ELECTRON HEATING IN COLLISIONLESS SHOCKS

ANATOLY SPITKOVSKY, VASILEIOS TSIOLIS,
PATRICK CRUMLEY (PRINCETON)

Parameter Space of shocks

$$\sigma \equiv \frac{B^2/4\pi}{(\gamma-1)nmc^2} = \frac{1}{M_A^2} = \left(\frac{\omega_c}{\omega_p}\right)^2 \left(\frac{c}{v}\right)^2 = \left[\frac{c/\omega_p}{R_L}\right]^2$$

$$M_A = \frac{v}{v_A} \qquad M_s = \frac{v}{v_{th}} \qquad \beta = \frac{M_A^2}{M_s^2} \qquad \frac{m_i}{m_e}$$

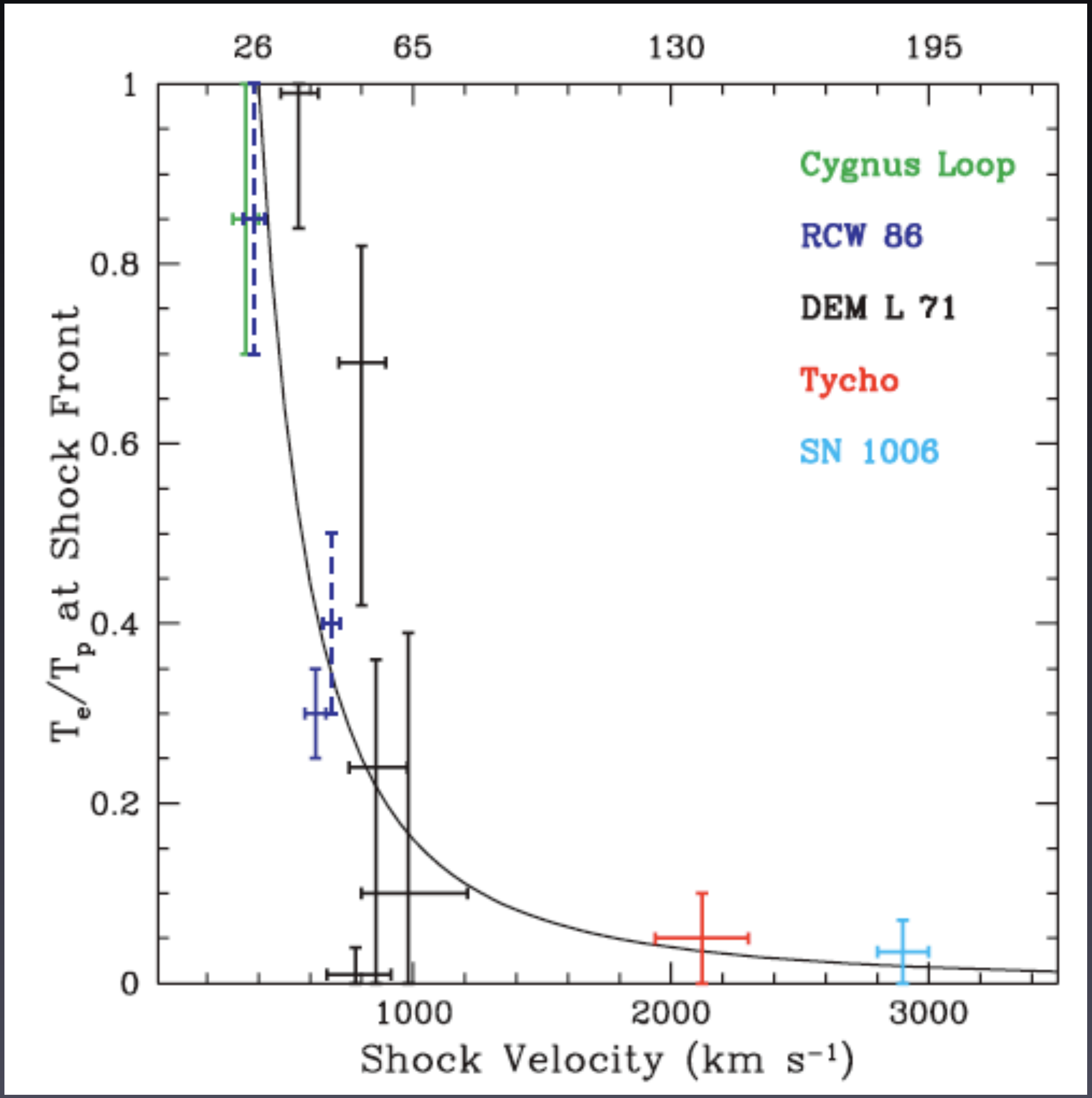
In ISM: beta ~ 1, M_s=M_A, c_s~v_A~10 km/s
SNRs: v=1000-15000 km/s, M_s=M_A=100-1500; With B amplification M_A can decrease to 10-30.

In galaxy clusters: beta ~ 100, M_s = M_A/10
Relics: v=1000 km/s, M_s= few, M_A = 10-20

Virial shock: v=1000 km/s, M_s~M_A~100, similar to SNR

Field orientation:
can be anything in viral shocks and SNRs, mostly transverse in relics.

Shock diagnostics:



Ghavamian, Laming & Rakowski (2007)

also work by Heng and van Adelsberg (2008)

- In SNRs partition of energy between electrons and ions can be studied with Balmer lines (narrow and broad components from charge-exchange) [Ghavamian et al 07]. Surprising result -- constant electron energy independent of velocity!

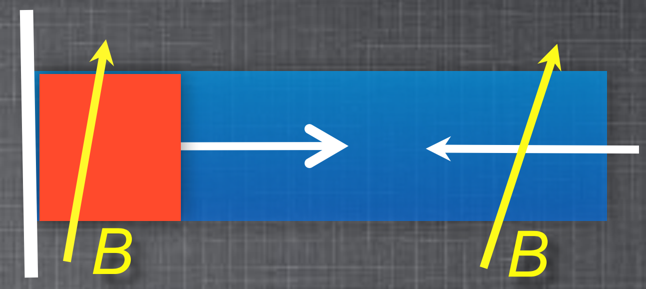
- Significant energy transfer to electrons in relativistic e-ion shocks (ε_e~10%) in GRBs

We wanted to study Te/Ti ratio in shocks of various Mach numbers, approaching the regime of SNRs: high Ma and Ms (complementing Guo and Sironi)

Focus mainly on perpendicular shocks

Nonrelativistic shocks: shock structure

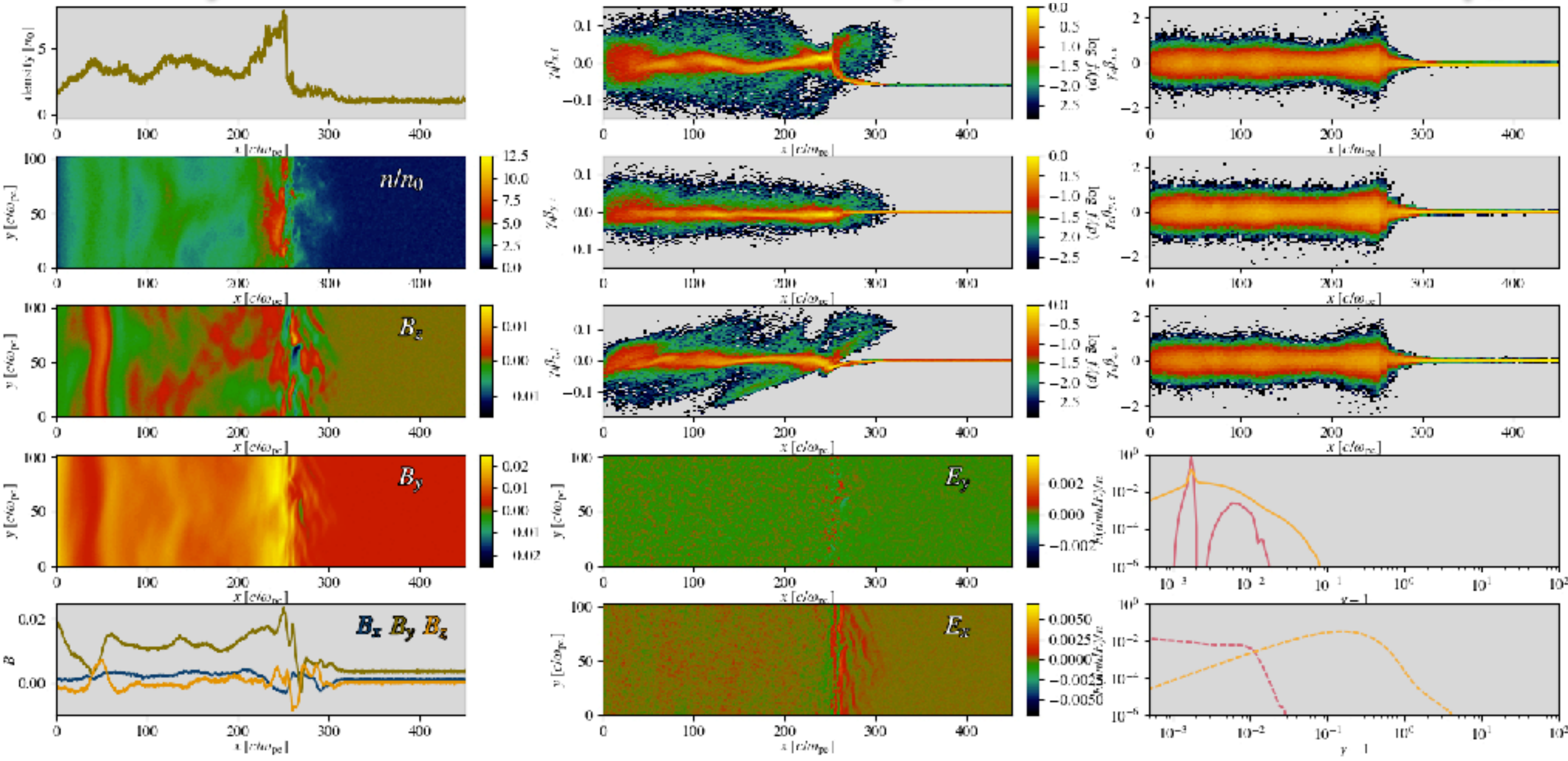
mi/me=400, v=18,000km/s, M_A=5, quasi-perp 75° inclination



Density

x-p_x ion

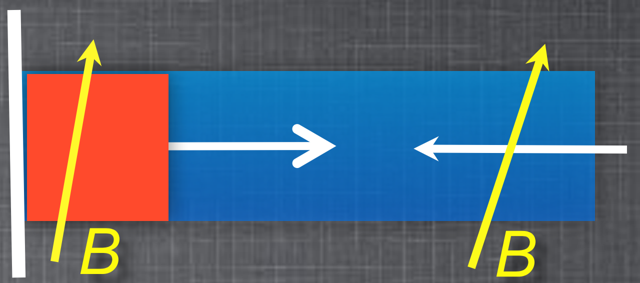
x-p_x e-



PIC simulation: Shock foot, ramp, overshoot, returning ions, electron heating, whistlers

Nonrelativistic shocks: shock structure

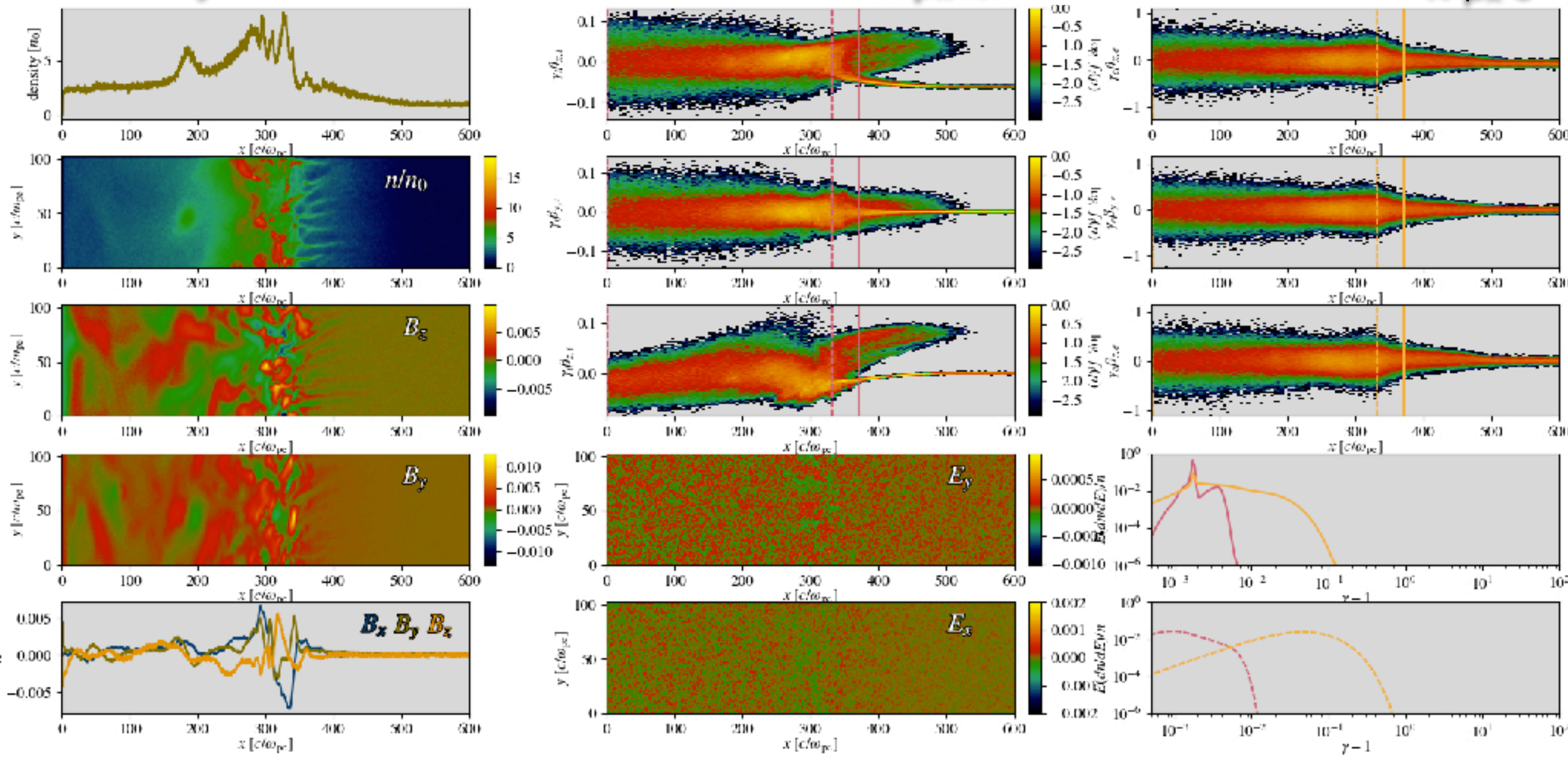
mi/me=100, v=18,000km/s, M_A=45 quasi-perp 75° inclination



Density

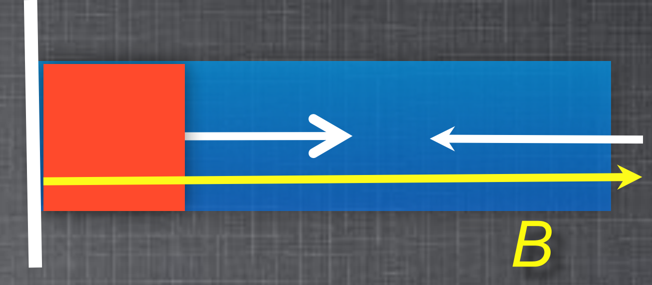
x-p_x ion

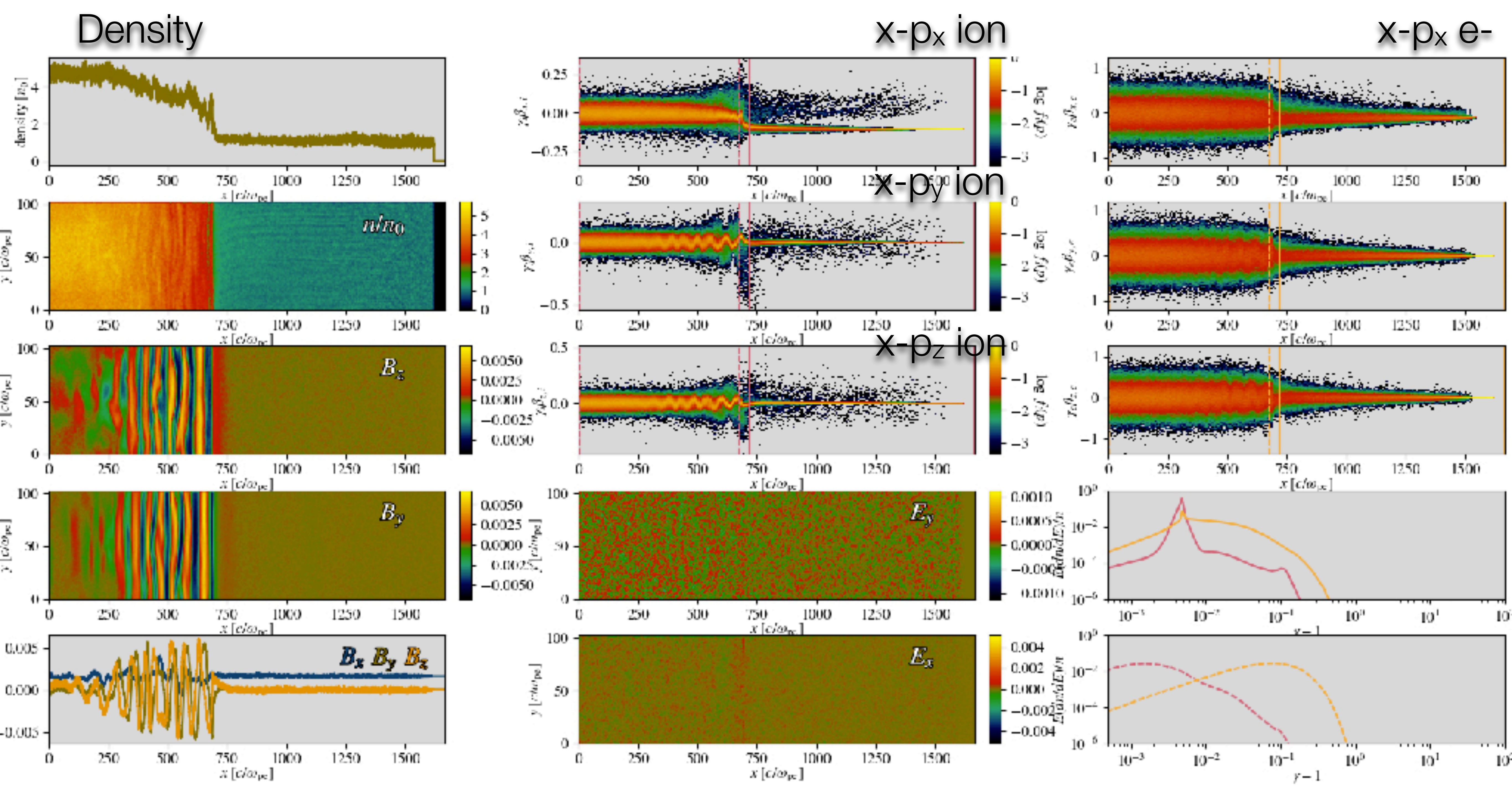
x-p_x e-



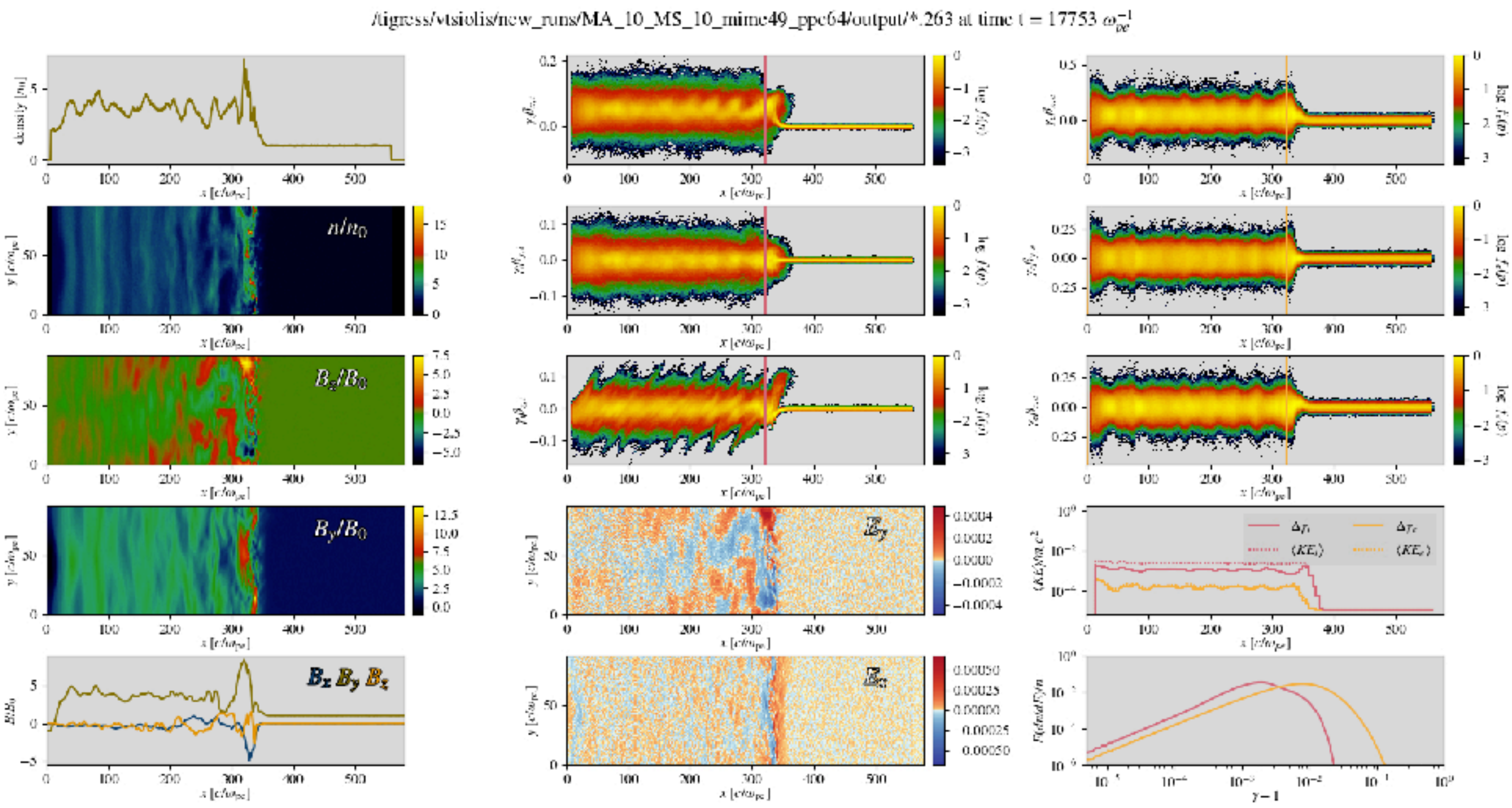
Nonrelativistic shocks: quasiparallel shock

mi/me=30, v=30,000km/s, M_A=5   parallel 0° inclination

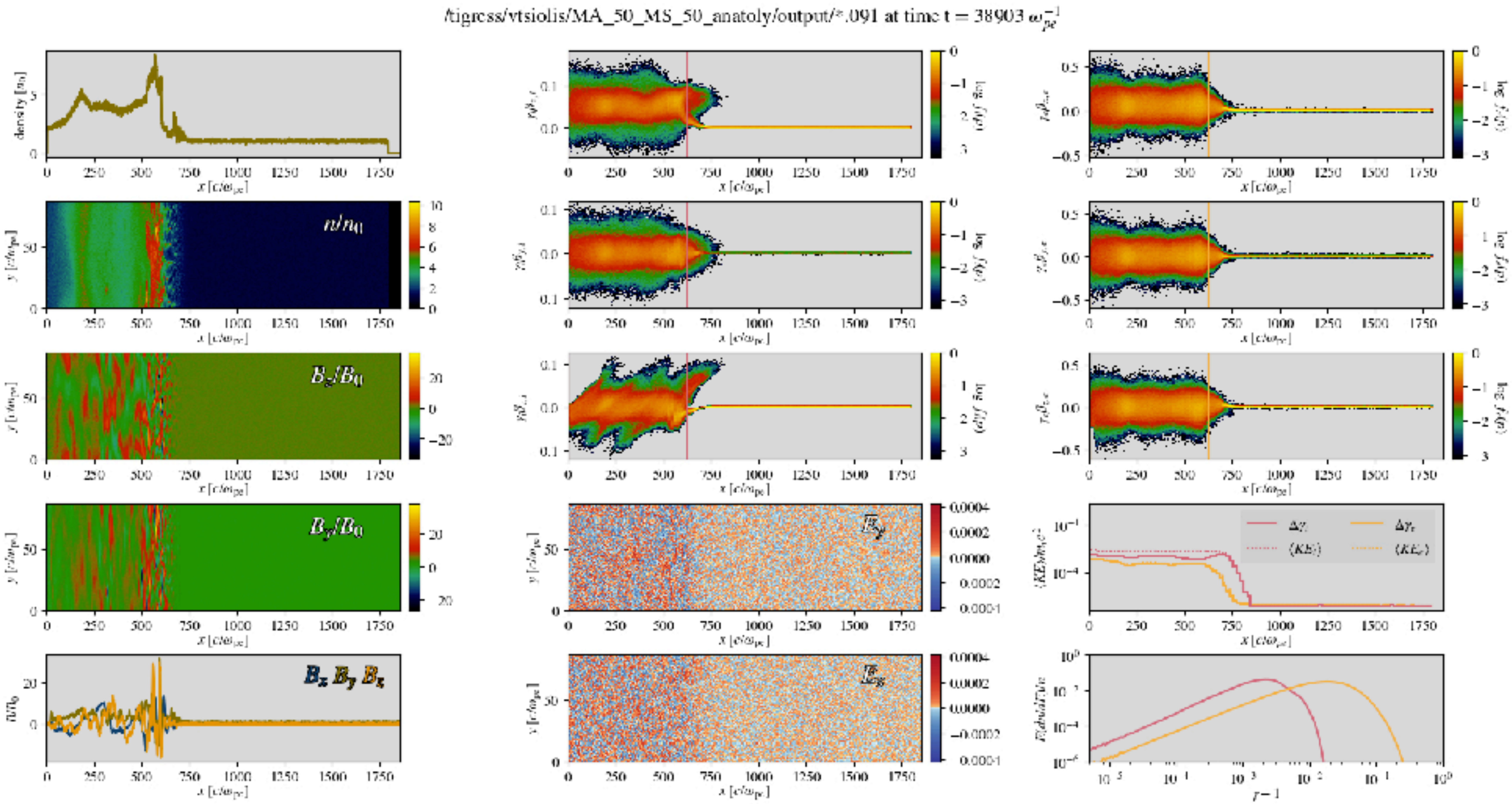




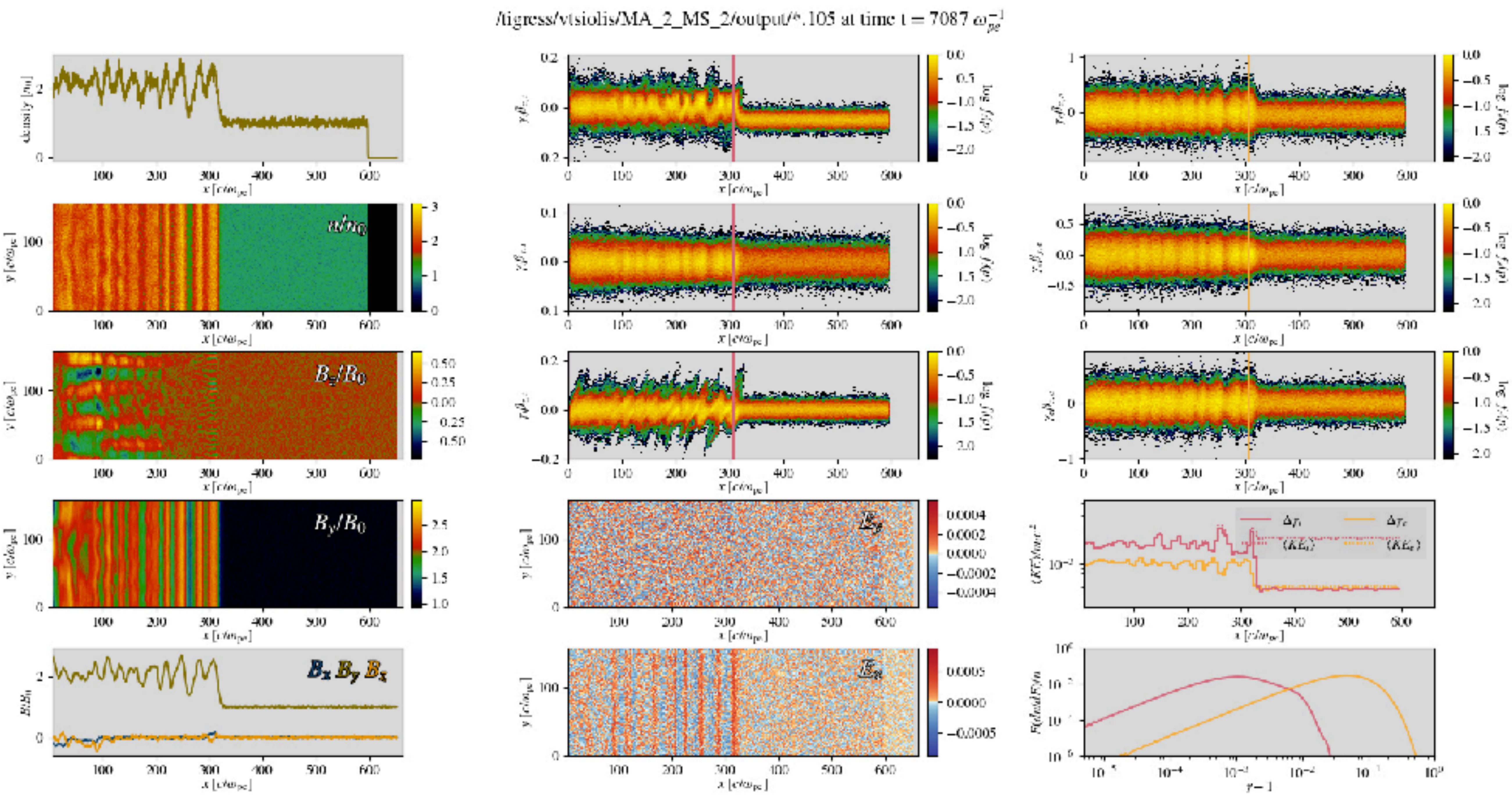
Fiducial run: Ma=10, Ms=10, mi/me=49



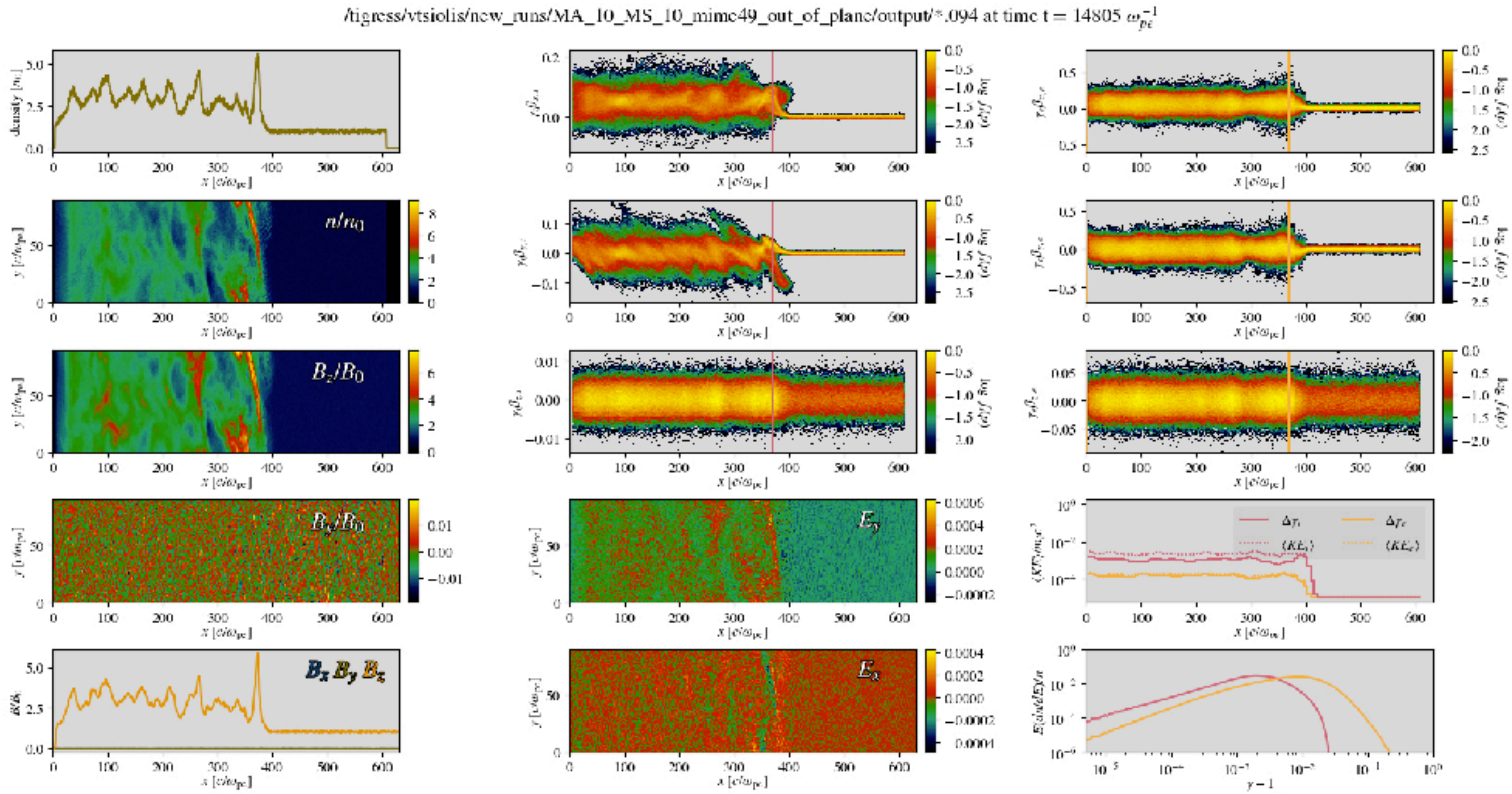
Ma=50, Ms=50, mi/me=49



Ma=2, Ms=2, mi/me=49

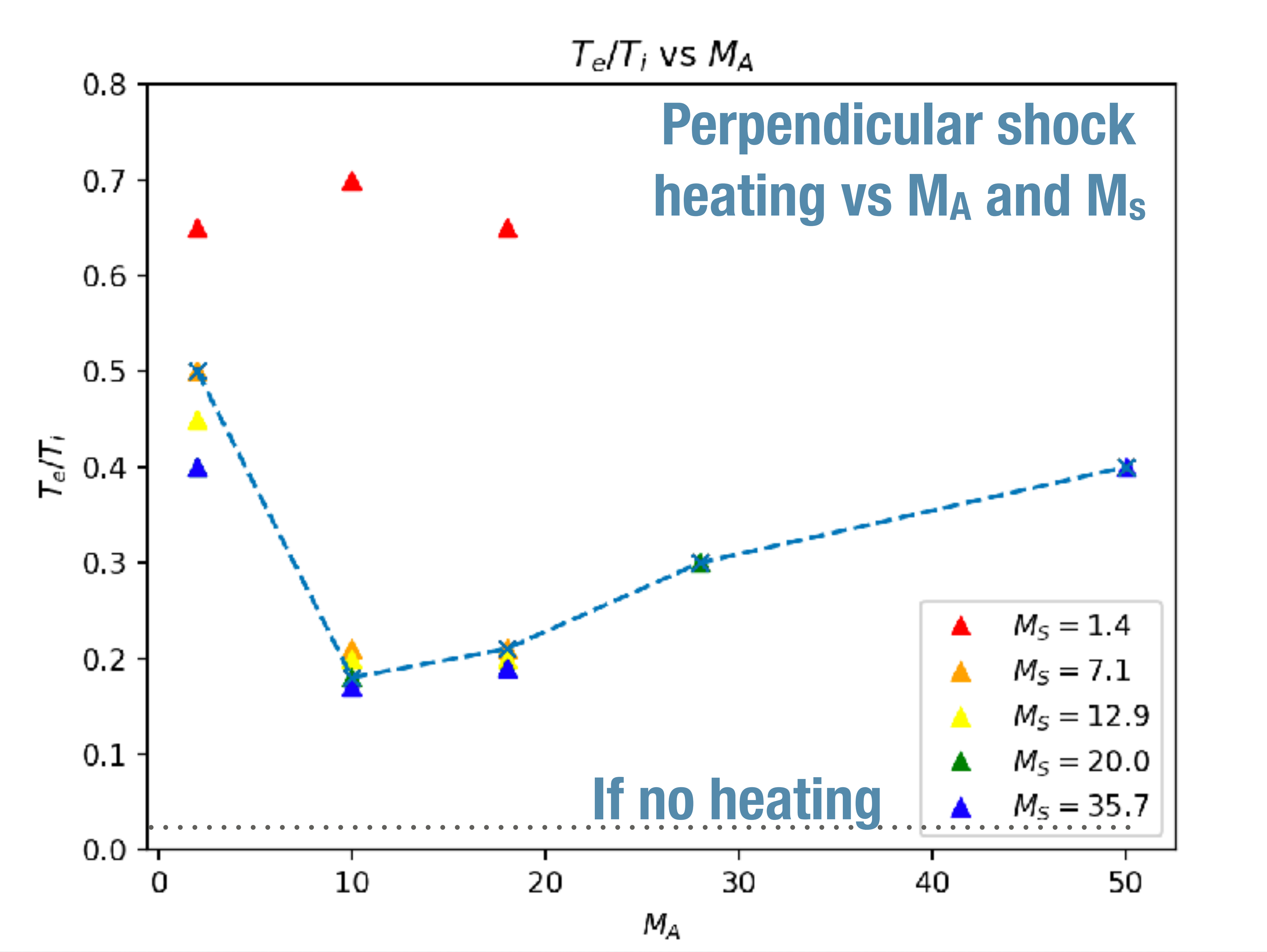


Out of plane B: Ma=10, Ms=10, mi/me=49



Nonrelativistic shocks: heating

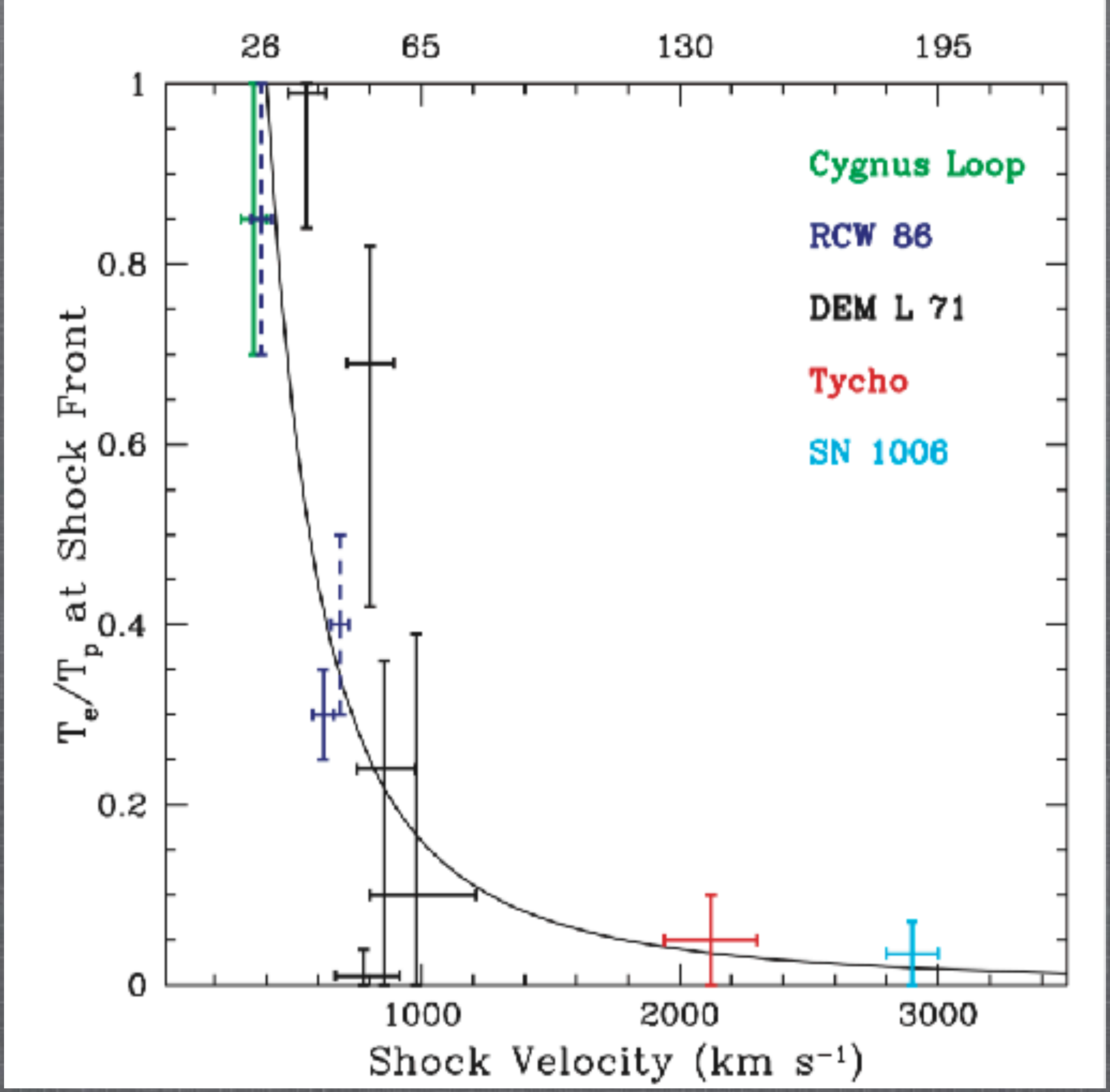
Heating varies between 20% of equipartition for perp shocks, to 50% in parallel



Not much dependence on mass ratio, speed; Weak with Mach # (as long as it's large)

Nonrelativistic shocks: heating

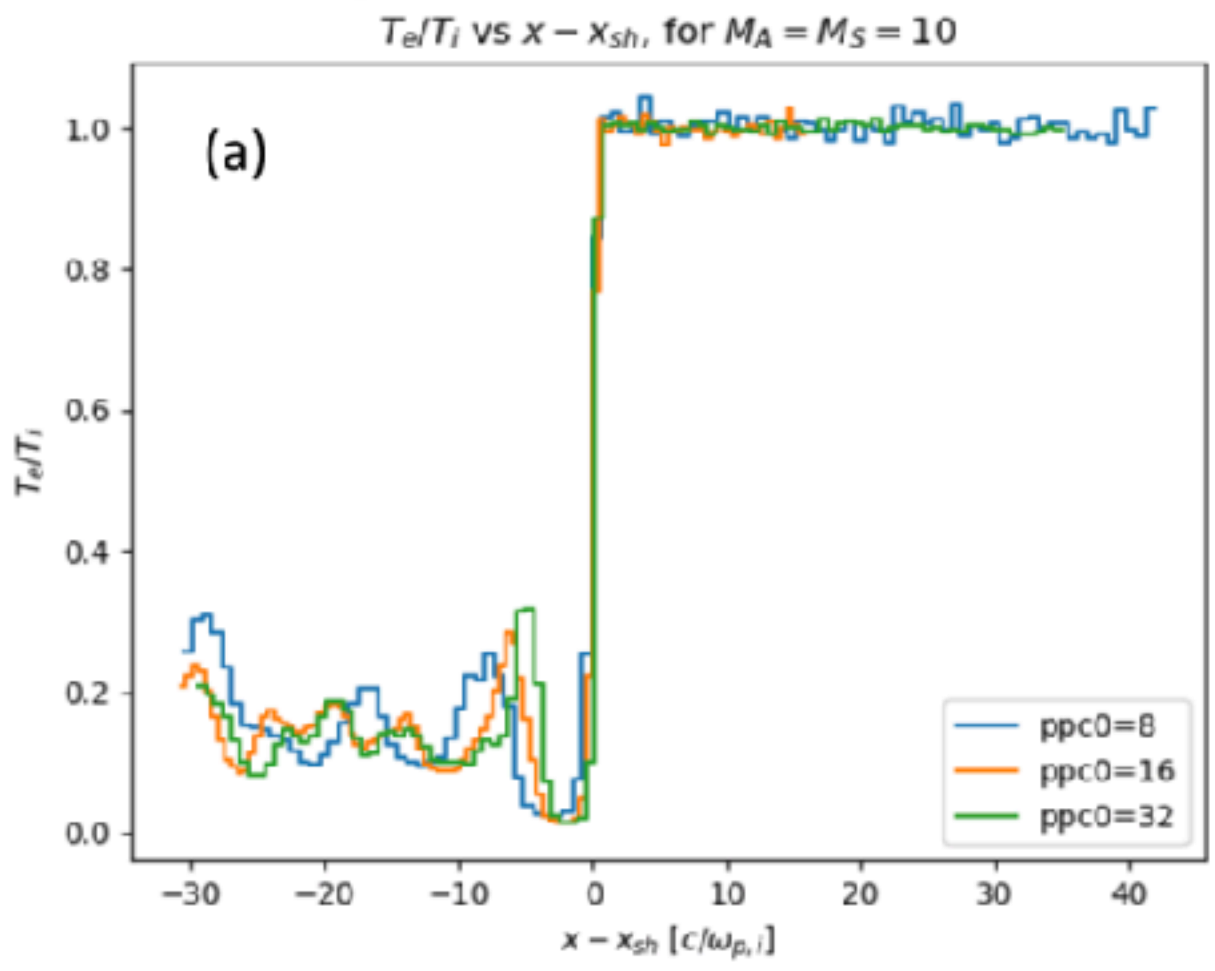
Don't easily see the dependence on shock velocity inferred from Balmer lines: are there more variables besides shock velocity?



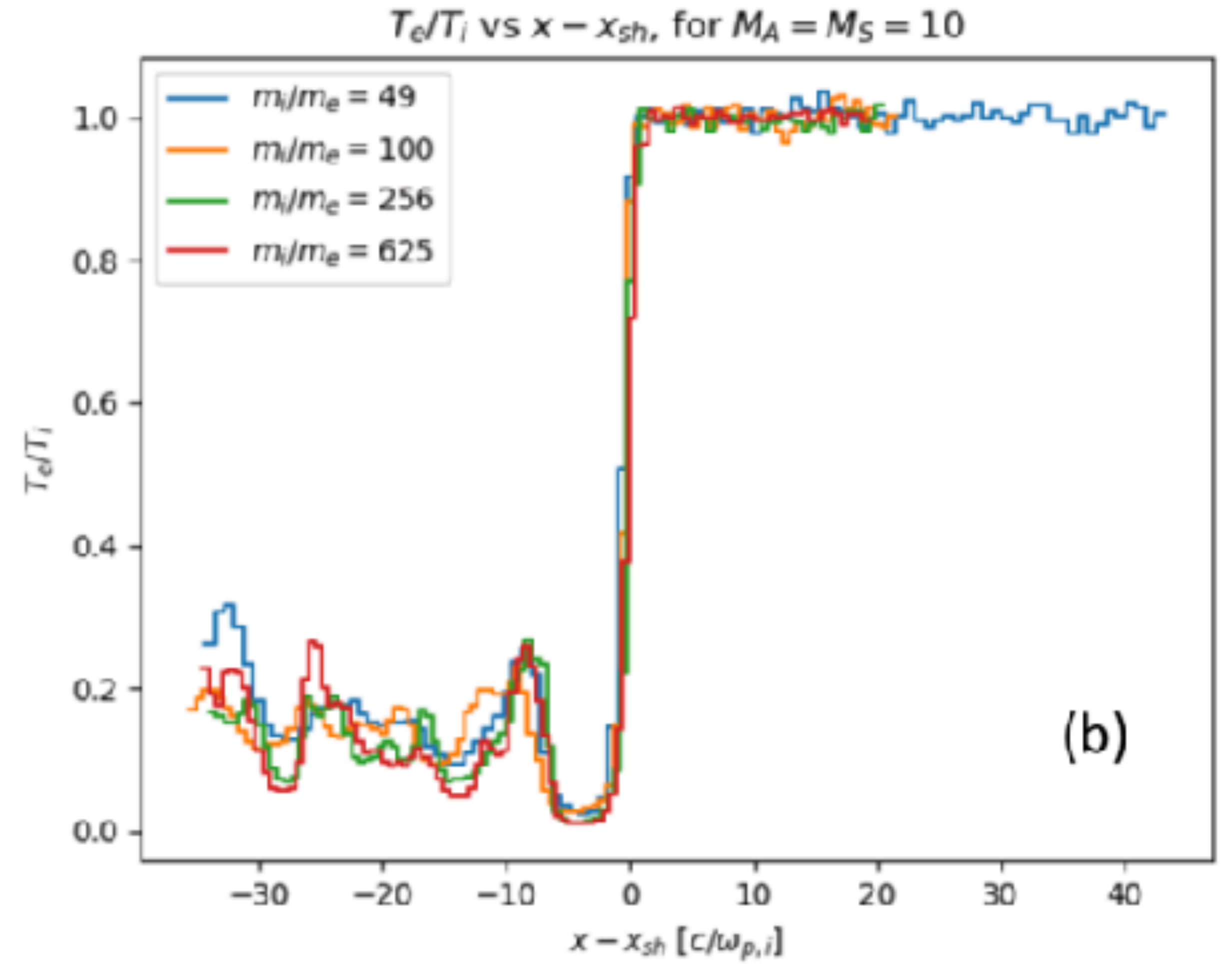
Ghavamian et al 2007

Convergence:

With particle number:

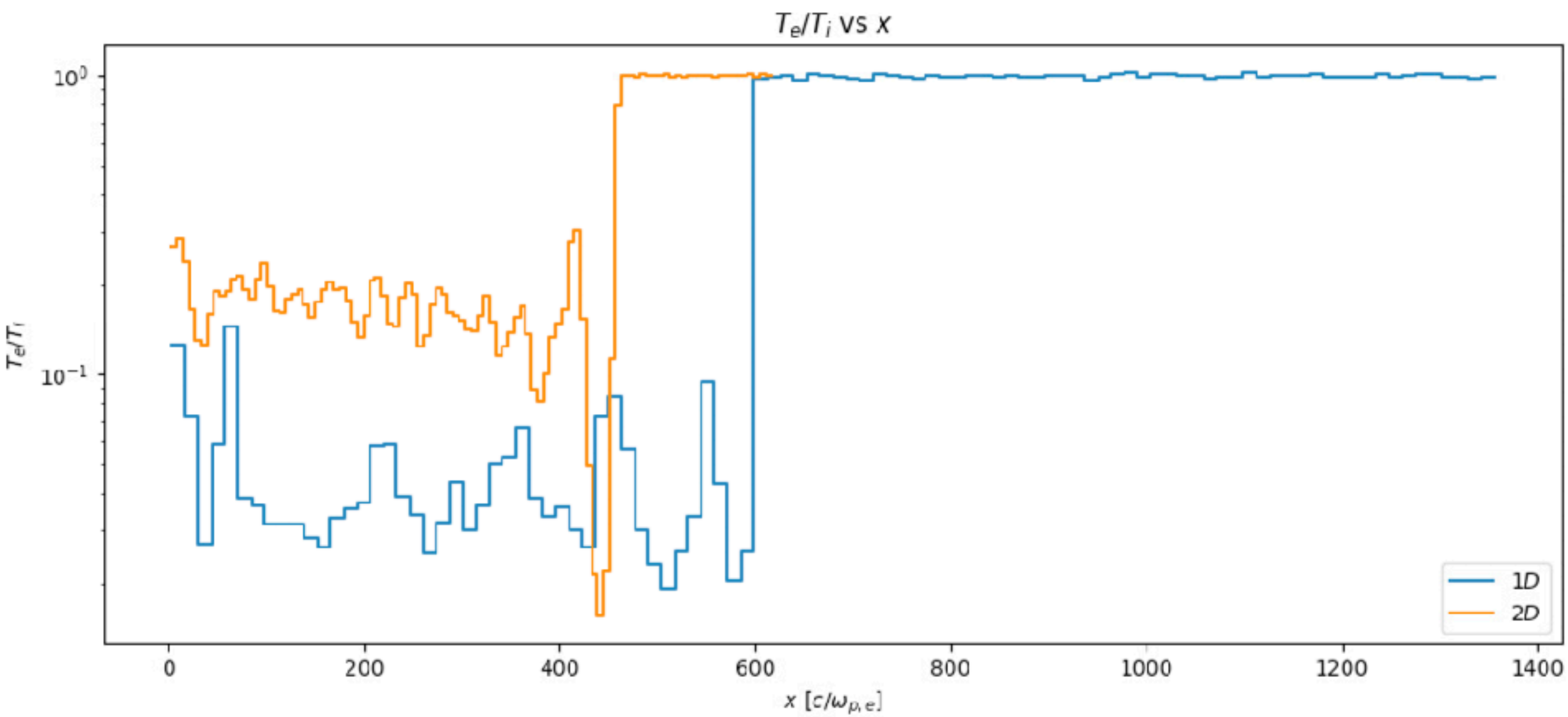


With mass ratio:



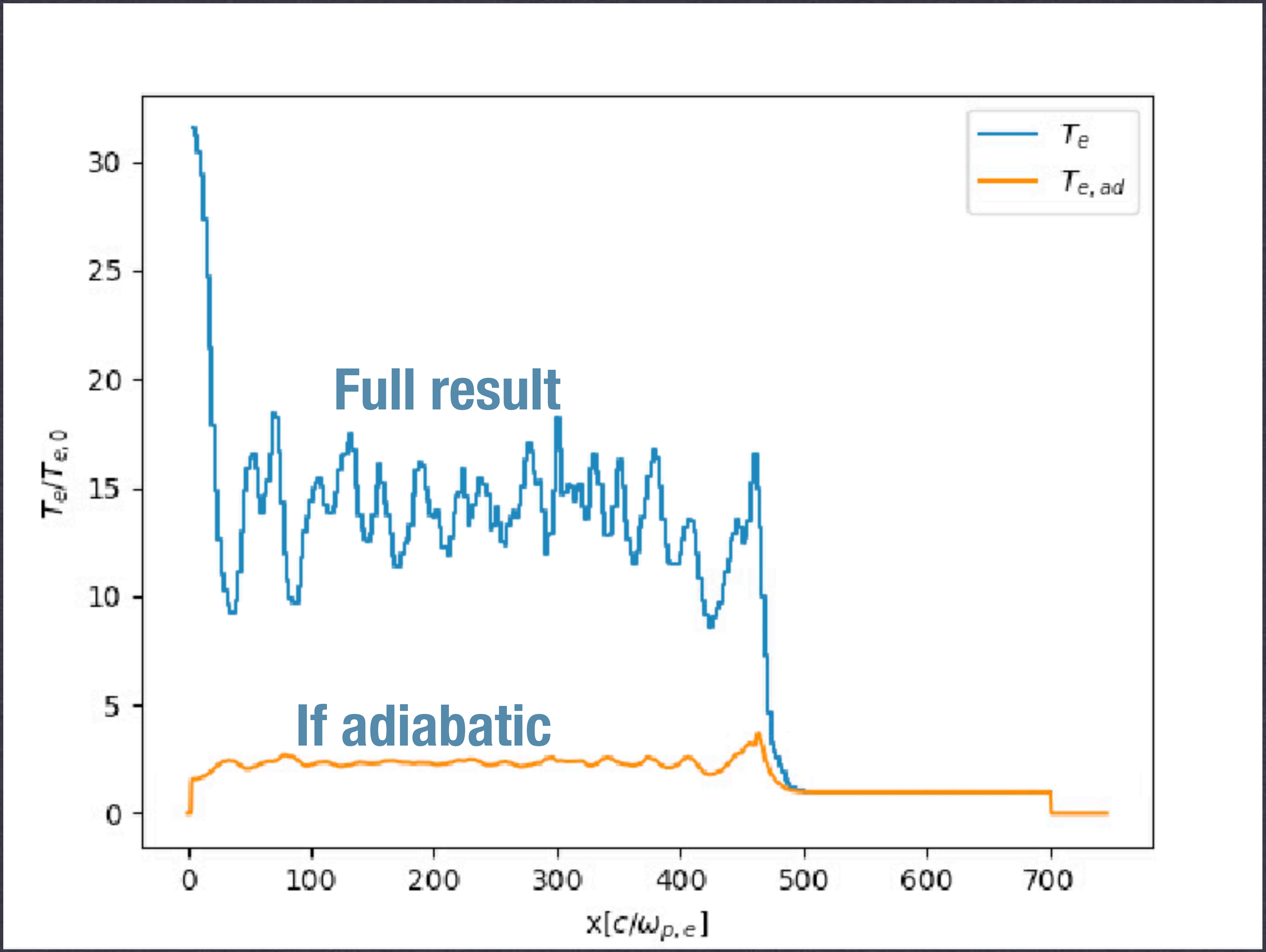
Convergence:

Dimensionality:

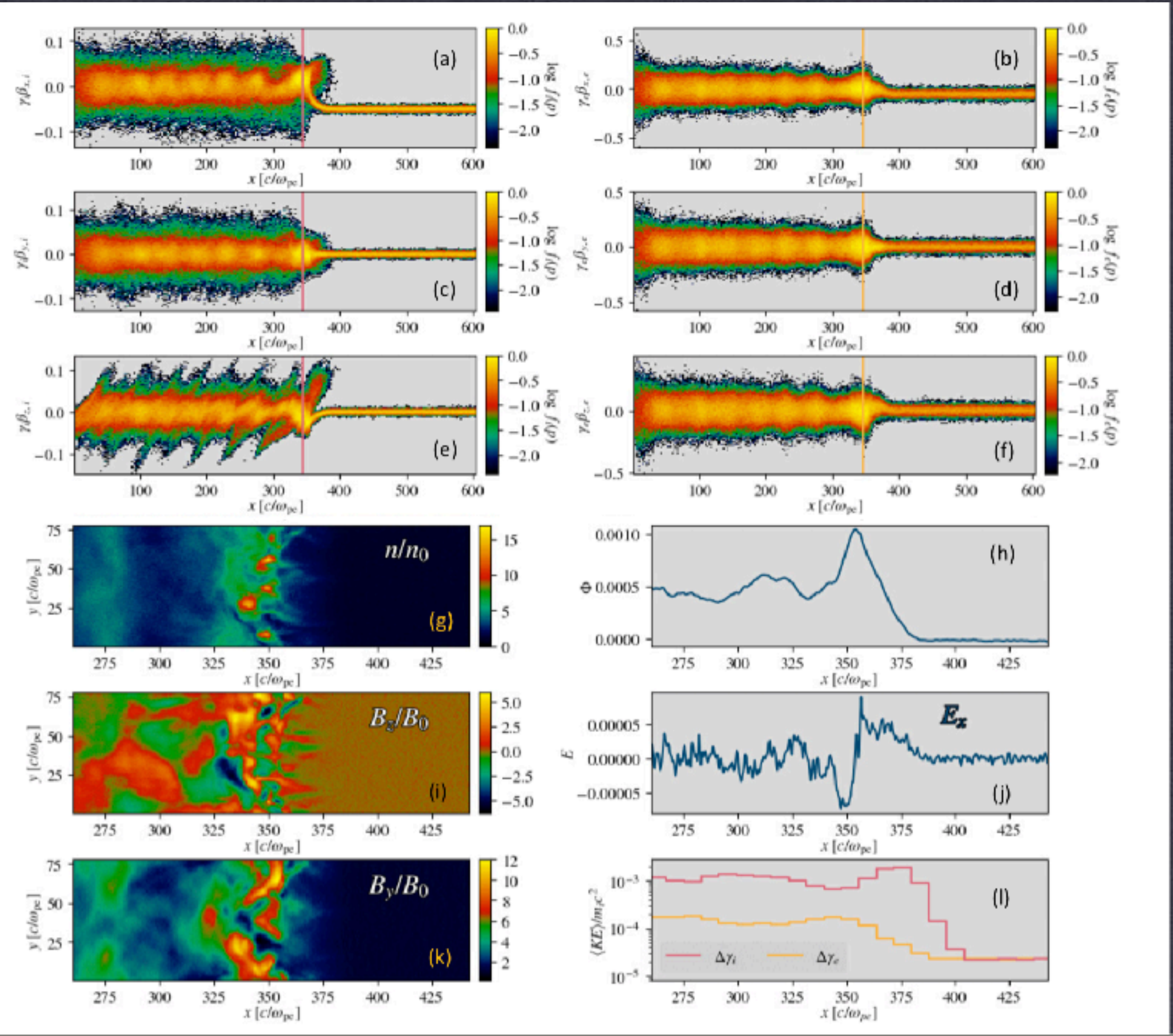


Being in 2D is important!

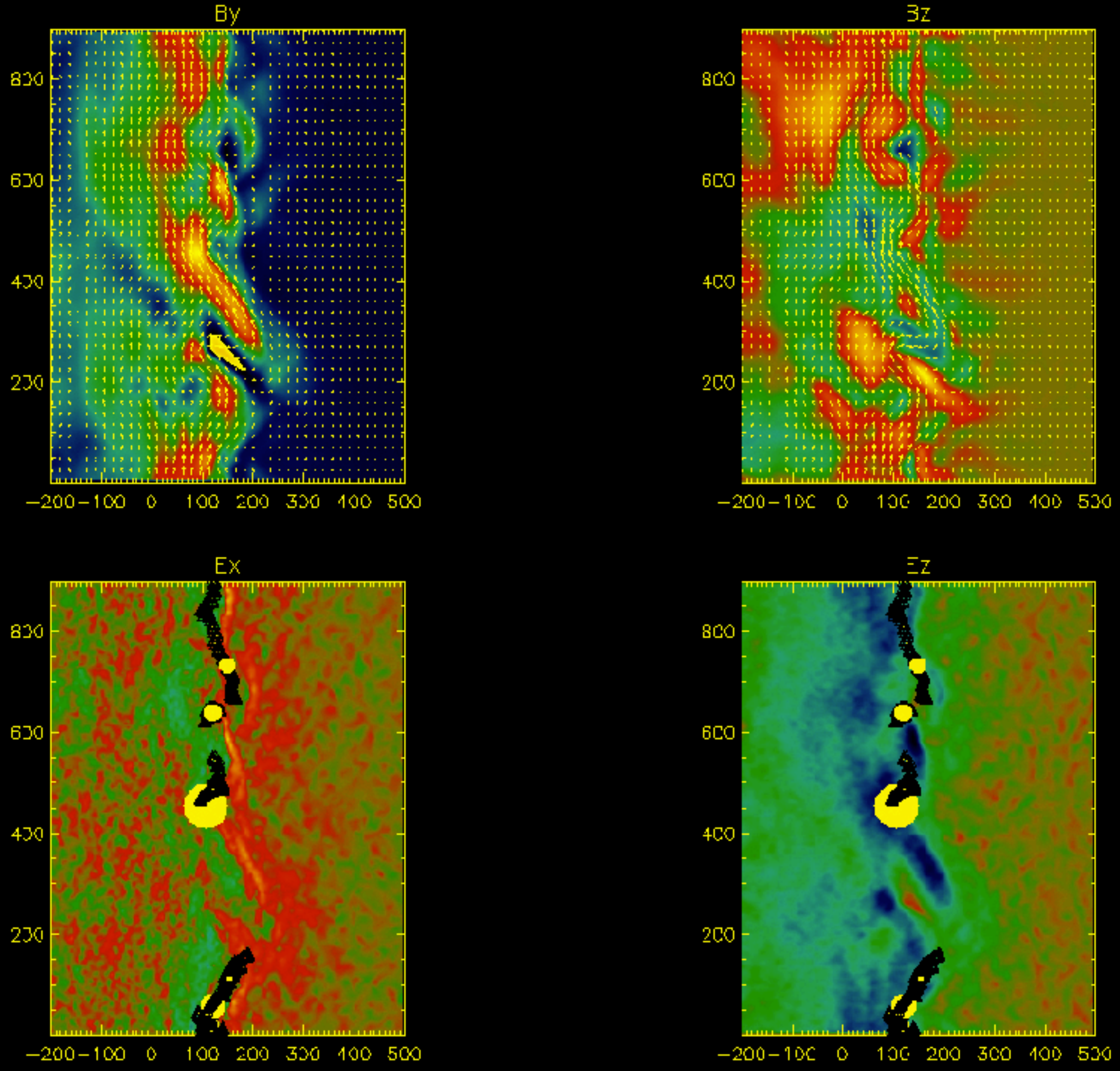
Is it heating?



Ma=10, Ms=10



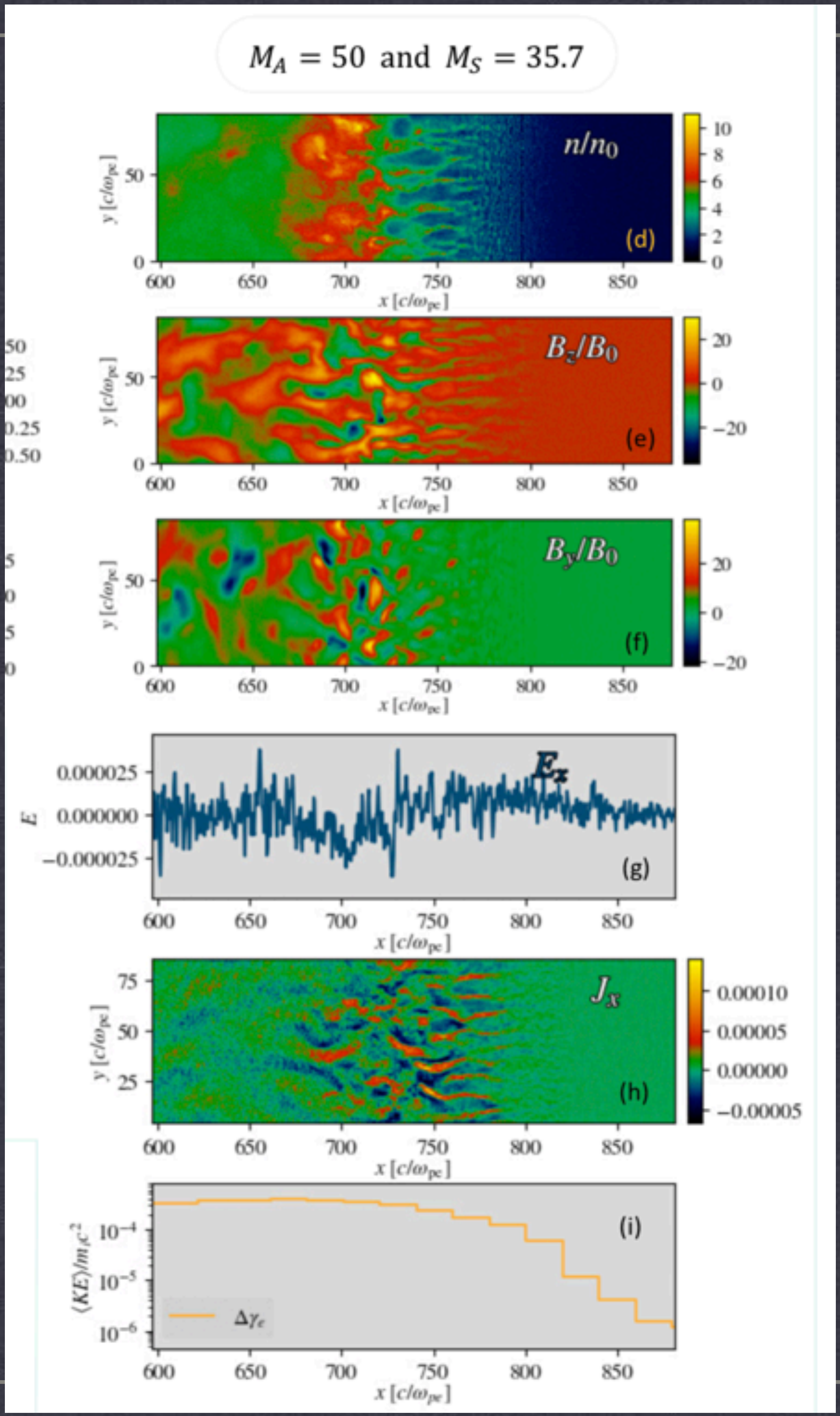
(a)
(b)
(c)
(d)
(e)
(f)
n/n_0
(g)
(h)
B_z/B_0
(i)
E_x
(j)
B_y/B_0
(k)
(l)
$\Delta\gamma_i$
$\Delta\gamma_e$
$x\,[c/\omega_{pe}]$
$y\,[c/\omega_{pe}]$
$\log f(p)$
Φ
E
$\langle KE\rangle/m_ec^2$



By
Bz
Ex
Ez
800
600
400
200
−200 −100 0 100 200 300 400 500

Ma=50, Ms=35

At higher Mach numbers, heating in filaments is more important, electrons reach significant energy before reaching the shock.



Conclusions:

We observer significant electron heating in non-relativistic shocks. Always Te/Ti > 15%, can reach 50% for high Mach numbers

Heating is localized to the shock transition, or shock foot.

Interplay of cross-shock potential and scattering due to shock corrugation to cause non-reversible energy gain.

Detailed theory still missing.

NEXT YEAR: KITP PROGRAM IN SANTA BARBARA
AUGUST 12 — OCTOBER 18, 2019; CONFERENCE SEPT 9-12, 2019

[HTTPS://WWW.KITP.UCSB.EDU/ACTIVITIES/ASTROPLASMA-C19](https://www.kitp.ucsb.edu/activities/astroplasma-c19)

Kavli Institute for Theoretical Physics
University of California, Santa Barbara

HOME | DIRECTORY | ACTIVITIES | PROPOSE ACTIVITY | APPLY | FOR VISITORS | TALKS ARCHIVE | OUTREACH

Multiscale Phenomena in Plasma Astrophysics

Coordinators: Eliot Quataert, Christopher Reynolds, Anatoly Spitkovsky, and Ellen Zweibel

Scientific Advisors: James Drake and Alexander Schekochihin

Most of the observable matter in the Universe is in the form of plasma, or tenuous ionized gas, and the complicated behaviors of plasmas underly many astrophysical processes. Kinetic instabilities and collective effects in plasmas are responsible for particle acceleration, heating, and dissipation of free energy. These intrinsically microscopic processes affect the appearance of macroscopic astrophysical systems such as supernova remnants or accretion disk coronae, and must be included in large-scale models. The macroscopic evolution can also affect the small-scale physics, necessitating the solution of coupled multiscale problems that go beyond the simple parameterization of microphysics.

This program will facilitate progress on astrophysical problems that involve the coupling between microscopic plasma scales and macroscopic observables. We will focus on three areas where recent progress in the understanding of microphysics allows the study of new macroscale astrophysical connections: 1) acceleration and dynamics of galactic cosmic rays and their role in cosmic ray-driven galactic winds; 2) collisionless accretion flows around black holes and the emission signatures of disks, jets and coronae; and 3) the transport properties of magnetized turbulent plasmas and their effect on the structure of intracluster medium in galaxy clusters. Despite large differences in astrophysical context, these areas are surprisingly similar in the plasma processes involved, and researchers working in these subfields will strongly benefit from extended dialog. Computational tools that have been developed to study microphysical plasma processes are also broadly similar across these subfields. The program will devote special attention to developing and comparing new numerical techniques for bridging the multiscale divide between the kinetic plasma models and global simulations of astrophysical systems.

DATES

Aug 12, 2019 - Oct 18, 2019

INFORMATION

Apply

Application deadline is:
Sep 16, 2018.
Primary deadline above date.
Rolling admissions after until the program is filled.

QUICK LINKS

- Associated KITP Conference: Connecting Micro and Macro Scales: Acceleration, Reconnection, and Dissipation in Astrophysical Plasmas