Generation and Saturation of Magnetic Fields in the ISM Regulated by SF Feedback

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2015. 10. 6.

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Galactic Magnetic Fields

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  - **b**: Random (turbulent) magnetic fields
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- How (rapidly) is **b** generated?
- Is **b** saturated? at what level?
- Is **b** correlated with galactic properties?
- In the presence of (substantial) mean magnetic fields

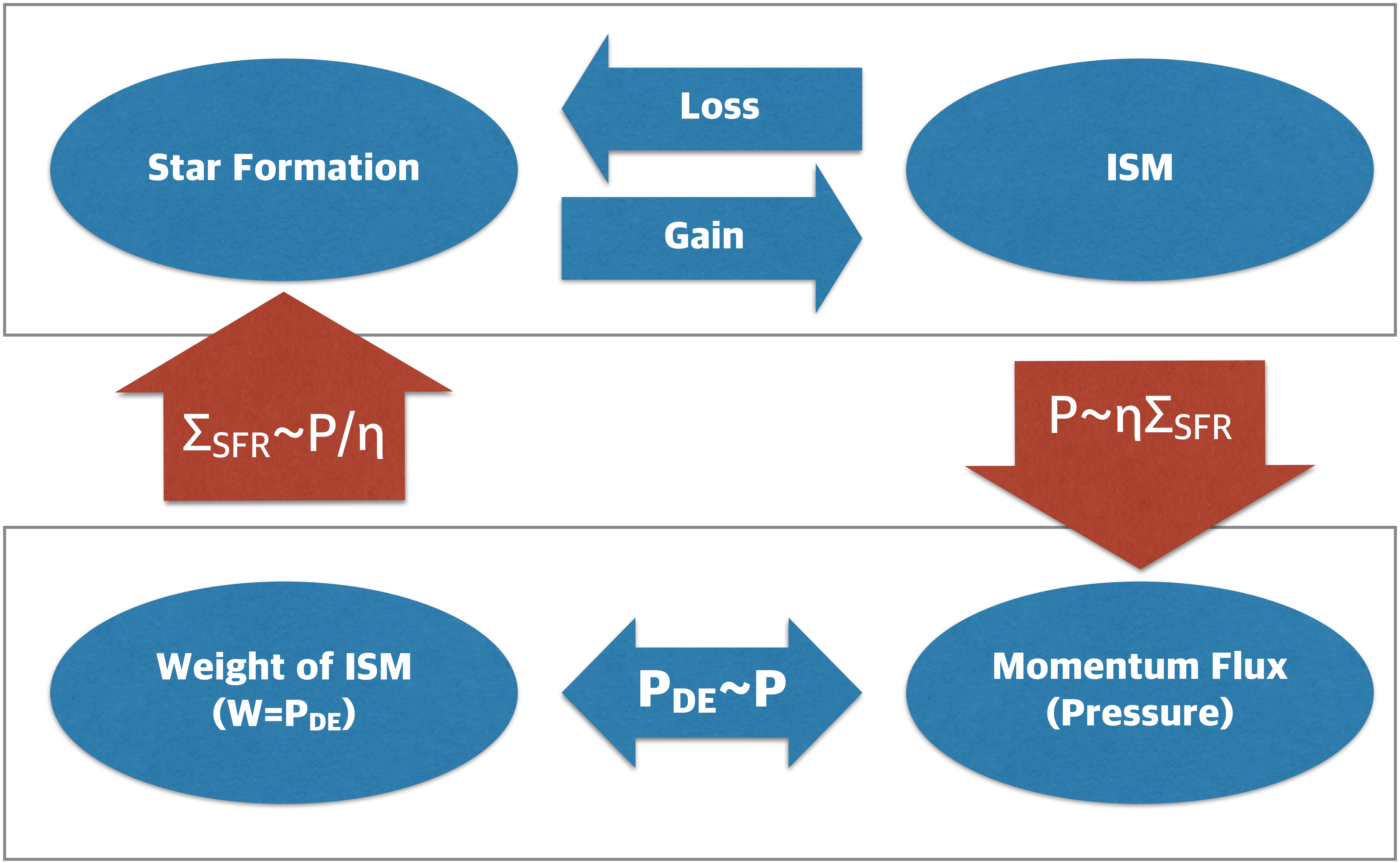
How to generate b

- Beck et al. (1996)
    - “tangling of the large-scale field by turbulence and from Parker and thermal instabilities,
    - compression of ambient magnetic fields by shock fronts associated with supernova remnants and stellar winds, and
    - self-generation of random magnetic fields by turbulence (small-scale dynamo).”
- We need **turbulence** to generate **b**
    - TI, GI, differential-rotation, and **Supernovae!**

What do we need to saturate b correctly for given galactic conditions?

Self-Regulation of SFR

(a) Energy and Momentum Equilibrium



(b) Vertical Dynamical Equilibrium

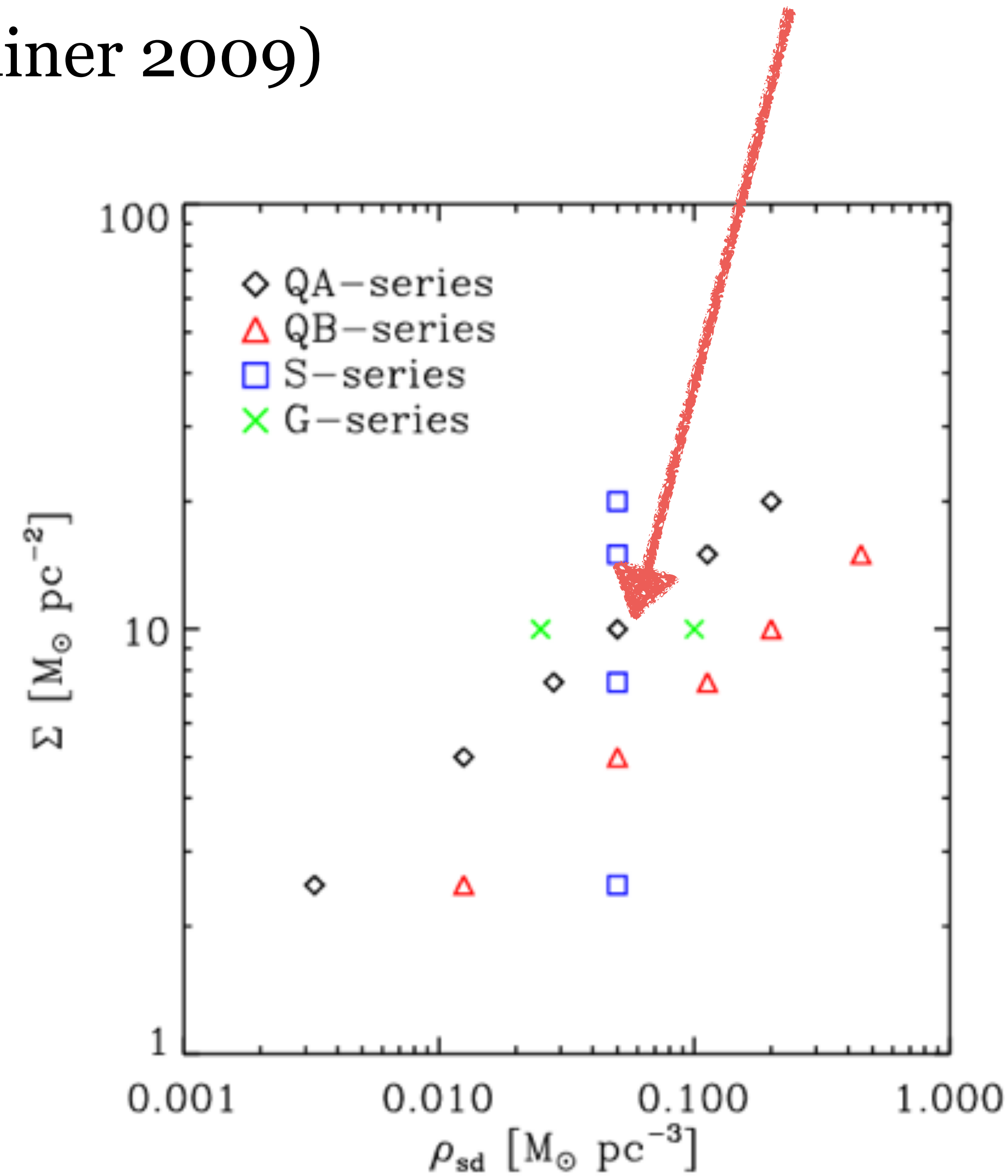
Ostriker, McKee, Leroy (2010); Ostriker & Shetty (2011); CGK, Kim, Ostriker (2011)

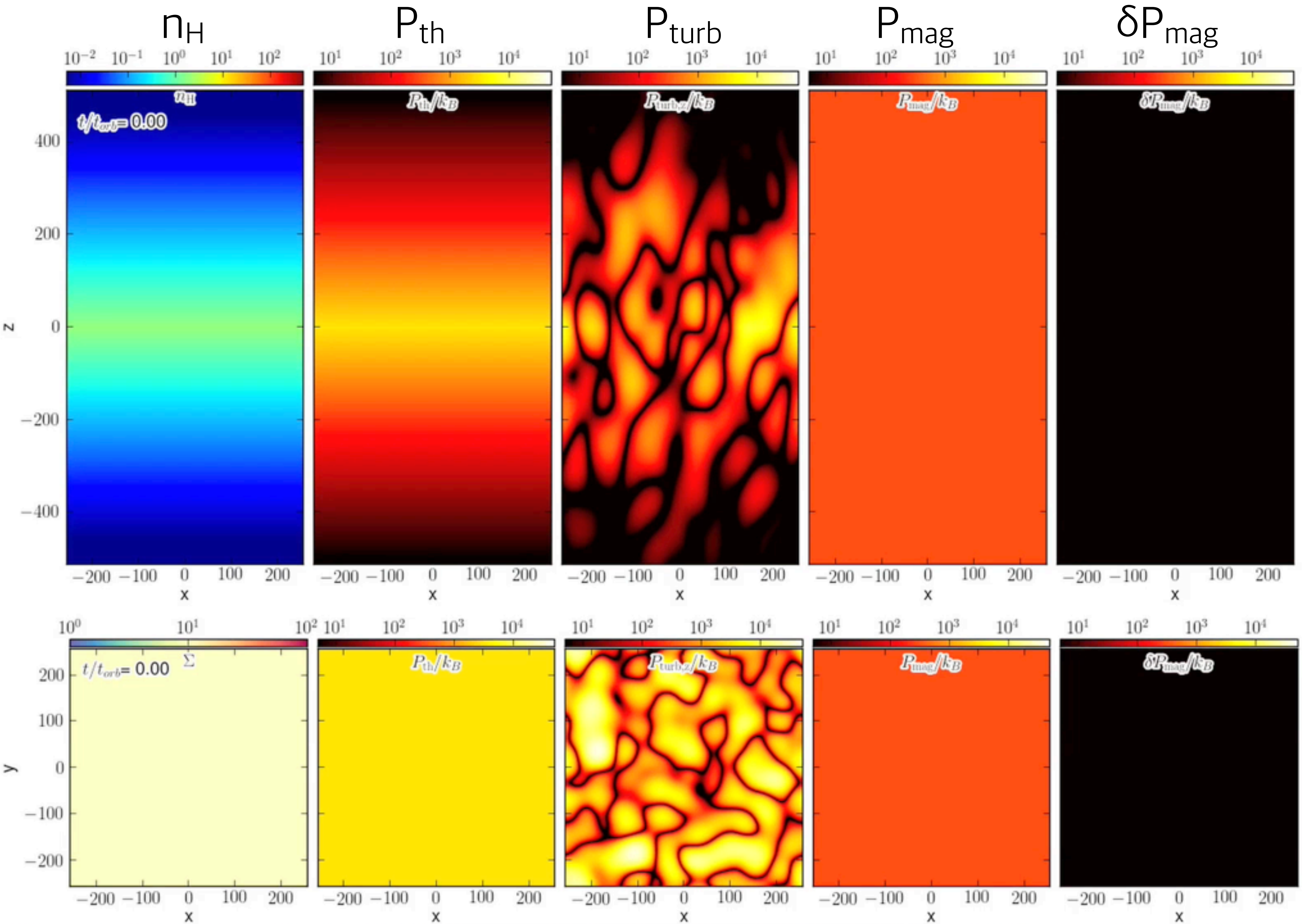
Numerical Simulations

CGK, Kim, Ostriker (2011); CGK, Ostriker, Kim (2013); CGK & Ostriker (2015b)

Additional parameter variations for heating efficiency & magnetization

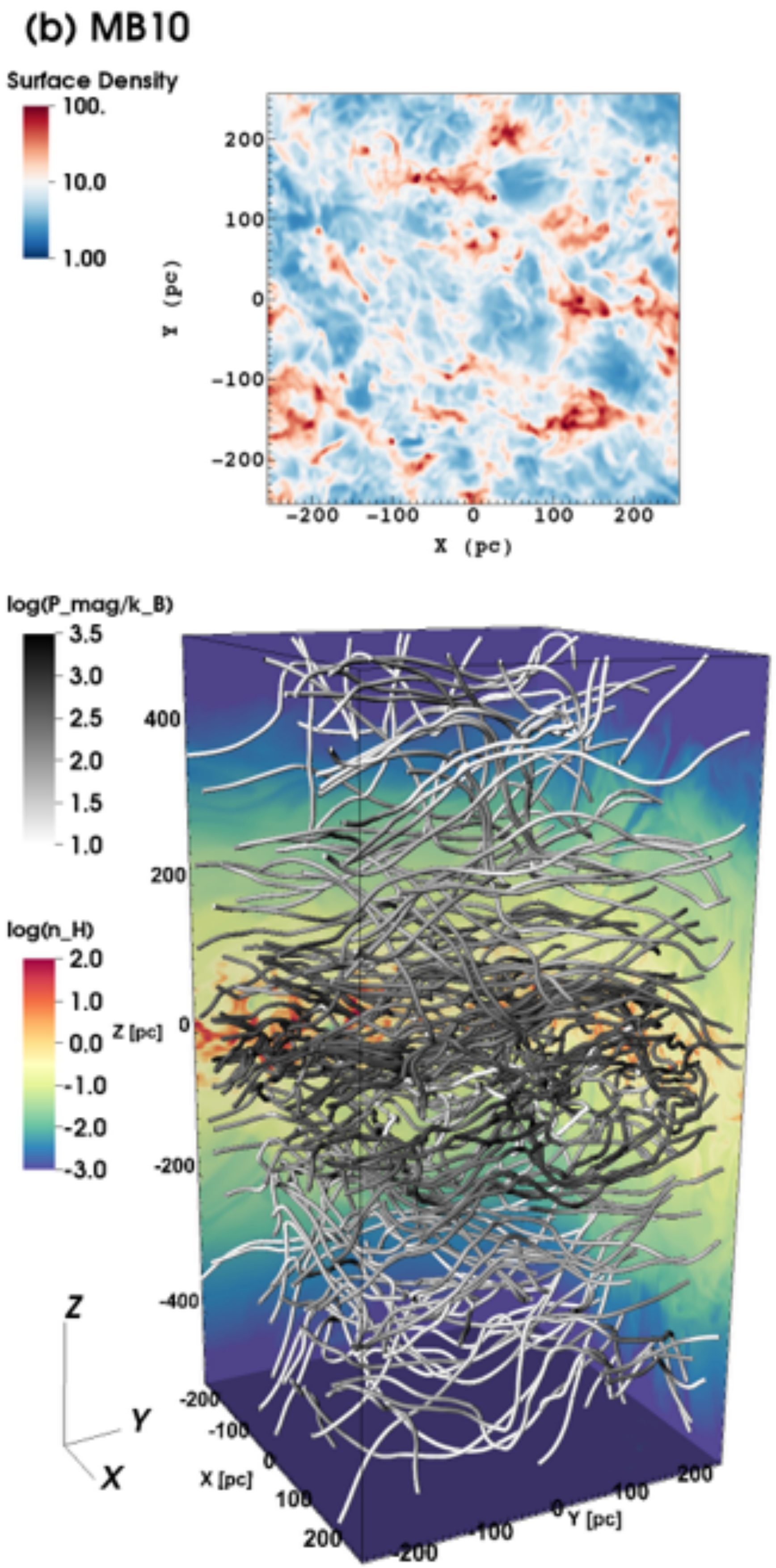
- ✓ Athena (Stone et al. 2008; Stone & Gardiner 2009)
- ✓ Local Shearing-Box
- ✓ SF feedback (momentum, heating)
- ✓ Optically thin cooling
- ✓ external gravity (fixed potential)
- ✓ gaseous self-gravity
- ✓ galactic differential rotation
- ✓ initial azimuthal magnetic fields
- \- hot gas

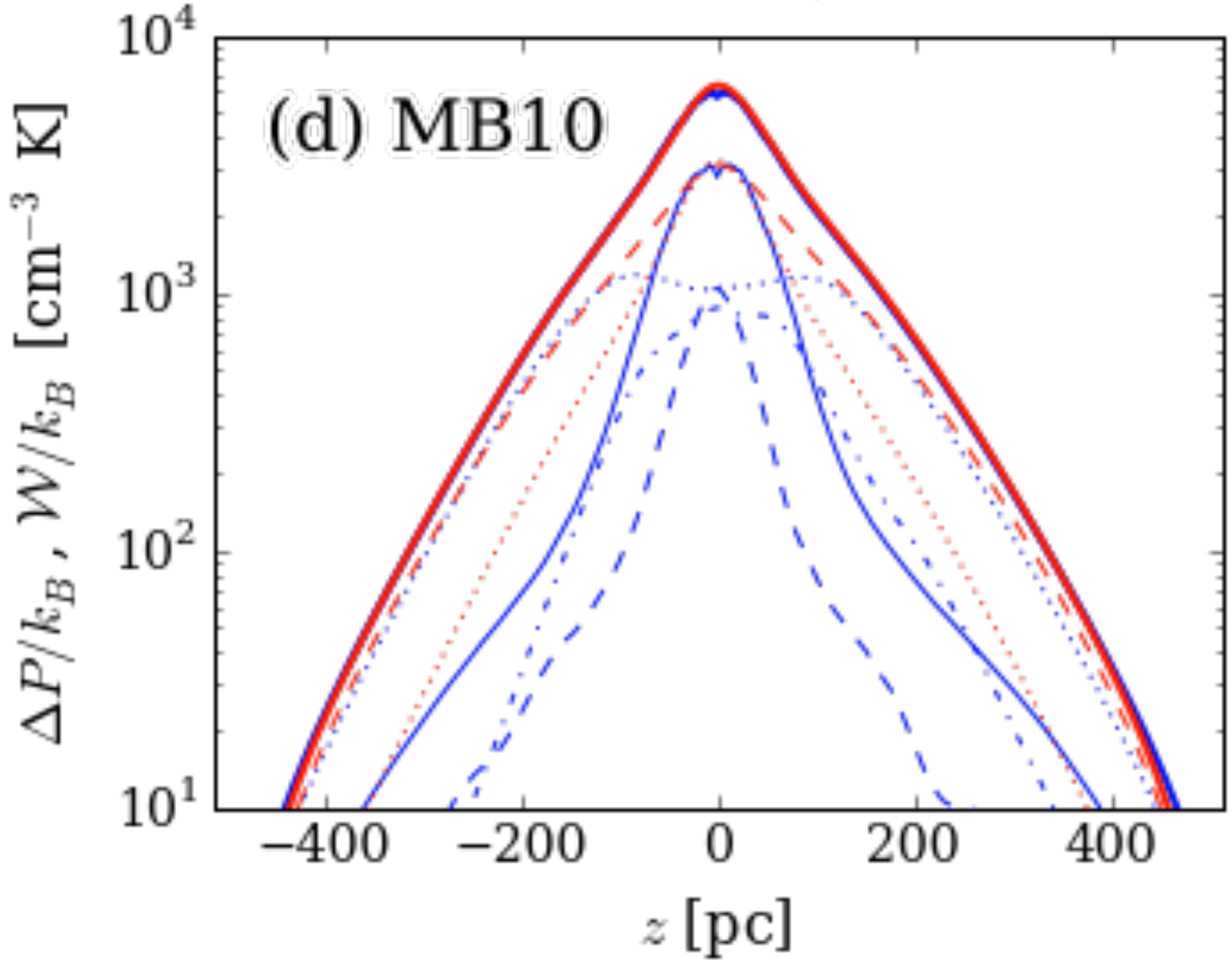




n_H
P_{th}
P_{turb}
P_{mag}
δP_{mag}
t/t_{orb}= 0.00
Σ
P_{th}/k_B
$P_{turb,z}/k_B$
P_{mag}/k_B
$\delta P_{mag}/k_B$
x
z
y

Pressures in Blue; Weights in Red

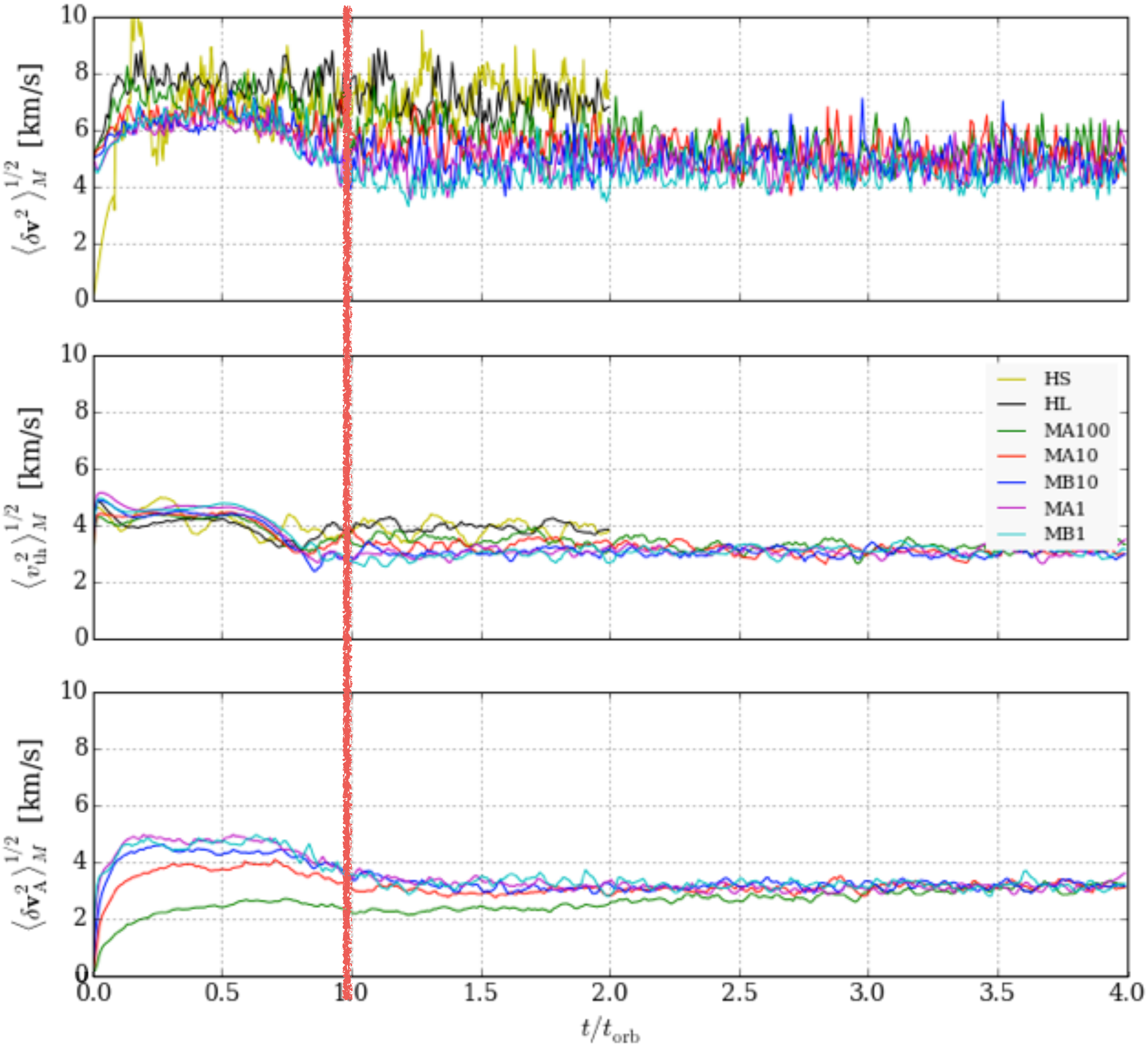




- $\Delta P_{tot} = P_{turb} + P_{th} + \Delta\Pi_{mag} + \Delta P_{cr} + \Delta P_{rad}$
  - $\Delta\Pi_{mag} = \Delta(B_x^2 + B_y^2 - B_z^2)/8\pi$
- $W = \Sigma(g_{sg} + g_{ext})/2$

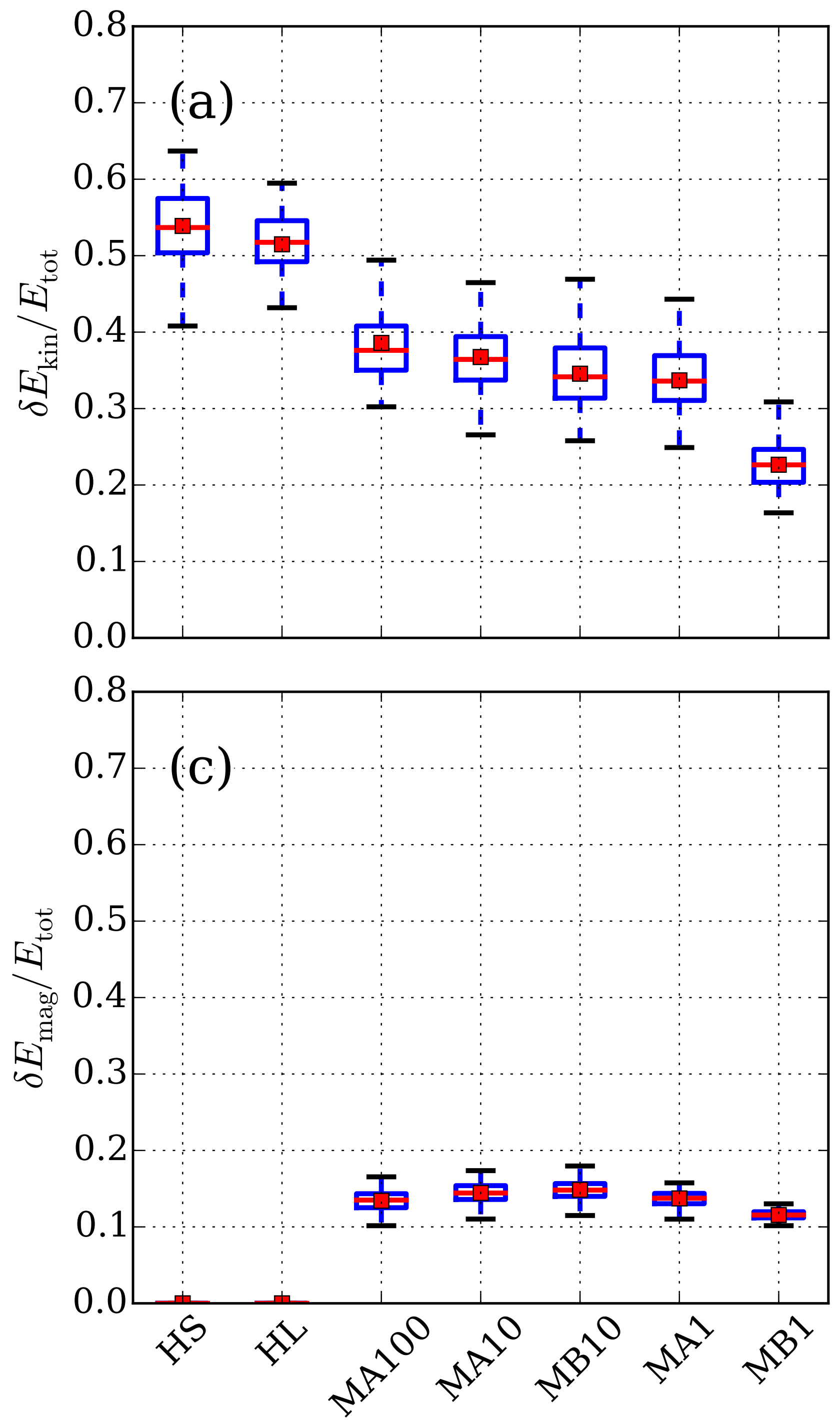
  $\sim \pi G \Sigma^2/2 + \Sigma \sigma_z (2G\rho_*)^{1/2}$

Saturated State



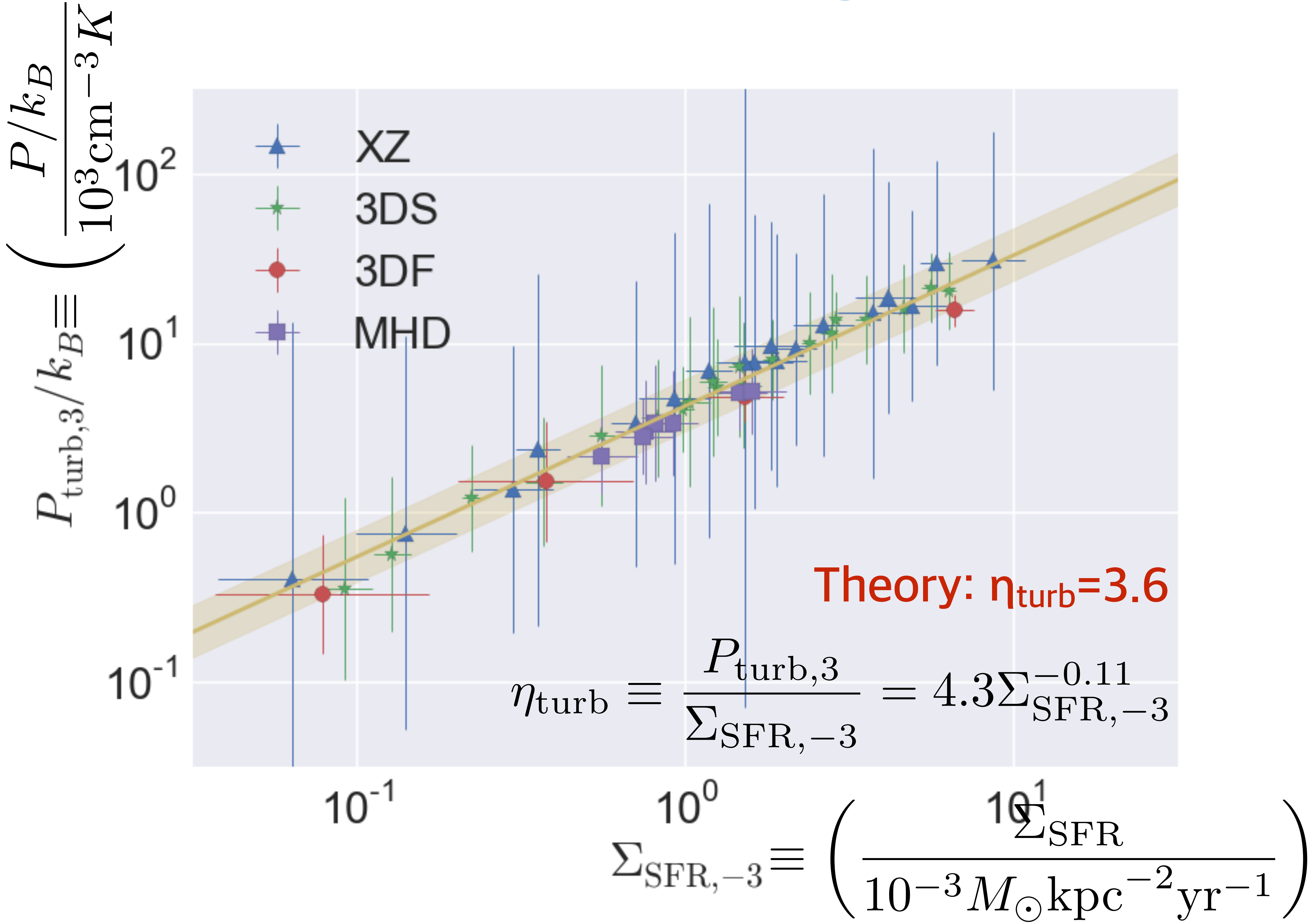
- Total energy is well saturated
- Rapid generation of turbulent magnetic fields
  - Saturation of turbulent fields
  - $\delta E_{kin} \sim (2\text{-}2.5)\delta E_{mag}$

Saturation of b

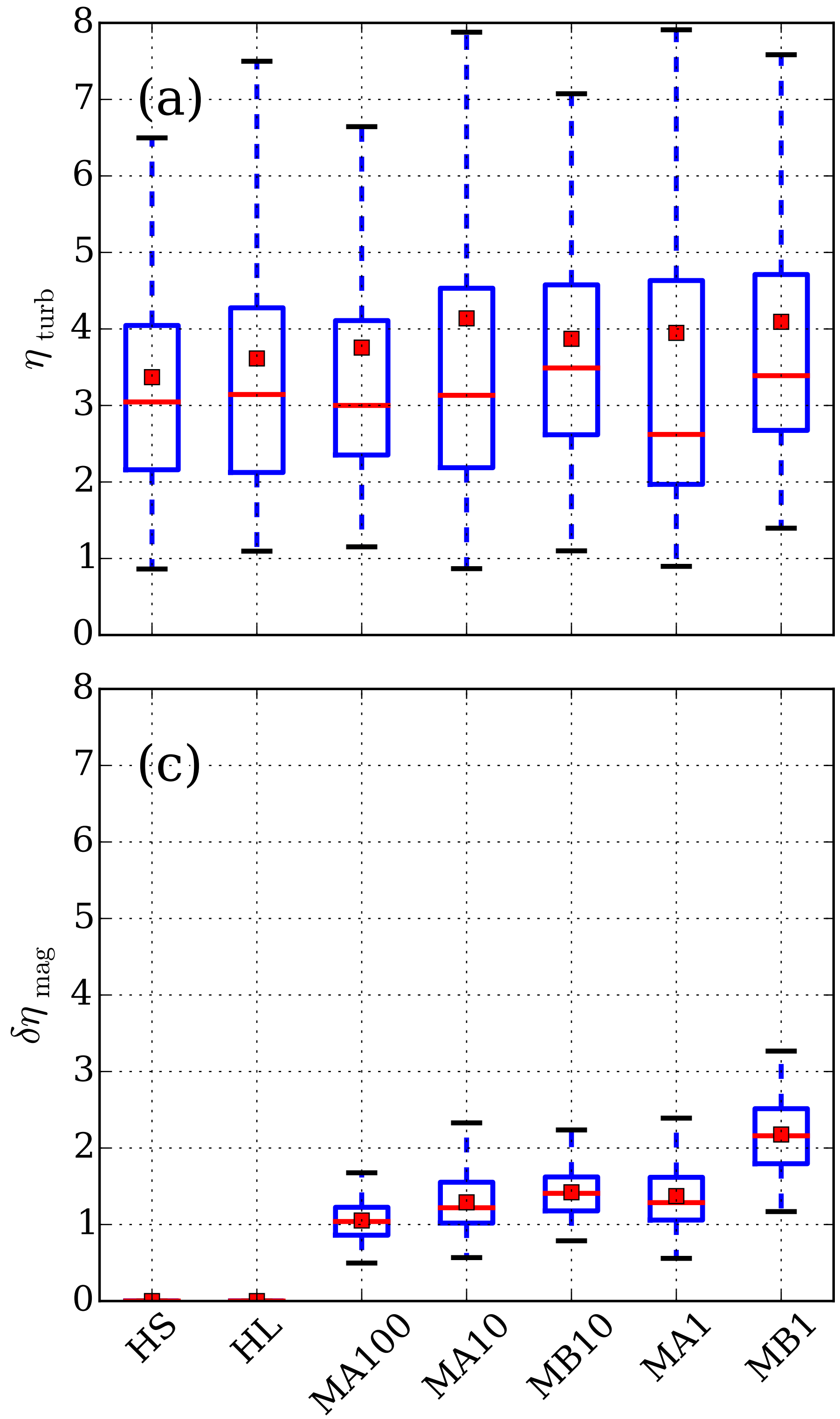


- random magnetic fields saturate at around the equipartition between the magnetic and kinetic energy in the turbulence (e.g., Haugen et al. 2004; Cho et al. 2009)
  - **$b \sim B_{eq} = (4\pi\rho\sigma^2)^{1/2}$**
  - our simulation shows $\delta E_{kin} \sim (2\text{-}2.5)\delta E_{mag}$
  - **$b \sim (0.6\text{-}0.7)B_{eq}$**

Σ_{SFR} —> Turbulence Driving —> P_{turb}



Regulation of SFR

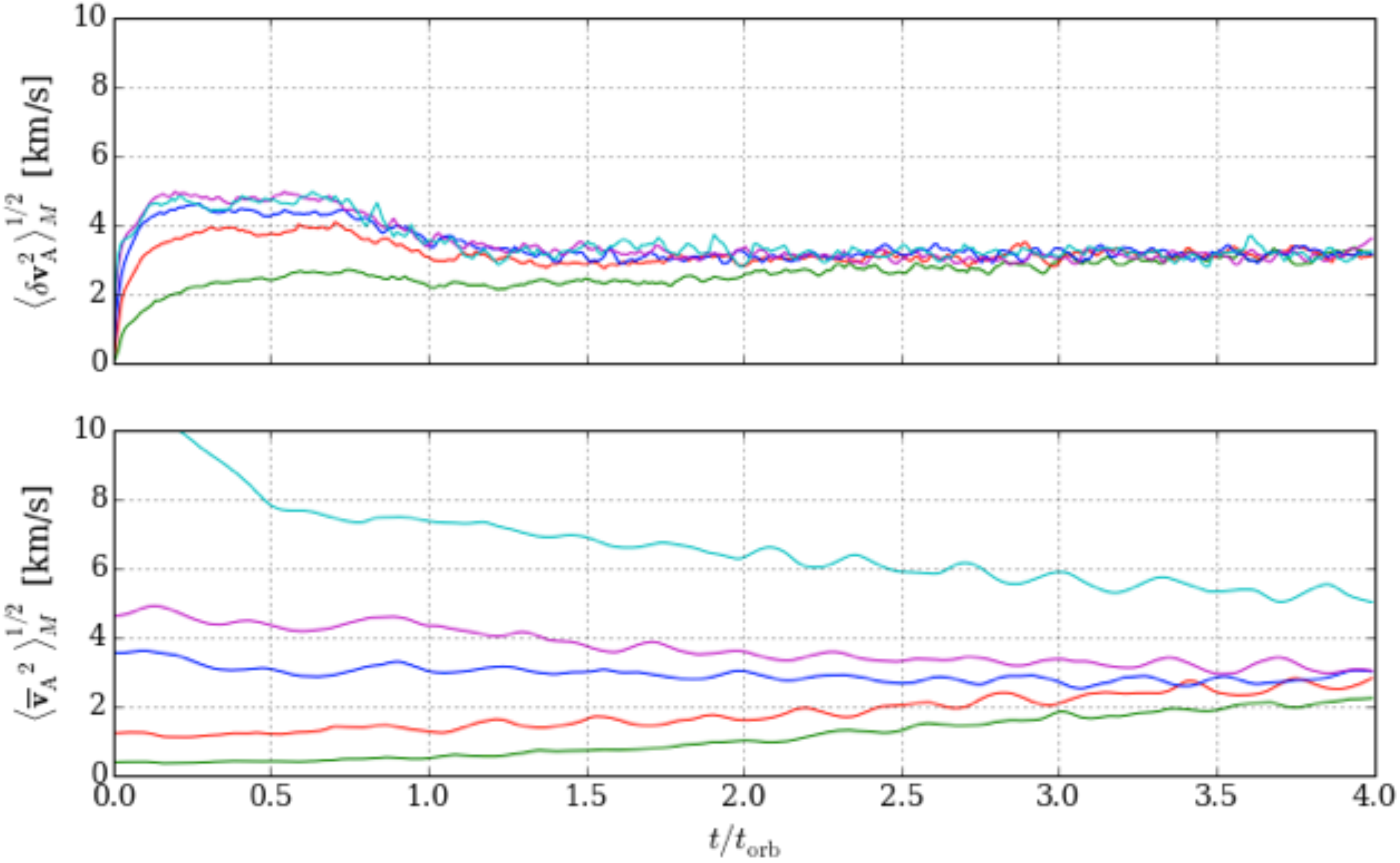


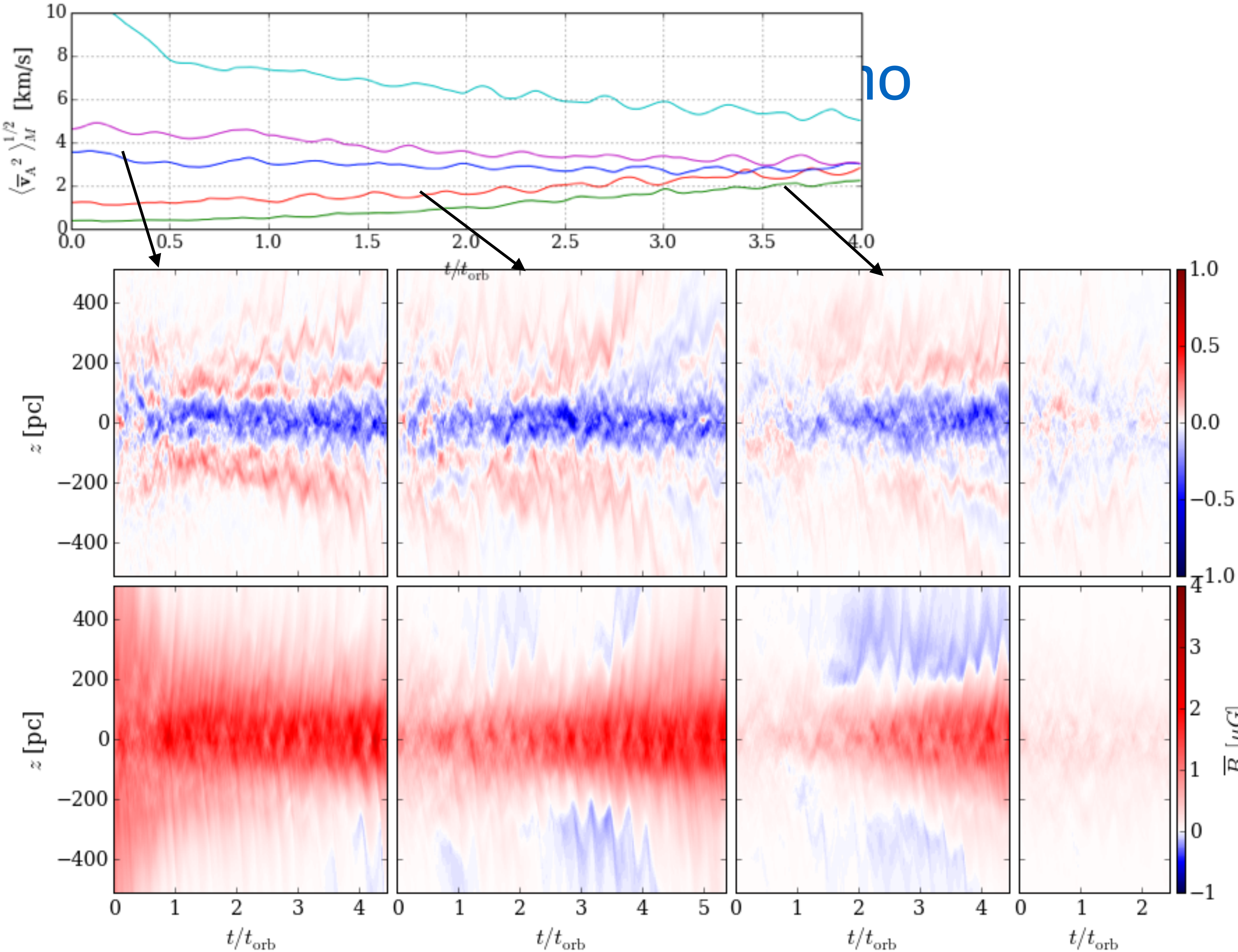
- Feedback yields: $\eta \sim P/\Sigma_{SFR}$ (in suitable units)
- If we have 1 SF, we will get
  - ~4 turbulent kinetic support (both HD and MHD)
  - ~1 thermal support
  - ~1 turbulent magnetic support
- Vertical force balance requires the same total support for given surface density and external gravity
  - SFR can be reduced in MHD models

Concluding Remarks

- SF feedback provides pressure support and VDE constrains SFR
  - $\boldsymbol{W(\Sigma, \Sigma_*, \sigma_g, \sigma_*, \ldots)=P_{tot}=\eta\Sigma_{SFR}}$
- Saturation level of turbulent magnetic fields is set by equipartition (δE_{mag}~$\delta E_{kin}/2$), which depends on the SFR
  - $\delta\Pi_{mag} \approx P_{turb}/4=\eta_{turb}/4\Sigma_{SFR}$
  - $\mathbf{b \sim 2\mu G\ (\Sigma_{SFR}/10^{-3} M_{sun}\ pc^{-2}\ yr^{-1})^{1/2}}$
- **Cosmic rays can amplify magnetic fields and provide additional vertical support**

Mean field dynamo





Non-rotating model cannot generate the mean magnetic fields!!

Mean field dynamo

- growth time
  - (0.3-1) Gyr
- magnetic pitch angle
  - $\tan(p_B) \approx -0.17$
  - trailing
- overall in good agreement with $\alpha\Omega$-dynamo