Review of ion heating at coherent structures

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Aim

- Review the relevance of coherent structures in dissipative processes at the kinetic scales in solar wind
- Concentrate mainly on papers dedicated to the topic
- Attempt at being completely unbiased
- Try to pose questions to the audience

Plan

- Why?
- Dissipative processes
- Parameters
- Evidence supporting the role of coherent structures
- But what about other processes?
- Where to go from here?

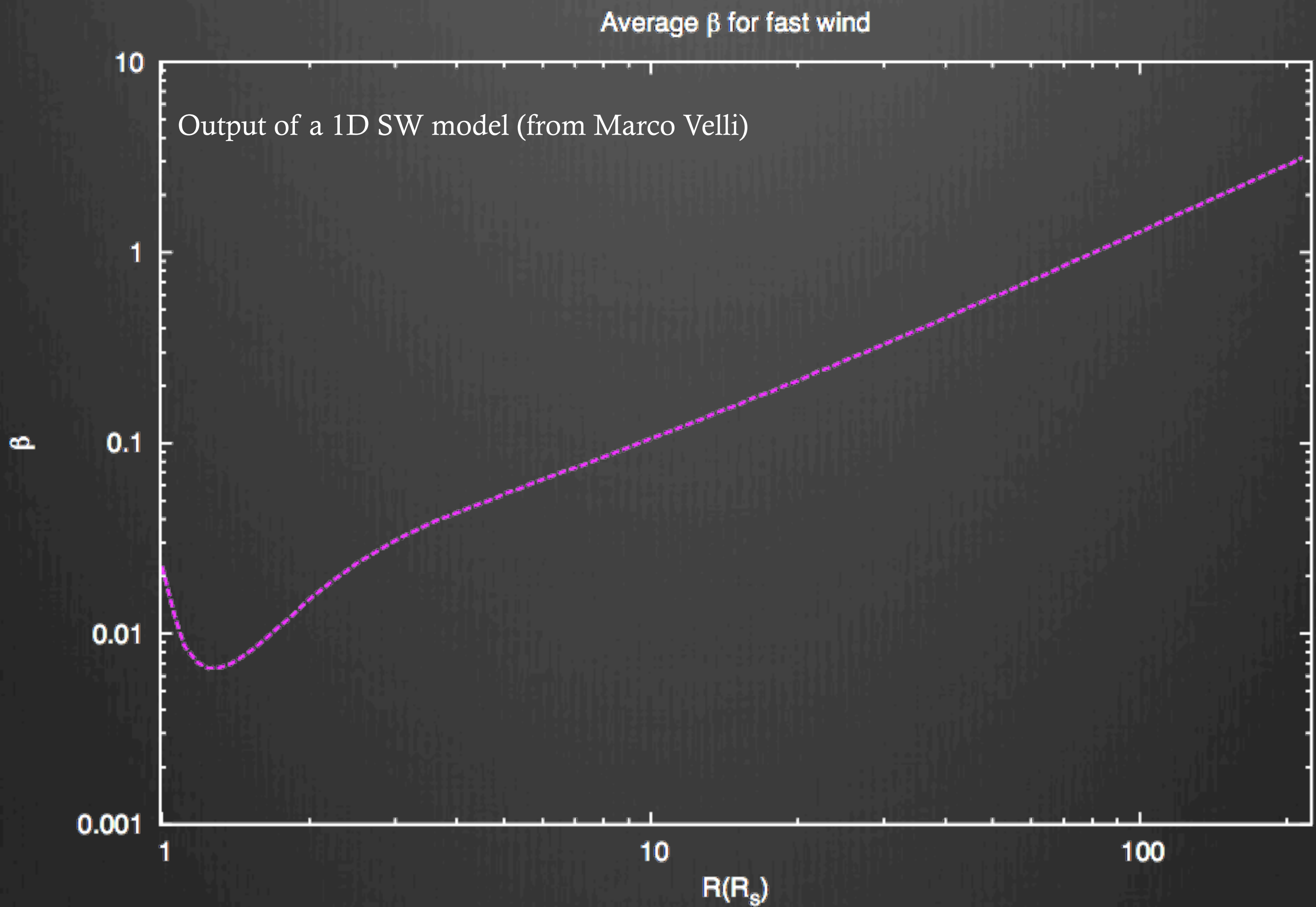
Why?

- Nature of fluctuations at kinetic scales: implications for solar wind dynamics
  - Another (nonlinear) cascade?
  - Dispersion?
  - Dissipation?
- Eventually: Better large scale models via better modeling of kinetic physics

Dissipative processes

- Requirements
  - Collisionless
  - Anisotropic
- Wave particle interactions
  - Cyclotron resonance
  - Landau damping
- Interaction with coherent structures e.g. current sheets and reconnection sites.
- Island contraction
- Shocks
- Stochastic heating

Parameters



Don't we expect the nature of physical processes expected to vary?

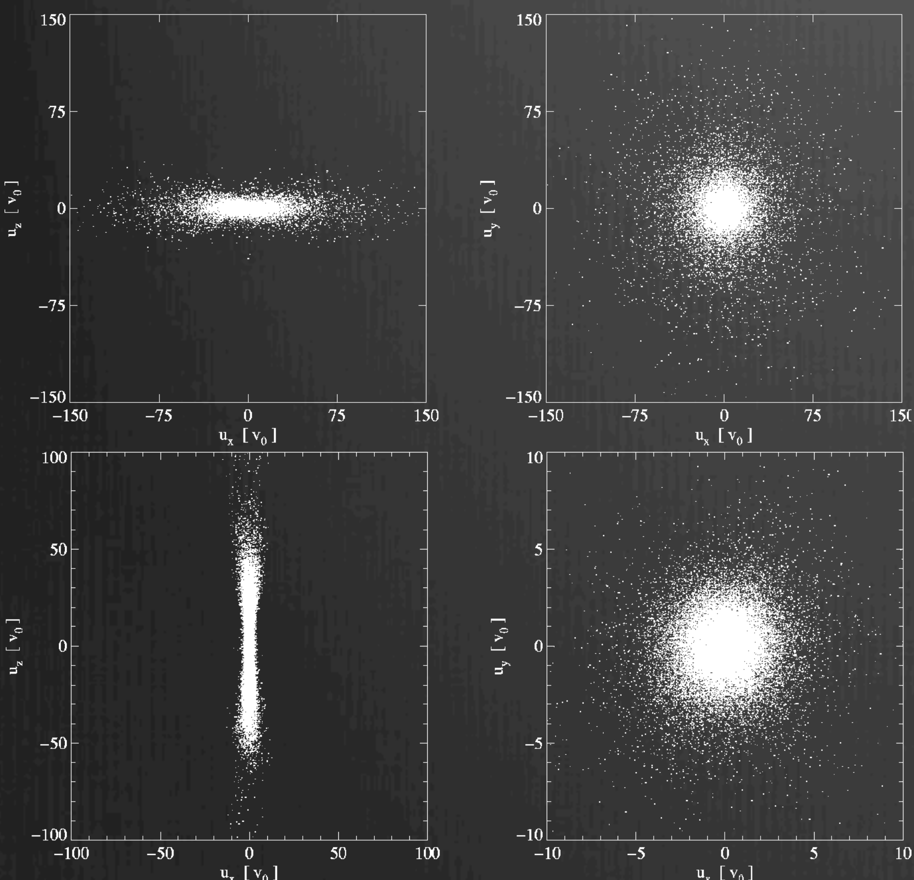
Dissipation at current sheets

- Corona:
  - Nanoflares
  - Simulations
  - Observations
- Inner Heliosphere - ?
  - Observations?
  - Theory mainly concerned with Wave-Particle Interactions
- 1AU
  - Simulations
  - Cluster, Wind, ACE observations

Evidence from simulations

- Hendrix 1996, Dmitruk 1999, Rappazzo 2006 – Coronal context
- Dmitruk 2004
- Parashar 2011
- Greco 2012
- Wan 2012, Karimabadi 2013
- Haynes 2013
- Tenbarge 2013

MHD – Test Particles



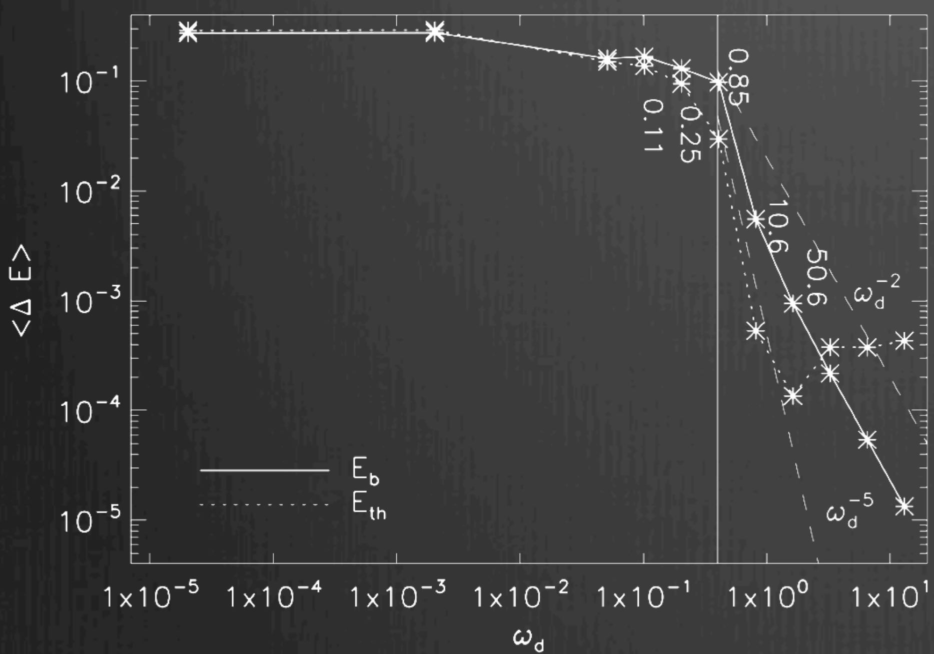
protons

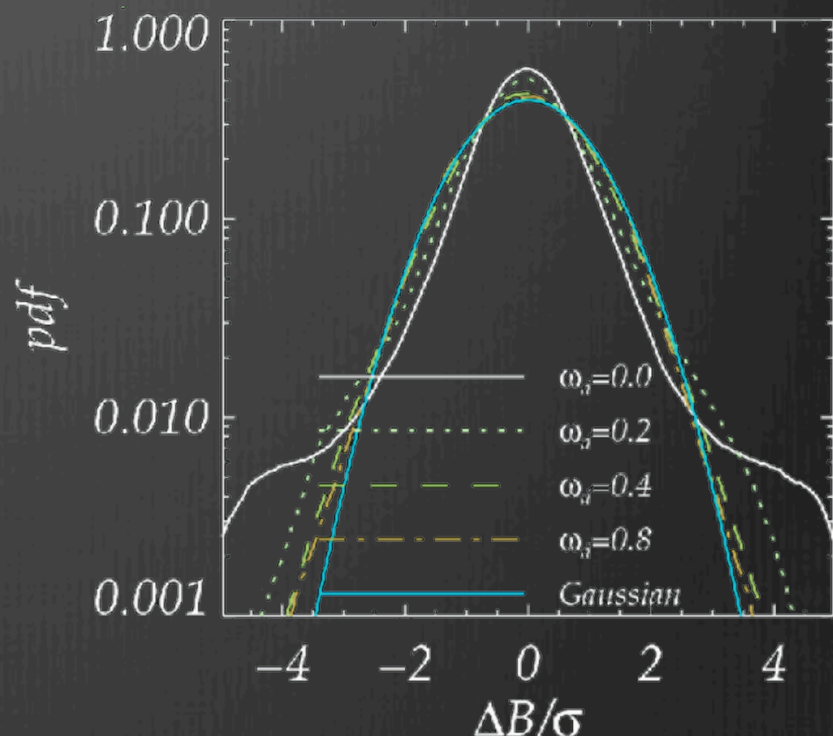
electrons

- Protons heat perpendicular to the mean field
- Electrons parallel to the mean field

Dmitruk et. al., ApJ 2004

Hybrid PIC

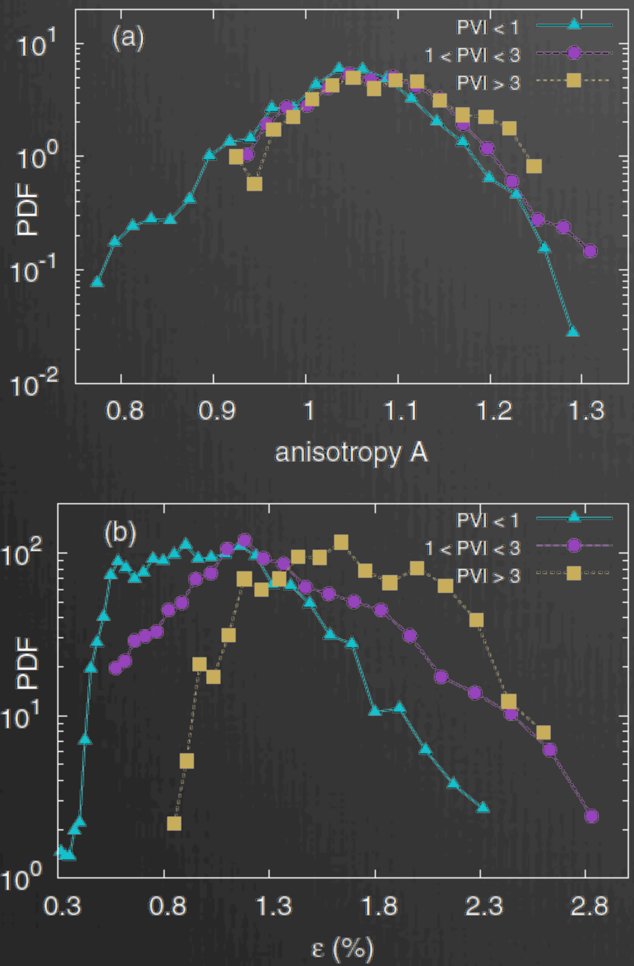




Driven quasi 2D “turbulence”

Parashar et. al., PoP, 2011

Hybrid Vlasov



$$\Delta \mathbf{B}(t, \Delta t) = \mathbf{B}(t + \Delta t) - \mathbf{B}(t)$$

$$I = \frac{|\Delta \mathbf{B}|}{\sqrt{\langle |\Delta \mathbf{B}|^2 \rangle}}$$

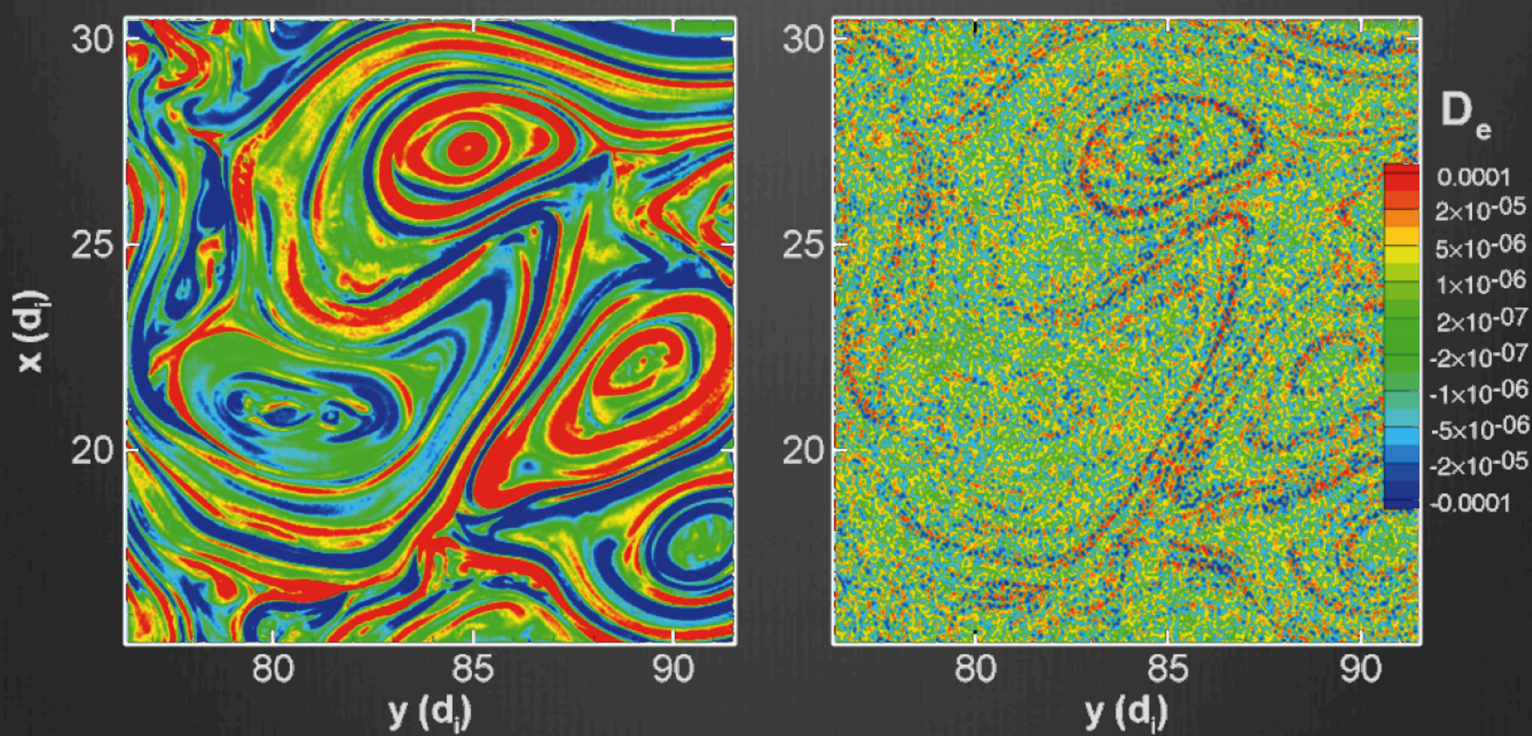
Intermittent, anisotropic heating, associated with higher order PVIs

$$\epsilon(x, y) = \frac{1}{n}\sqrt{\int (f - g)^2 d^3 v}$$

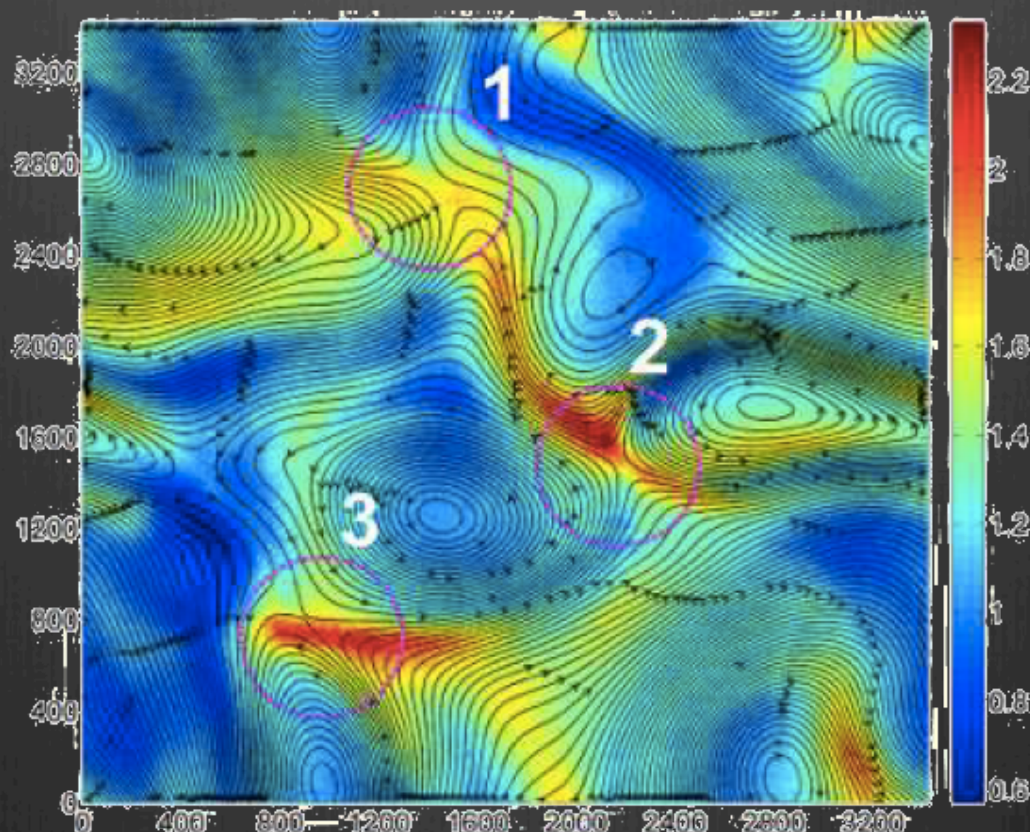
where g is the associated equivalent Maxwellian distribution computed from the parameters of f.

Greco et. al., PRE, 2012

PIC

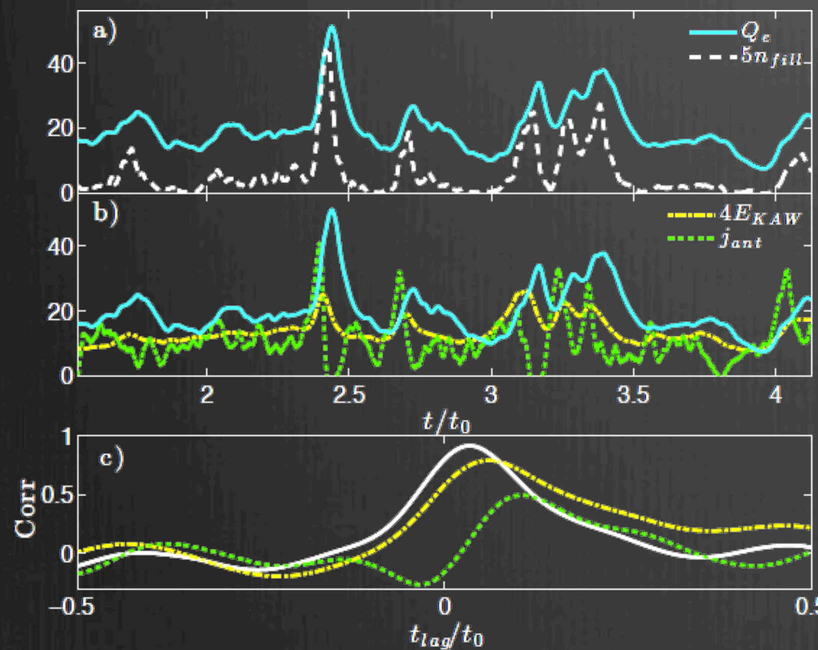


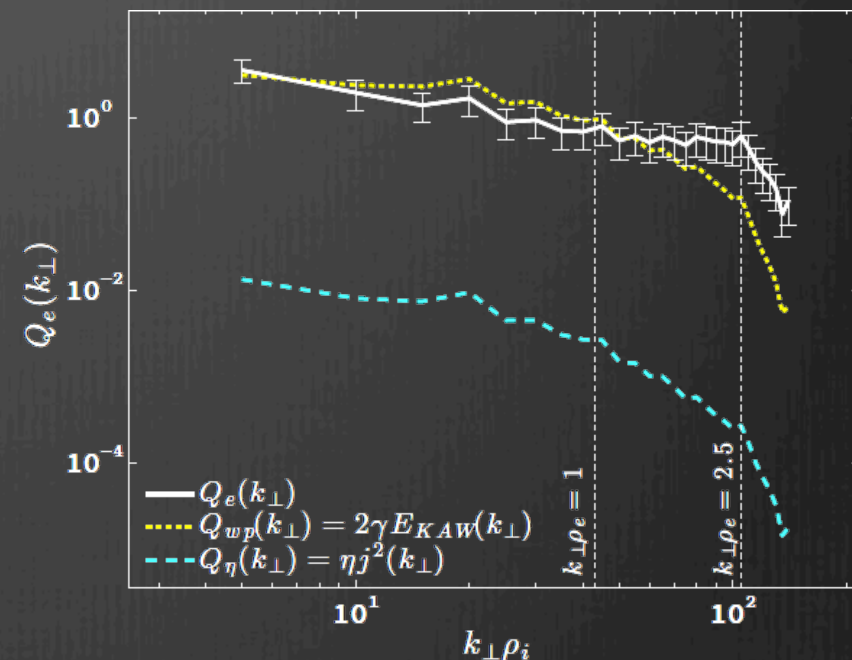
Wan et. al., PRL 2012,
Karimabadi et. al., PoP 2013



Haynes et. al., arXiv, 2013

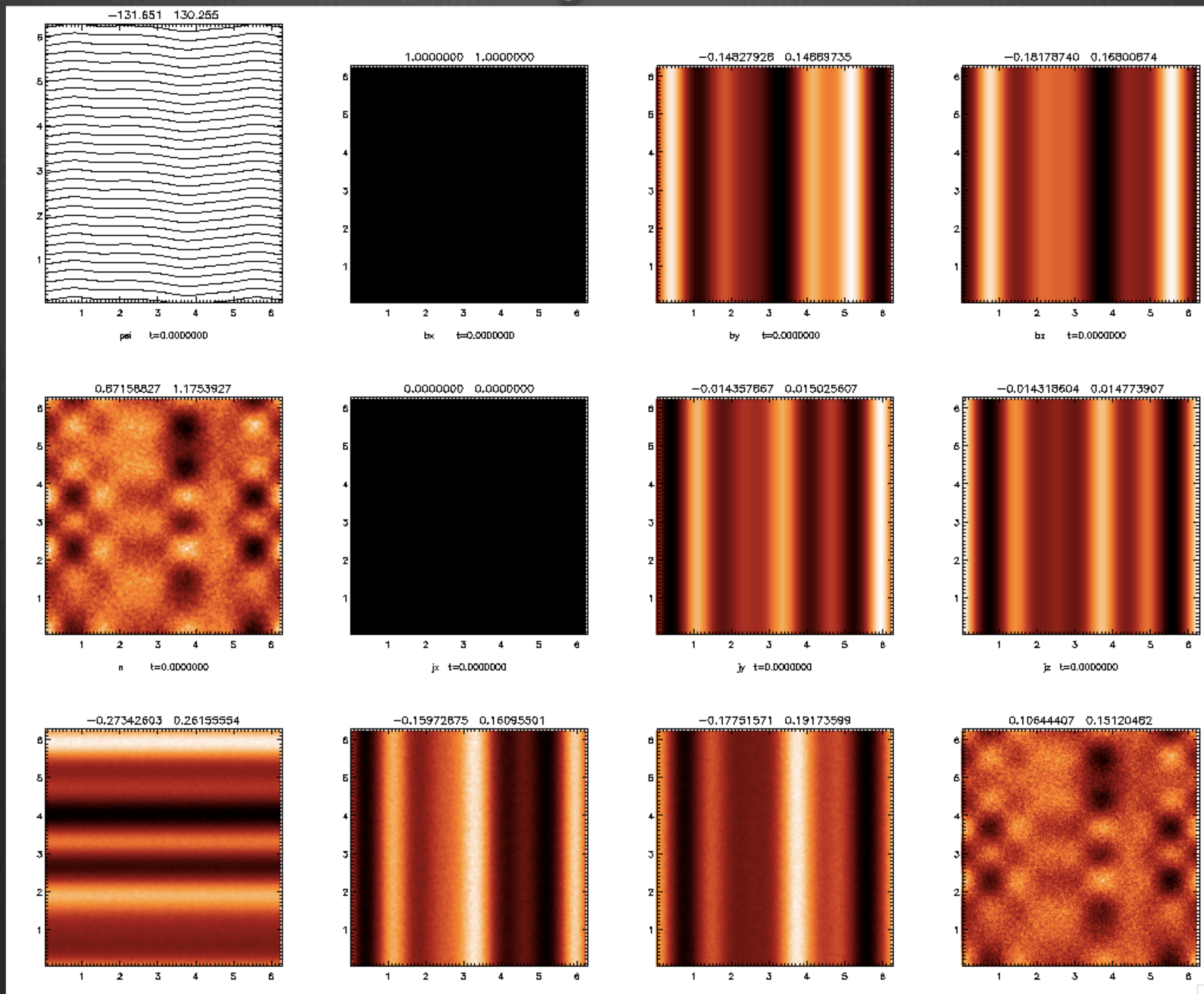
Gyrokinetics



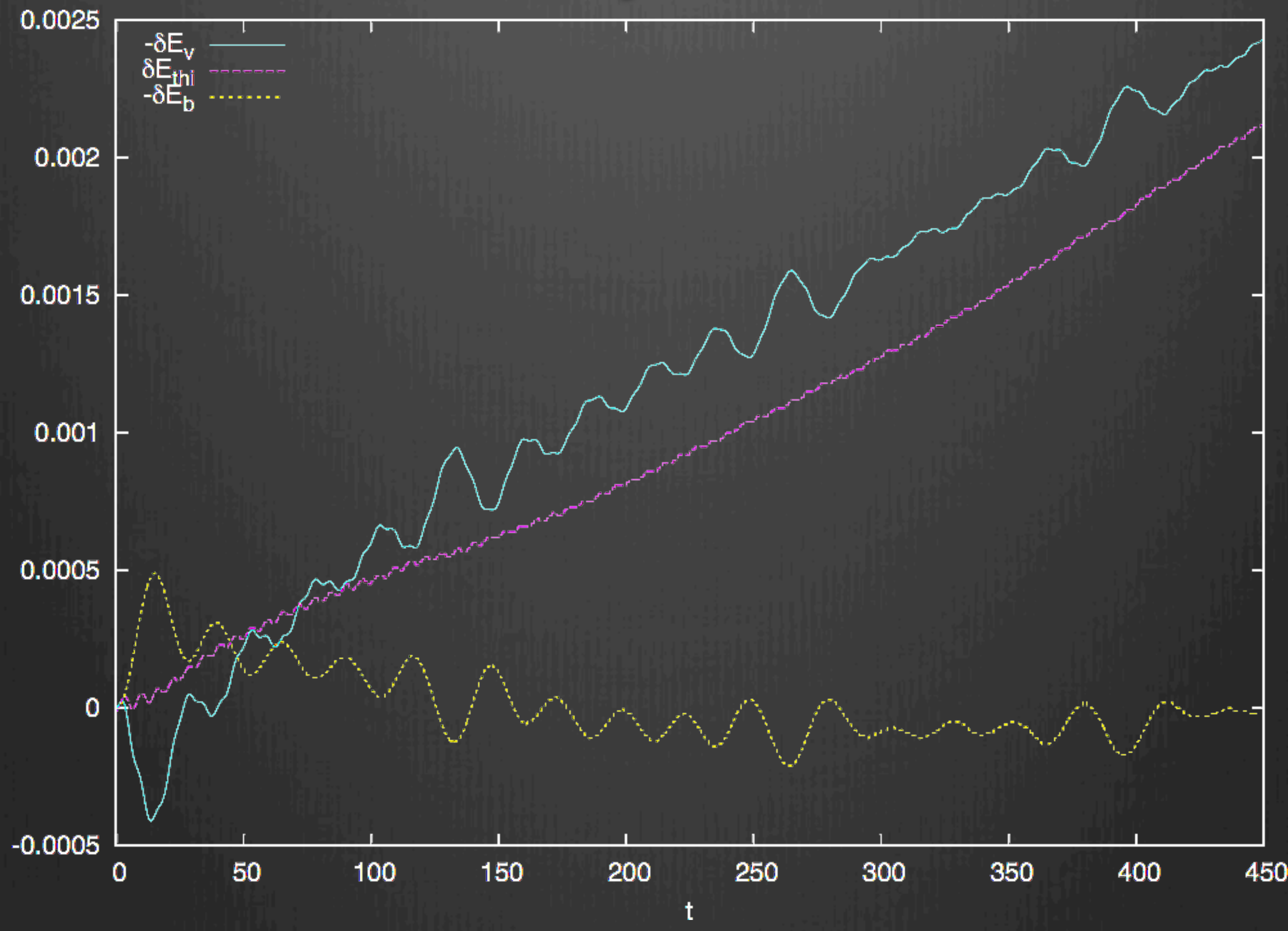


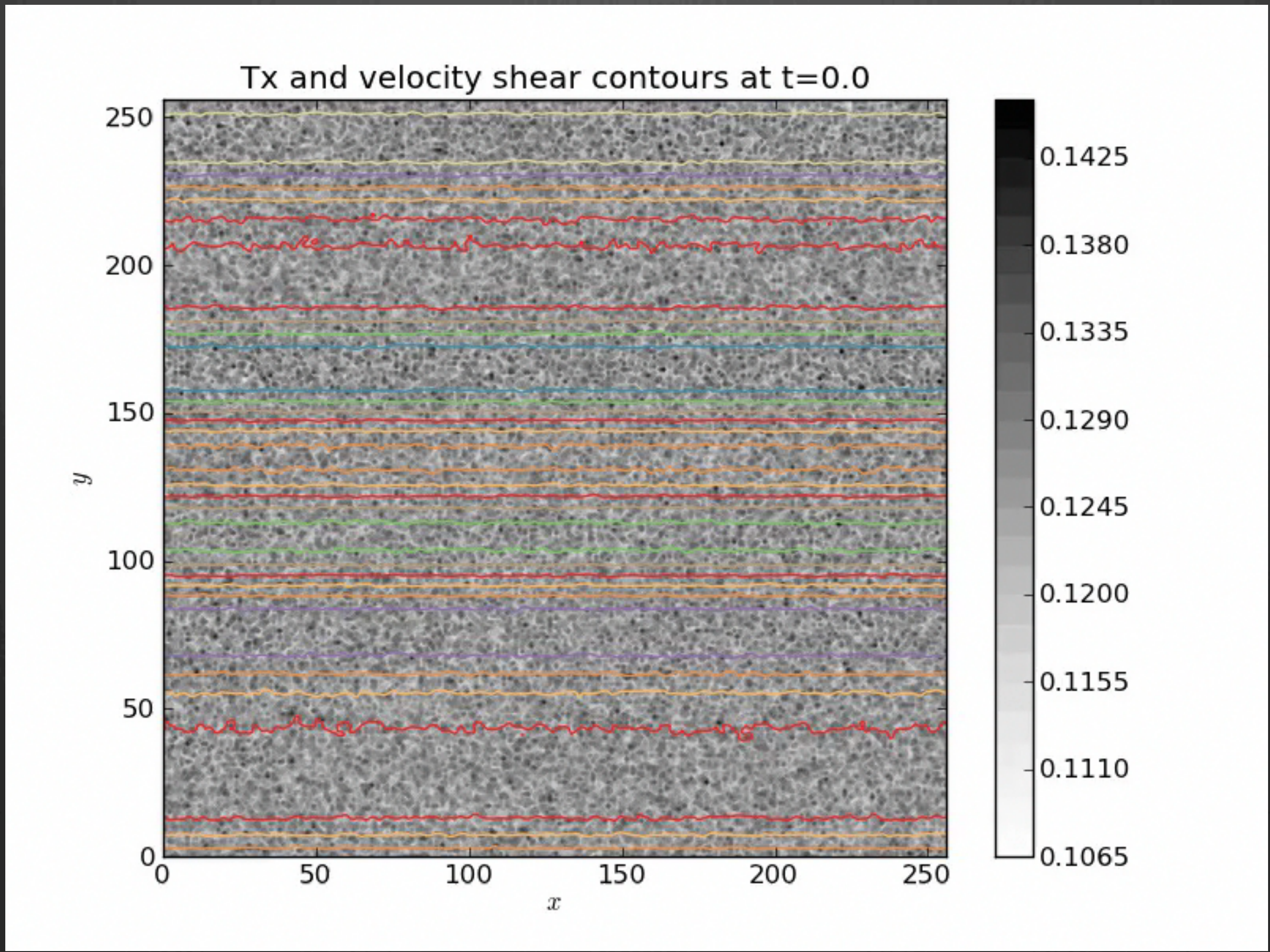
Tenbarge & Howes, arXiv, 2013

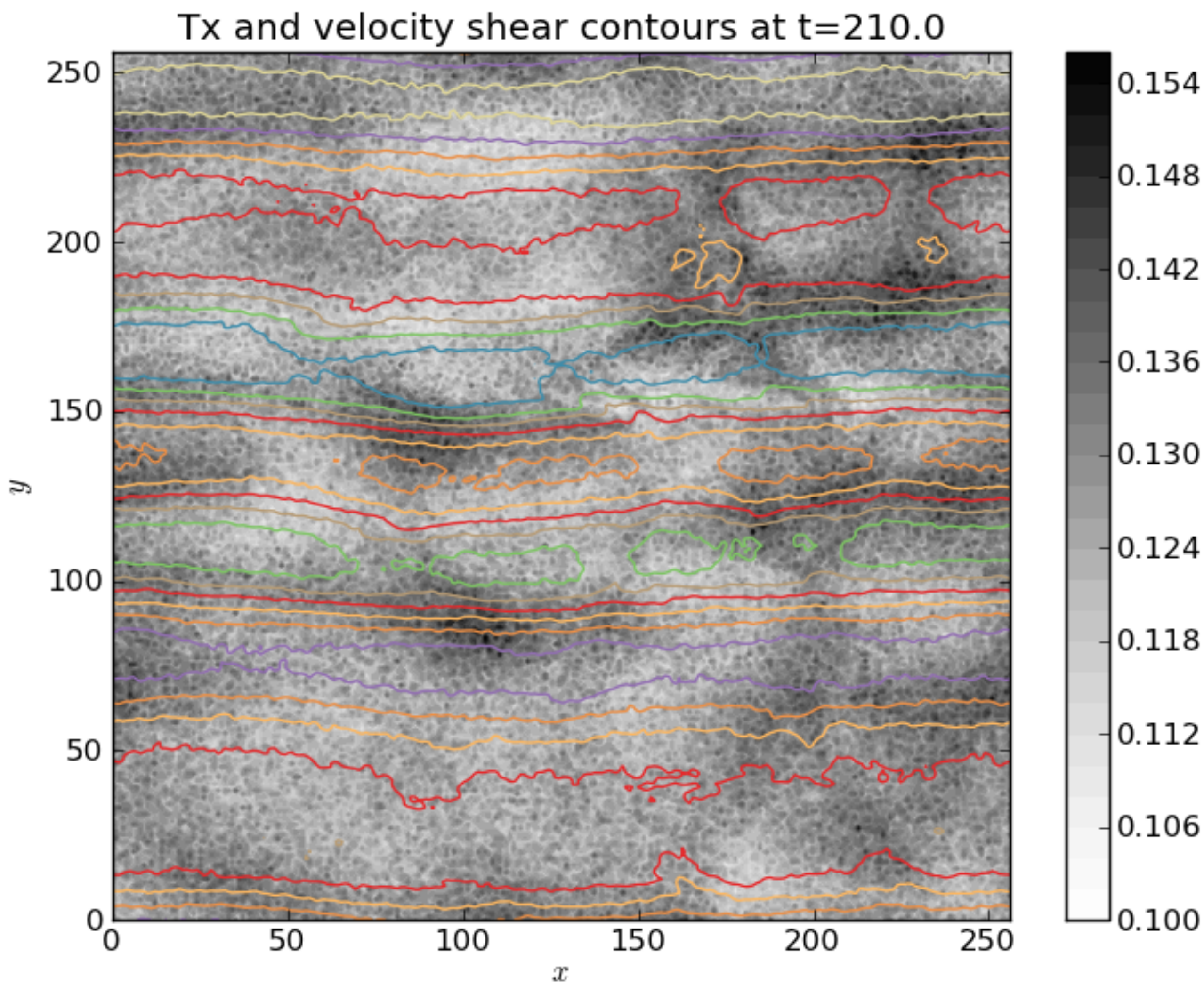
Velocity Shears



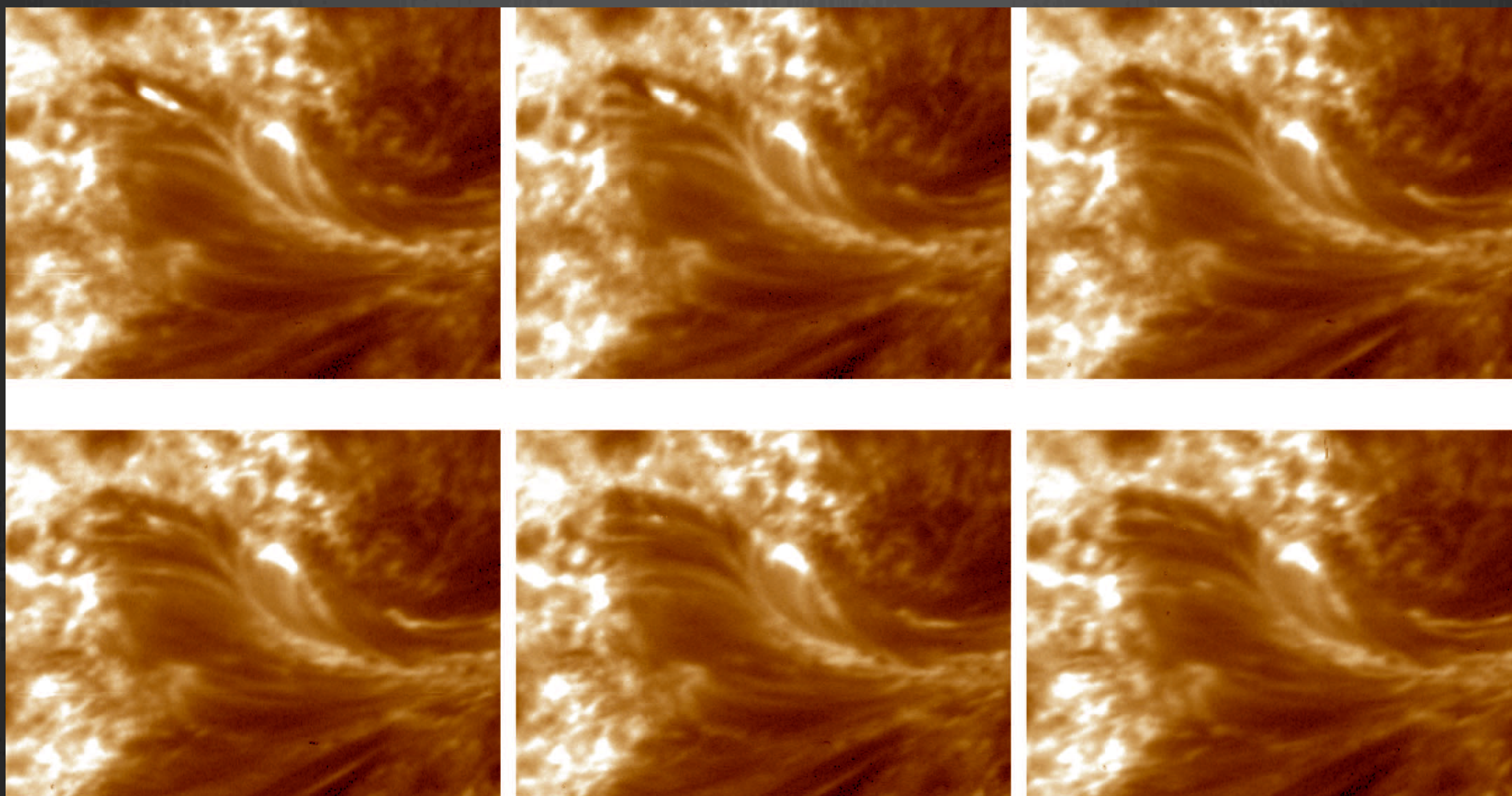
Velocity Shears




Tx and velocity shear contours at t=0.0
250
200
150
100
50
0
y
0
50
100
150
200
250
x
0.1425
0.1380
0.1335
0.1290
0.1245
0.1200
0.1155
0.1110
0.1065

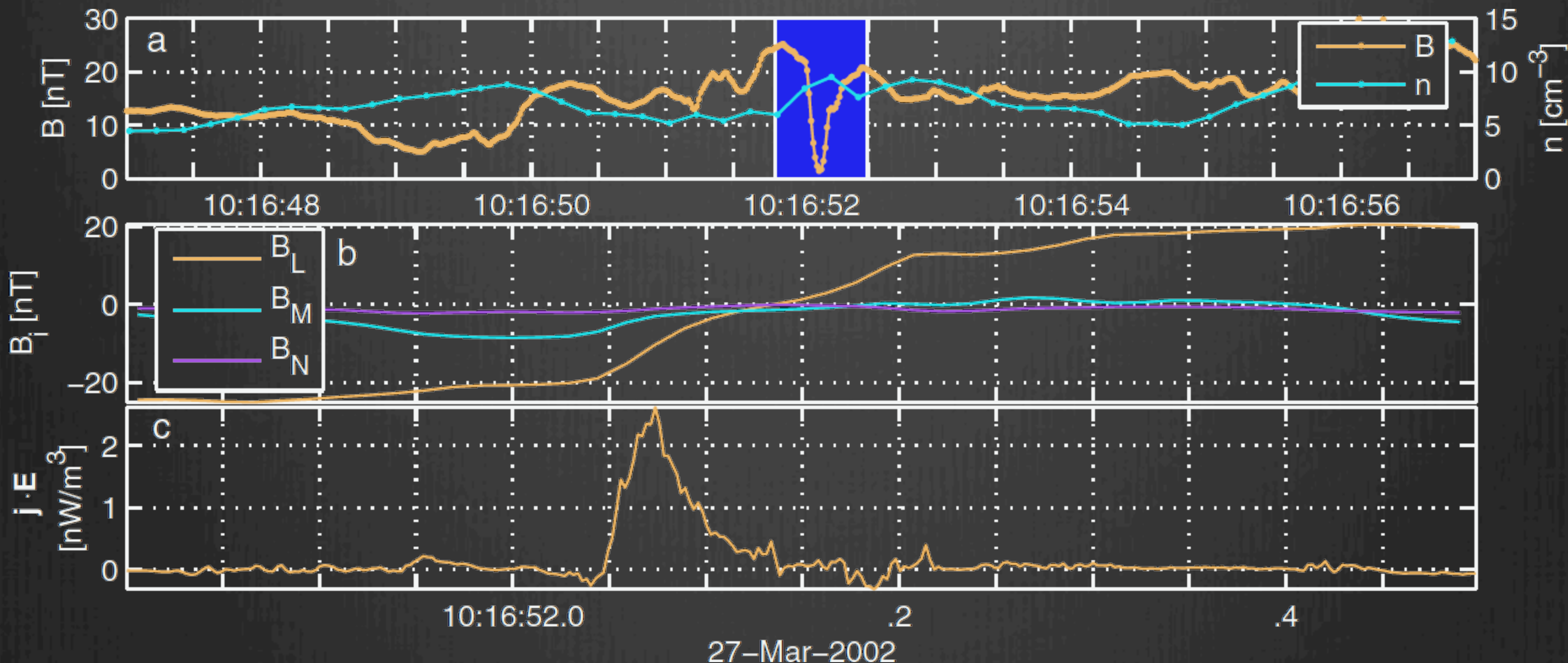

Tx and velocity shear contours at t=210.0
250
200
150
100
50
0
y
0
50
100
150
200
250
x
0.154
0.148
0.142
0.136
0.130
0.124
0.118
0.112
0.106
0.100

Evidence from observations



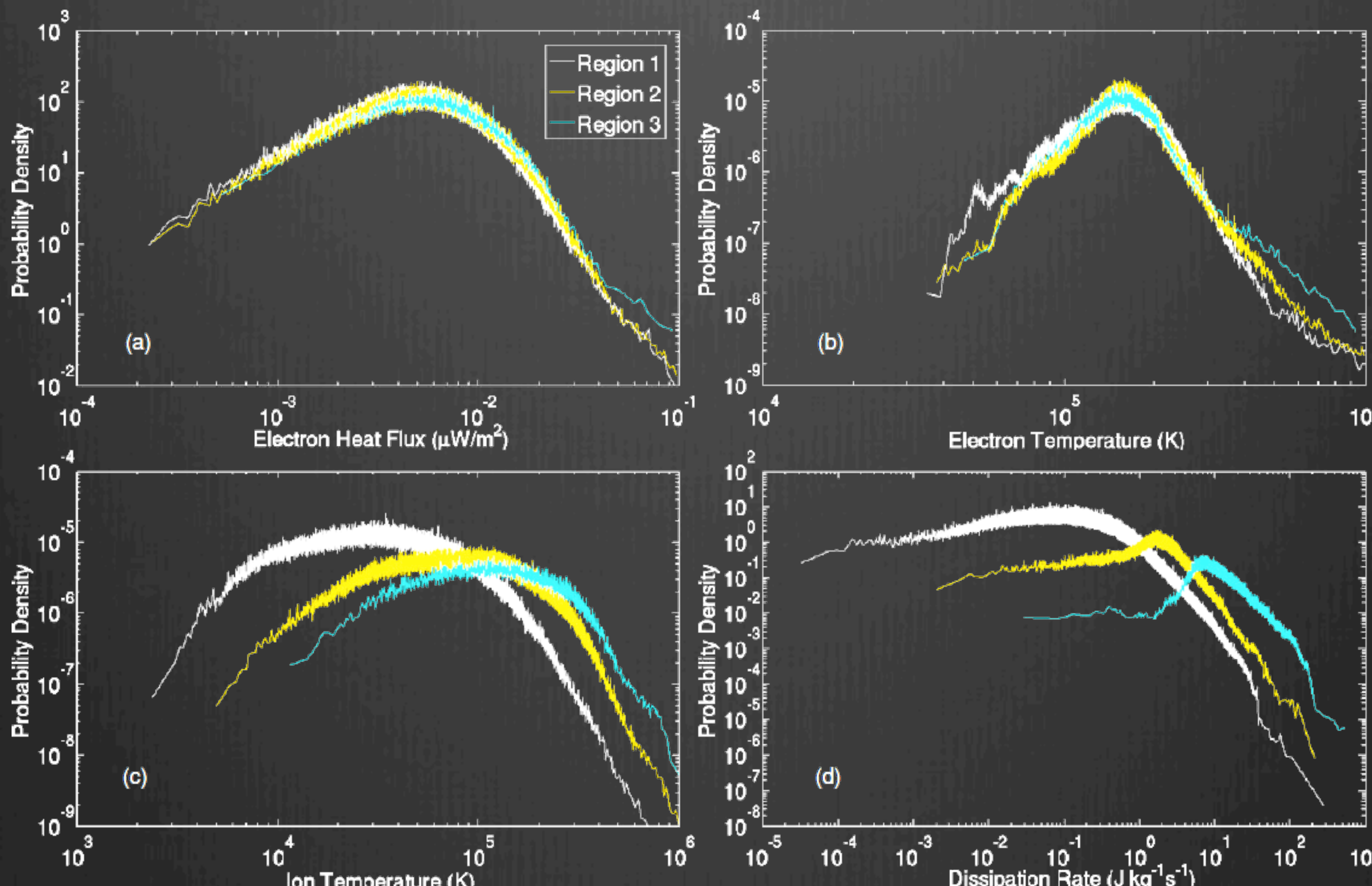
Much larger than kinetic scales but one step closer to nanoflares idea.

Bow Shock

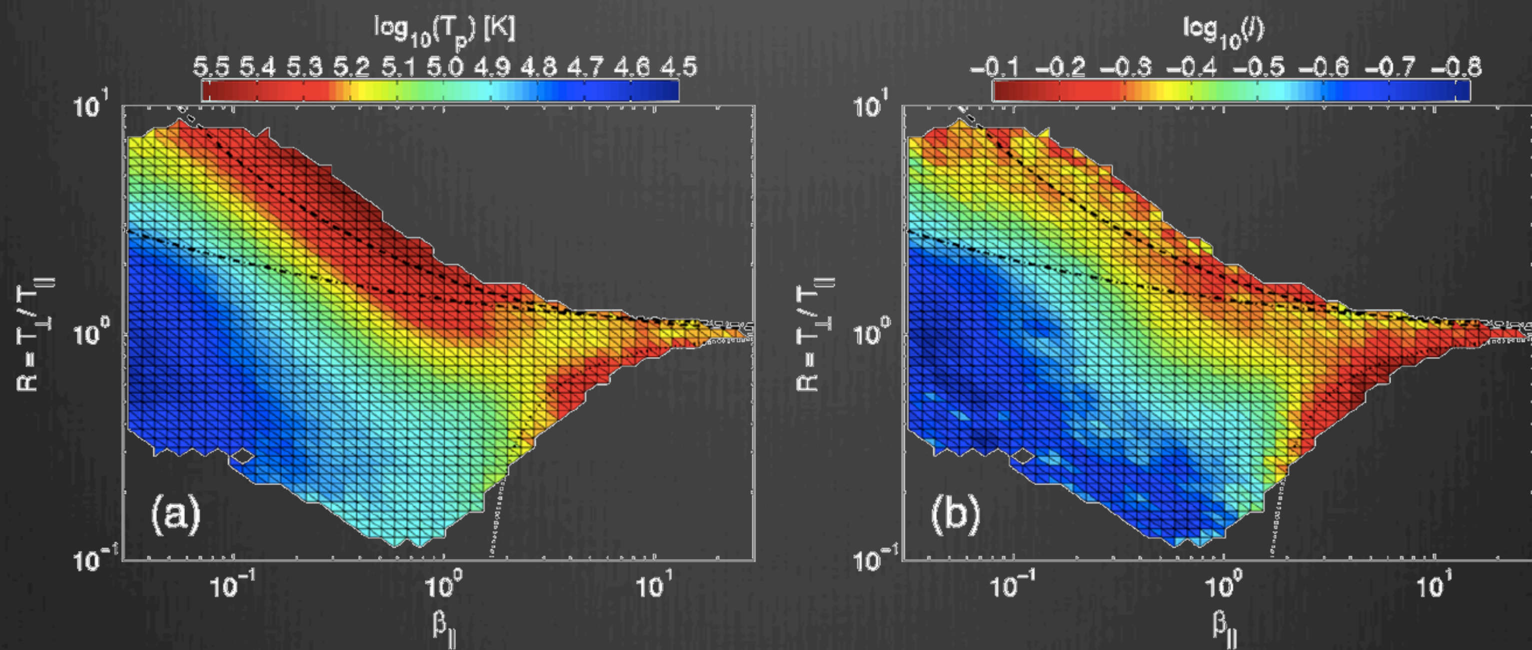


Sundkvist et. al., 2007

ACE & WIND Data

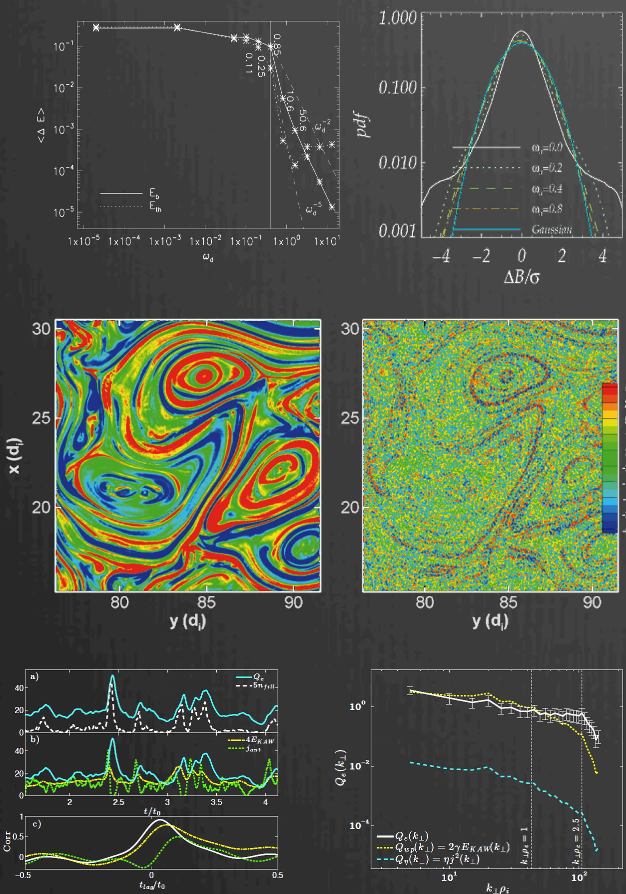


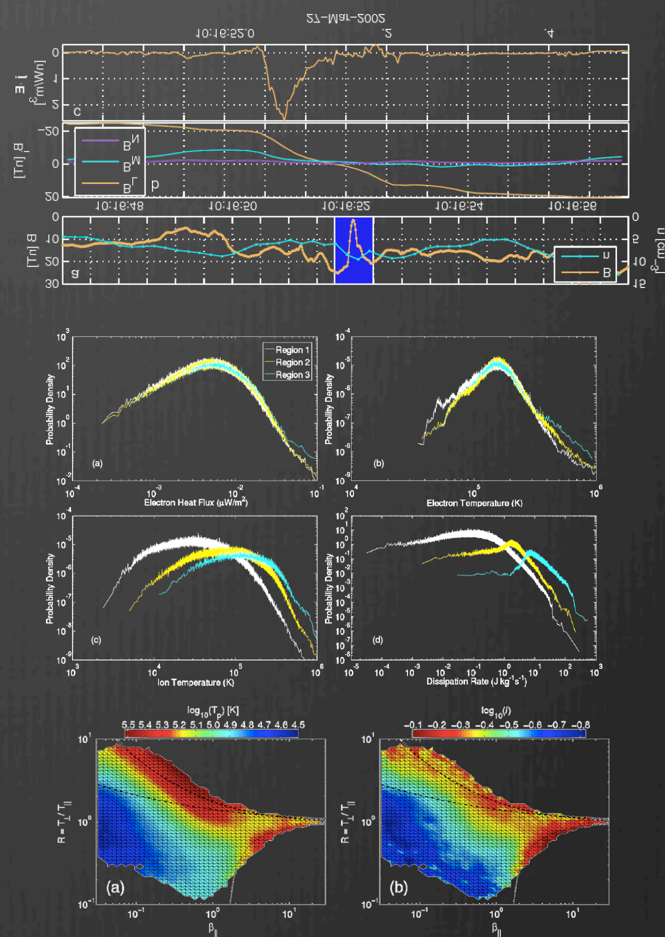
Osman et. al., ApJL 2011



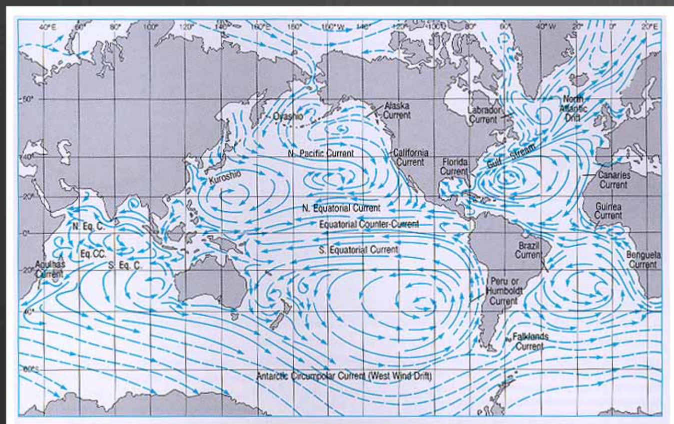
Osman, PRL, 2012

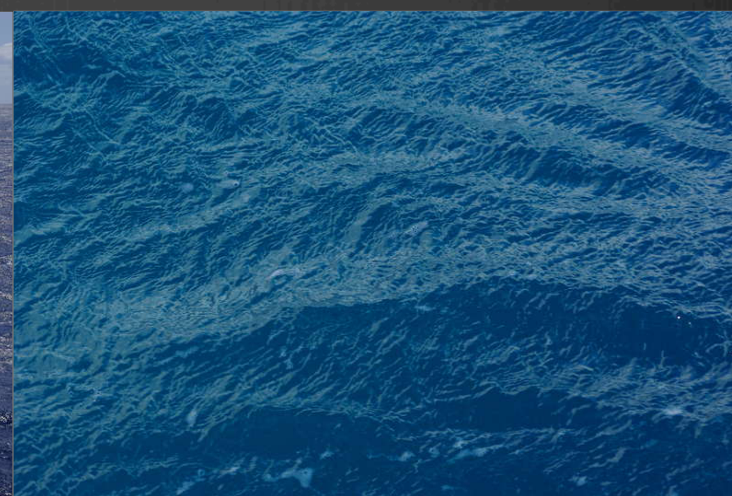
Put together





What about other processes?





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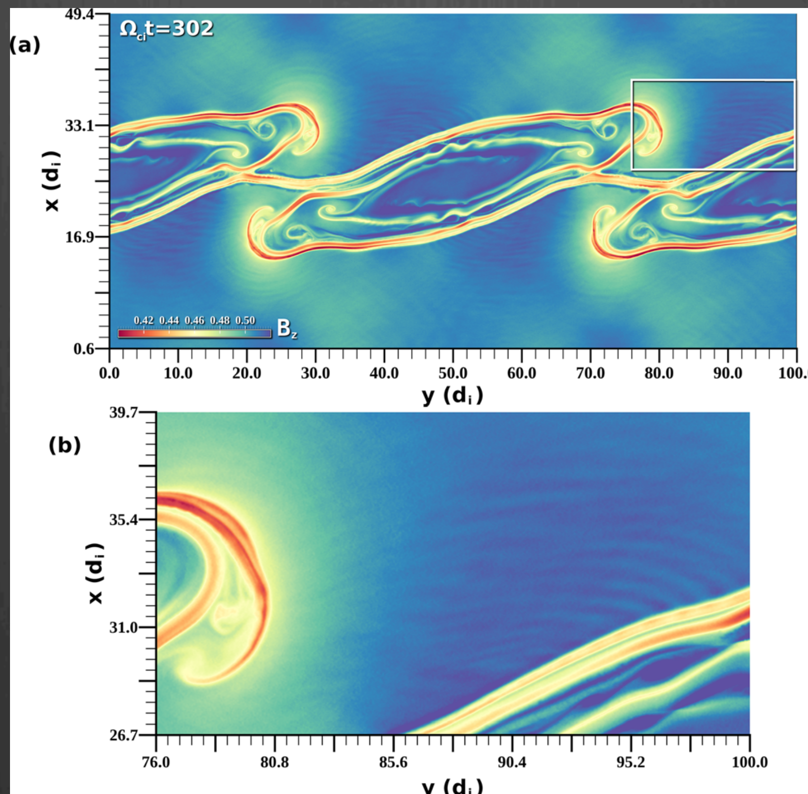


Can wave-particle interactions in the bulk of the plasma have a significant contribution?

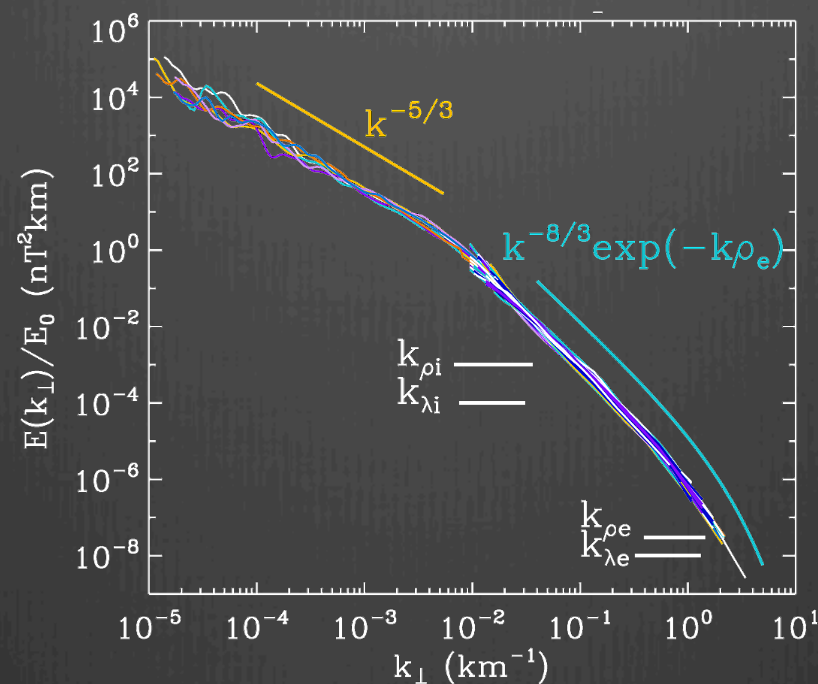
What about other processes?

- Classification issues?
- A “simple” scenario: Reconnection
  - Direct energization by the electric field
  - Outflow shocks
  - Waves in the reconnection exhaust
  - Island contraction
- Do all these classify as “low frequency”?
- If not, how do we separate the contributions?
- Similar issues with unstable regions (cyclotron, firehose etc.)

Where to go from here?

- Misleading to characterize dissipation as a couple of simple processes – in terms of general description (personal view)
- (Personal) Favorite approach
  - Understand the strengths of different processes in idealized conditions
  - Understand the relative play in simple but tractable systems
  - Find ways to empirically quantify the effects of above processes using spacecraft data

Where to go from here



Alexandrova et. al. 2012

- Use the above understanding to improve (empirical) models
  - Landau Fluid

    + (?)
  - Stochastic Heating $Q_\perp = \dfrac{c_1(\delta v_i)^3}{\rho_i}\exp\left(-\dfrac{c_2}{\varepsilon_i}\right)$
- Turbulent Dissipation Challenge!!

Thanks!