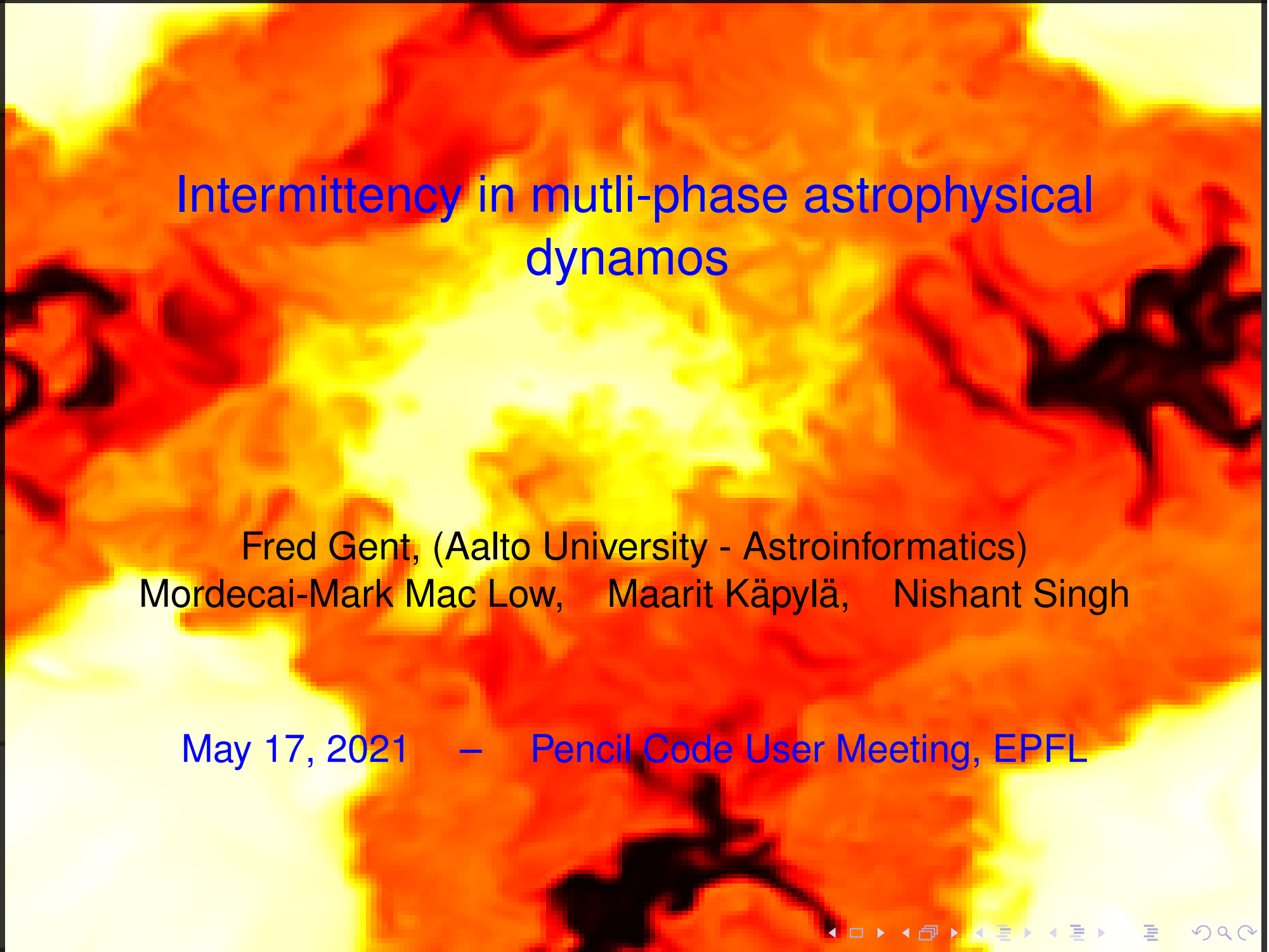

Intermittency in mutli-phase astrophysical dynamos

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Mordecai-Mark Mac Low, Maarit Käpylä, Nishant Singh

May 17, 2021 – Pencil Code User Meeting, EPFL

Galactic dynamo - large and small scale

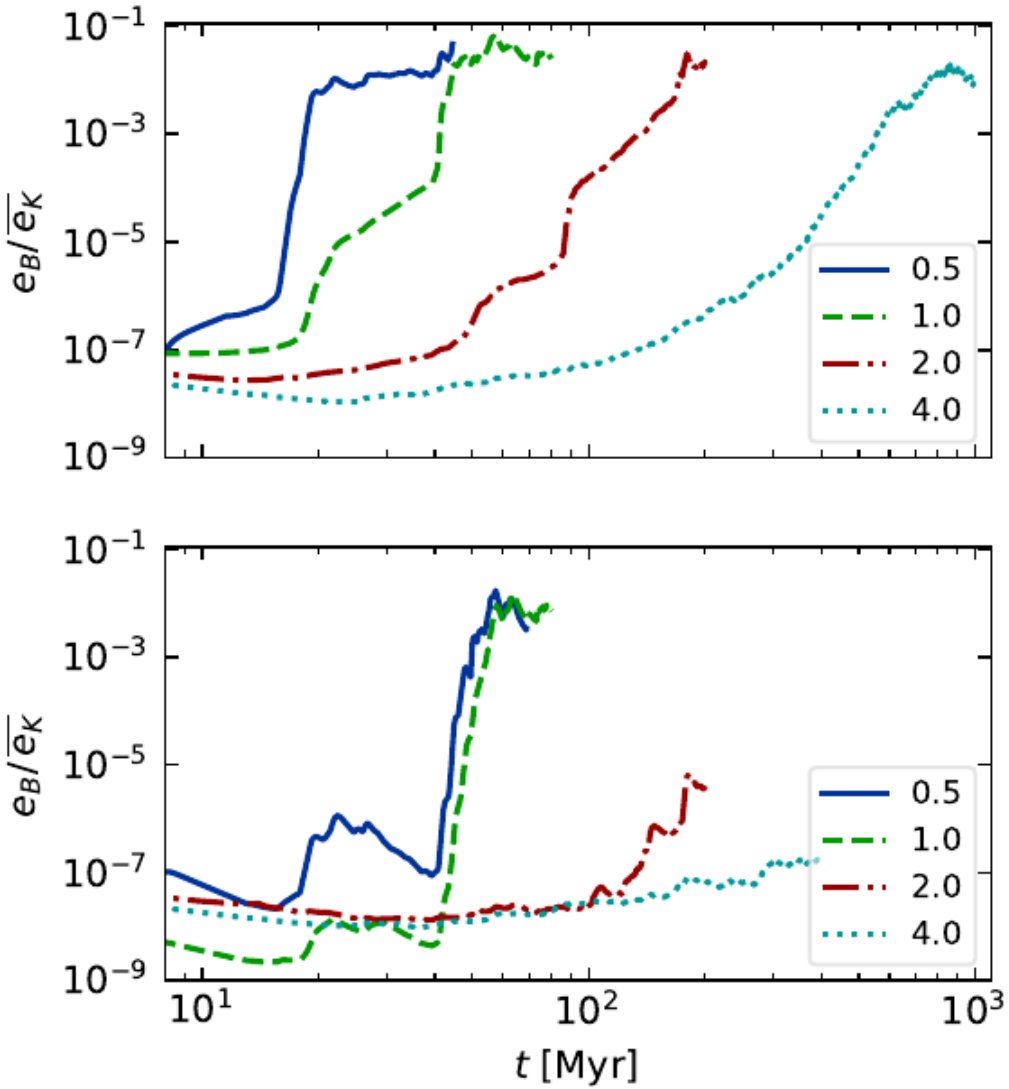
(Gent et al. 2013)
(Gressel et al. 2008, Gressel & Elstner 2020)

(Korpi et al. 1999, Hanasz et al. 2009, Wang & Abel 2009, Rieder & Teyssier 2016, Rieder & Teyssier 2017*a*, Rieder & Teyssier 2017*b*, Pakmor et al. 2017, Steinwandel et al. 2019) show no LSD or LSD without SSD.

Small-scale dynamo (SSD) – Experimental setup

- 3D periodic ISM 1 ppcc 256(200) pc on each side
- SN rate comparable to solar neighbourhood 0.2 – 8 $\dot{\sigma}_{\rm sn}$
- Energy: radiative cooling and UV-heating, hyperdiffusion and shock diffusion
- Induction: hyperdiffusion and $\eta \in [0, 0.05]$ kpc km s^{-1}
- Momentum: hyperdiffusion and shock diffusion $\nu \in [0, 0.001]$
- Continuity: shock diffusion
- Resolution 0.5, 1, 2 and 4 pc

Magnetic energy growth rates



Magnetic energy density for resolutions $\delta x = 0.5$–$4\ \mathrm{pc}$,

scaled to time-averaged kinetic energy density $\overline{e_K}$

for resistivity (a) $\eta = 10^{-4}$ & (b) $10^{-3}\,\mathrm{kpc\,km\,s^{-1}}$.

Dependence on Mach number (Haugen, Brandenburg & Mee 2004)

Magnetic energy growth rates

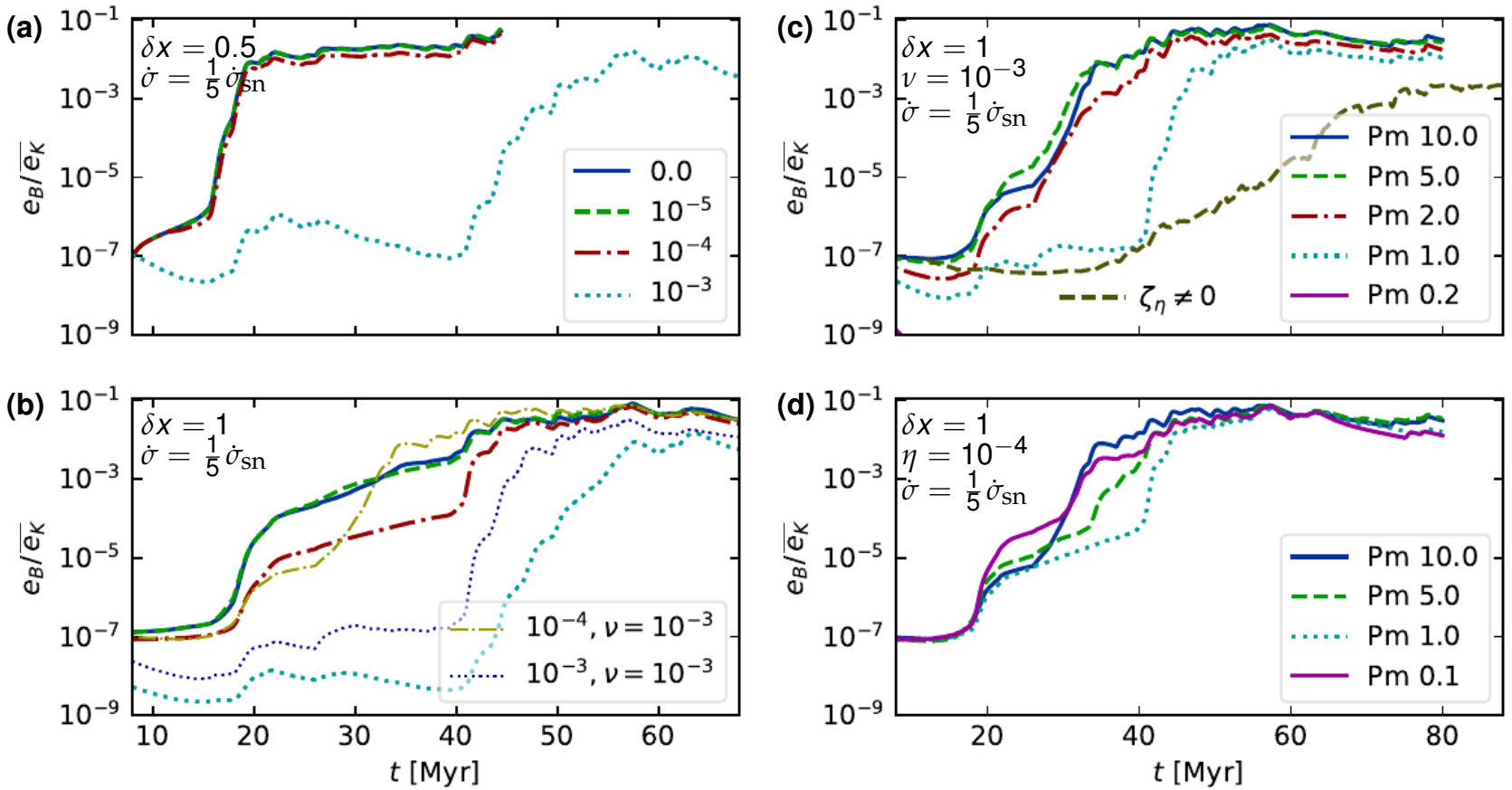
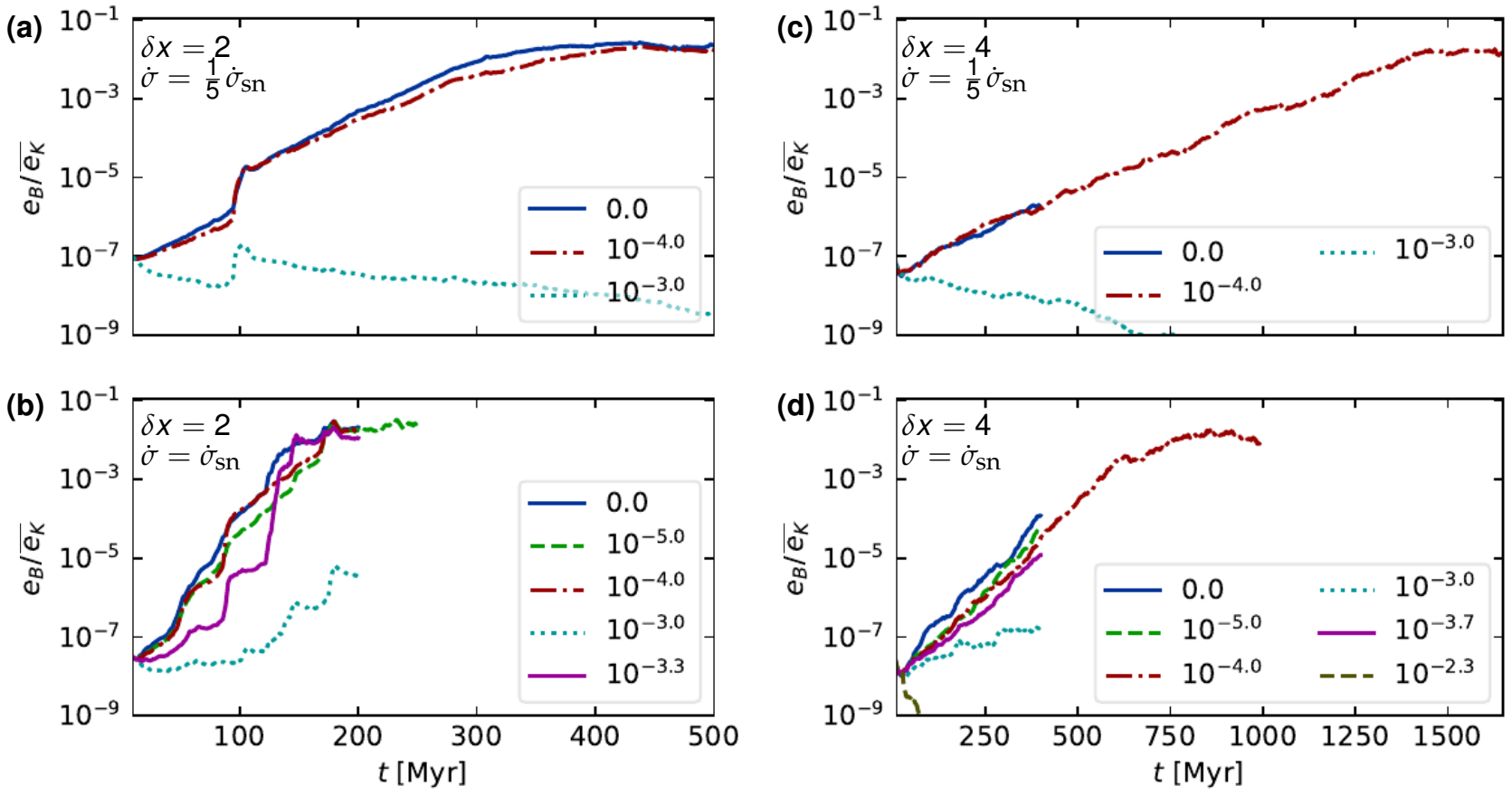


Figure: Magnetic energy density e_B normalized by the time-averaged kinetic energy $\overline{e_K}$ for various resistivities η for values given in each panel of resolution δx and SN rate $\dot{\sigma}$ normalized by the solar neighborhood rate $\dot{\sigma}_{\rm sn} \simeq 50\,{\rm kpc}^{-3}\,{\rm Myr}^{-1}$. $\nu = 0$, except where Pm is varied with ν fixed (c) or η fixed (d). Dependence on Pm (Haugen, Brandenburg & Dobler 2004)

Magnetic energy growth rates



caption agnetic energy density e_B normalized by the time-averaged kinetic energy $\overline{e_K}$ for various resistivities η for values given in each panel of resolution δx and SN rate $\dot{\sigma}$ normalized by the solar neighborhood rate $\dot{\sigma}_{\rm sn} \simeq 50\,{\rm kpc}^{-3}\,{\rm Myr}^{-1}$. $\nu = 0$ η fixed (d).

Energy spectra by resolution and resistivity

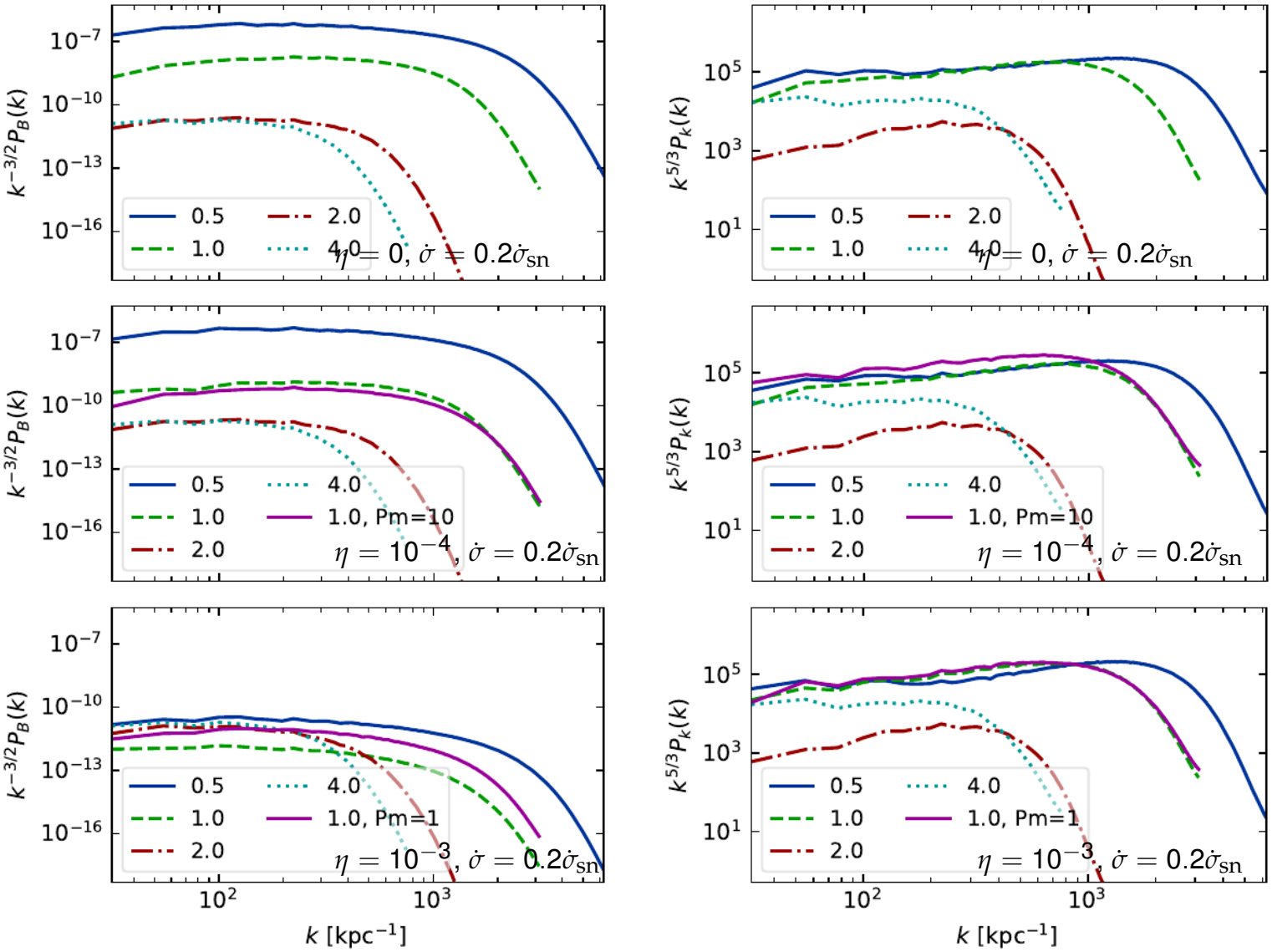


Figure: Compensated power spectra magnetic (left) and kinetic (right). Resistivity η & supernova rate $\dot{\sigma}$, 19.5 Myr ($\delta x = 0.5$, 1 pc), 100 Myr (2, 4 pc).

Multi-phase structure of SSD

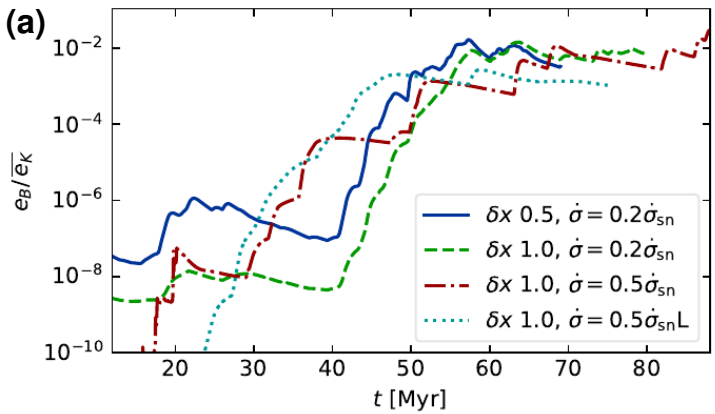
Magnetic enegy growth mainly associated with warm gas

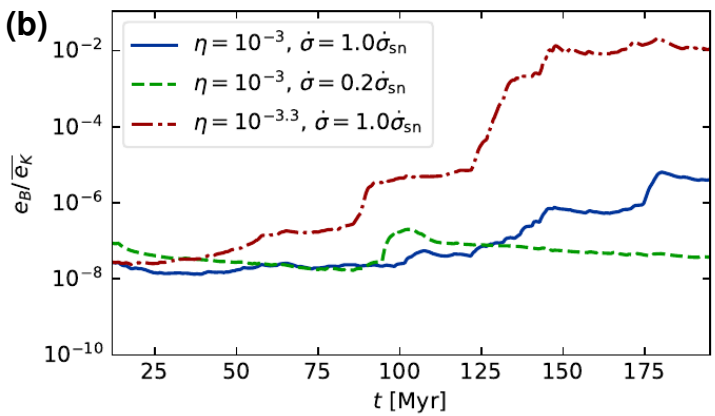
Occasional rapid acceleration in mature hot bubbles (Gent et al. 2021)

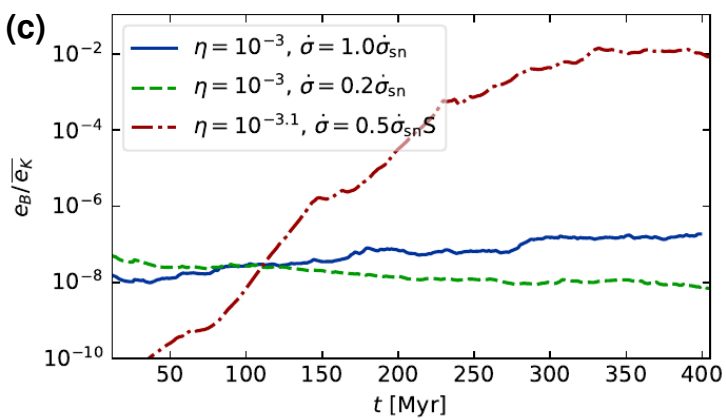
Experimental setup

- Sliding periodic ISM horizontally $L_x = 512$ pc $L_z = 3072$ pc and $L_y = 512$, 1024 and 1536 pc (Mean field suppressed with 512)
- 1 ppcc intially at the midplane
- SN rate compared to solar neighbourhood 0.3 – 0.8 $\dot{\sigma}_{\rm sn}$ to reduce mass loss (eventually use mass conservation)
- Energy: UV-heating varied to support disk with pressure missing from CR, ionization
- Resolution 1, and 4 pc

Magnetic energy SSD growth - domain effects







(a) High resolution simulations confirm SSD unconstrained by domain $L_y \simeq 128$ pc (periodic boxes).

(b) Low resolution dynamo growth dependence on resistivity and SN rate $\dot{\sigma}$ (periodic boxes).

(c) Low resolution SSD more efficient in stratified ISM vs periodic box.

Thin disk ISM with large scale rotation and shear

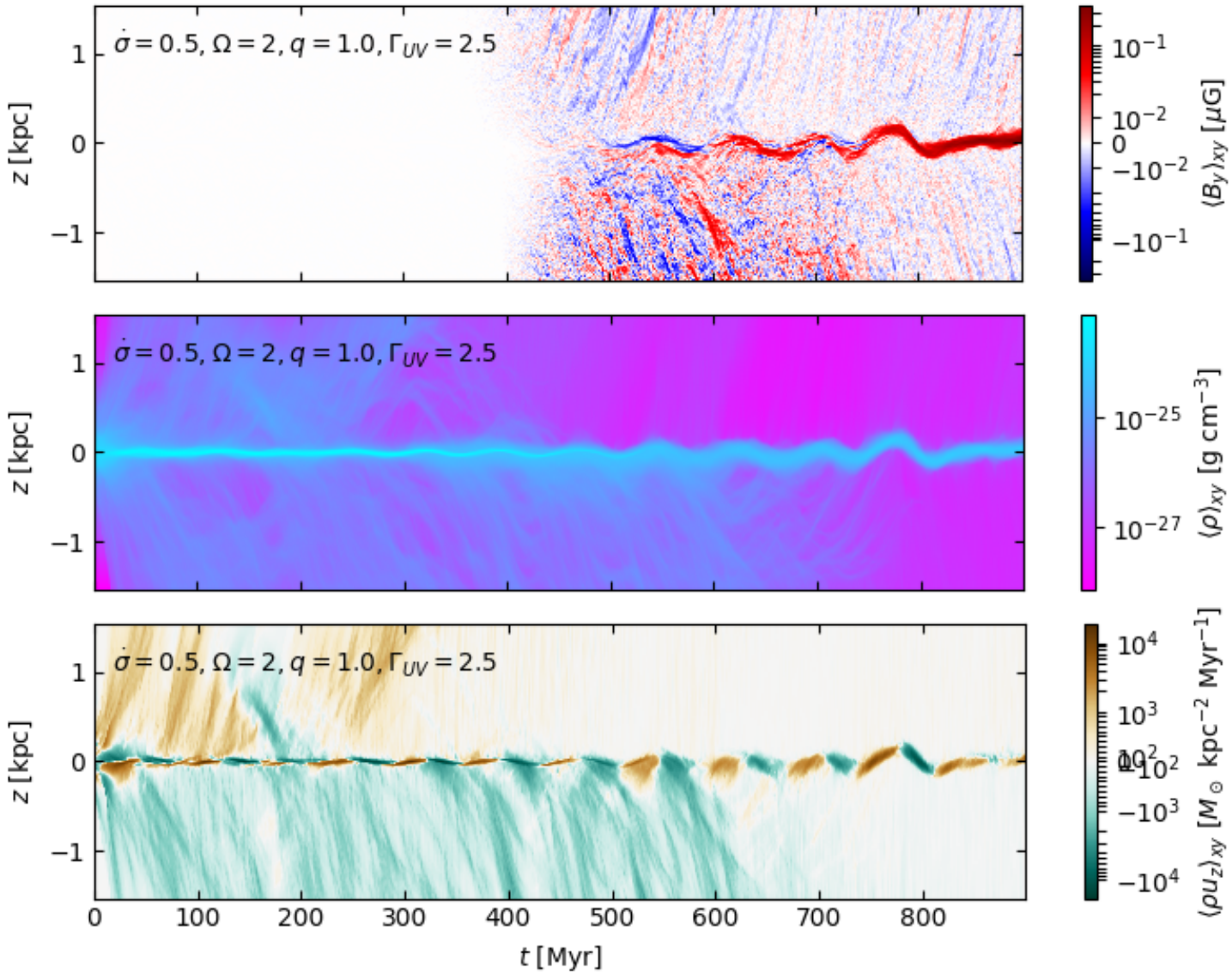


Figure: Horizontal averages 4 pc resolution with UV-heating $\Gamma_{\rm UV}$ 2.5 times the solar vicinity model

Interdependence of SSD and LSD

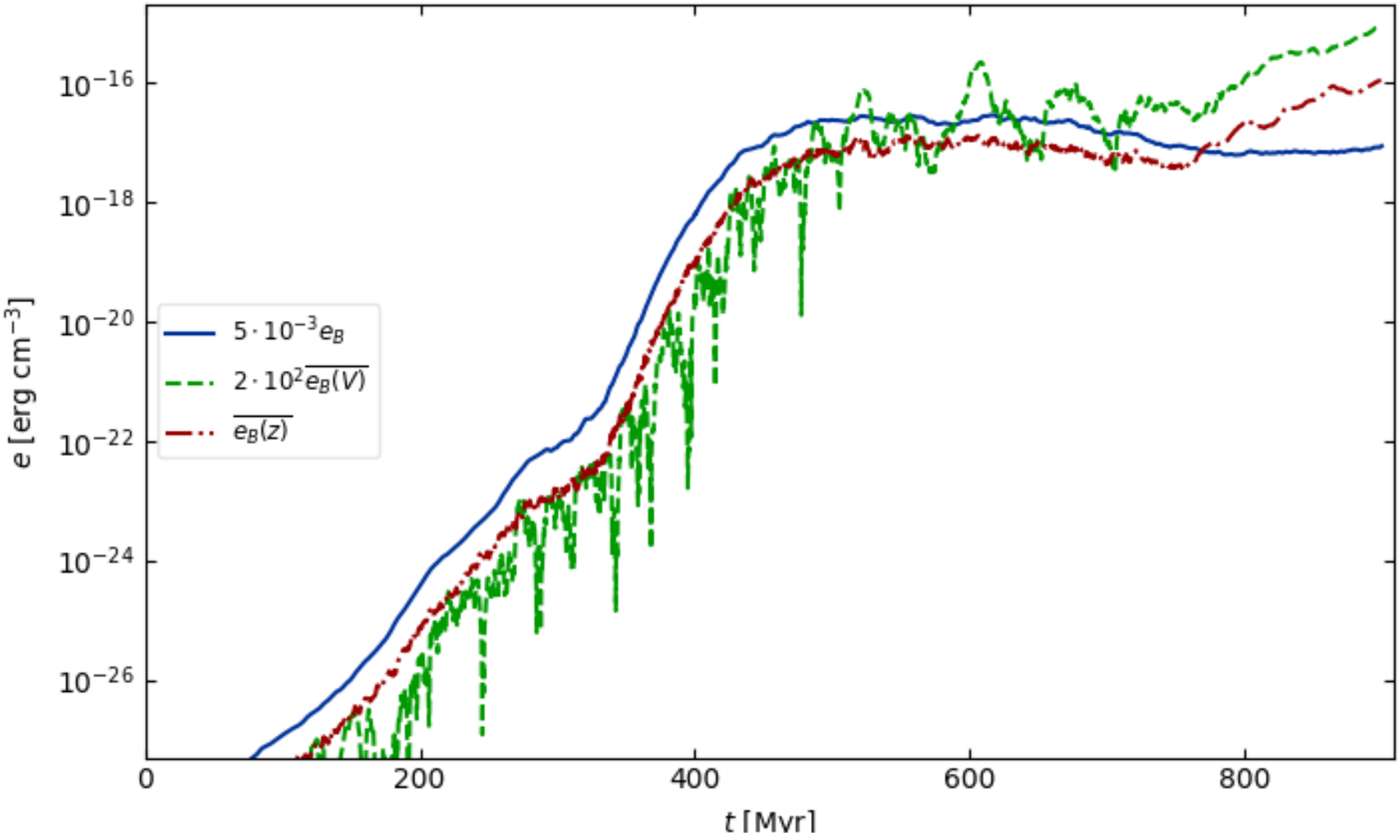


Figure: Energy of the total and mean magnetic field $\Gamma_{\mathrm{UV}} = 2.5$

Thick disk ISM with large scale rotation and shear

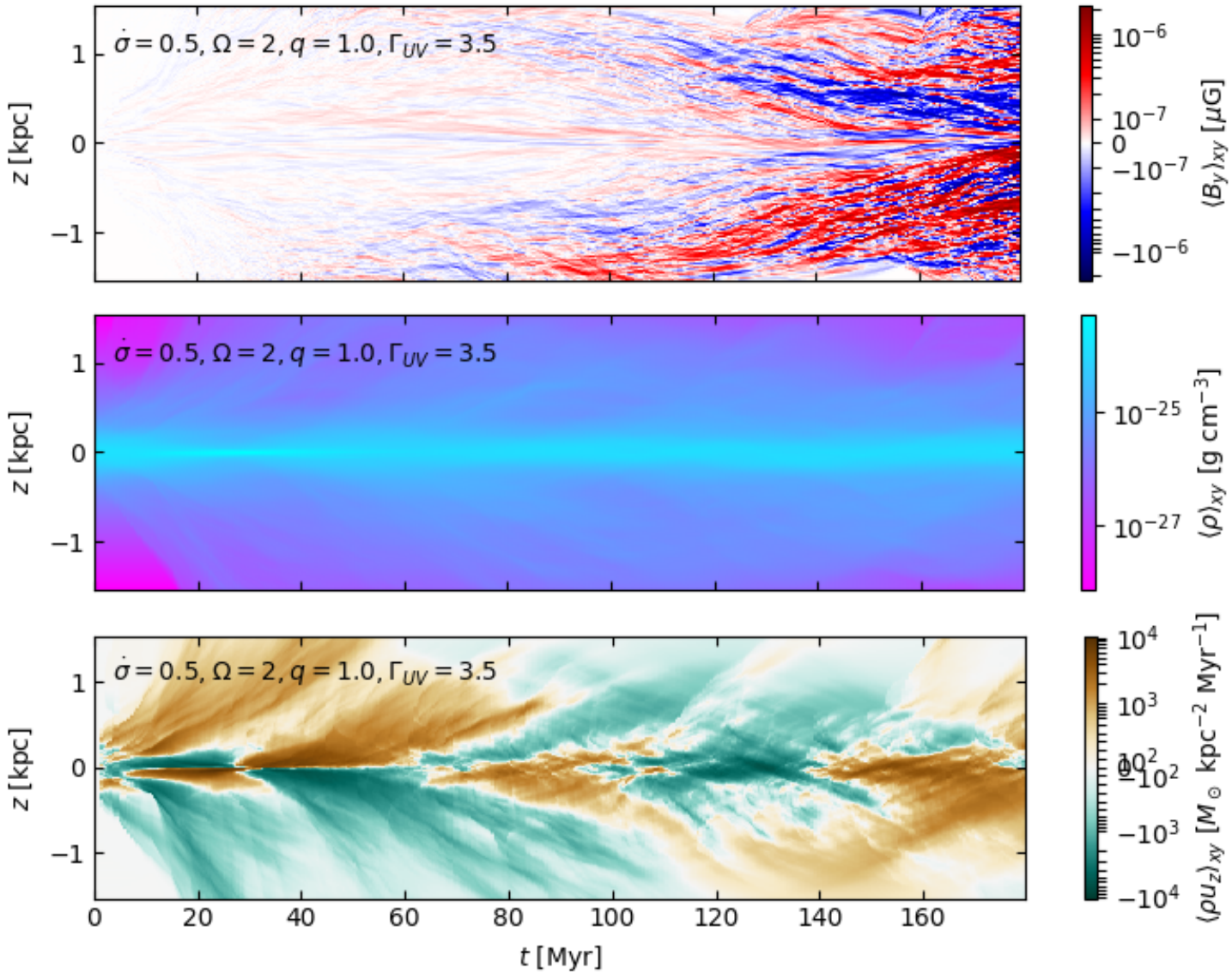


Figure: Horizontal averages 4 pc resolution with UV-heating $\Gamma_{\rm UV}$ 3.5 times the solar vicinity model

Large scale dynamo

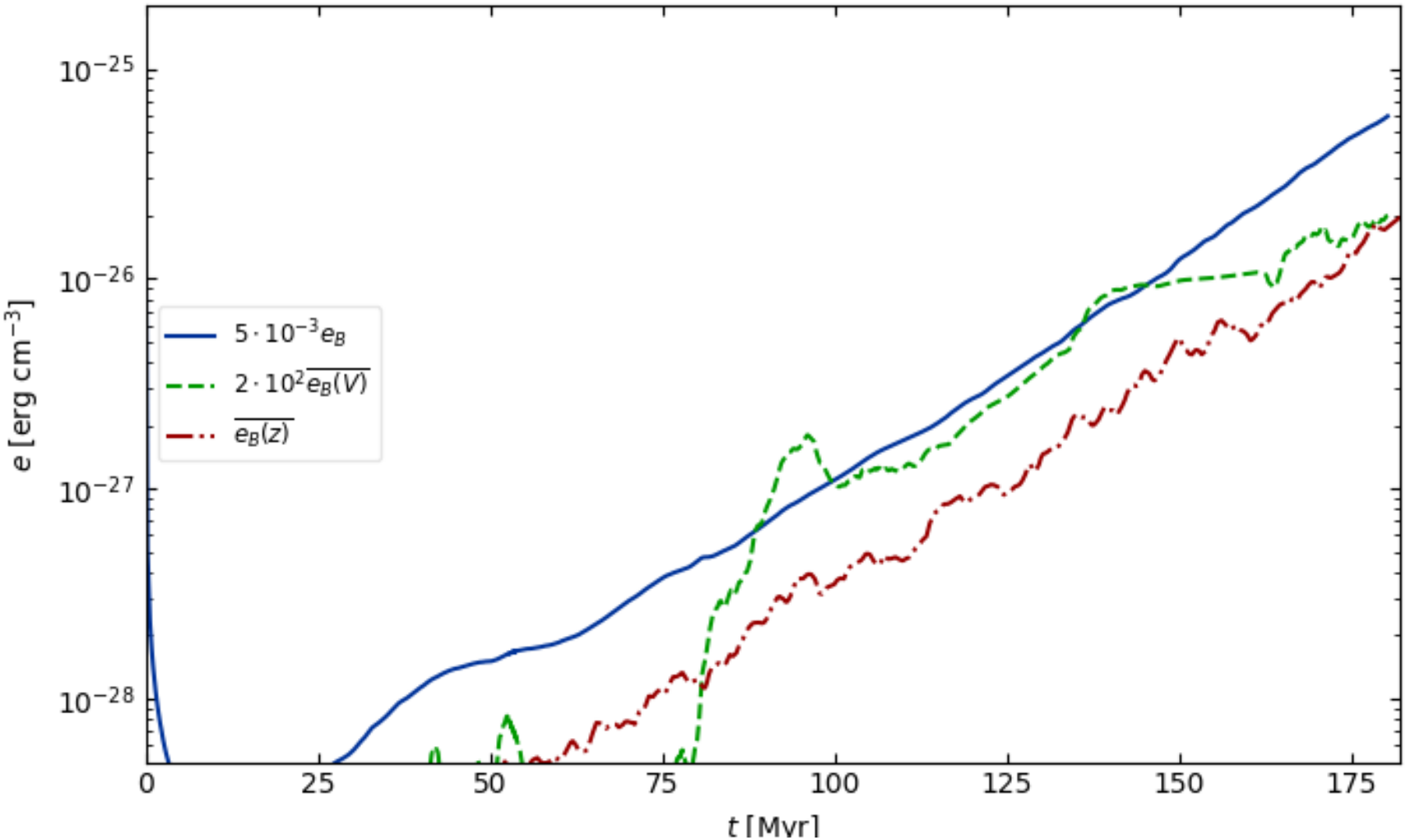


Figure: Energy of the total and mean magnetic field $\Gamma_{\rm UV} = 3.5$.
Growth 2 orders of magnitude in 100 Myr

Summary of results

- SN turbulence convergent for $\delta x \lesssim 1$ pc
- SSD is very easily excited in the ISM - contrast isothermal high (Haugen, Brandenburg & Mee 2004)
- (Balsara et al. 2004) experiment confirmed as SSD and not tangling
- Critical dynamo number and growth rates not clearly Pm or Rm dependent in multi-phase ISM contrast isothermal SSD (Haugen, Brandenburg & Dobler 2004) – (Käpylä et al. 2018) baroclinic effects vs (Federrath et al. 2011)
- For $\dot{\sigma} \in (0.2\dot{\sigma}_{\rm sn}, 8\dot{\sigma}_{\rm sn})$ SSD critical dynamo number decreases with $\dot{\sigma}_{\rm sn}$
- SSD saturates at $\sim 5\%$ energy equipartion independent of Rm or δx, depends on resistiivty η for constant ν
- LSD during SSD kinematic phase dependent of SSD. In non-linear stage LSD exponential.
- Effect of resolution Reynolds numbers effect SSD (indirectly early LSD). Hi resolution confirmation of LSD growth rate unconfirmed.

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Growth in warm/hot gas

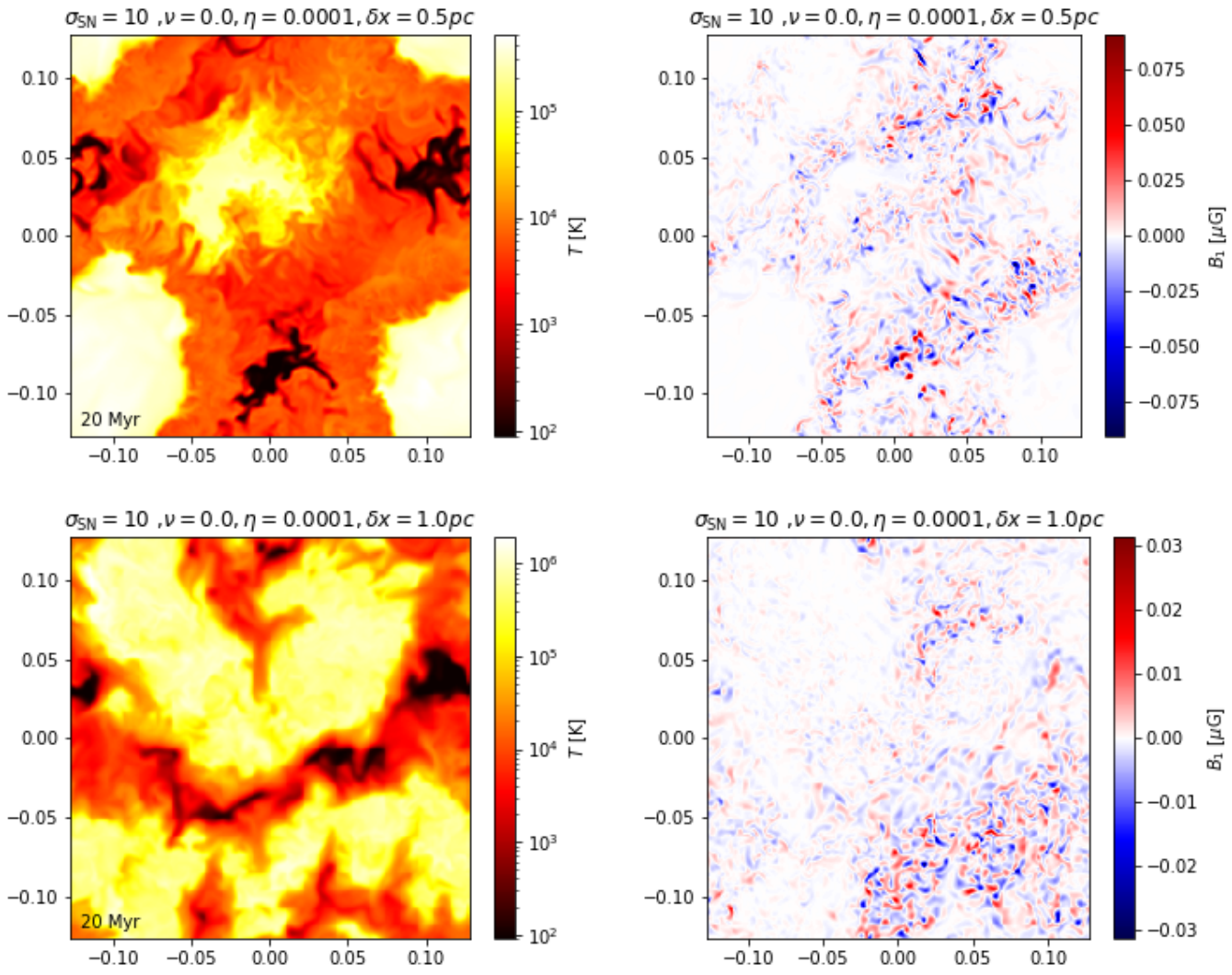

Figure: Slices for resolution of 0.5 pc and 1 pc sampled from the kinematic dynamo state.