Stochastic echoes and fluidization

Romain Meyrand (at SHINE meeting this week)

also: Anjor Kanekar, Bill Dorland, Alex Schekochihin

11th Plasma Kinetics meeting, 2018

Kinetic Reduced MHD

- Alfven waves decouple:

$$\left(\frac{\partial}{\partial t} \mp v_A \frac{\partial}{\partial z}\right) \omega^{\pm} = -\left[\zeta^{\mp}, \omega^{\pm}\right] - \left[\partial_i \zeta^{\mp}, \partial_i \zeta^{\pm}\right]$$

- This is in Elsasser potential form. Decoupling occurs because perpendicular wavelengths are long compared to ion gyroradius — this is a convenient feature of KRMHD

- Kinetic equations for the ions are simple

$$\frac{dg^{(i)}}{dt} + v_{\parallel} \nabla_{\parallel} g^{(i)} + v_{\parallel} F_0 \nabla_{\parallel} \phi^{(i)} = 0$$

- But the operators are the nonlinear ones

$$d/dt = \partial/\partial t + \mathbf{v} \cdot \nabla \quad \text{and} \quad \nabla_{\parallel} = v_A \partial/\partial z + \mathbf{b} \cdot \nabla$$

Kinetic Reduced MHD

- The electrons are isothermal with zero gyroradius. B_0 is straight.
- The two ion distributions are essentially the lowest two Laguerre moments. The rest of the Laguerre's are passive.
- The physical perturbations of density and magnetic field strength can be obtained from a linear combination of the integrals of the two ion distributions (over parallel velocity).
- So this is a physically meaningful ordering that allows us to study Landau and Barnes damping in a nonlinear, electromagnetic context.
- How are the inertial range compressive perturbations thermalized?
- Basic question: Do we really need high resolution for *g*?

Kinetic Reduced MHD

- Without collisions or Alfven waves, compressive fluctuations damp, by Landau or Barnes mechanism

- Finite amplitude Alfven waves change the fate of the energy in the compressive fluctuations

- Our approach:

  - Force critically balanced Alfvenic turbulence (random forcing around the box scale)

  - Force compressive fluctuations separately (random forcing around the box scale, proportional to $v_{||}\, F_0\,(v_{||})$ in v-space)

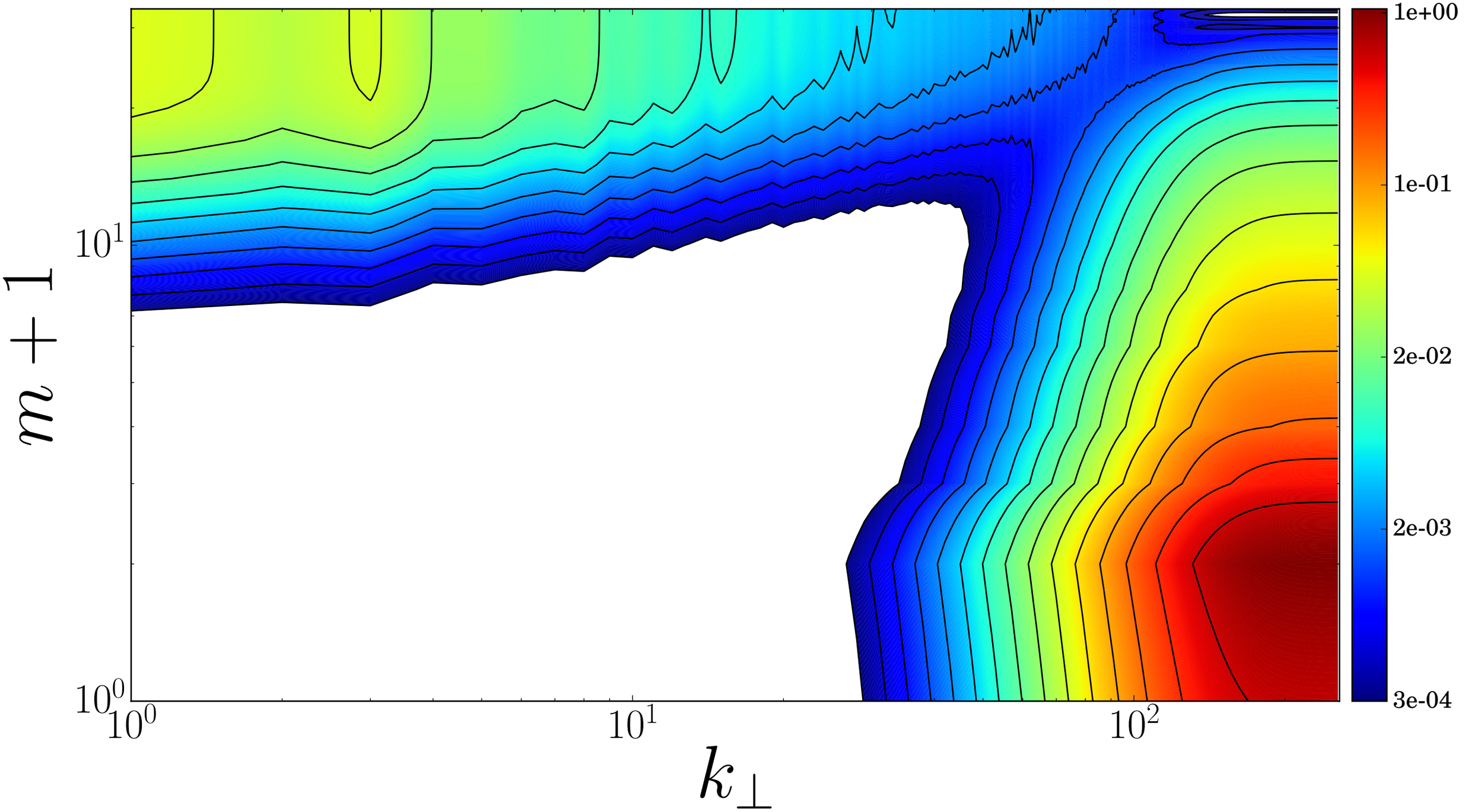
  - Measure spectra and infer fluxes of free energy thru phase space

Findings

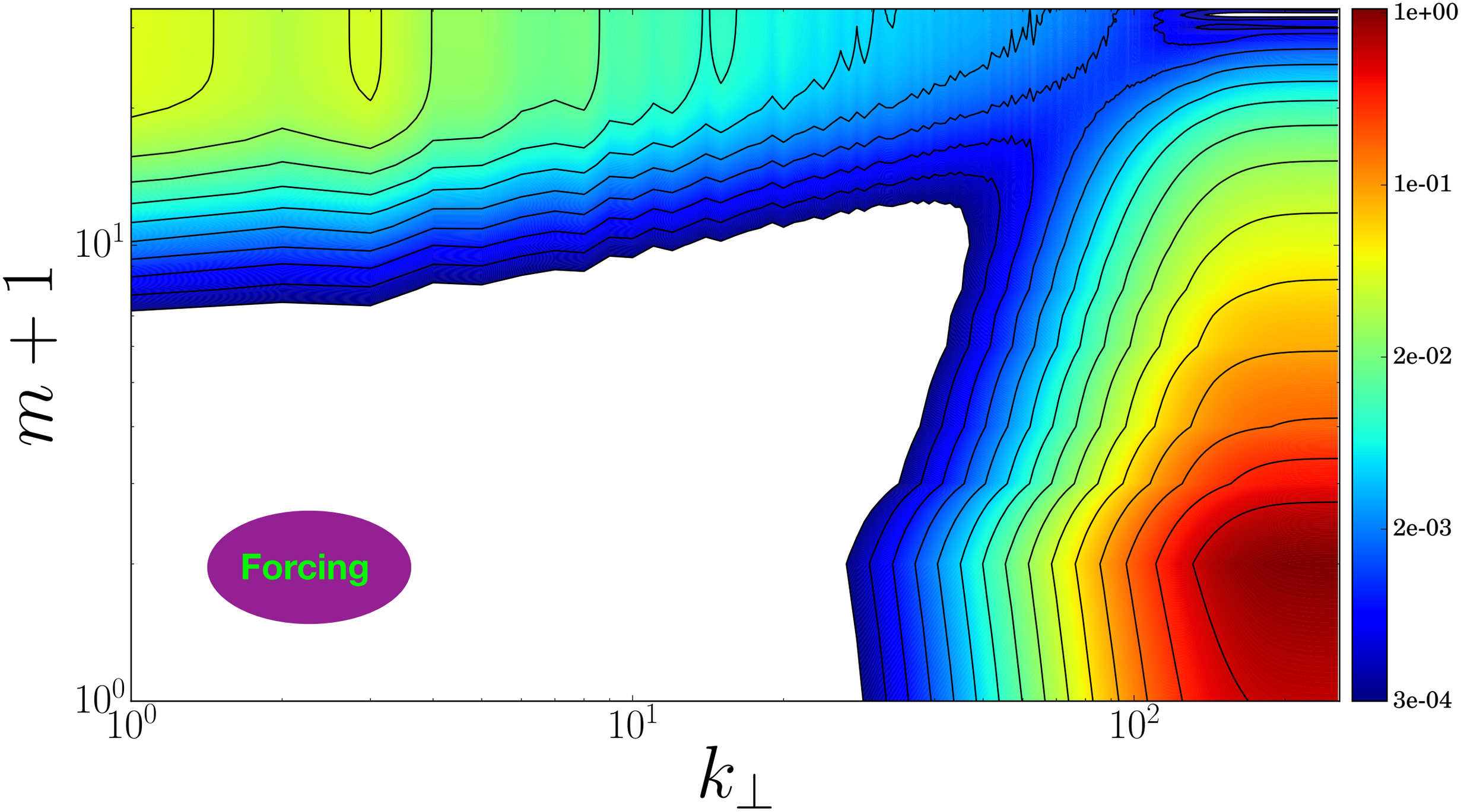
- Compressive perturbations develop a parallel cascade
- This increases the parallel wavenumber and thus the Landau damping rate
- Small scales do not develop in *v*-space. Dissipation is mainly at small spatial scales

- Compressive fluctuations behave on average like a (generalized) fluid — a fluid described by more moments than usual.
- On average, stochastic echoes inhibit flux of free energy to small *v*-scales
- Consistent with electrostatic findings (Parker, Kanekar, et Al).
- Implies opportunity exists for more efficient *v*-space representation

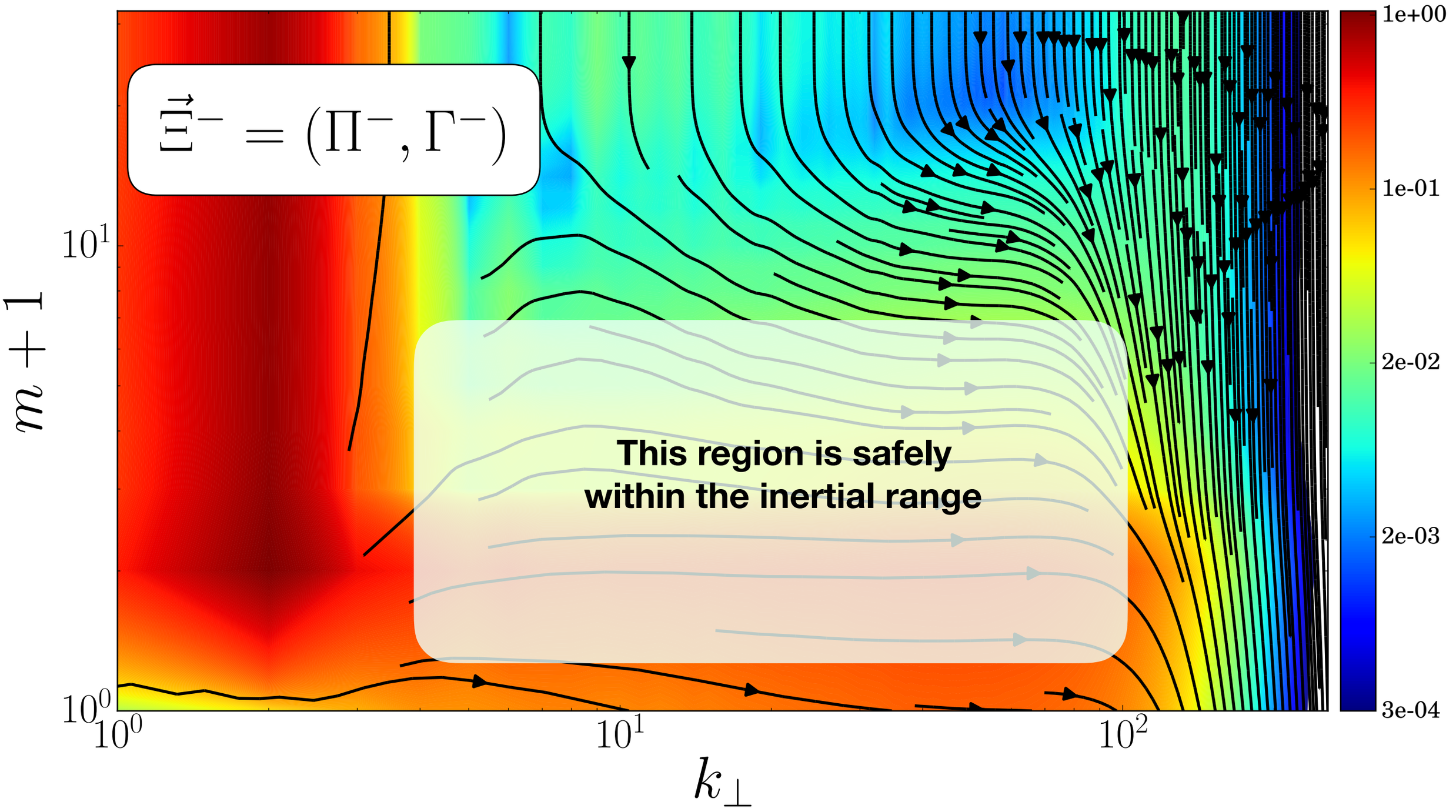
Measured dissipation



Measured dissipation and forcing used



Flux in *m* and wavenumber



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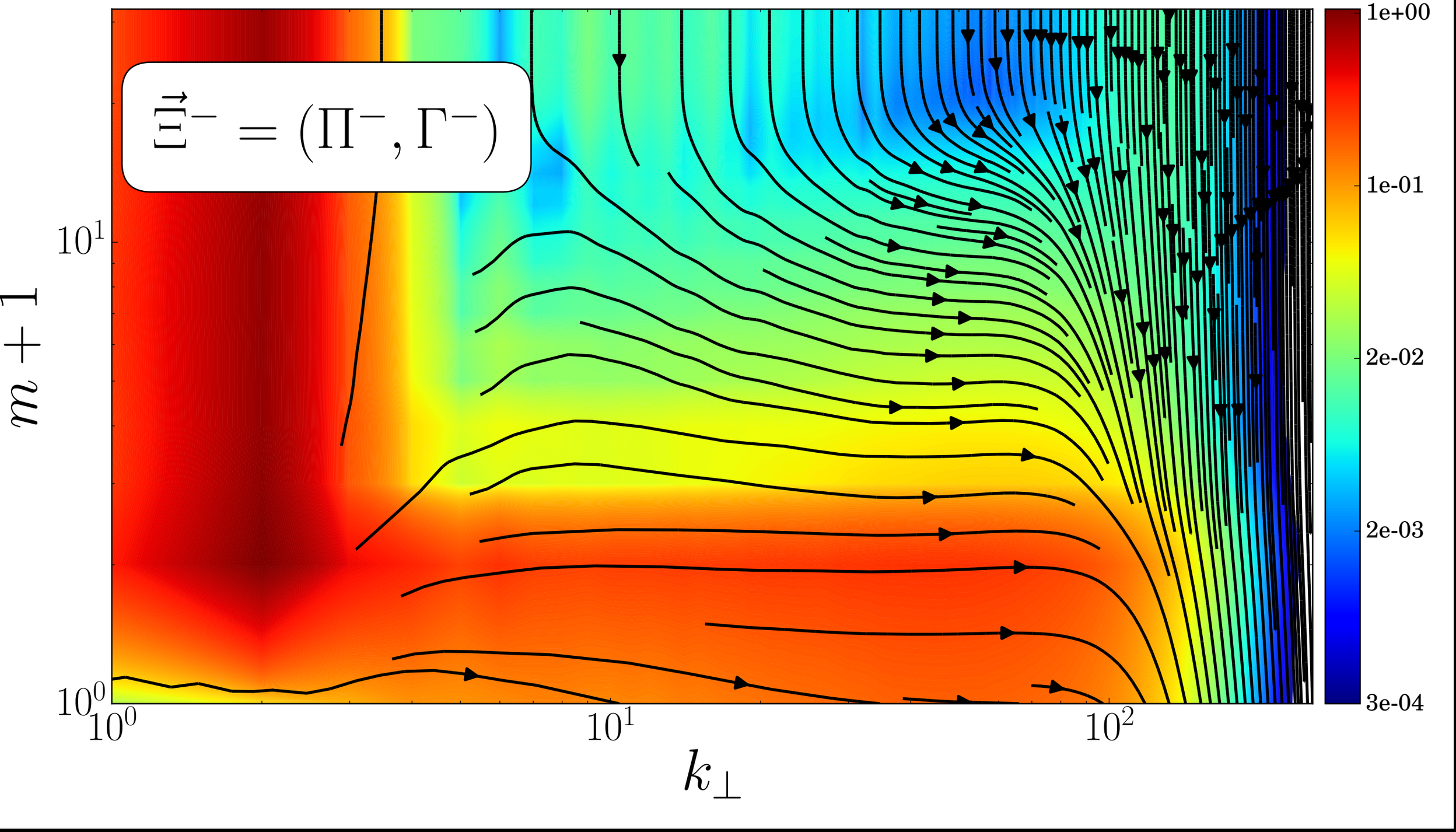
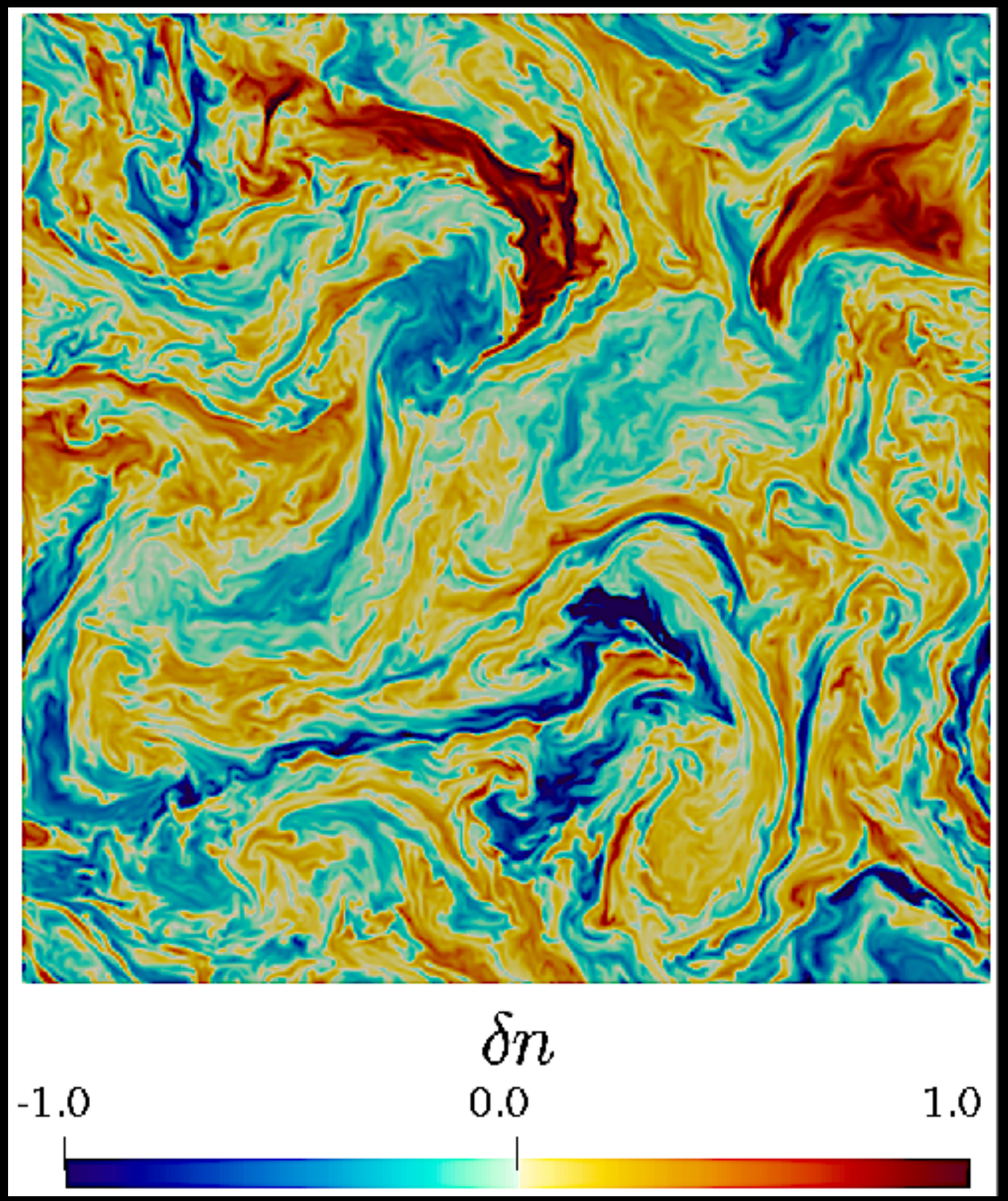
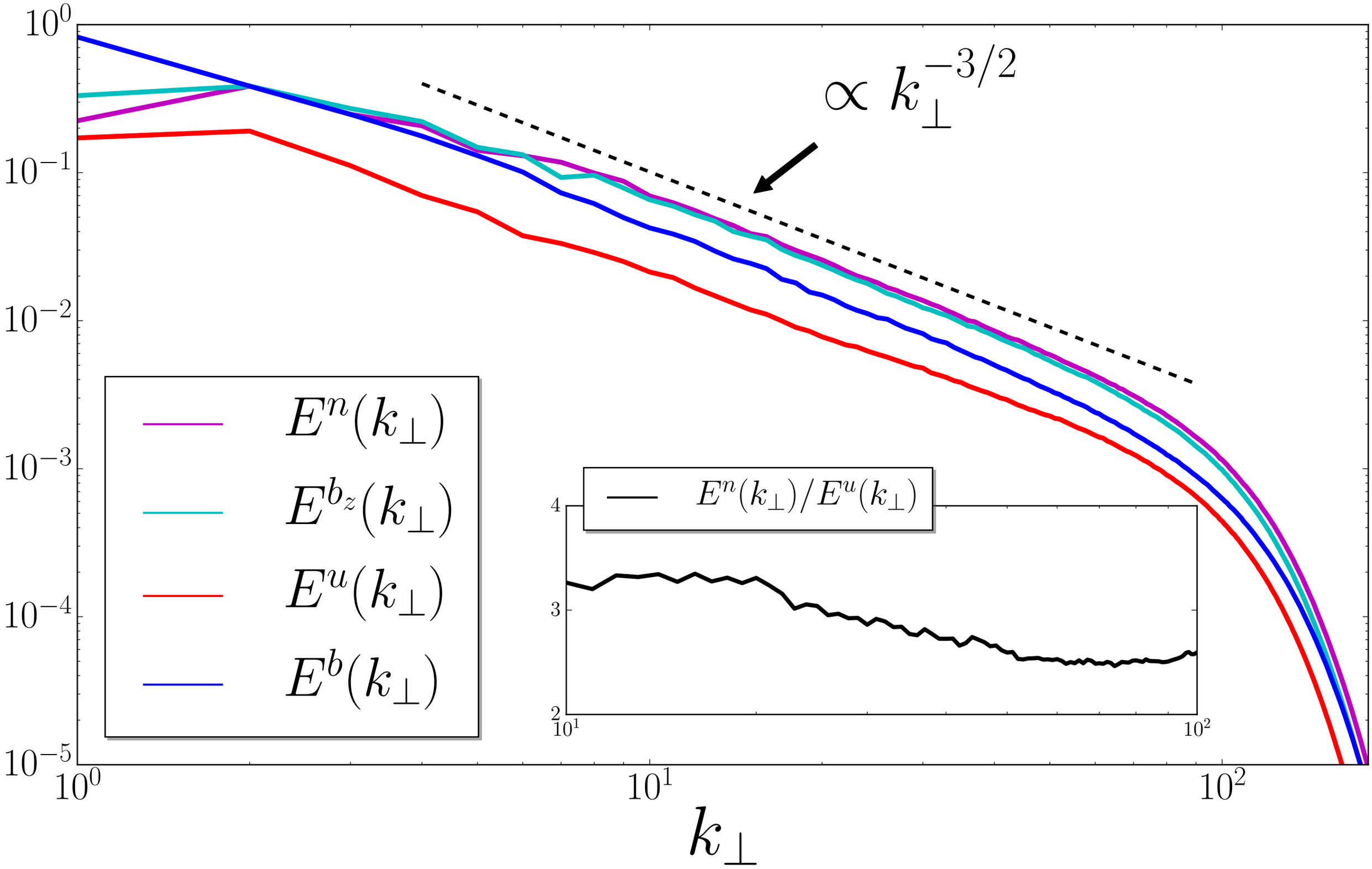


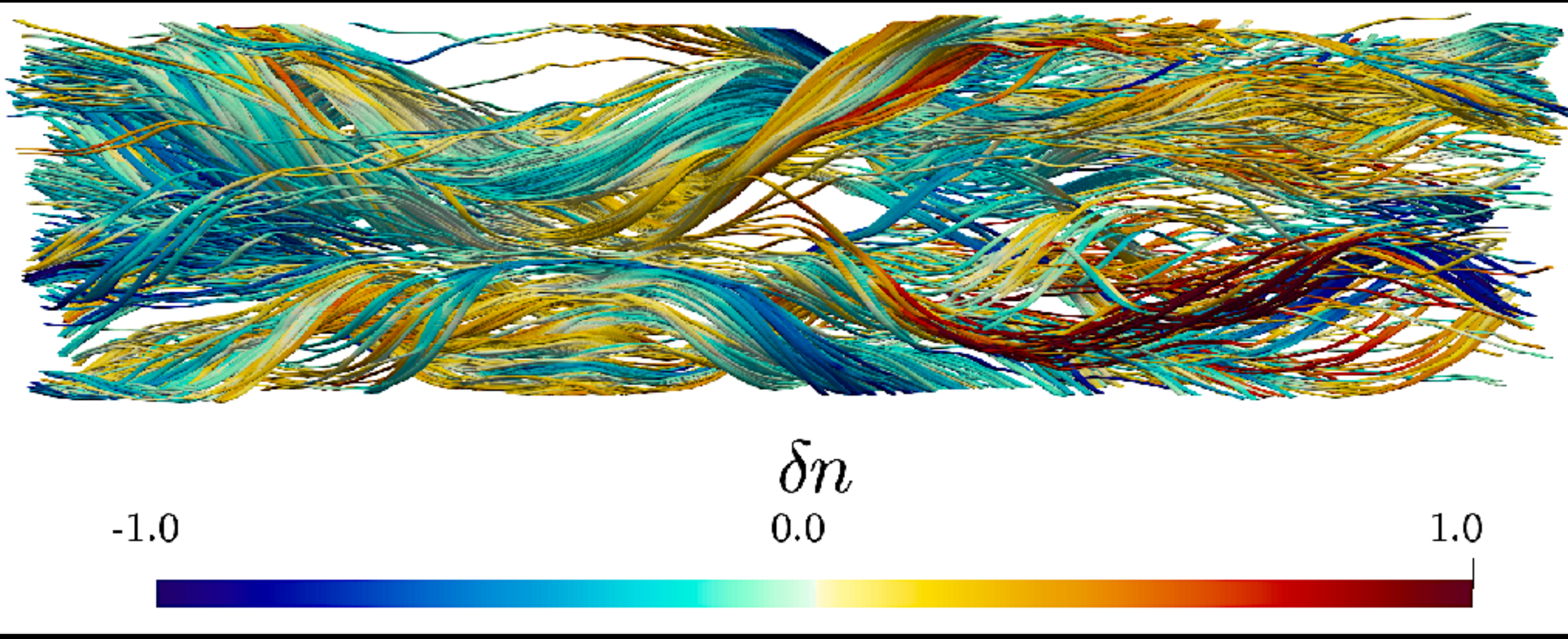
Density fluctuations in the perpendicular plane (snapshot)



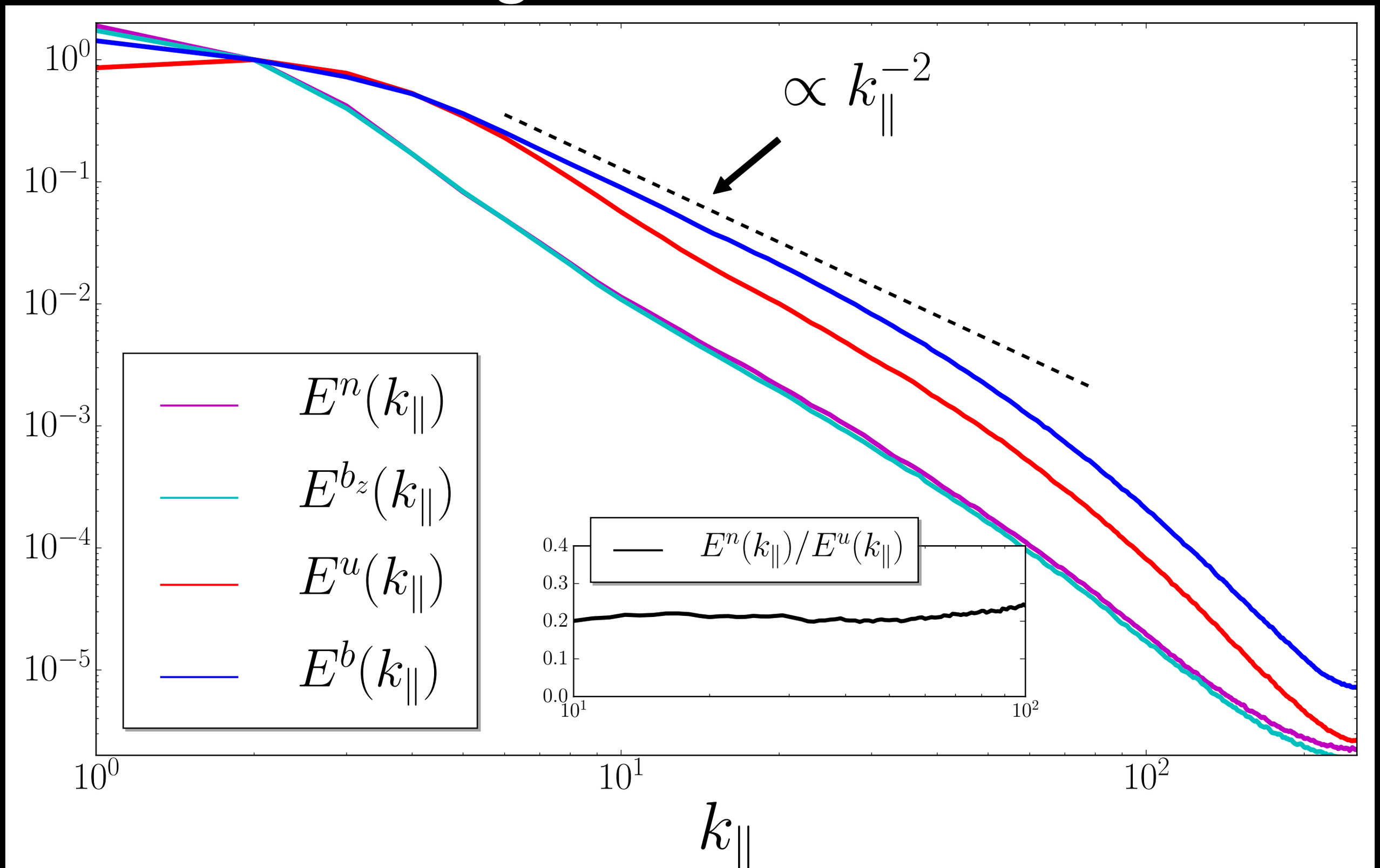
Density fluctuation spectra



Field lines painted with density fluctuations



Spectrum of density fluctuations along magnetic field lines



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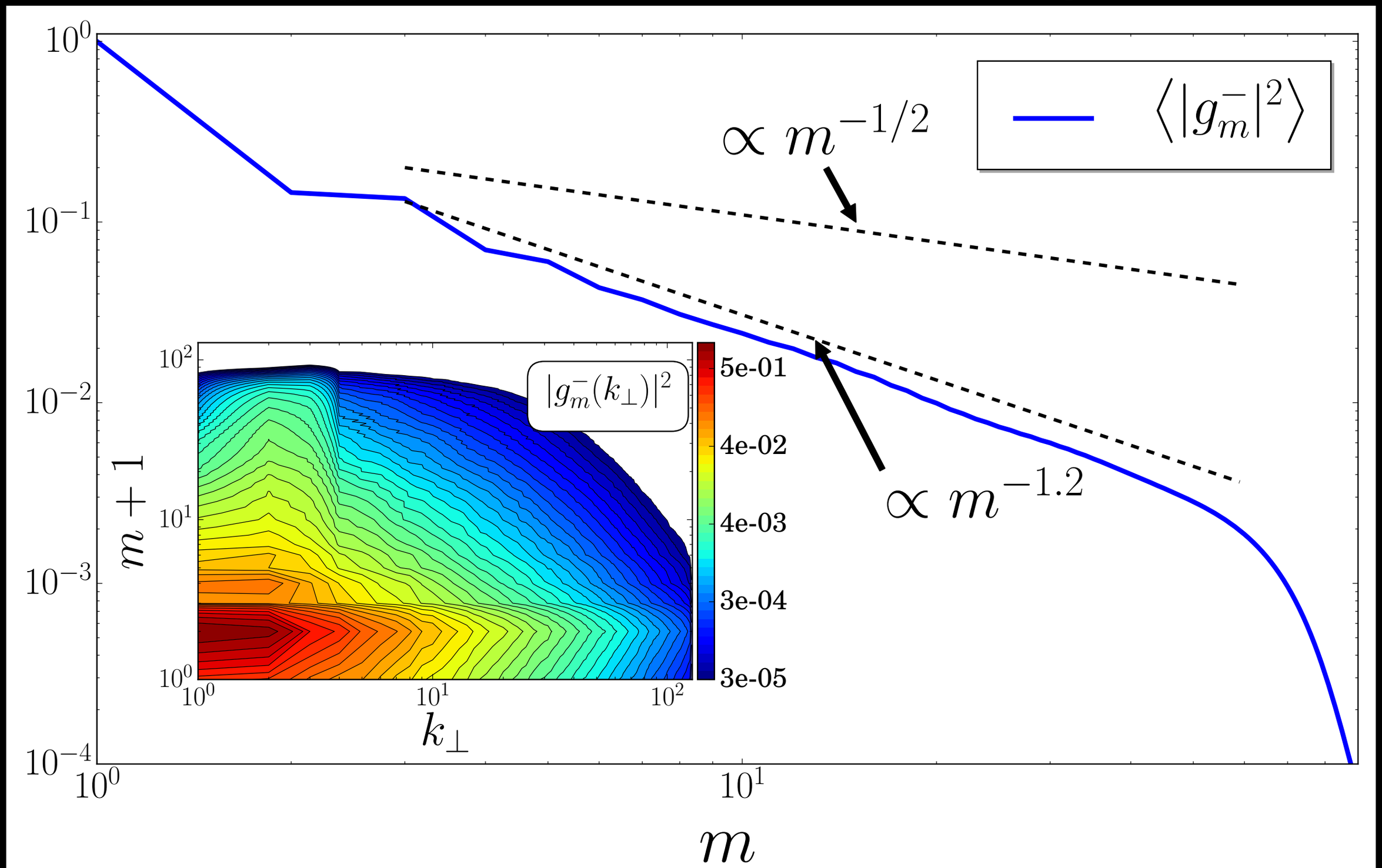
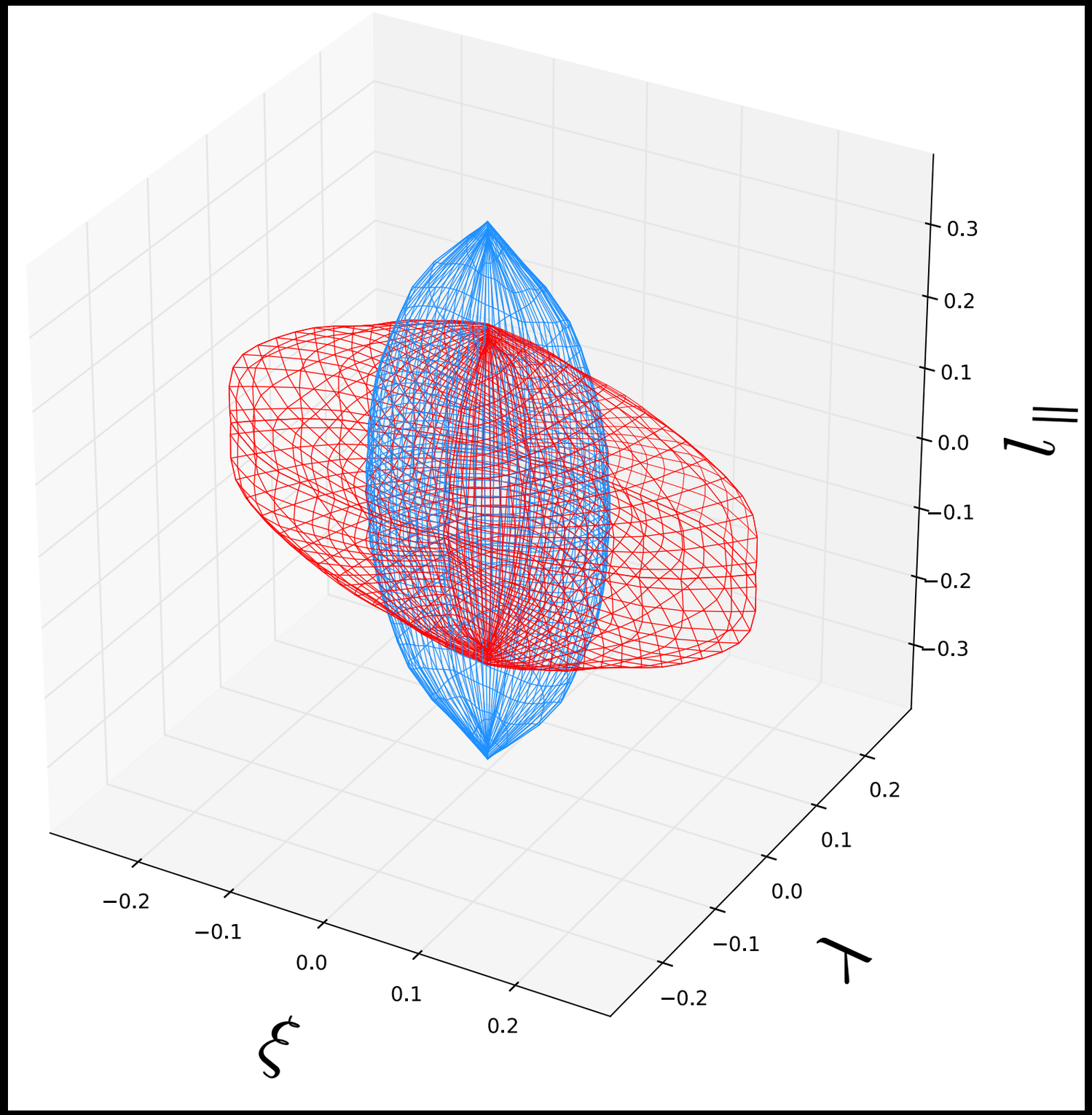


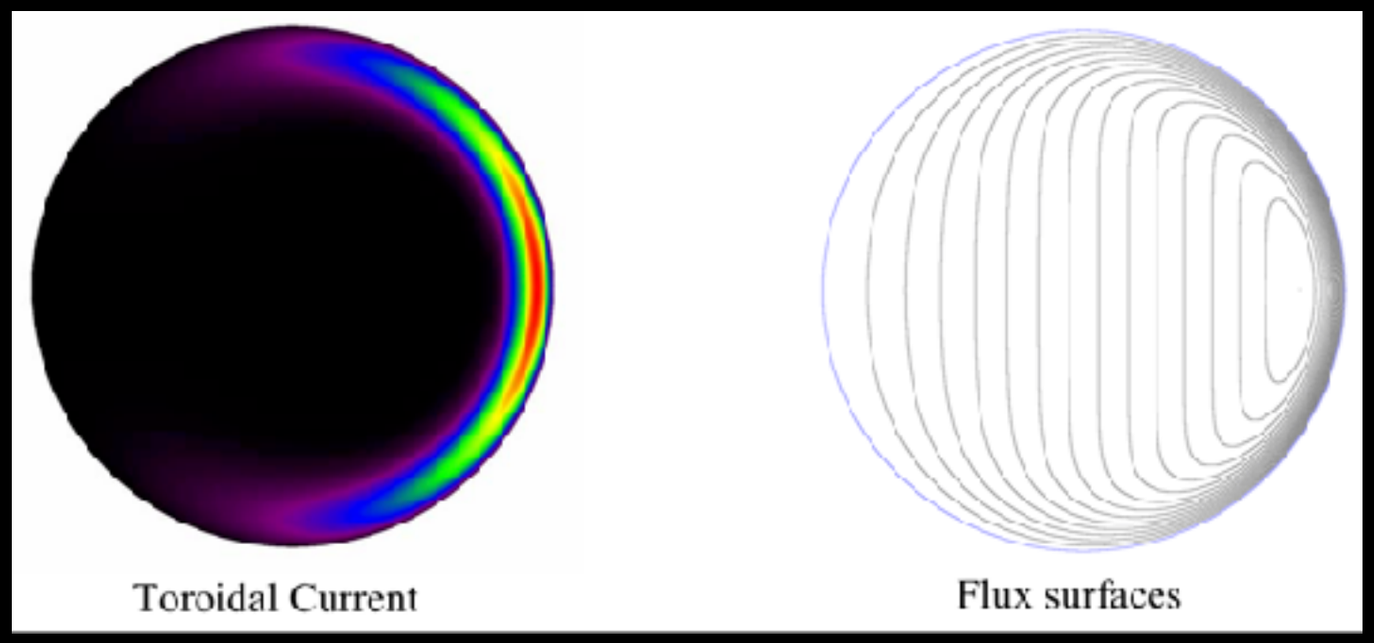
What should we expect to see in the solar wind (generically)?

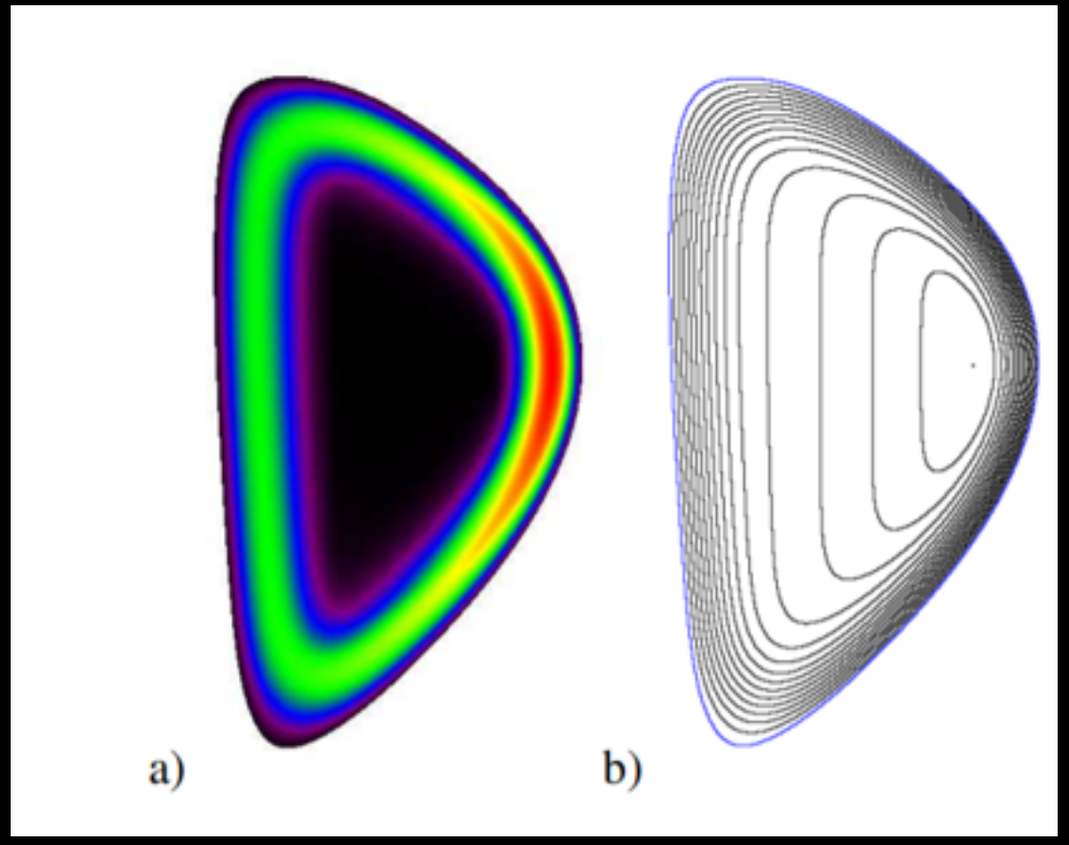


Discussion points of interest to me

- Assuming the basic processes are generic, how can we take advantage of fluidization in fusion device modeling?

- Working through conceptual ideas for reactors, we need to be able to treat high beta — existing GK codes labor to describe EM fluctuations. Opportunity?





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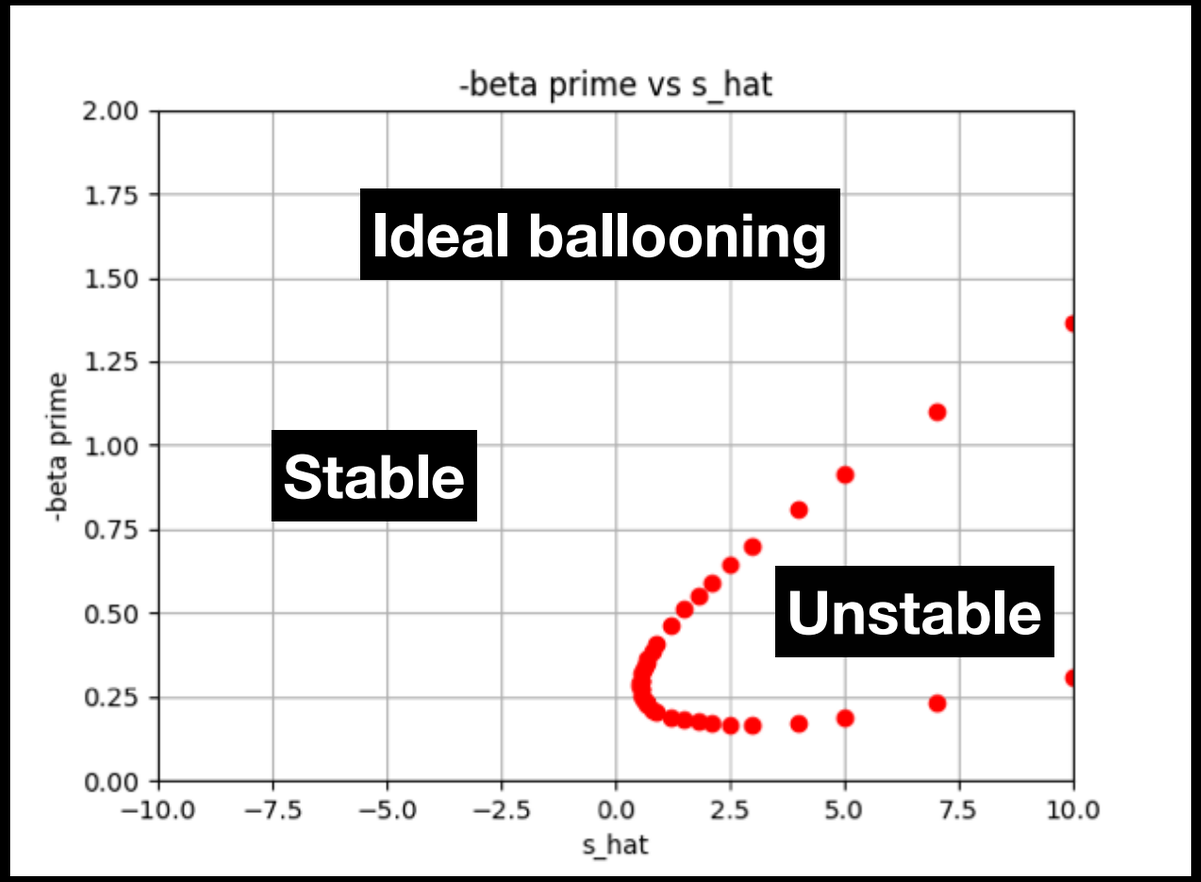

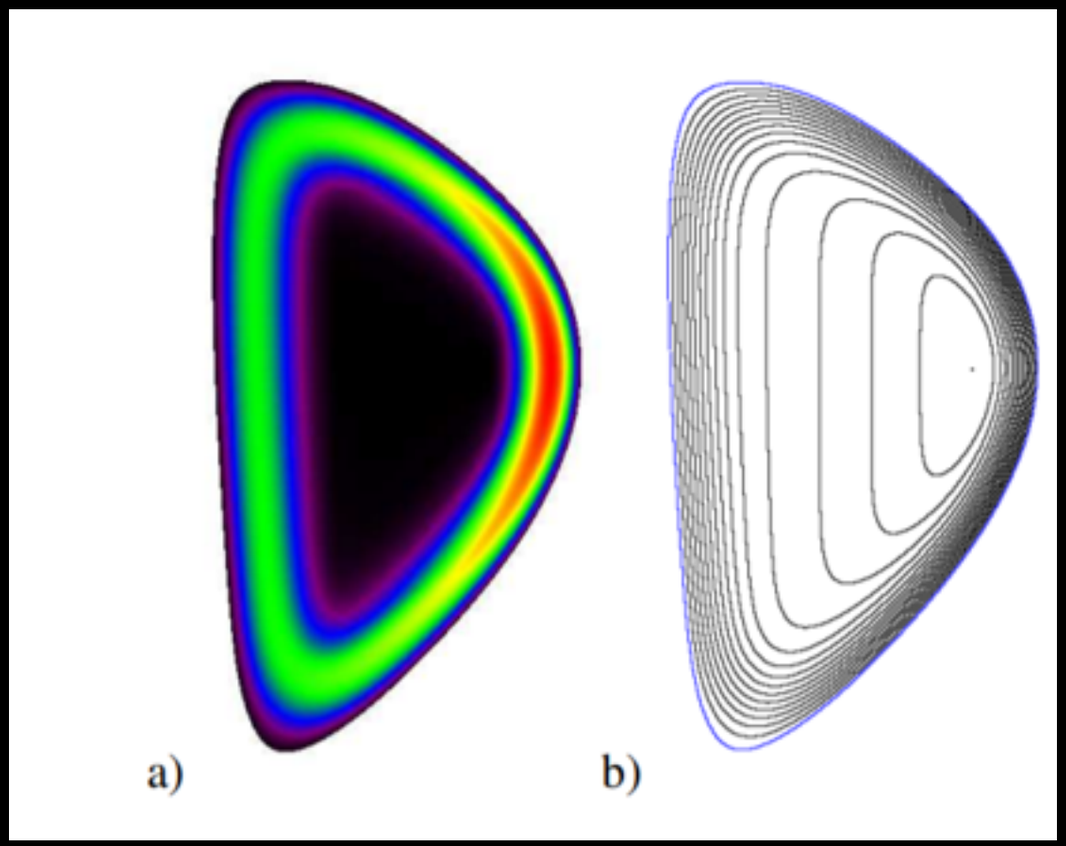

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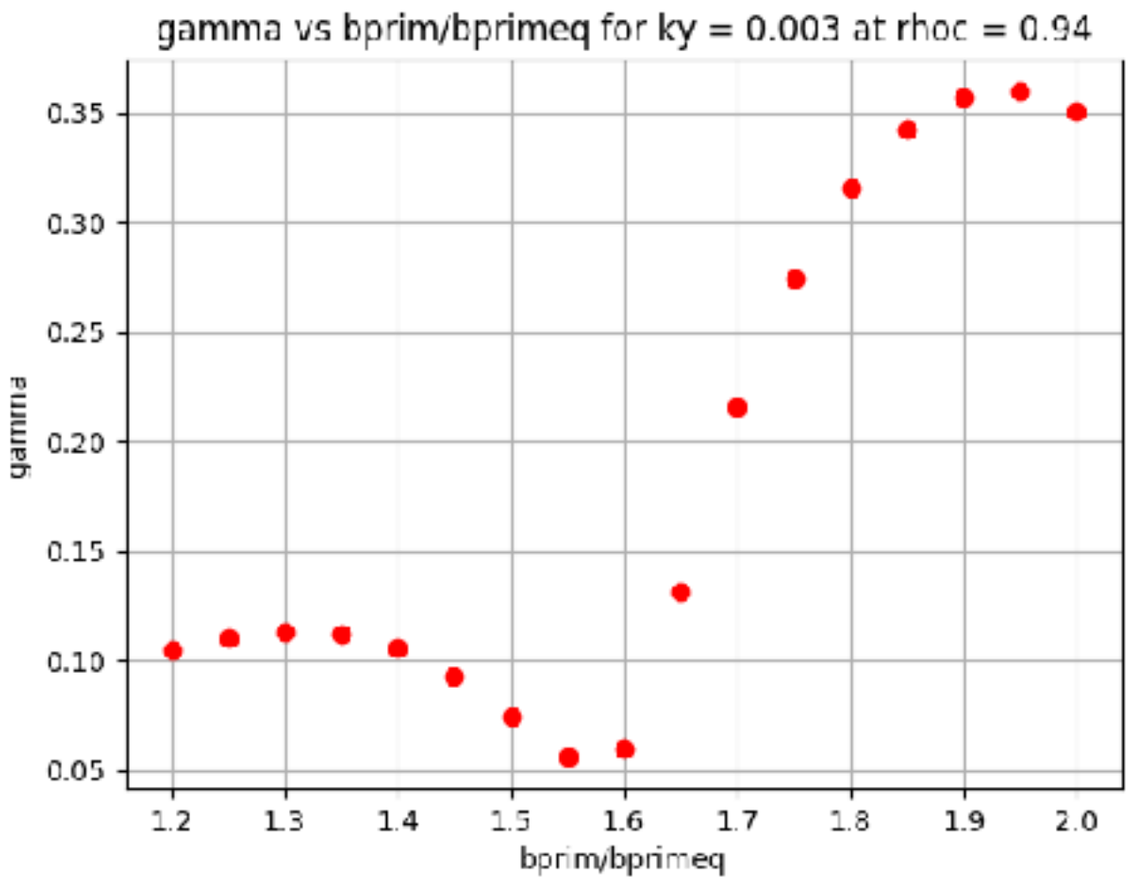
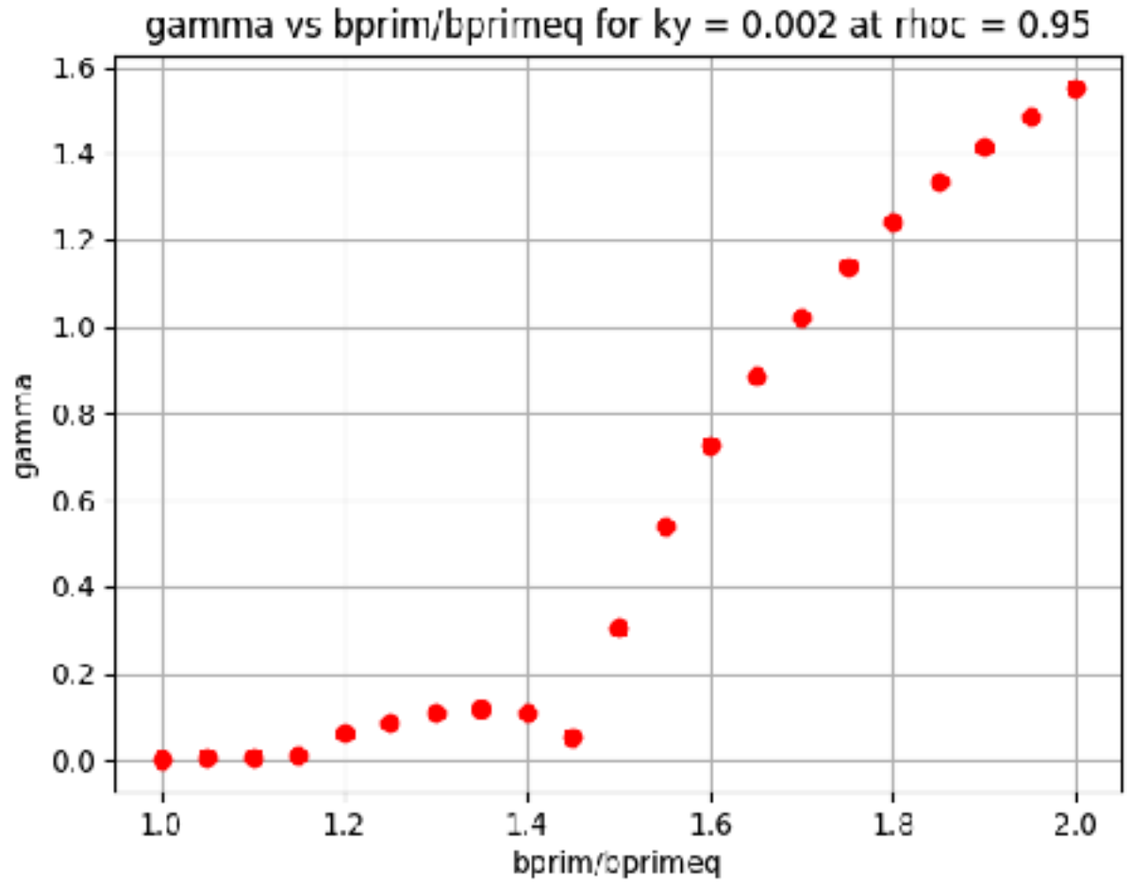
Gyrokinetic stability





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- Nonlinear simulations will be very demanding

- Need to develop more robust closure ideas (or basis for iterative scheme) to get this done. Michael Nastac is here to talk about this family of issues.

- Fluidization tells us that the situation is not always hopeless!