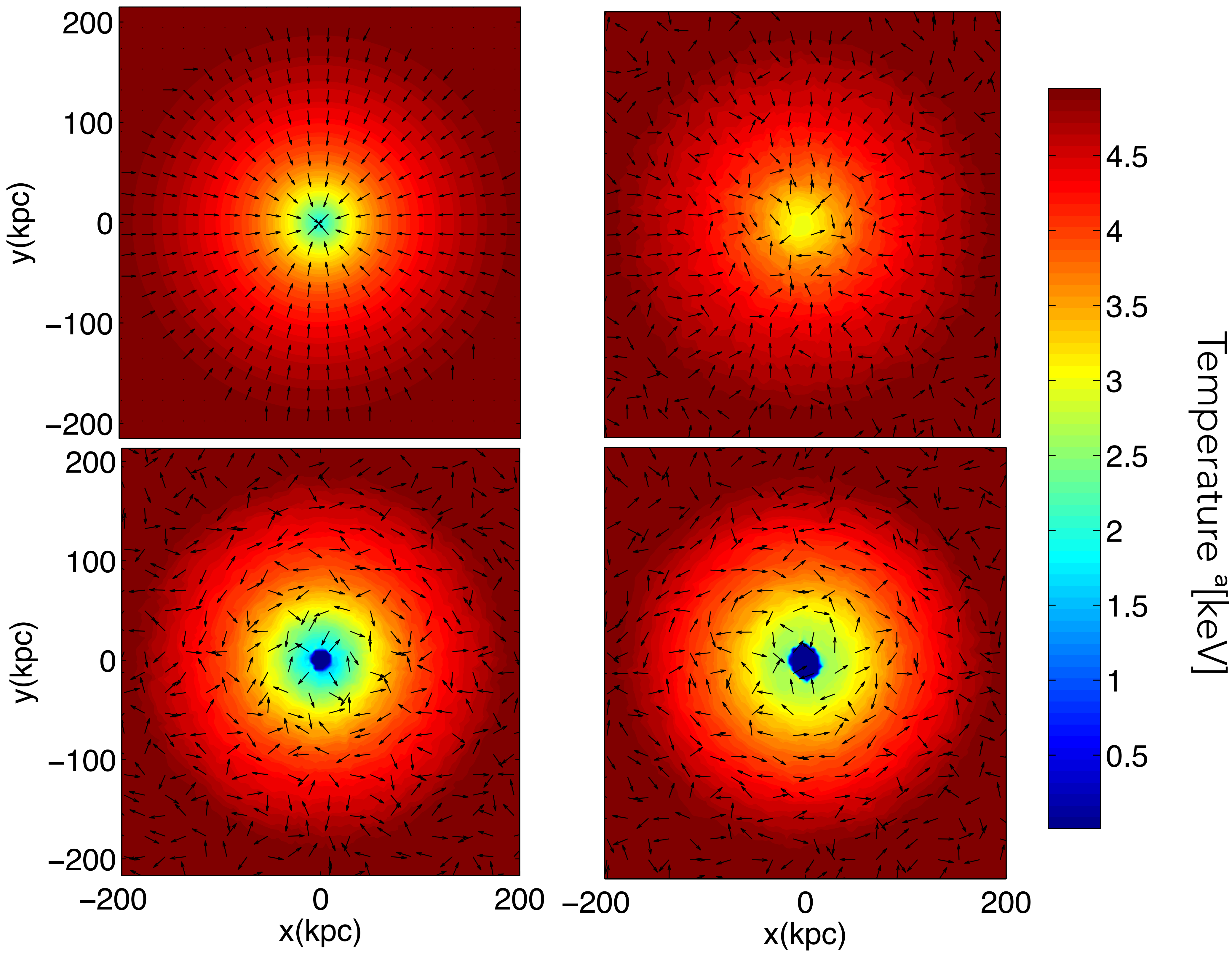





$2H_0$

Similar to Kunz et al. 2012

# GOAL: GLOBAL MODELS INCLUDING COMPOSITION




Parrish I. J., Quataert E. and Sharma P., 2009, ApJ, 703, 96