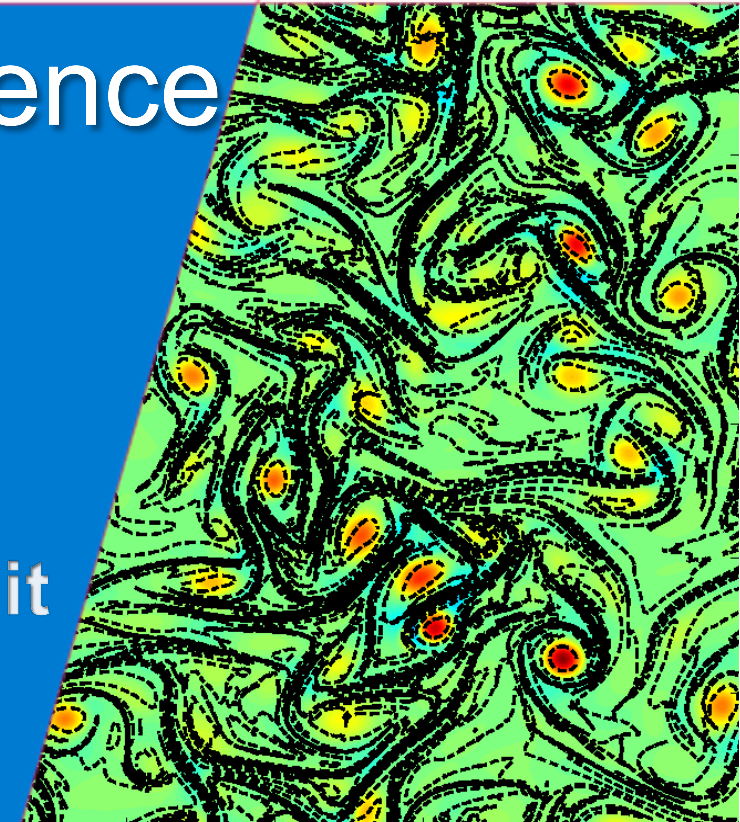
Two dimensional turbulence with polymer additives



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Where innovation starts

Acknowledgement

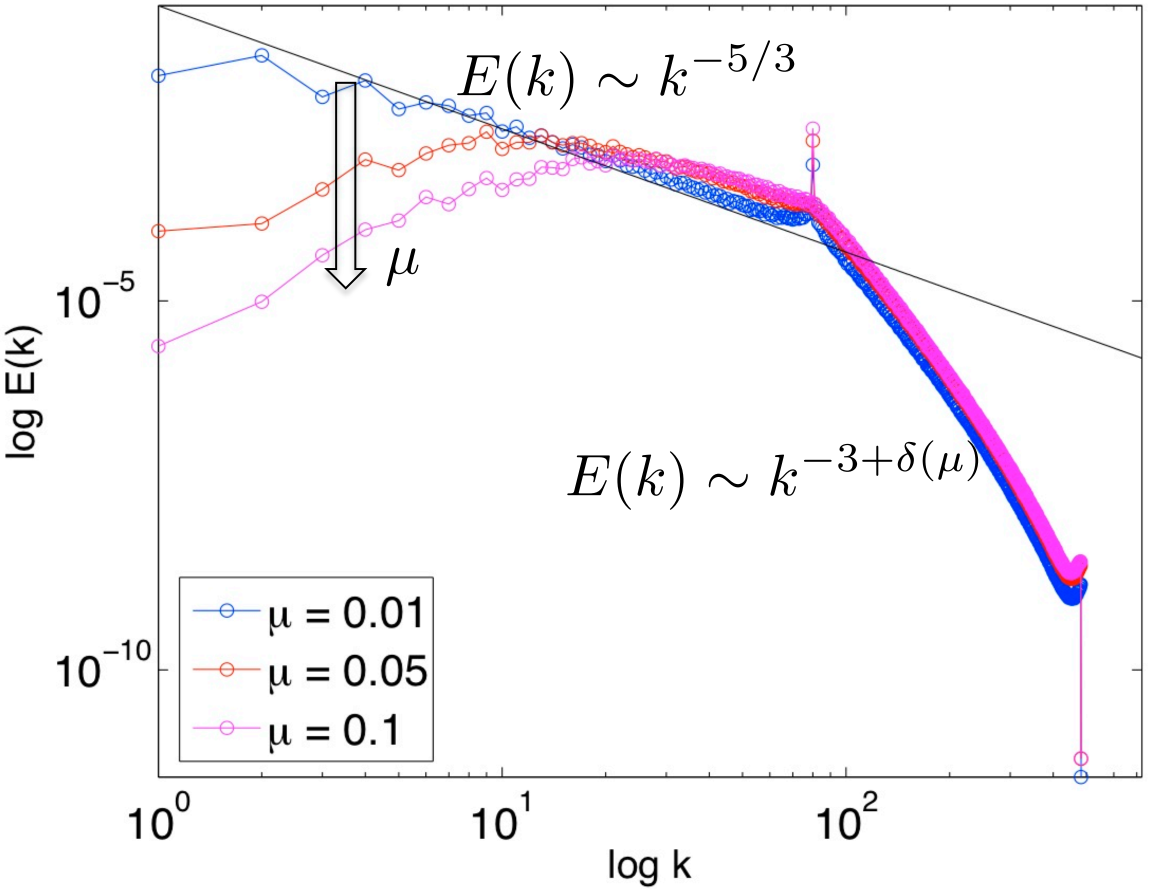
1. Dhrubaditya Mitra

2. Dario Vincenzi

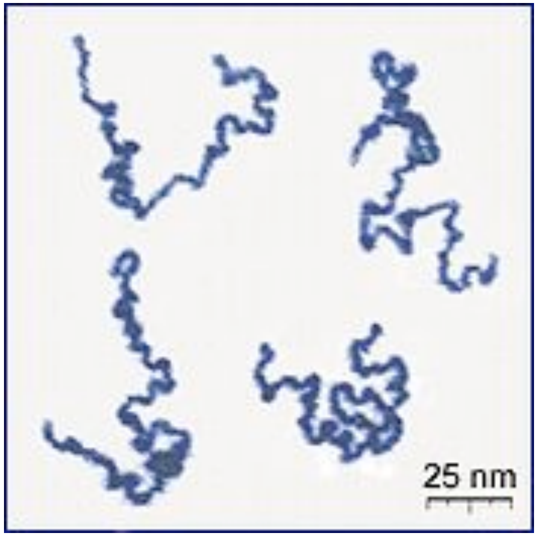
3. Roberto Benzi

2d turbulence

$$\partial_t \omega + u \cdot \nabla \omega = \nu \nabla^2 \omega - \mu\omega + F_\omega$$



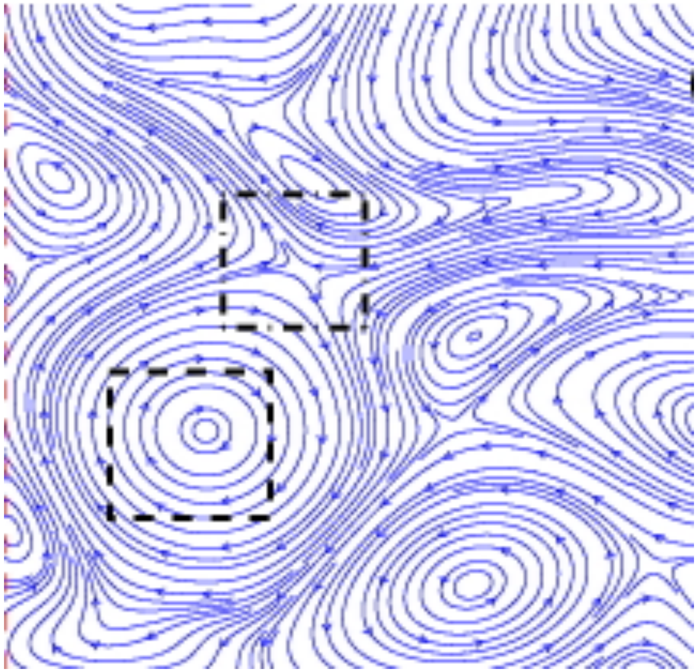
How polymer additives affect forward and inverse cascade?

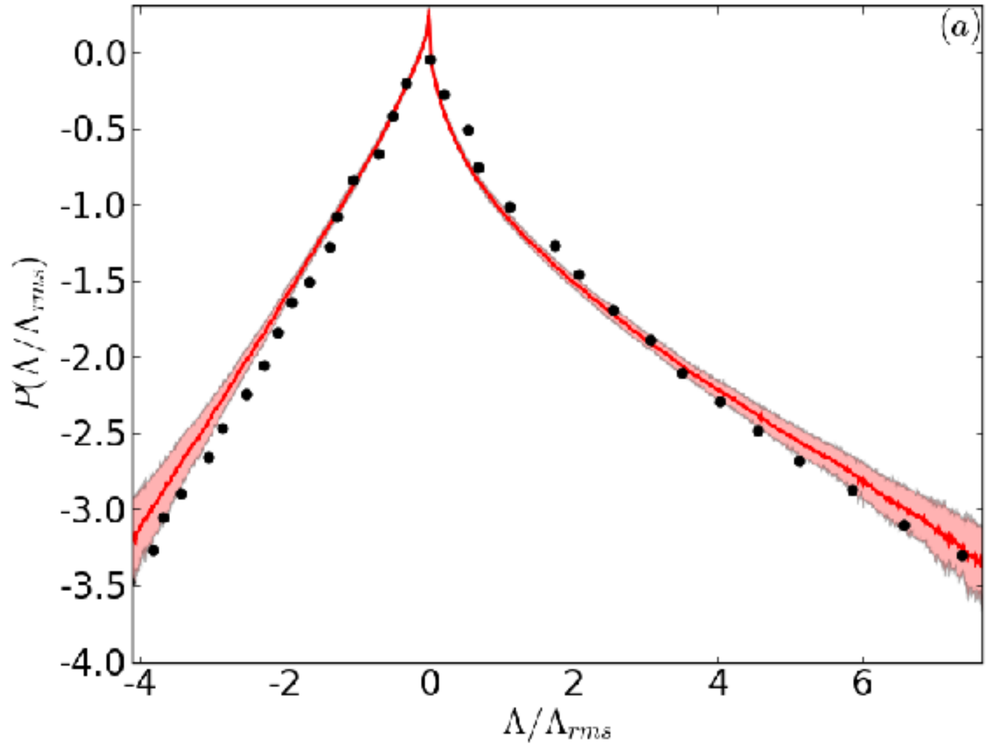


Perlekar et al., PRL (2011); Ray et al., PRL (2011); Boffetta et al., ARFM (2012).

Wiki: Linear polymer molecule

2d turbulence: Topological structures





$$\Lambda = (\omega^2 - \sigma^2)/4$$

How polymer additives affect the topological properties?

Expts: Daniel and Rutgers, PRL (2002);
Simulations: Perlekar and Pandit, NJP (2009).

Soap-film experiment-1/4

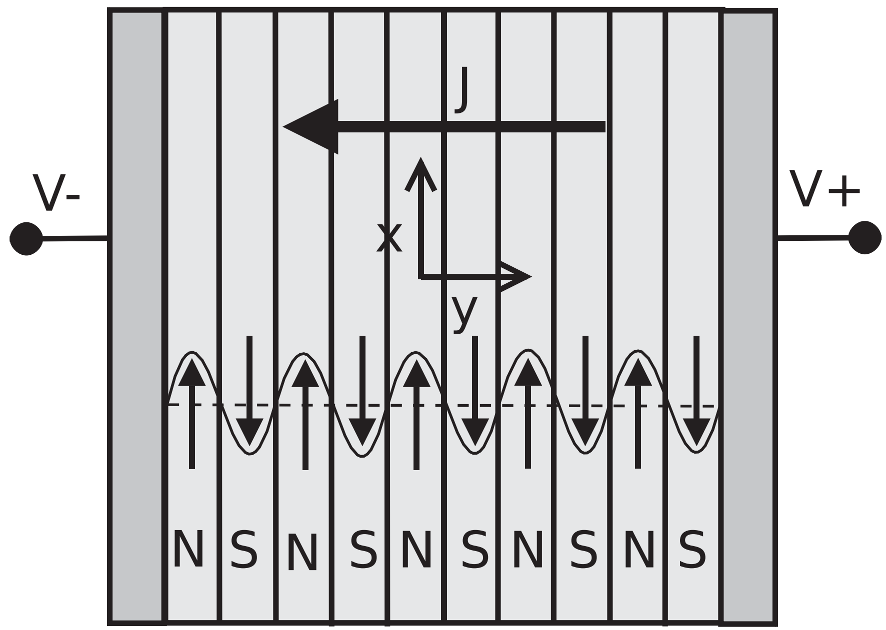
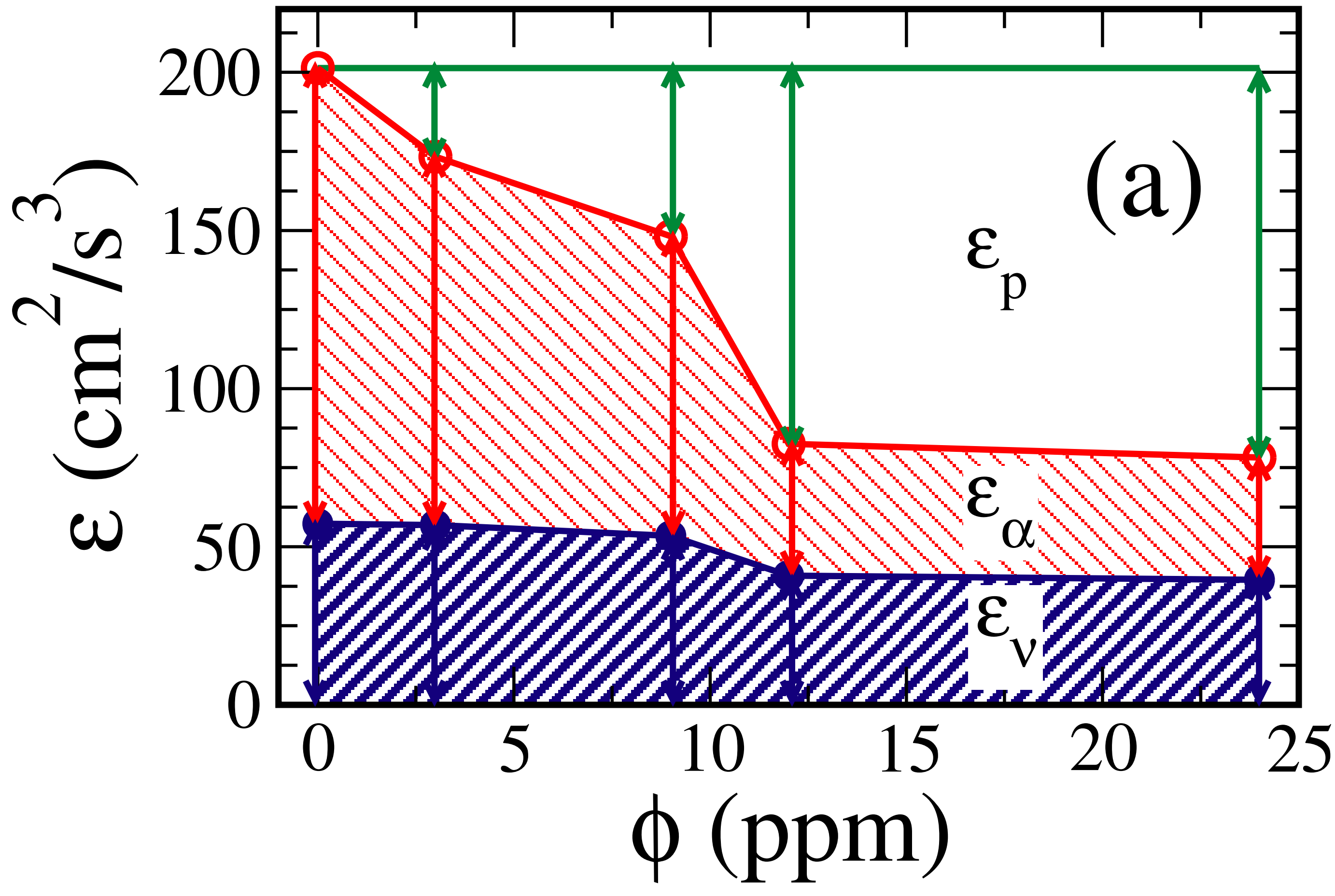


FIG. 1. Experimental setup. A voltage difference $V = V^{+} - V^{-}$ is applied to the film generating a uniform current density J. Beneath the film is a set of bar magnets with alternating poles.

Kolmogorov forcing generates turbulence in soap-films.

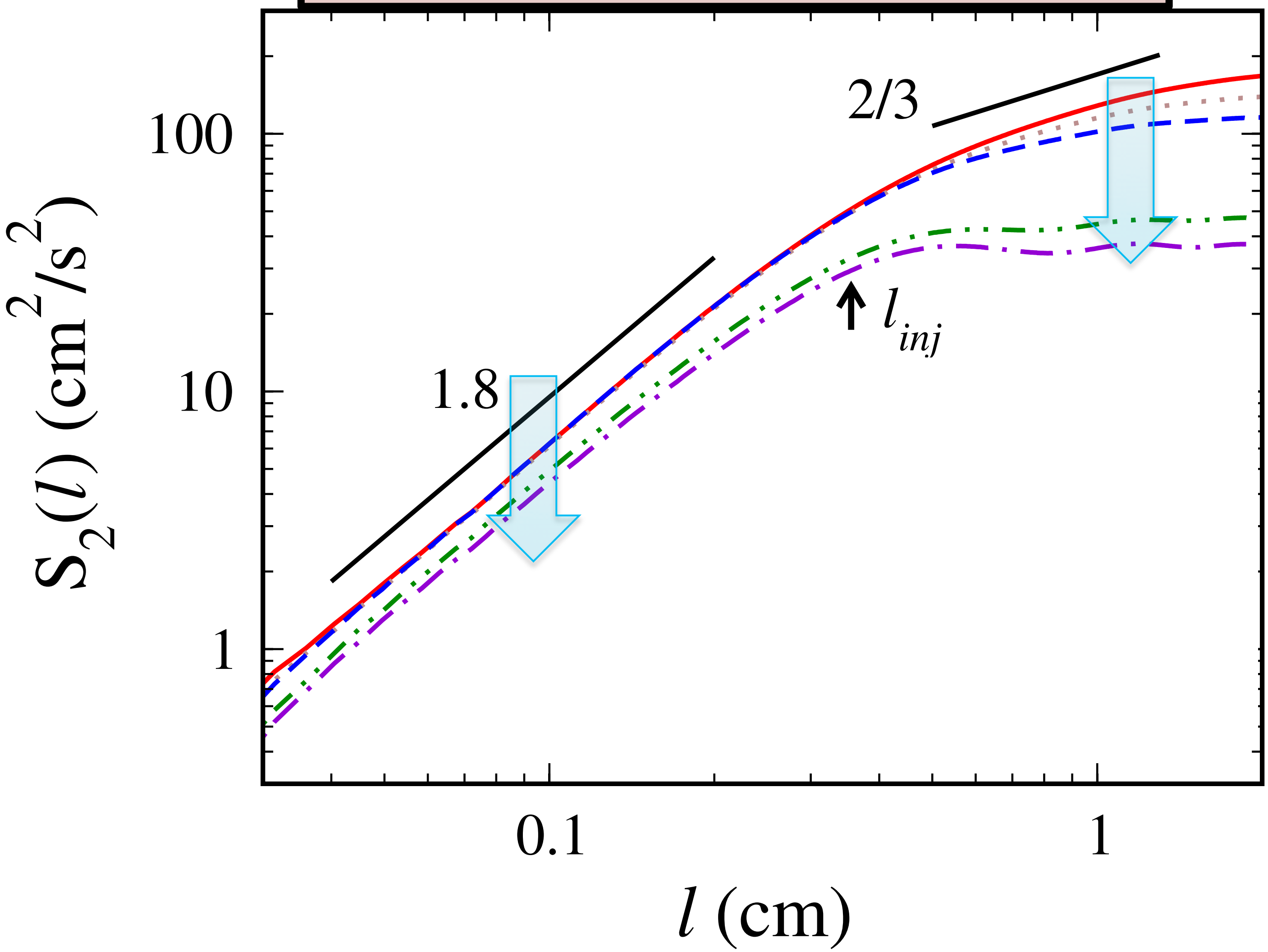
Jun et al., PRL, **96**, 024502 (2006)

Soap-film experiment-2/4

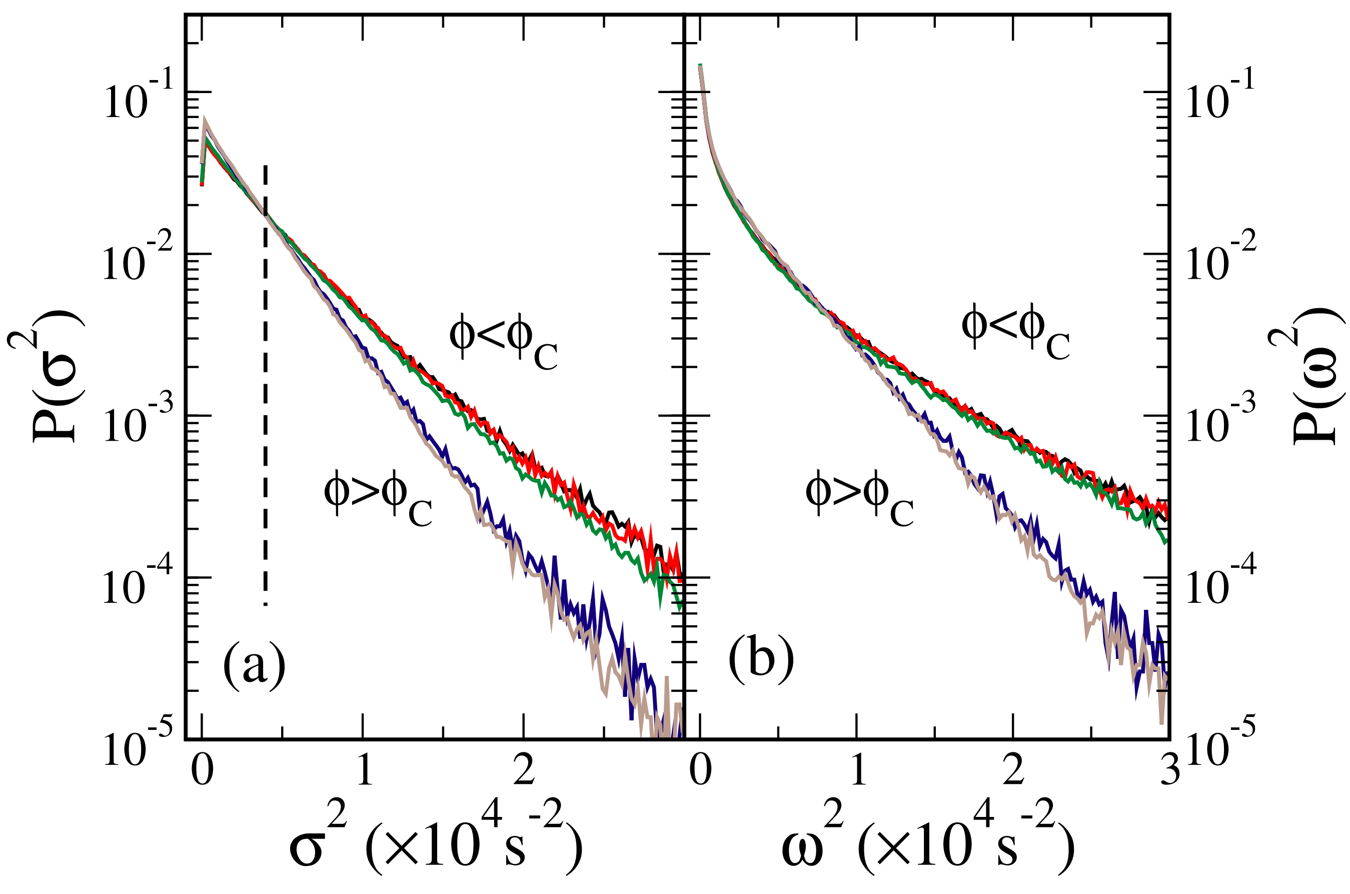


Soap-film experiment-3/4

Suppression of both large and small scales



Soap-film experiment-4/4



Modeling polymer solutions

FENE-P Model

$$\frac{\partial u_\alpha}{\partial t} + (u_\gamma \partial_\gamma) u_\alpha = -\partial_\alpha p + \nu \partial_{\gamma\gamma} u_\alpha + \partial_\gamma \mathcal{T}_{\alpha\gamma}$$

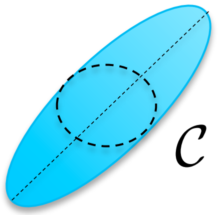
$$\frac{\partial \mathcal{C}_{\alpha\beta}}{\partial t} + (u_\gamma \partial_\gamma) \mathcal{C}_{\alpha\beta} = (\partial_\gamma u_\alpha) \mathcal{C}_{\gamma\beta} + \mathcal{C}_{\alpha\gamma} (\partial_\gamma u_\beta) - \frac{1}{\mu} \mathcal{T}_{\alpha\beta}$$

$$T_{\alpha\beta} = \mu \frac{f(r) \mathcal{C}_{\alpha\beta} - \delta_{\alpha\beta}}{\tau_P} \qquad f(r) = \frac{L^2 - 2}{L^2 - r^2}$$

Oldroyd-B Model

$$L^2 \to \infty$$

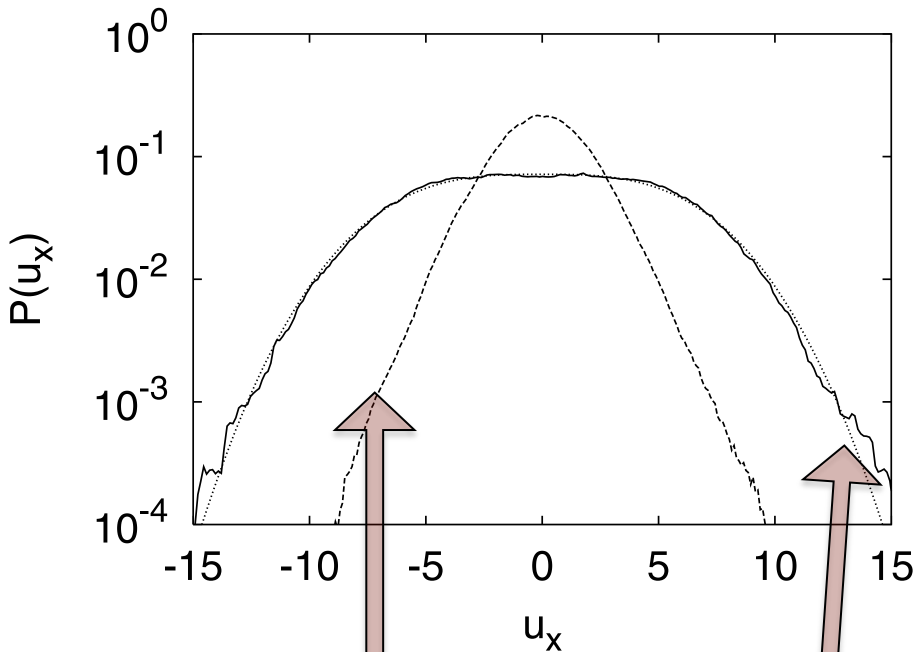
$$f(r) \to 1$$



Assumption: Smooth flow around polymer.

Earlier studies: Simulations

Homogeneous isotropic turbulence, 256^3 DNS



Pure fluid $P(u_x) \sim \exp(-c|u|^3)$

Fluid + polymers

Oldroyd-B model

Passive polymers

$$Wi = \lambda\tau > 1$$

Unbounded growth in polymer extension. No steady state.

Active polymers

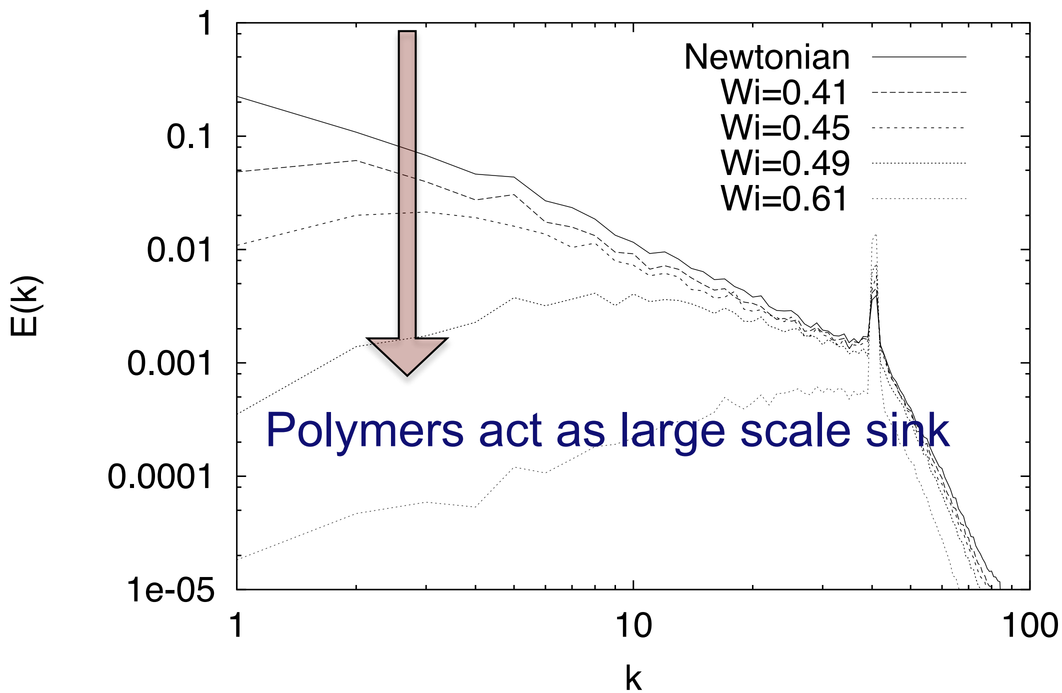
$$Wi = \lambda\tau < 1$$

1. Presence of back-reaction dramatically alters the steady state.
2. Steady state for polymer extension.
3. No coil-stretch transition!

Boffetta, Celani, and Mussachio, PRL, 034501 (2003)

Earlier studies: Simulations

Homogeneous isotropic turbulence, 256^3 DNS



Oldroyd-B model

Passive polymers

$$Wi = \lambda\tau > 1$$

Unbounded growth in polymer extension. No steady state.

Active polymers

$$Wi = \lambda\tau < 1$$

$$\epsilon_V = \epsilon_N - \frac{\mu}{\tau_P^2}(r^2 - 2)$$

Question raised in thesis (2003):
What happens in a well-resolved forward and inverse cascade?

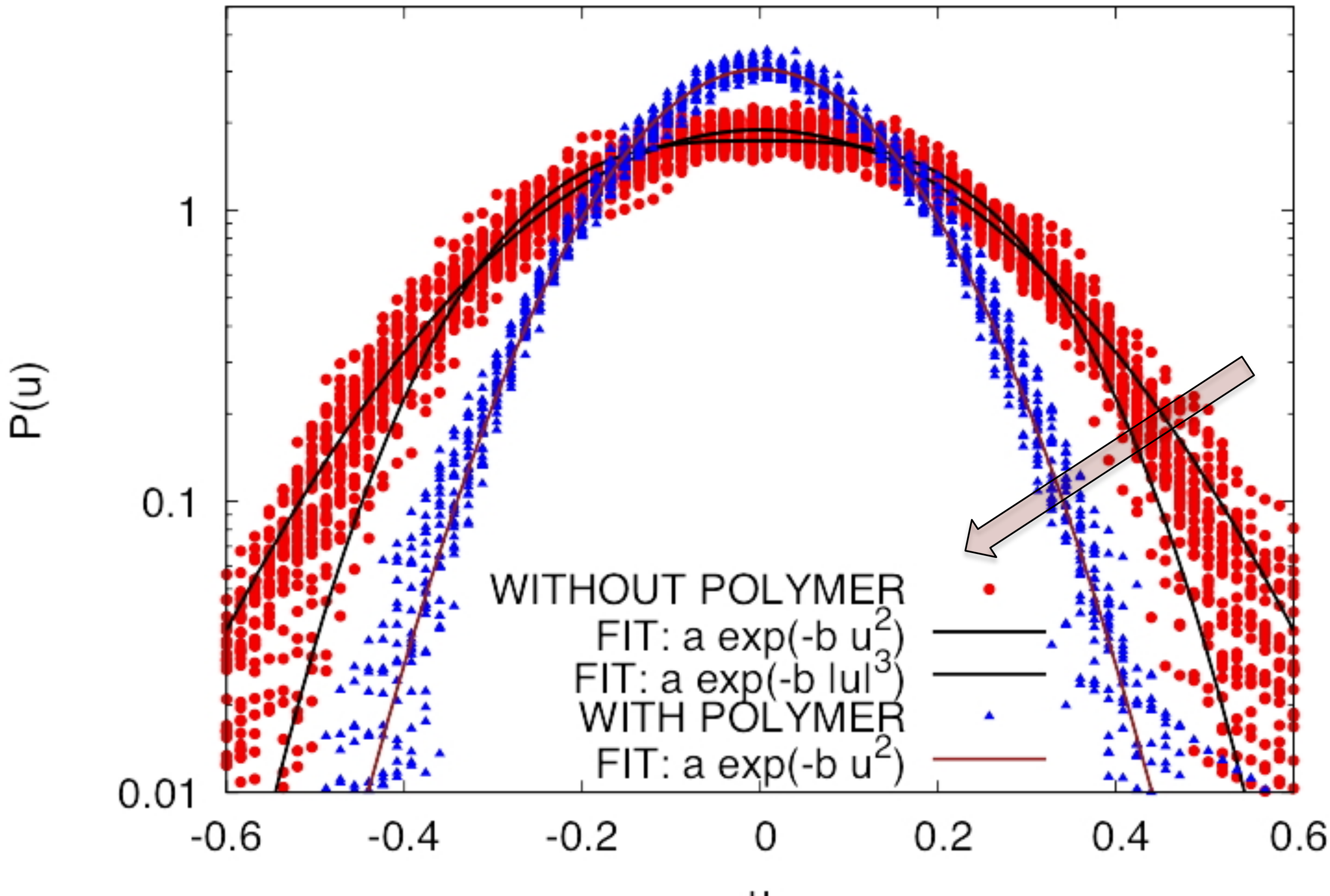
S. Mussachio, PhD Thesis

Results

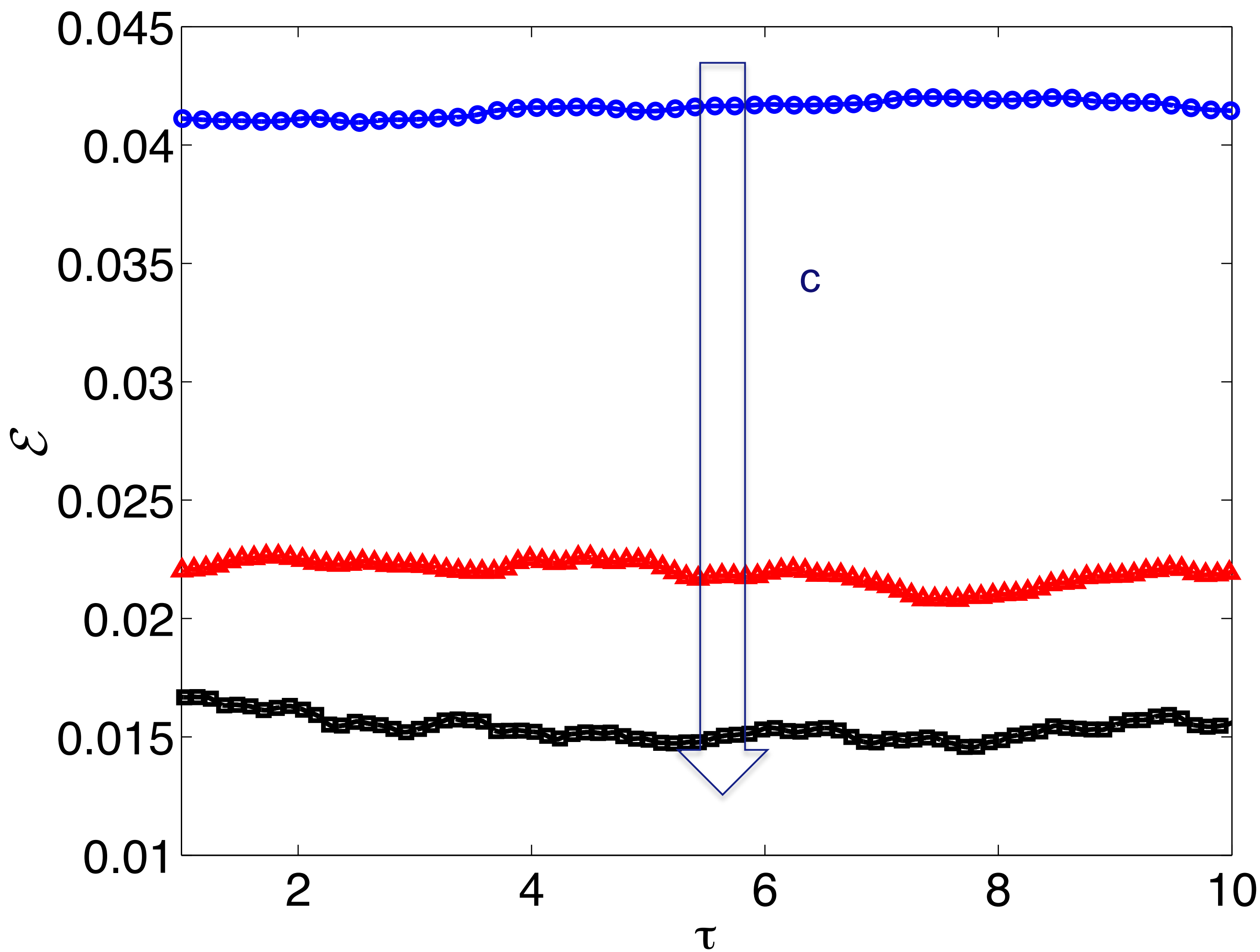
Our simulations:

1. DNS of Navier-Stokes + FENE-P equations.
2. Kolmogorov forcing to generate flows similar to experiments by rescaling forcing amplitude.
3. Maintain constant energy injection rate.

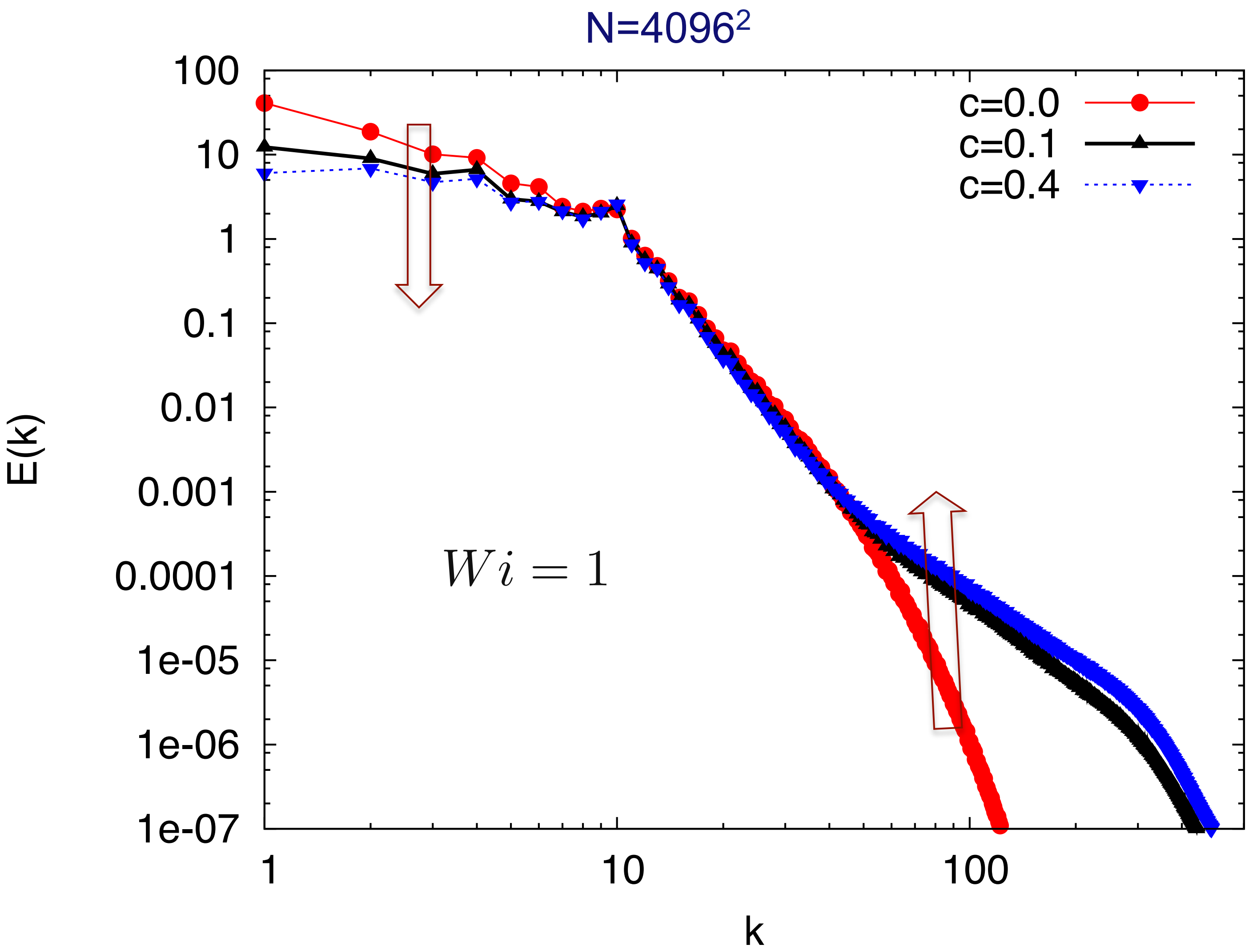
PDF of velocity



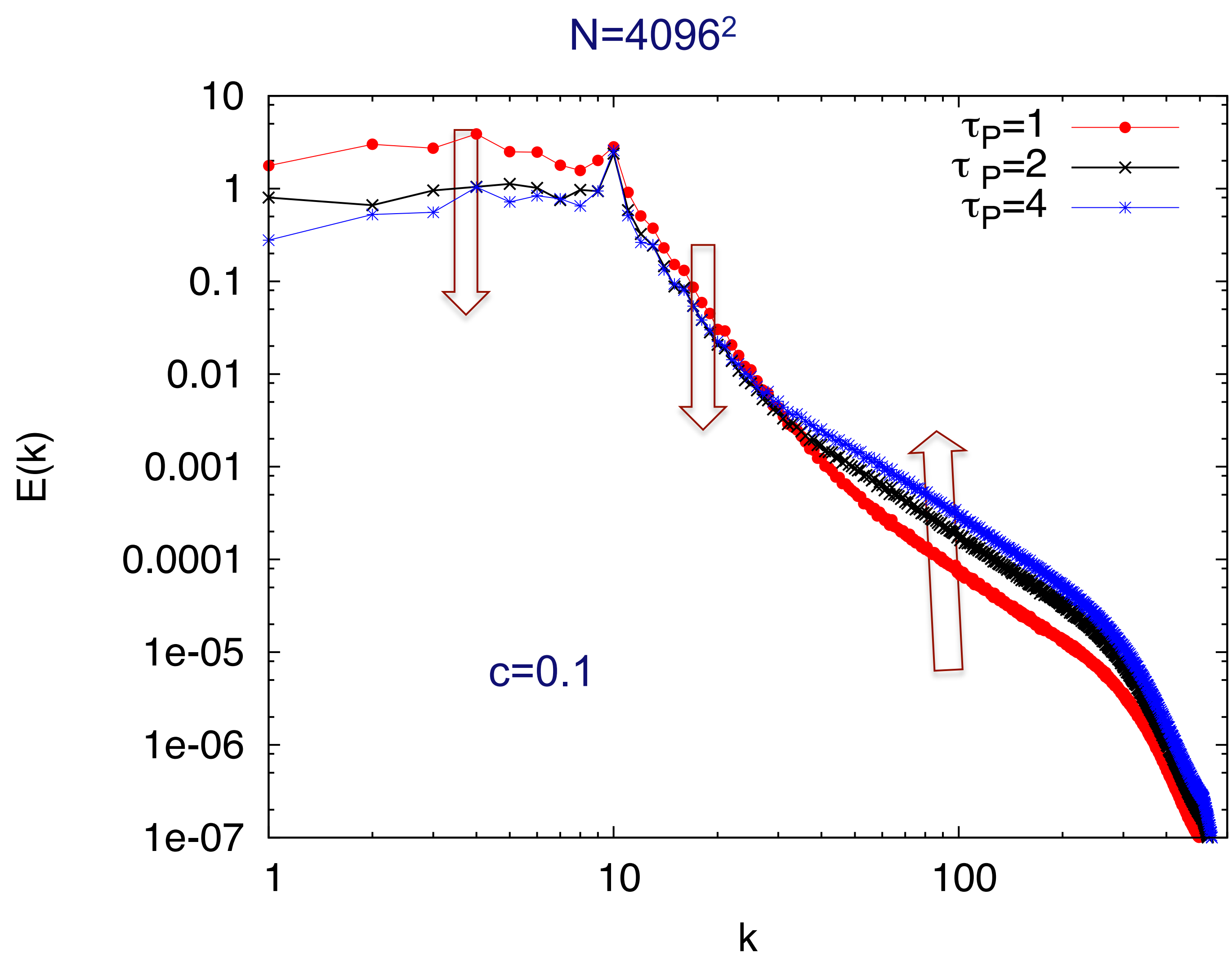
Energy suppression



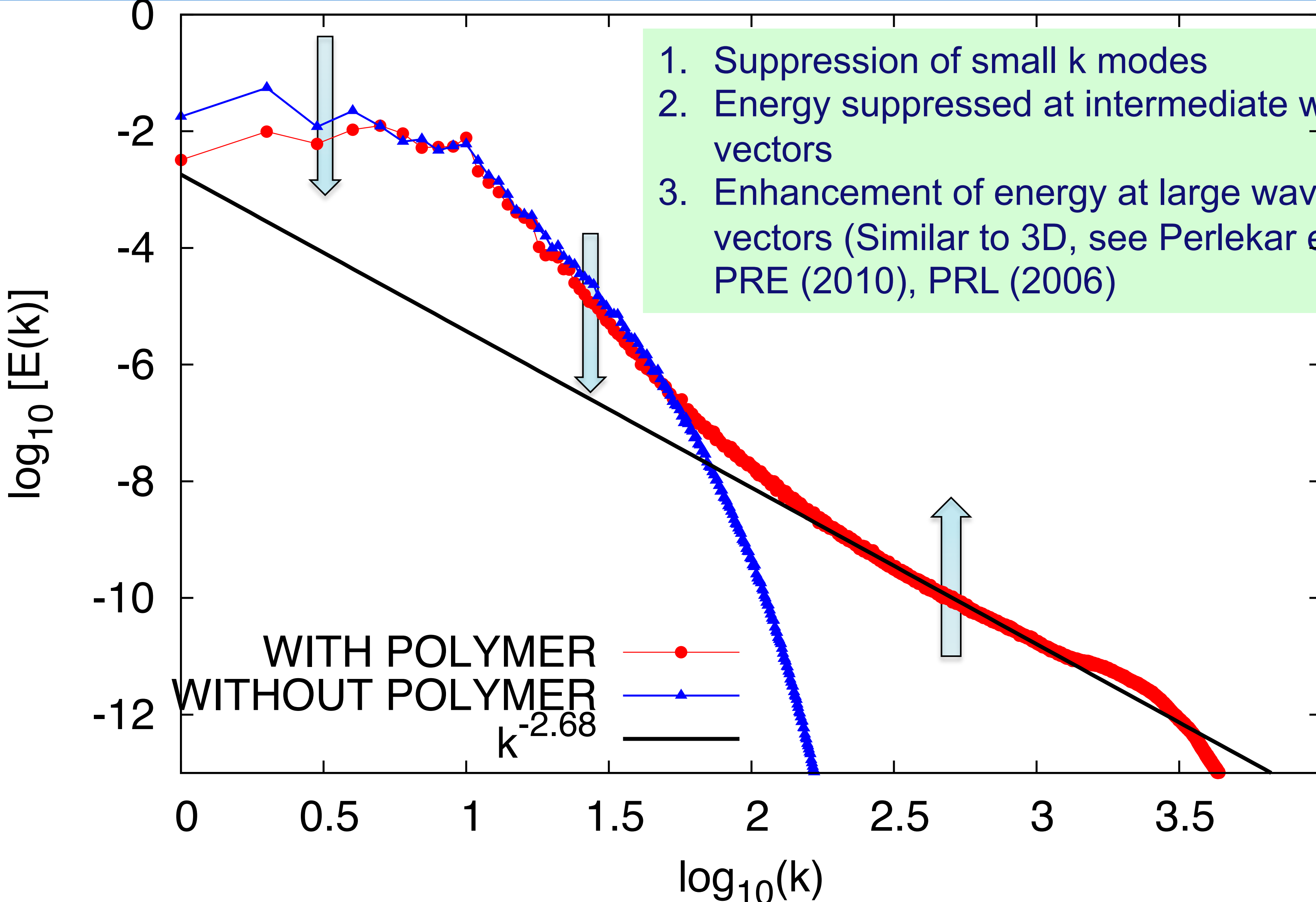
Energy spectrum: Small wave-vectors



Energy spectrum: Small wave-vectors

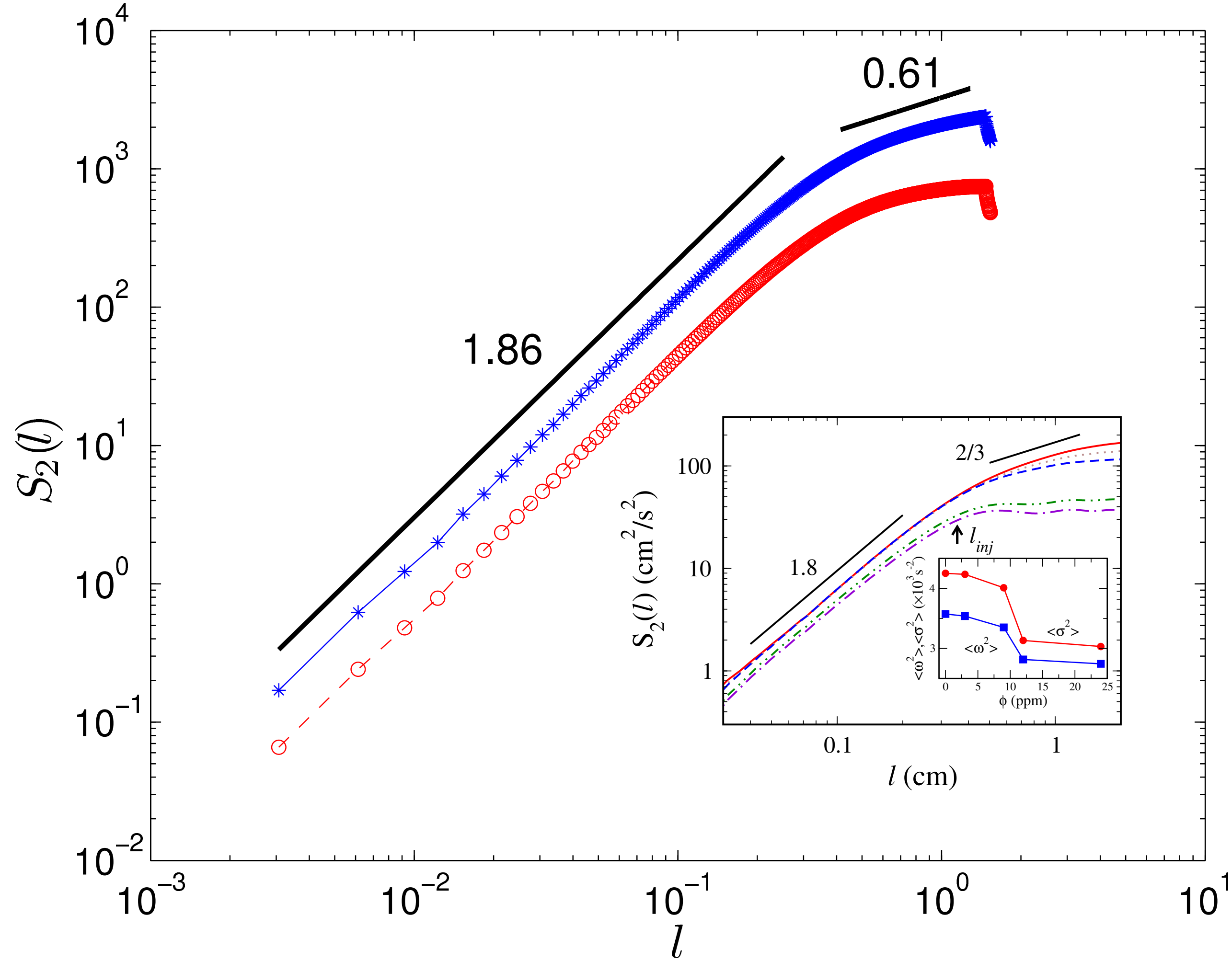


Energy spectrum: Suppression of small k

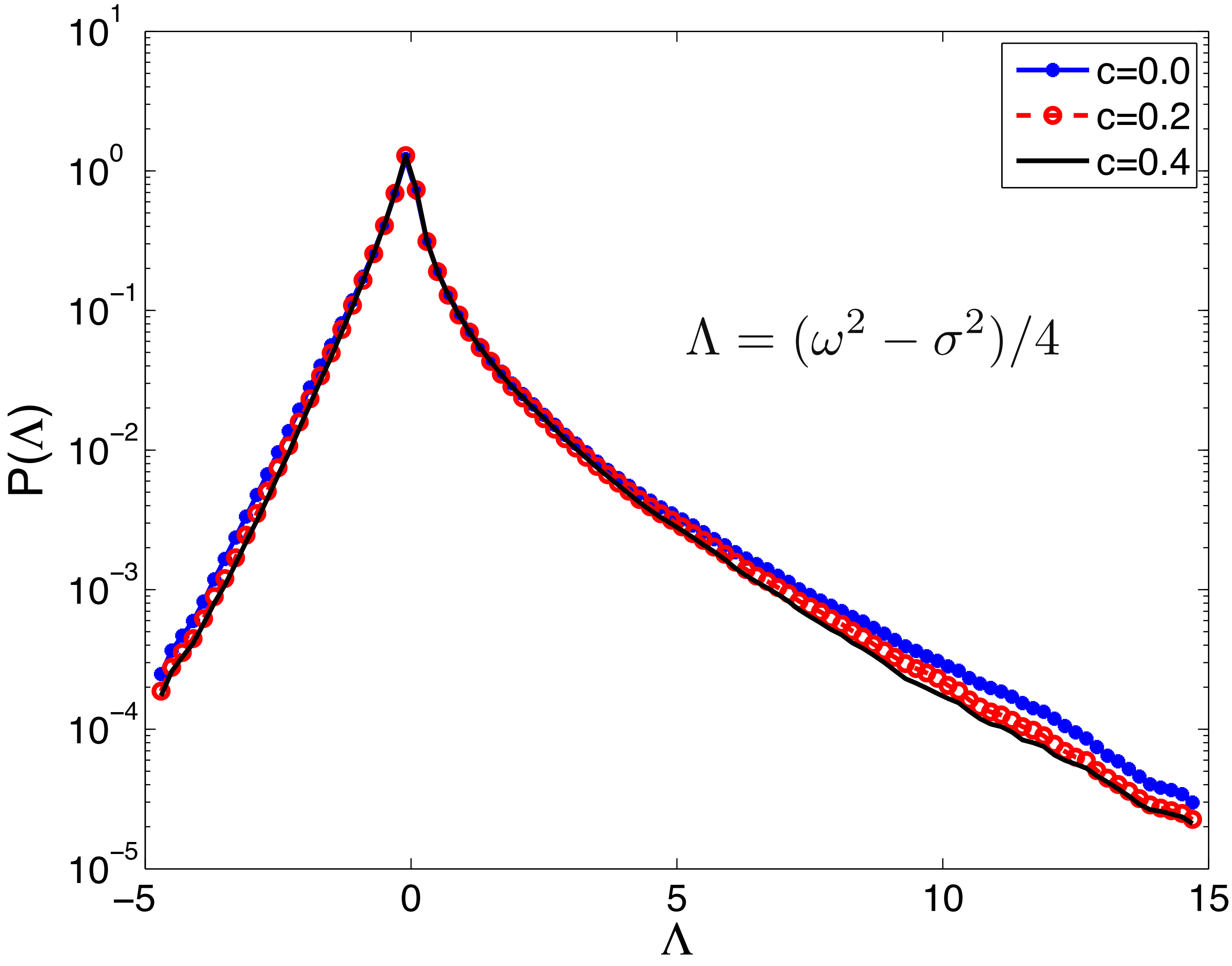


1. Suppression of small k modes
2. Energy suppressed at intermediate wave-vectors
3. Enhancement of energy at large wave-vectors (Similar to 3D, see Perlekar et al., PRE (2010), PRL (2006)

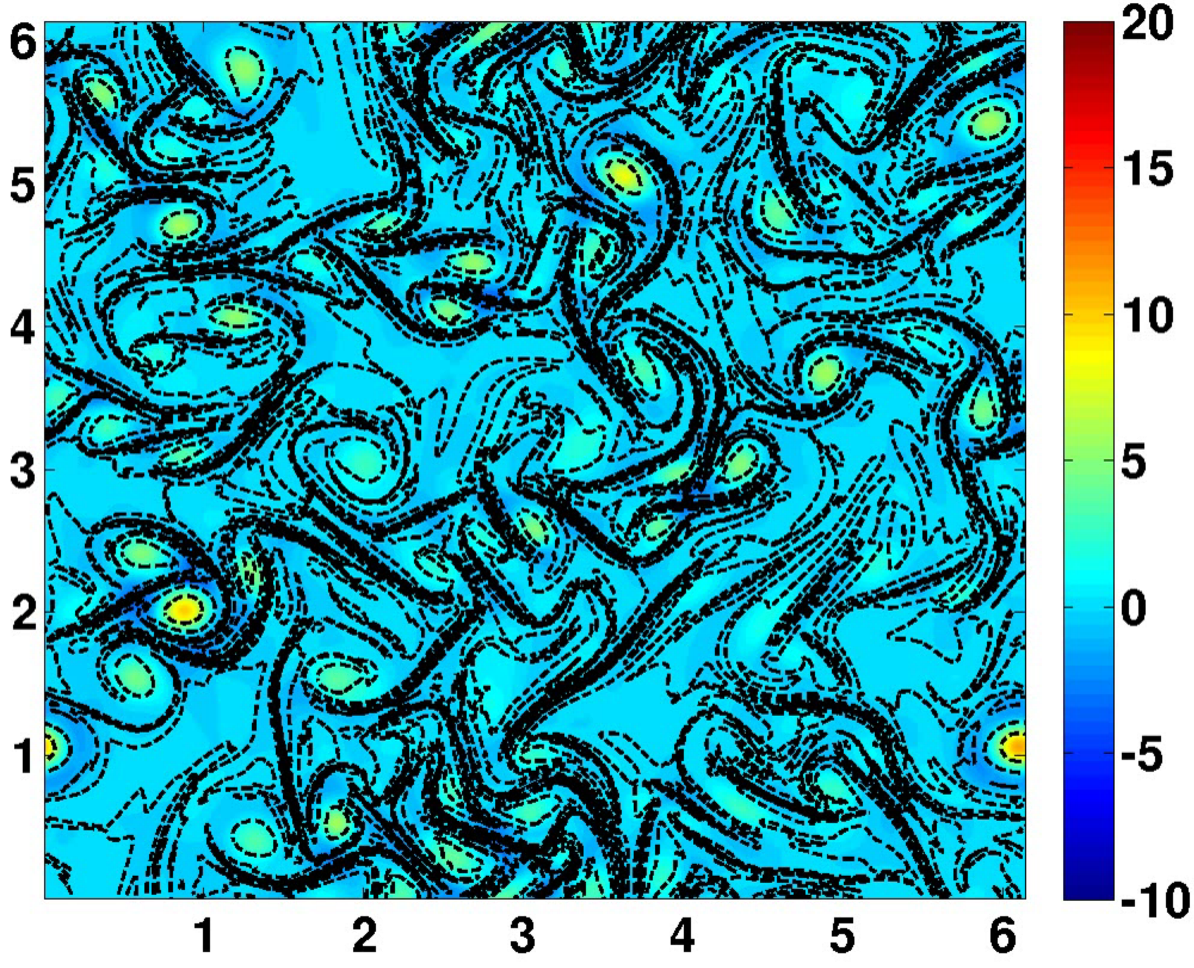
Structure function



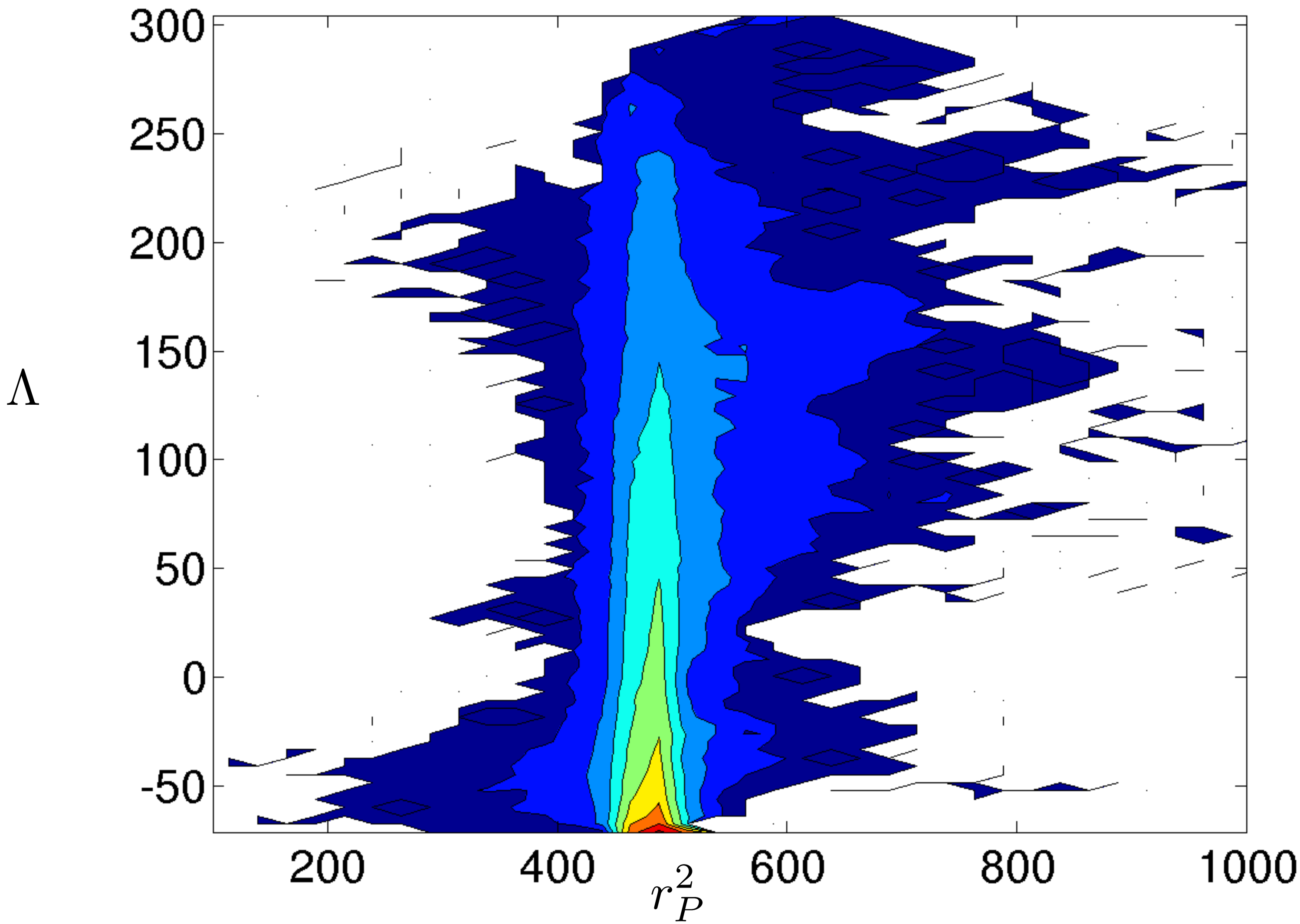
PDF of Λ



Polymer extension vs vorticity



Joint PDF



Conclusions

1. Energy spectra is strongly modified in presence of polymers.

2. For small concentrations, the distributions of saddles and centers is not dramatically modified by polymers.

3. Regions of polymer extensions are strongly correlated with the extensional regions

4. Similarities with 3D turbulence in forward cascade