kinetic simulations of relativistic harmonic magnetic equilibria

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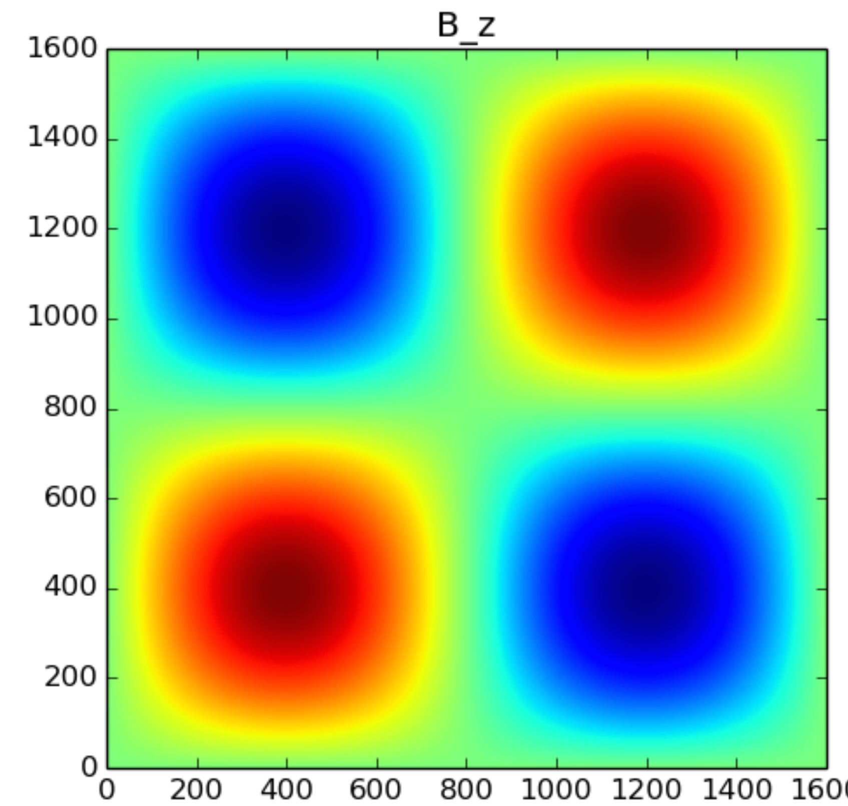
talking on inflation (Thu)

content of this talk

- kinetic particle-in-cell simulations
- Zeltron code (B. Cerutti)
- harmonic magnetic equilibrium ("ABC fields")
- fundamental unstable mode
- 2D periodic domain
- pair plasma
- focus on particle acceleration and evolution of current layers



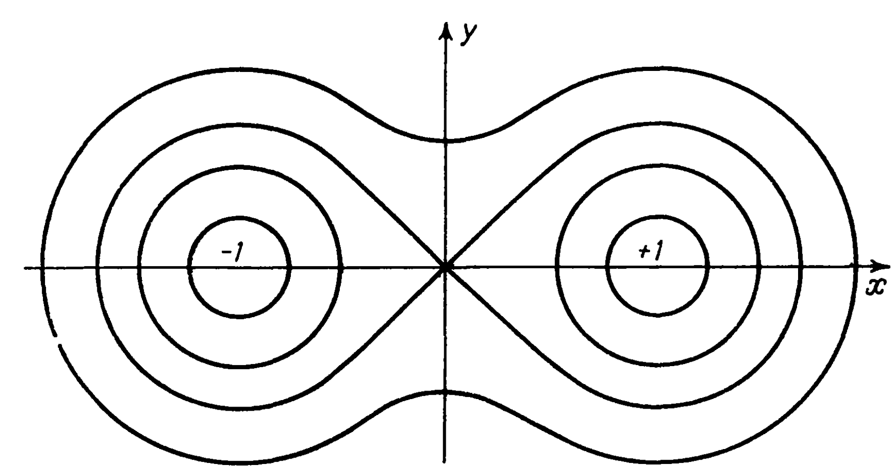
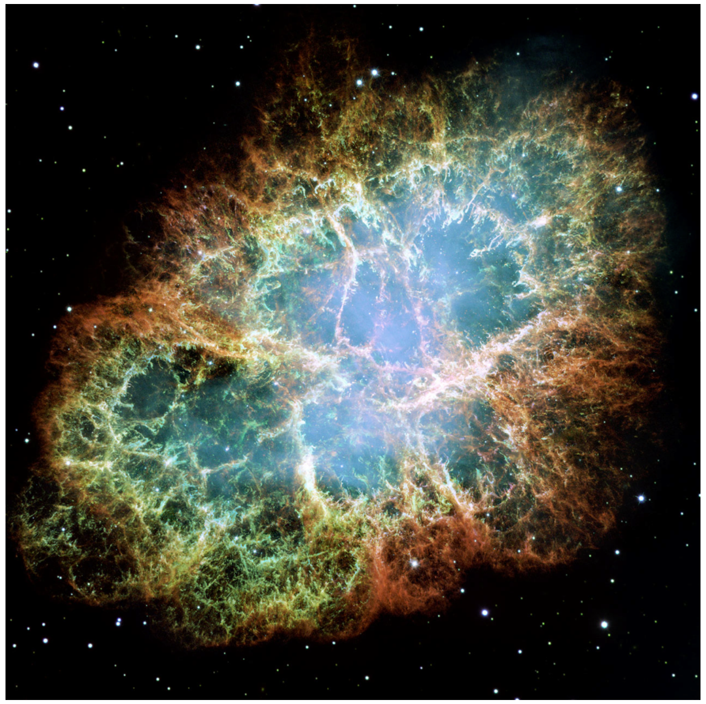


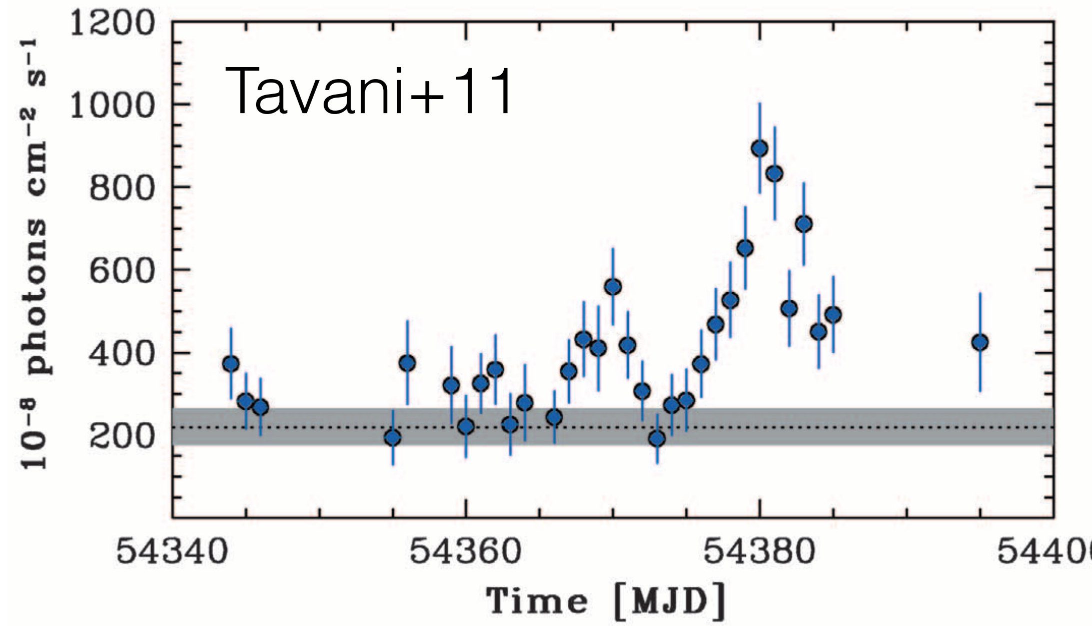
Fig. 1 Syrovatskii 66

similarities to Lyutikov, Sironi & Komissarov

motivation

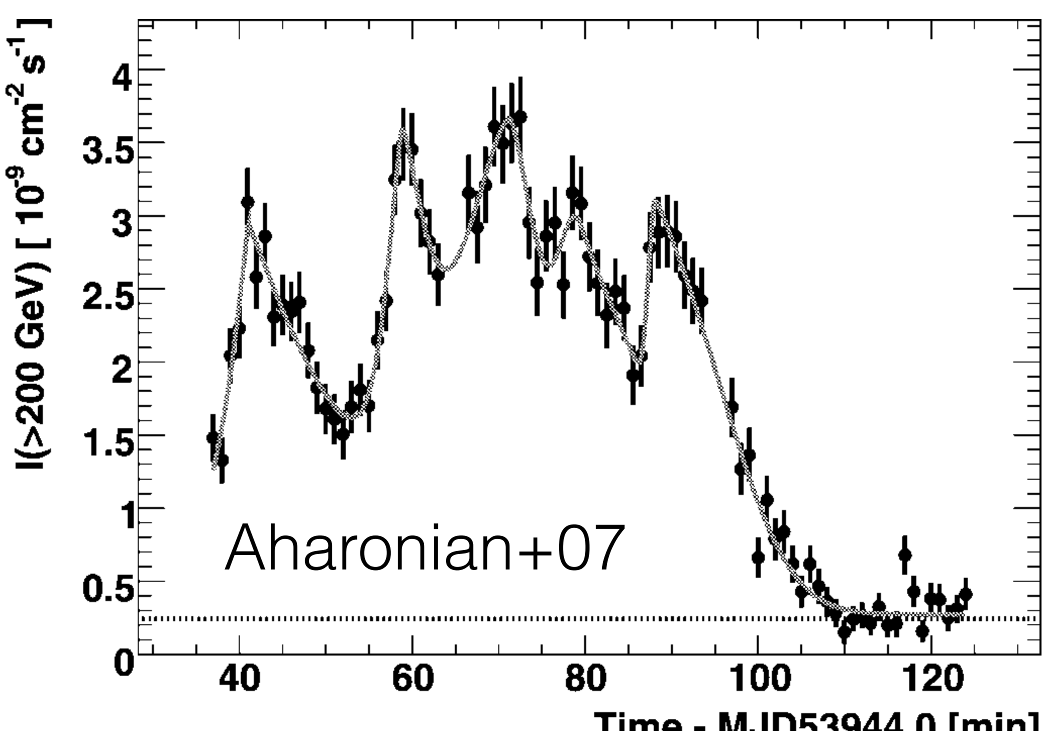
Crab Nebula

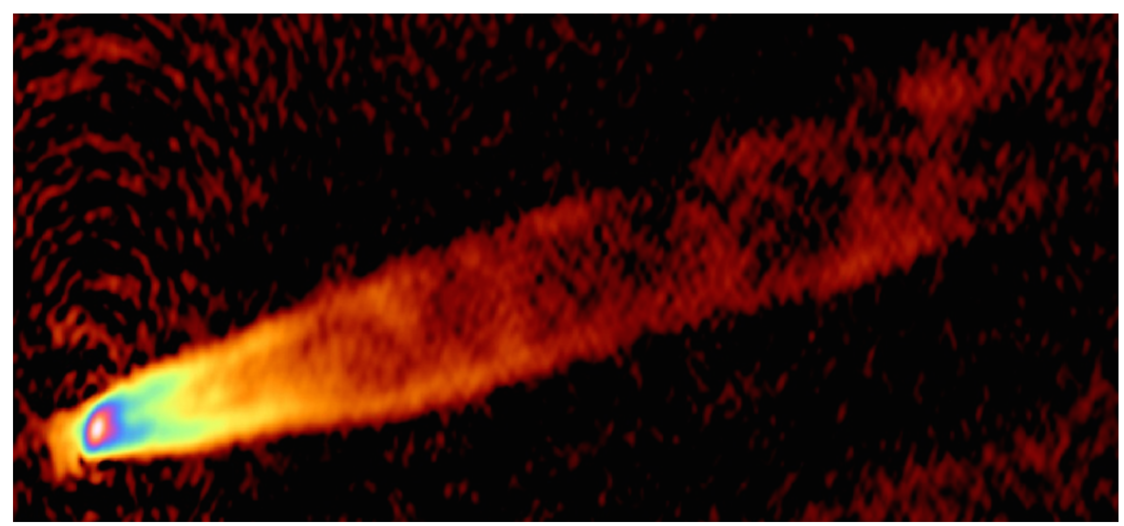




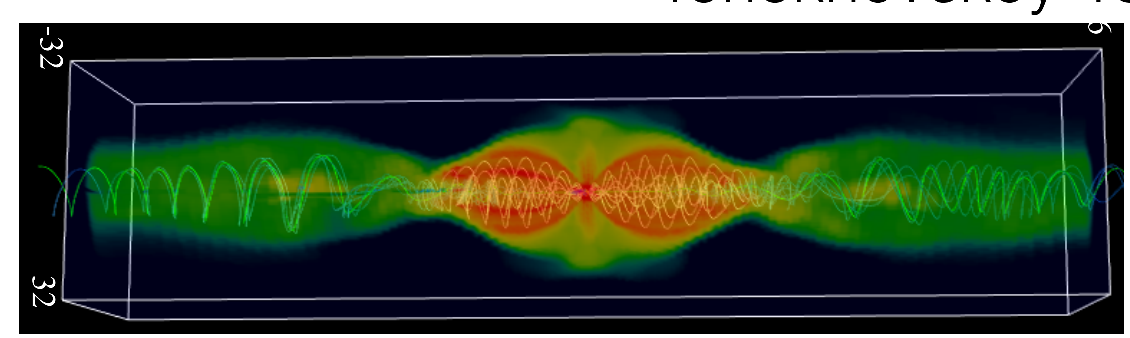
Porth+14

relativistic jets





Bromberg & Tchekhovskoy 15



magnetoluminescence

a process of extracting magnetic energy by means of dynamical instability (implosion) leading to transient current layers enabling efficient particle acceleration, and consequently a transient gamma-ray emission

Methods:

- analytical stability analysis (Y. Yuan)
- relativistic MHD (J. Zrake)
- relativistic force-free (W. East)
- particle-in-cell (this talk)
- radiative PIC (Y. Yuan)

harmonic magnetic equilibria

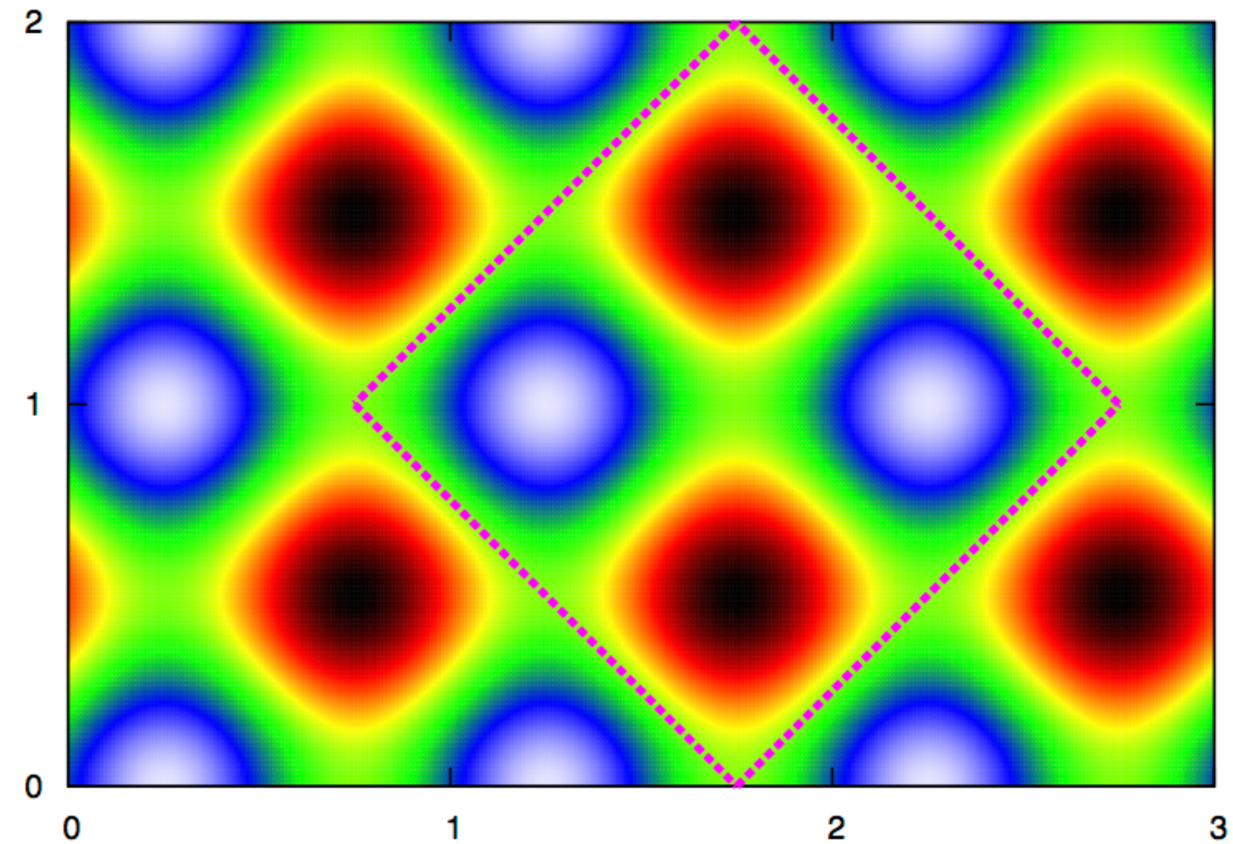
- Beltrami condition:
  $\nabla \times B = \alpha B$
  $B = \alpha A$, $j = -(\alpha c/4\pi)B$

- ABC field:
  $B_x = B_3 \sin(\alpha z) + B_2 \cos(\alpha y)$
  $B_y = B_1 \sin(\alpha x) + B_3 \cos(\alpha z)$
  $B_z = B_2 \sin(\alpha y) + B_1 \cos(\alpha x)$

- 2D: $B_1 = B_2 = 1$, $B_3 = 0$

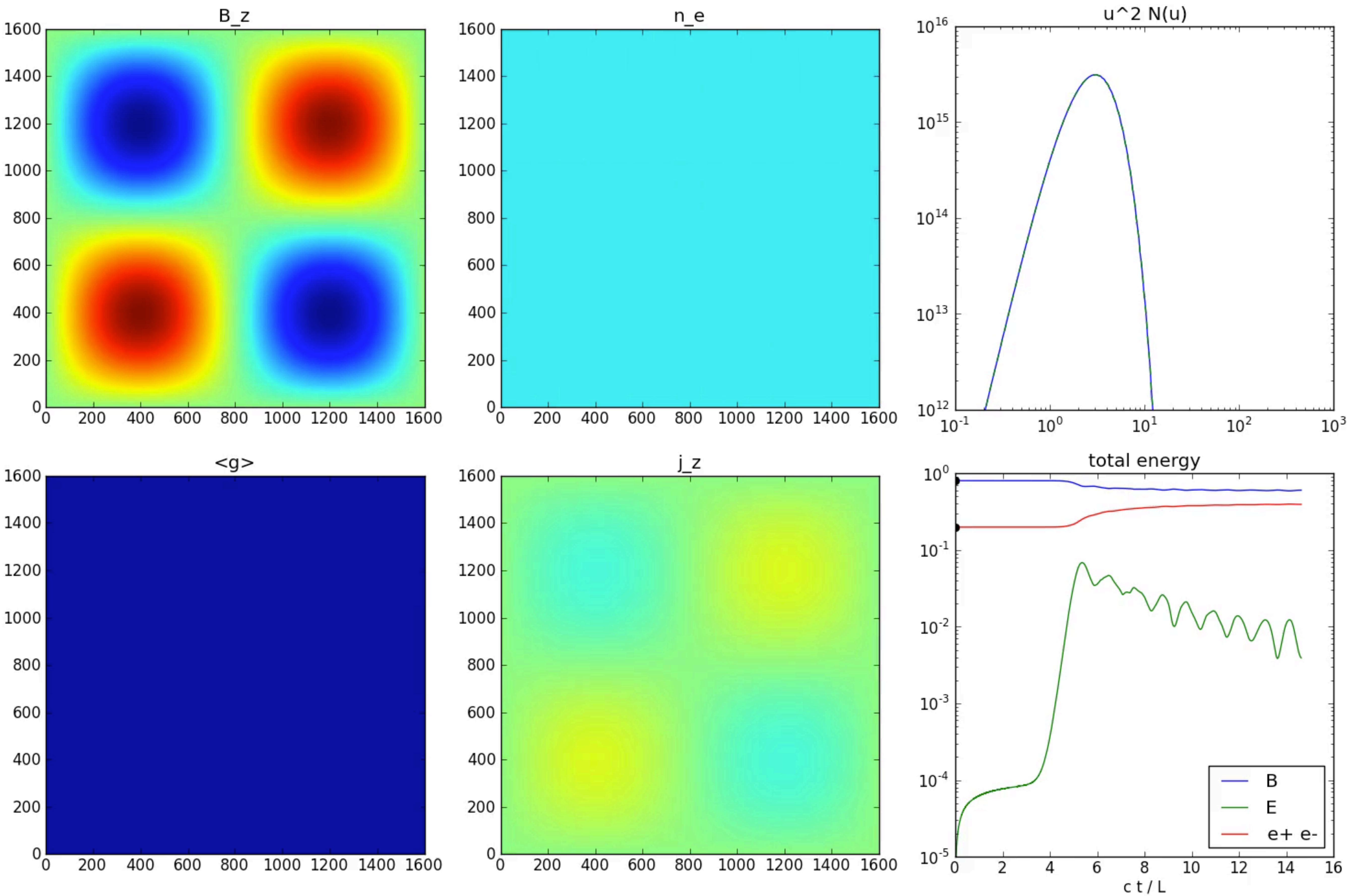
- fundamental unstable mode:
  2 maxima and 2 minima of A_z

- no kinetic-scale initial structure

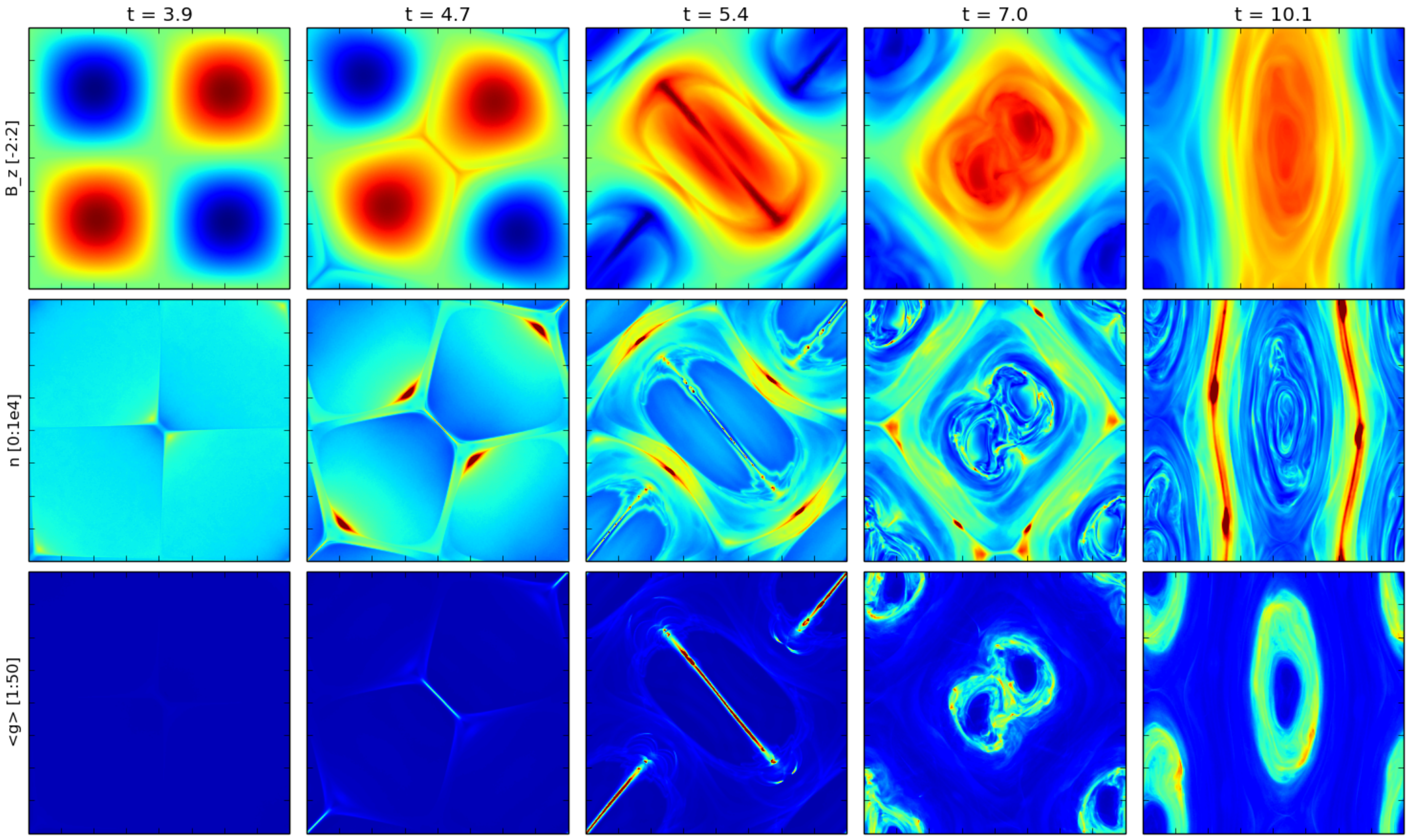


- current density from dipole moment a_1 in particle momentum distribution

- mean magnetization
  $\sigma \propto a_1(L/\rho_0)$

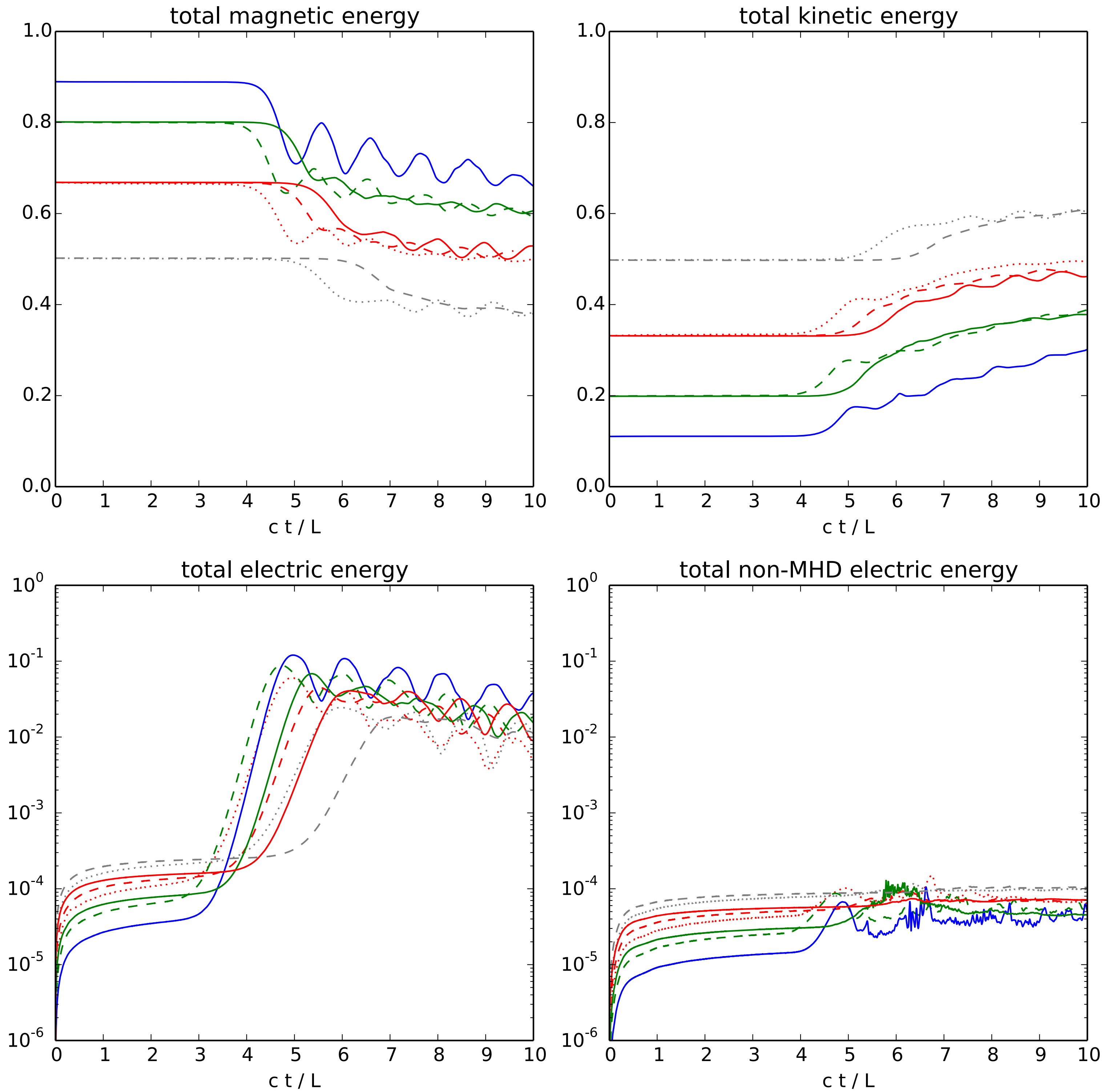


B_z
n_e
u^2 N(u)
<g>
j_z
total energy
B
E
e+ e-
c t / L

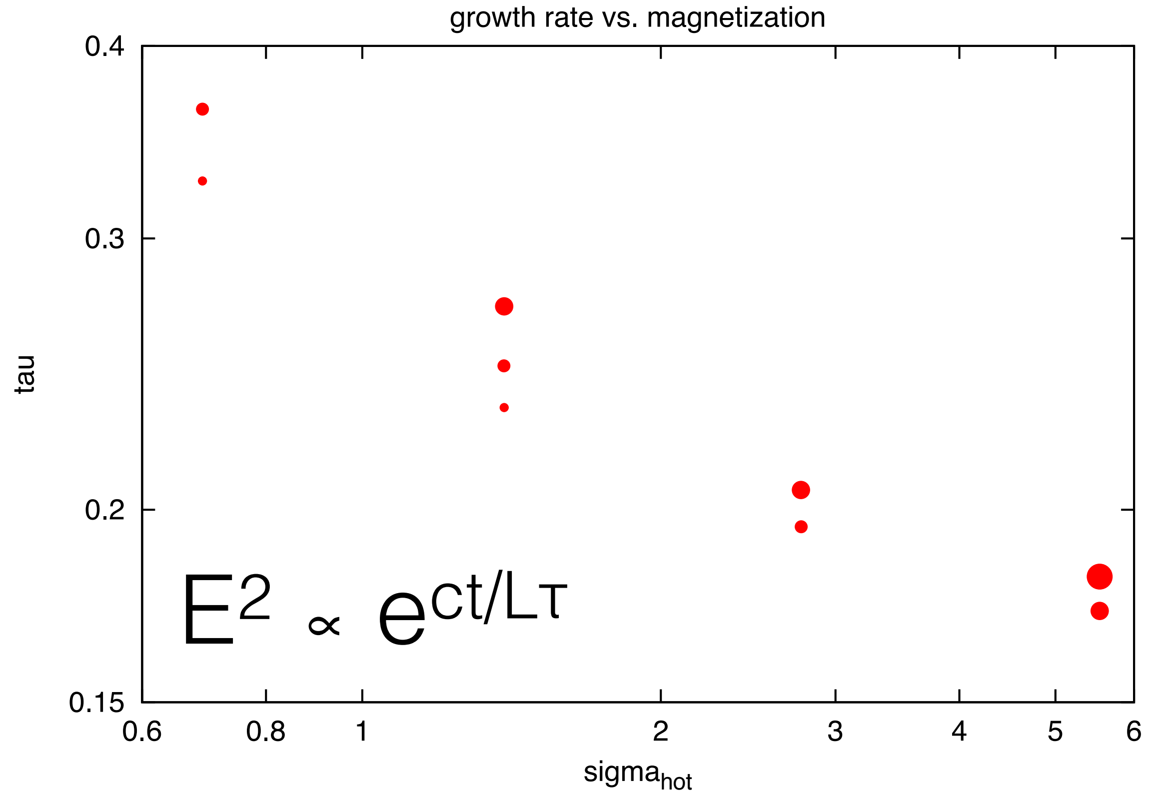


t = 3.9
t = 4.7
t = 5.4
t = 7.0
t = 10.1
B_z [-2:2]
n [0:1e4]
<g> [1:50]

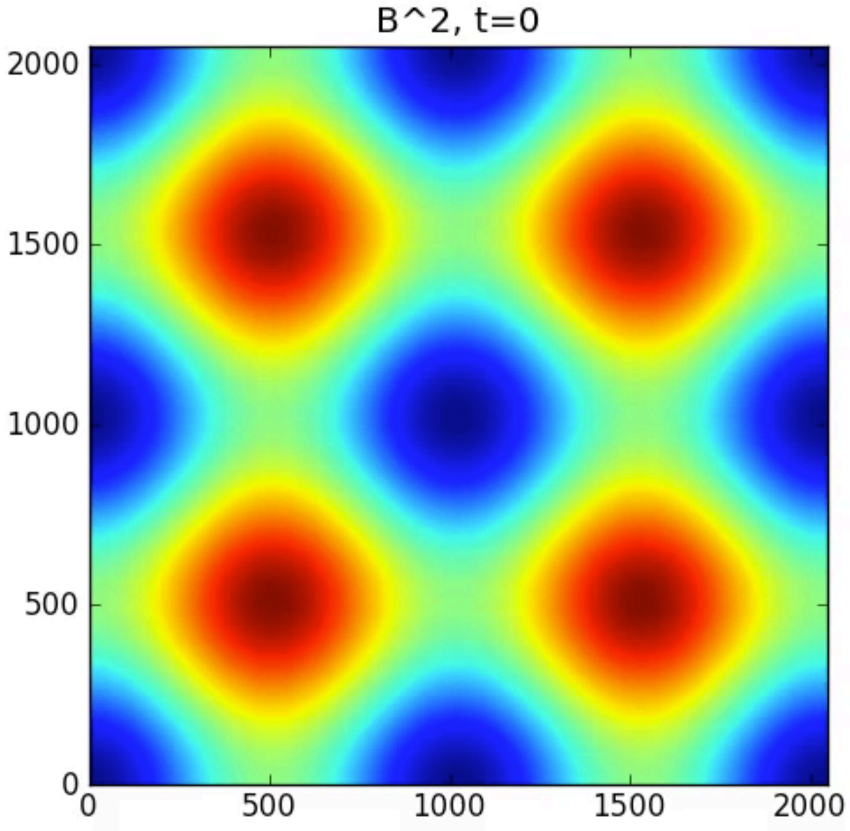
total energy

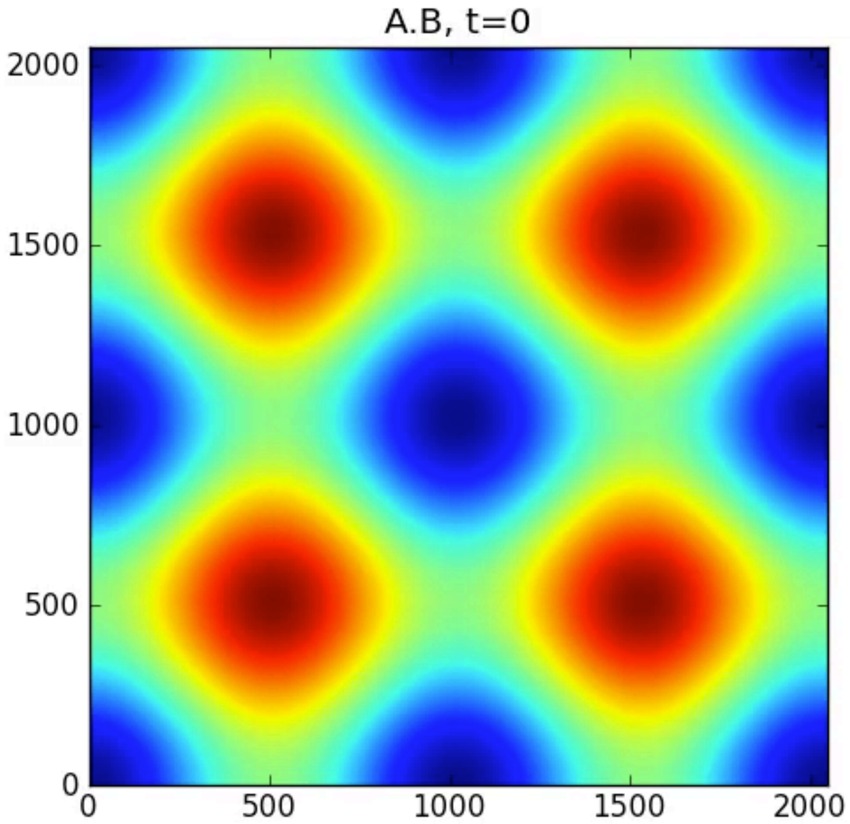


- linear instability seen in total electric energy
- non-ideal electric energy appears insignificant
- relative magnetic dissipation efficiency is constant

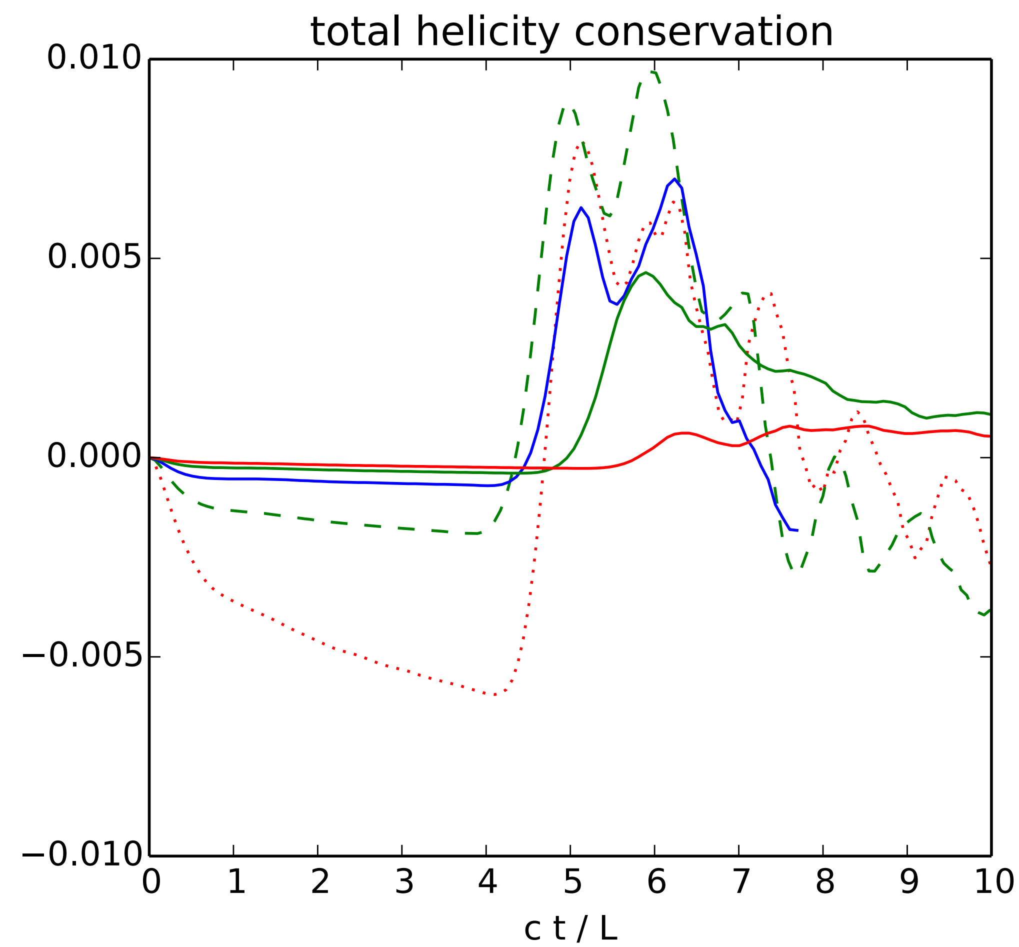


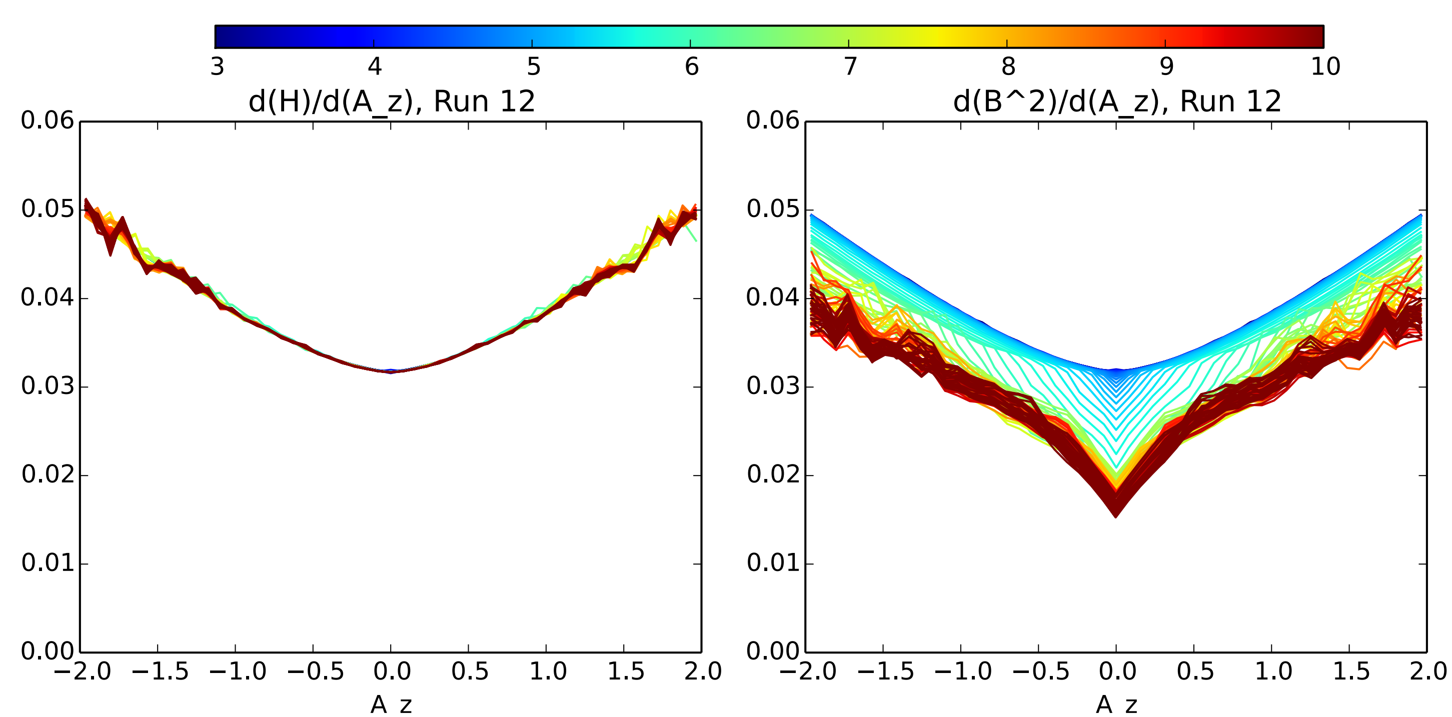
magnetic helicity



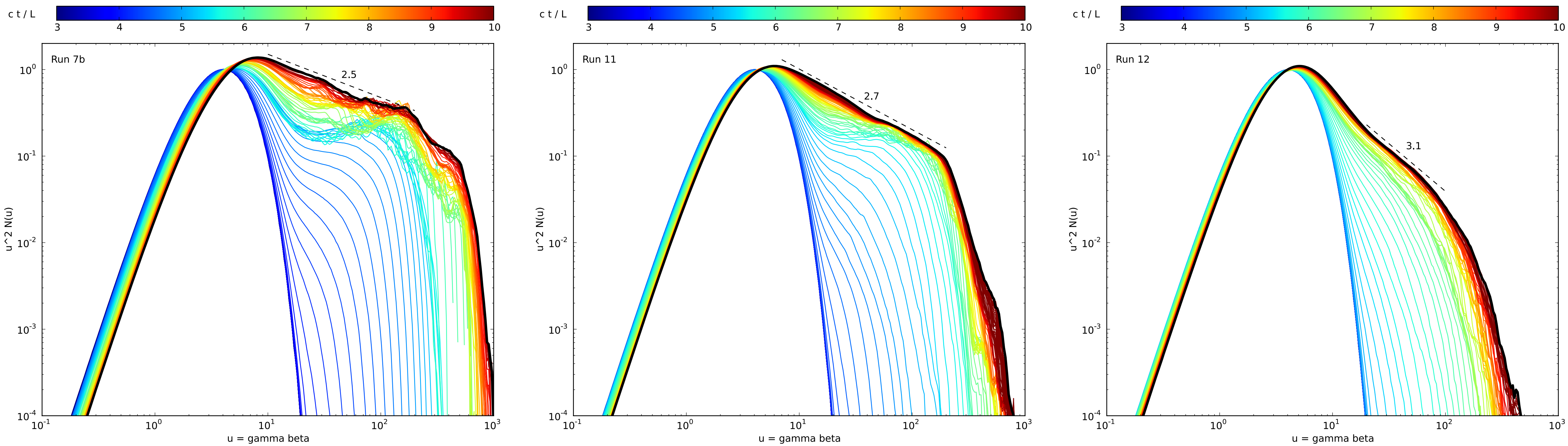


- $H = \int (A.B) dV$
- conserved quantity in ideal MHD
- conservation in PIC simulations better than 1%, especially for small dipole moment a_1



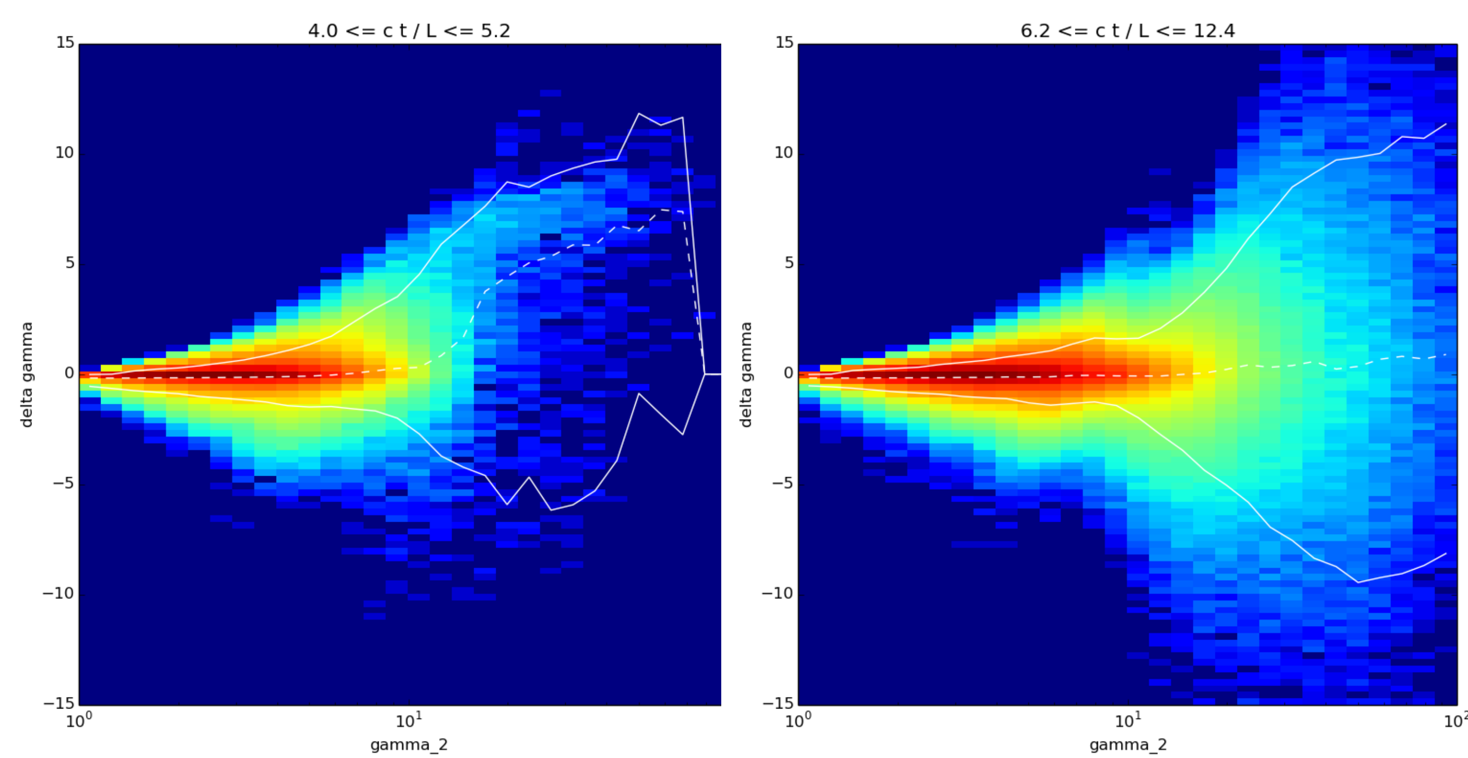


particle energy distribution



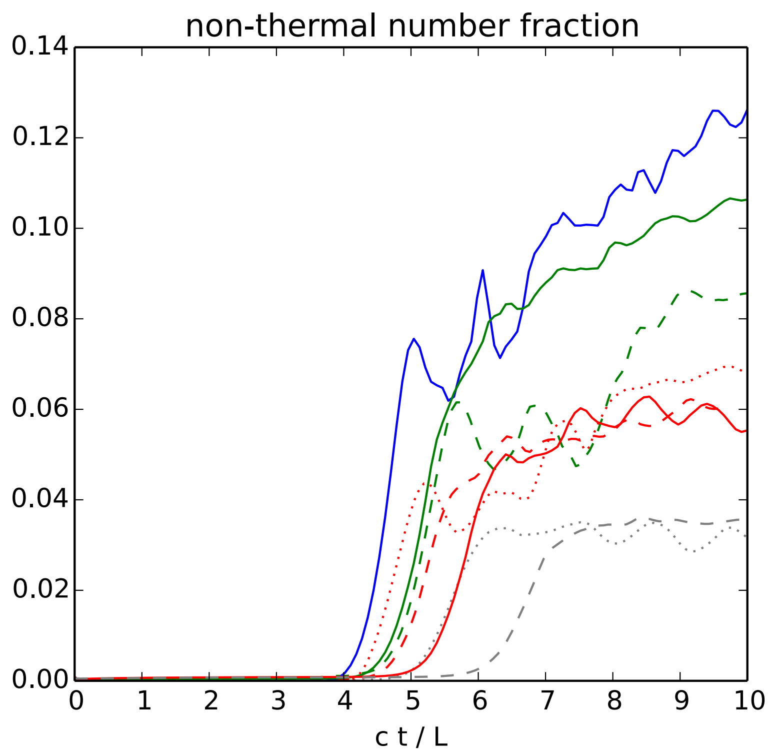
- steady direct acceleration in the linear phase

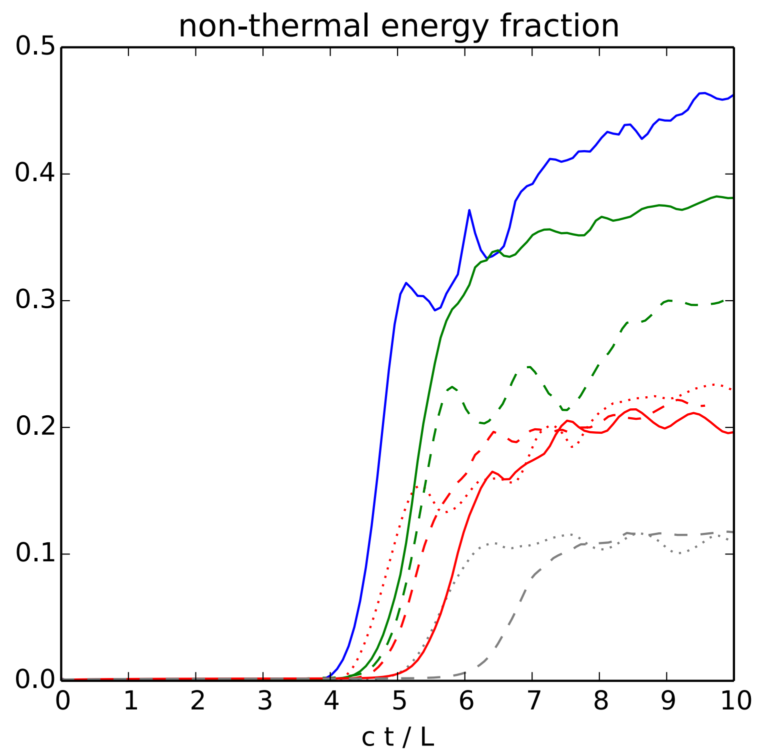
- stochastic acceleration in the non-linear phase produces a power-law

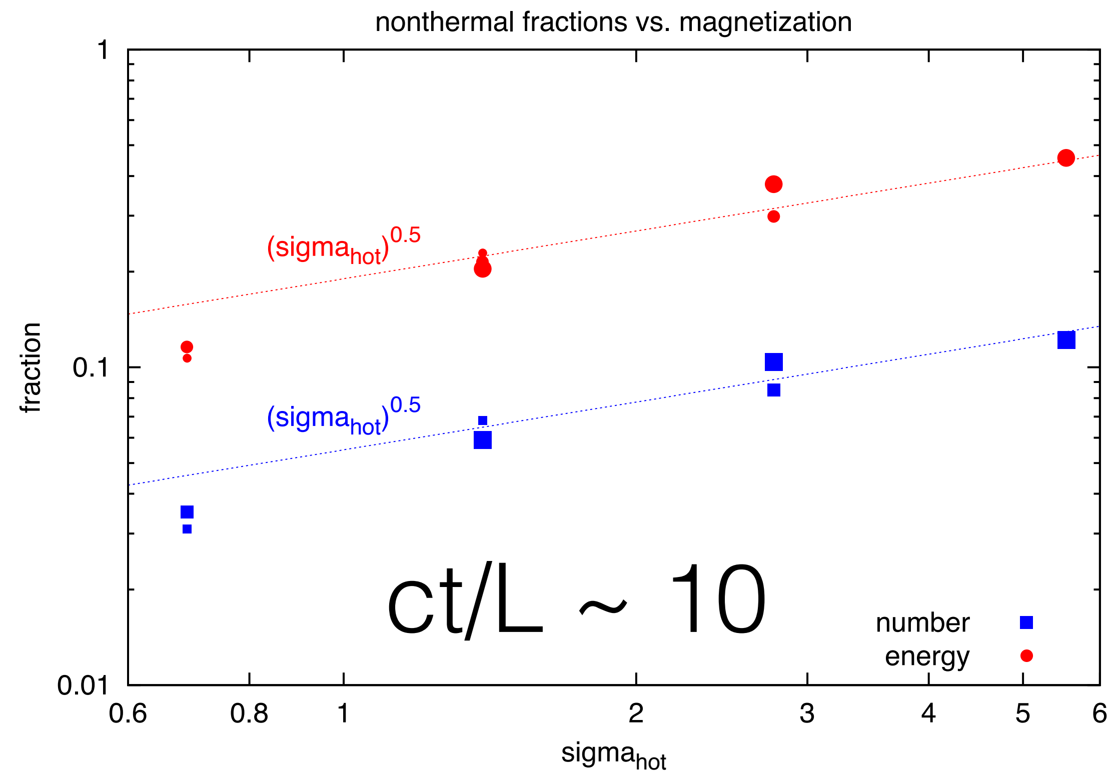


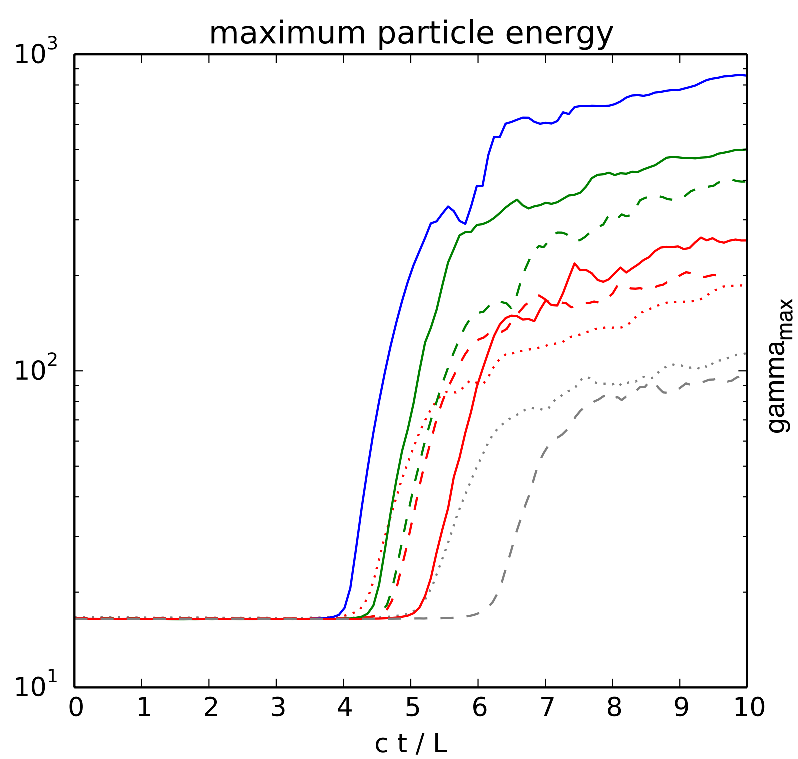
high-energy bump

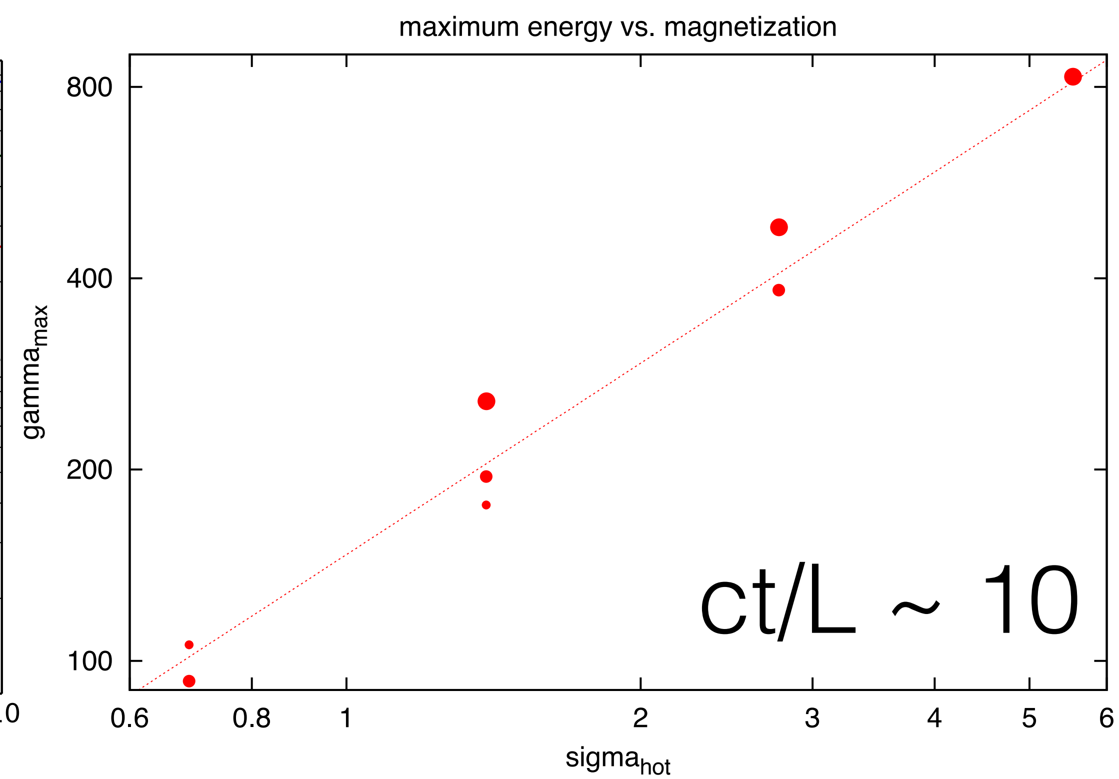
- particle number and energy fraction beyond the Maxwellian component
- both fractions systematically increase with the magnetization





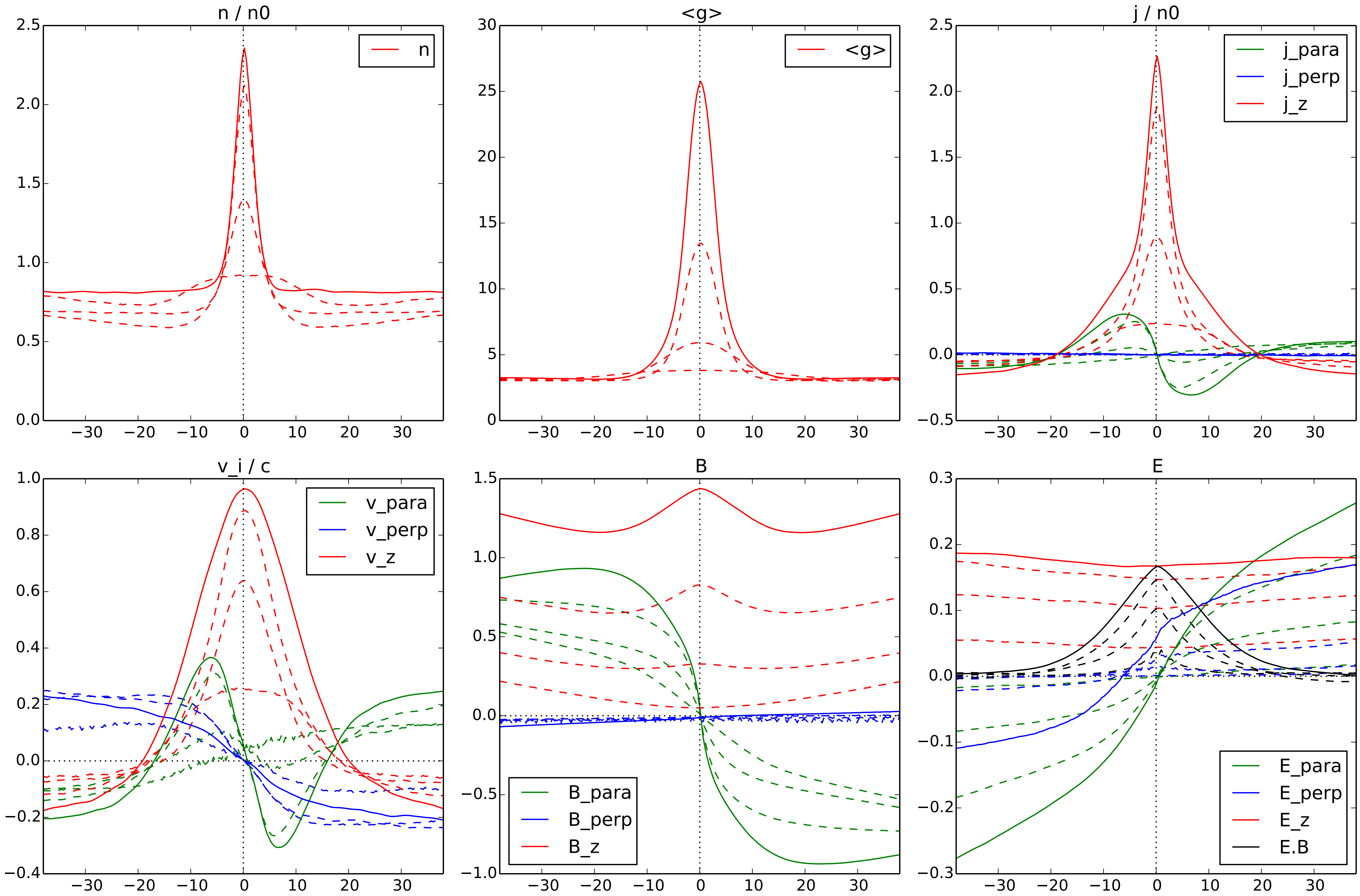






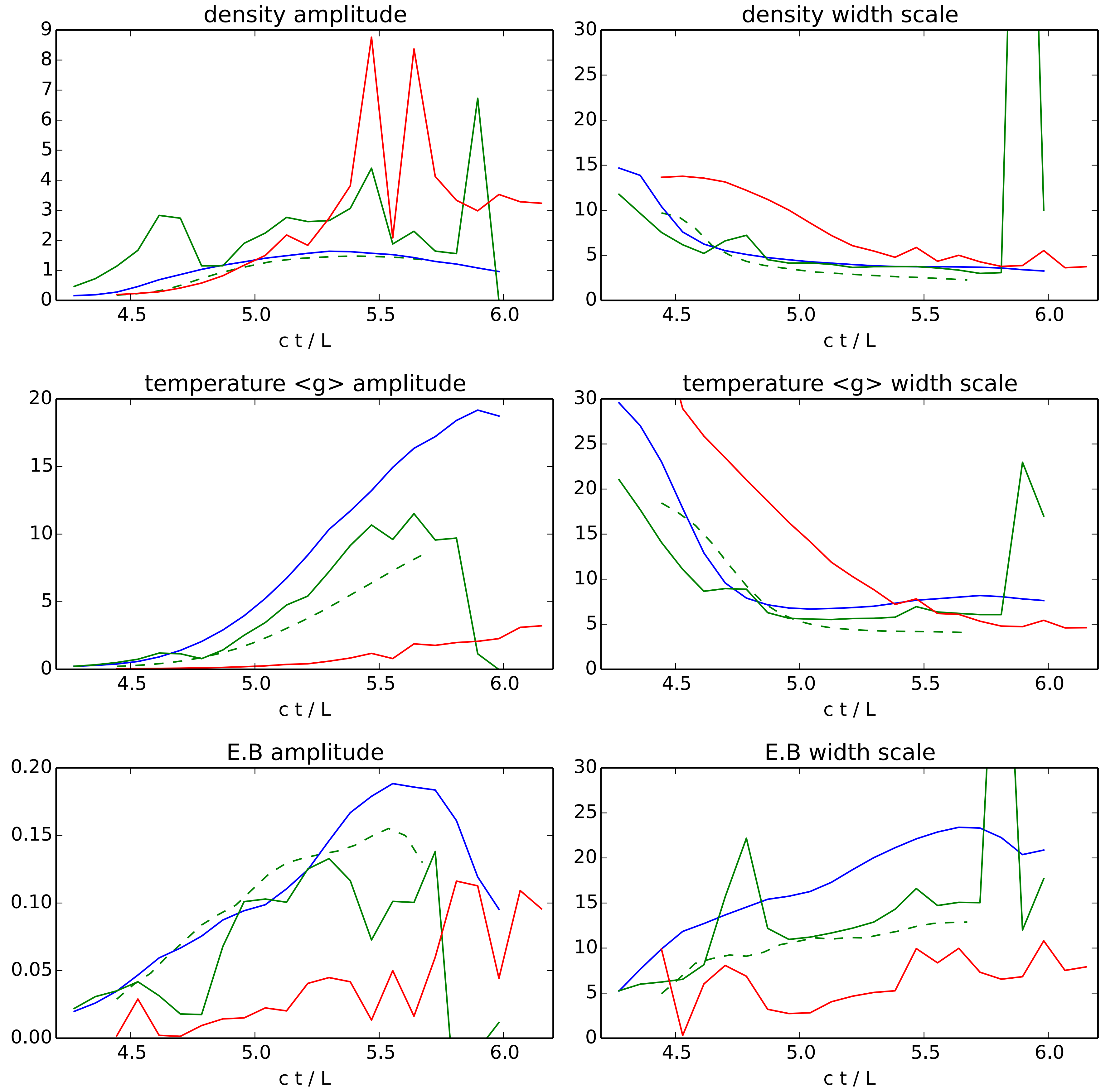
- maximum particle energy measured at $u^2N(u) = 10^{-3}$

structure of current layers



evolution of current layers

- density width scale consistent with the skin-depth
- E.B width scale consistent with the gyro radius
- E.B volume increasing with the magnetization



summary

- simulations of unstable harmonic magnetic equilibria provide a generic model of efficient particle acceleration in magnetic dissipation
- the current layers forming in the linear instability phase are evolving on dynamical time scale, and very different from the Harris equilibria
- the efficiency of magnetic dissipation is governed by the conservation of magnetic helicity
- the efficiency of particle acceleration depends on magnetization, as it regulates the volume of non-ideal electric fields