Intermittency in turbulent flows of elastoviscoplastic fluids

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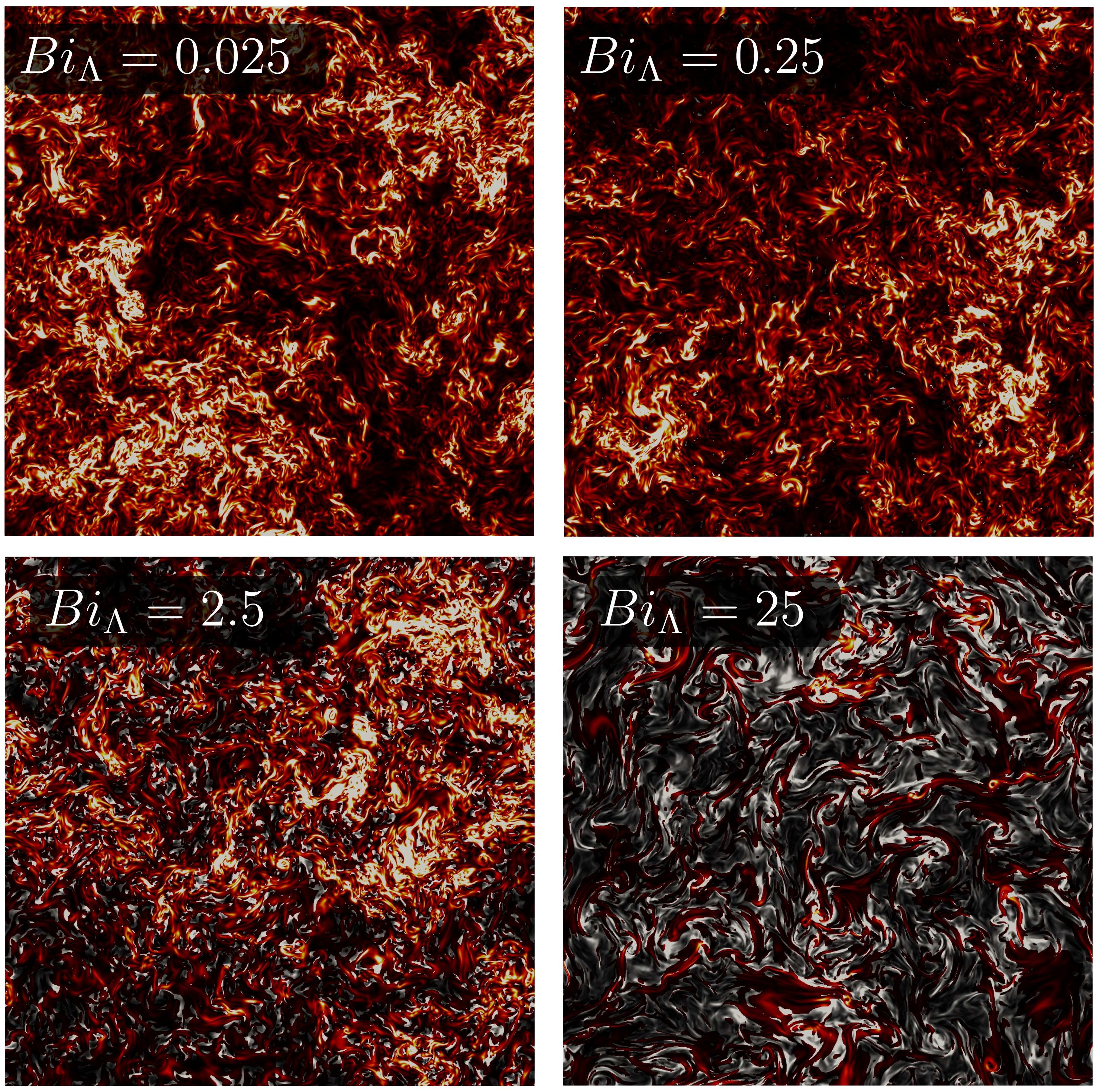

Introduction

Elastoviscoplastic (EVP) fluids are found in landslides and lava flows, they behave as a solid when the stress τ_d is less than the yield stress τ_y, and flow like a liquid otherwise.

$$\text{EVP} = \begin{cases} \textbf{solid} & \tau_d \leq \tau_y \\ \textbf{liquid} & \tau_d > \tau_y \end{cases}$$

The plasticity is parametrized by the Bingham number $Bi_\Lambda \equiv \tau_y \Lambda_0/\mu u'_0$, where μ is the total dynamic viscosity, Λ is the Taylor lengthscale, u' is the root-mean-square fluid velocity, and subscript 0 denotes quantities from the $Bi_\Lambda = 0$ case.

We make direct numerical simulations of an EVP fluid (Saramito, *J Non-newton Fluid Mech.* 2007) in homogeneous isotropic turbulence. This allows us analyse the flux of turbulent energy in wavenumber (κ) space,

$$\mathcal{F}_{\text{inj}}(\kappa) + \Pi(\kappa) + \mathcal{D}(\kappa) + \mathcal{N}(\kappa) = \langle \epsilon_{\text{f}} \rangle + \langle \epsilon_{\text{n}} \rangle .$$

On the left-hand side of this equation we have the energy flux due to the turbulent forcing, advection, Newtonian viscosity, and non-Newtonian stresses, respectively. On the right-hand side are the dissipation due to Newtonian viscosity and non-Newtonian stresses, respectively.

Figure 1.
Instantaneous colour maps of the turbulent fluid dissipation ϵ_{f}. Liquid regions are shown with a red-yellow colour scale, solid regions are in grayscale.

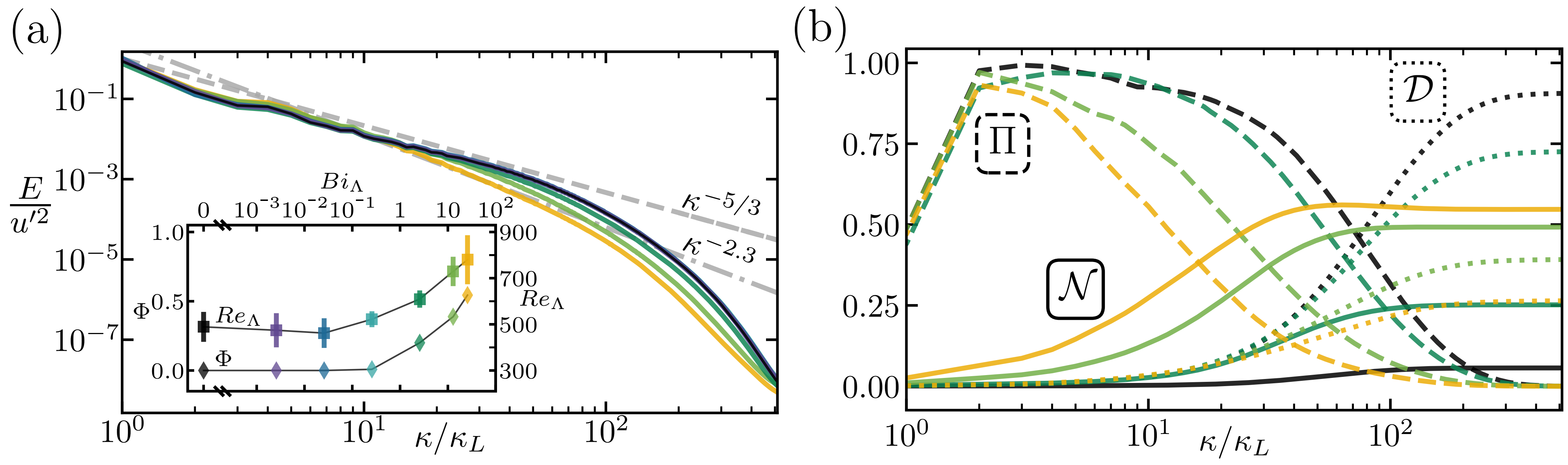

Figure 2.
(a): Energy spectra of EVP flows with various Bingham numbers Bi_Λ, plotted in colours from dark to light. Kolmogorov's turbulent scaling is shown by a grey dashed line, while the dash-dotted line shows an apparent new non-Newtonian scaling $E \sim \kappa^{-2.3}$. **Inset:** The Taylor-Reynolds number Re_Λ and solid volume fraction Φ. **(b):** Scale-by-scale energy balance, as Bi_Λ increases, the non-Newtonian flux appears at small scales.

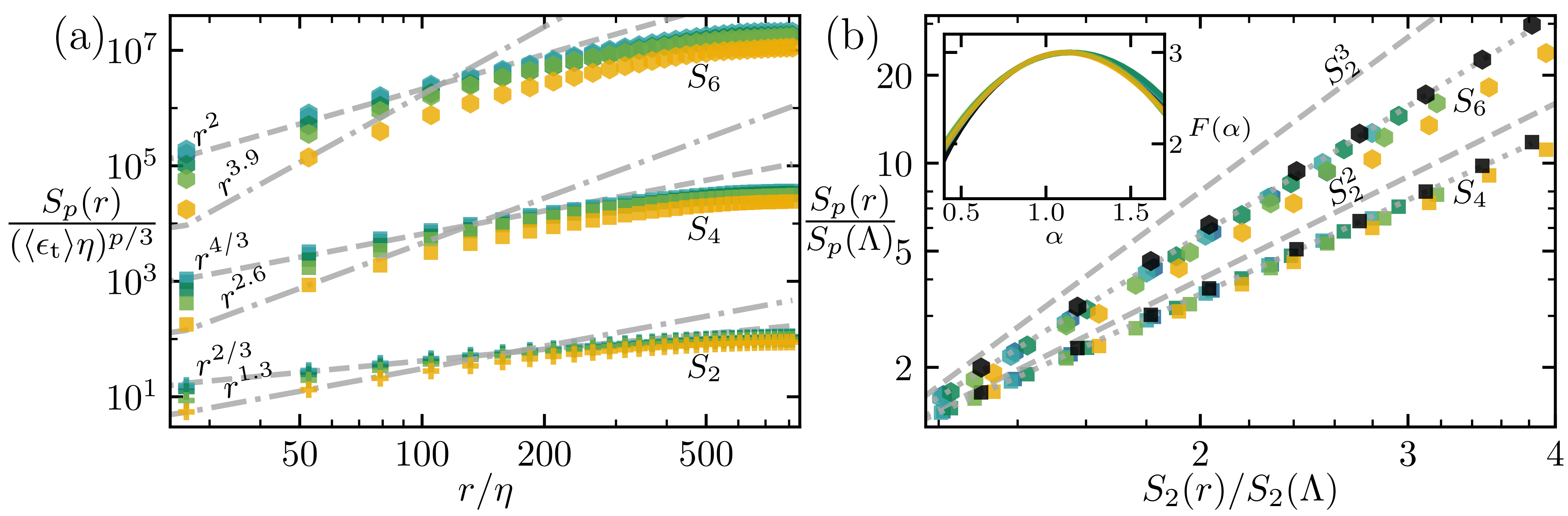

Figure 3.
(a): Longitudinal velocity structure functions S_2, S_4 and S_6. Dashed lines show scalings predicted by K41, and dash-dotted lines show scalings predicted using $E \sim \kappa^{-2.3}$. **(b):** The two scalings collapse onto a single line when we plot the structure functions in extended self-similarity form. The dotted line shows a best fit through the data for $Bi_\Lambda = 0$, which deviates from the K41 prediction (dashed line) due to intermittency. The inset in (b) reports the multifractal spectrum of ϵ_{f}.

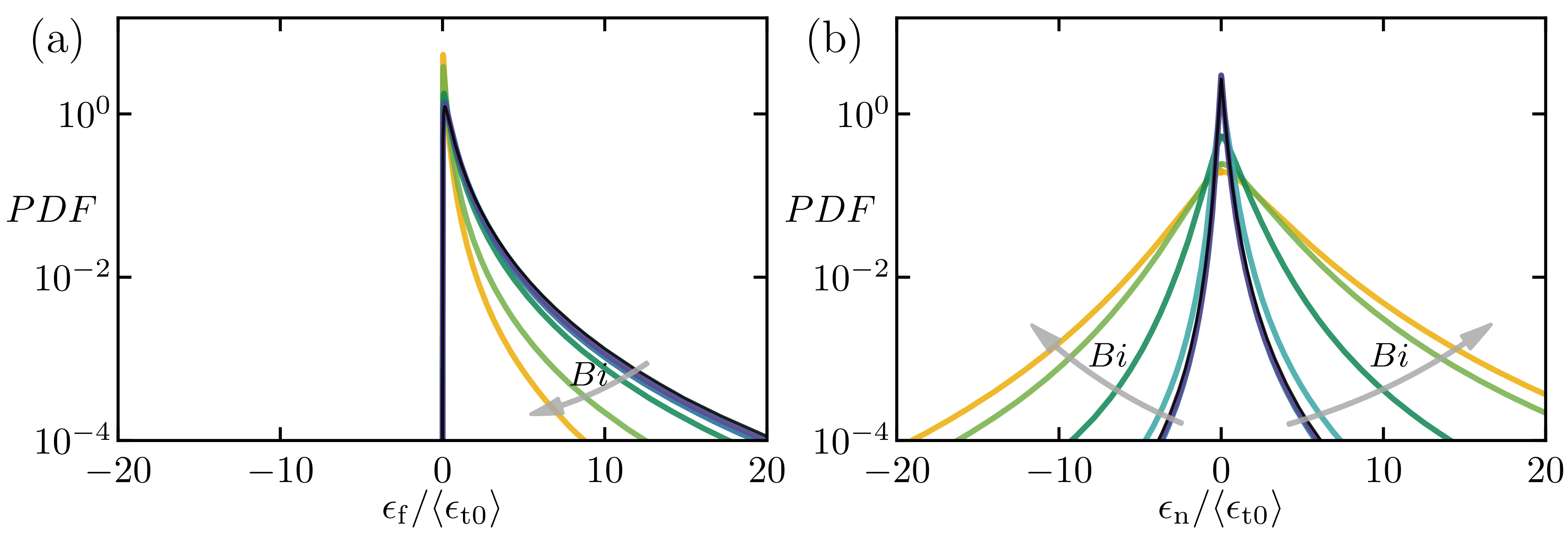

Figure 4.
Probability distribution function (PDF) of **(a)** ϵ_{f} and of **(b)** ϵ_{n}, normalised by $\langle \epsilon_{\text{t0}} \rangle$, the total dissipation of the $Bi_\Lambda = 0$ flow. As Bi_Λ increases, the PDF of the fluid dissipation rate ϵ_{f} slightly narrows, while the PDF of the non-Newtonian contribution ϵ_{n} significantly widens. It is these extreme values which are the source of intermittency in the structure functions.

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