# Turbulent energy cascade in viscoelastic isotropic turbulence

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# Outline

- Overview of the direct numerical simulations
- Added dissipation due to polymer additives in forced HIT
- Effect of polymer additives on the turbulence energy cascade
- The inter-scale energy cascade caused by the polymers
- Summary

# DNS of statistically steady viscoelastic turbulence

Numerical method

- Pseudo-spectral solver for velocity with 2/3rd de-aliasing
- Kurganov-Tadmor solver for conformation tensor
- Third-order Runge-Kutta in time
- FENE-P model for the polymer stress $T_{ij}^{[p]} \equiv \frac{\mu^{[p]}}{\tau}\left(\frac{L^2-3}{L^2-C_{ii}}C_{ij}-\delta_{ij}\right)$
- Alvelius (1999) forcing on first 4 waveno.

DNS parameters:

- $N=192^3$ (statistically steady)
- Polymer concentration: $\beta = 0.8$
- Relaxation time: $\begin{cases} \tau = [0.1, 0.125, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 1.0] \\ Wi \equiv \tau/(\nu/\varepsilon^{[N]})^{1/2} = [1.6, \ldots, 10.4] \\ De \equiv \tau/(\ell/u') = [0.3, \ldots, 1.8] \end{cases}$
- Max. polymer extension: $L = 100$, $3\% < \sqrt{C_{ii}}/L < 39\%$
- Reynolds number: $50 < Re_\lambda < 70$

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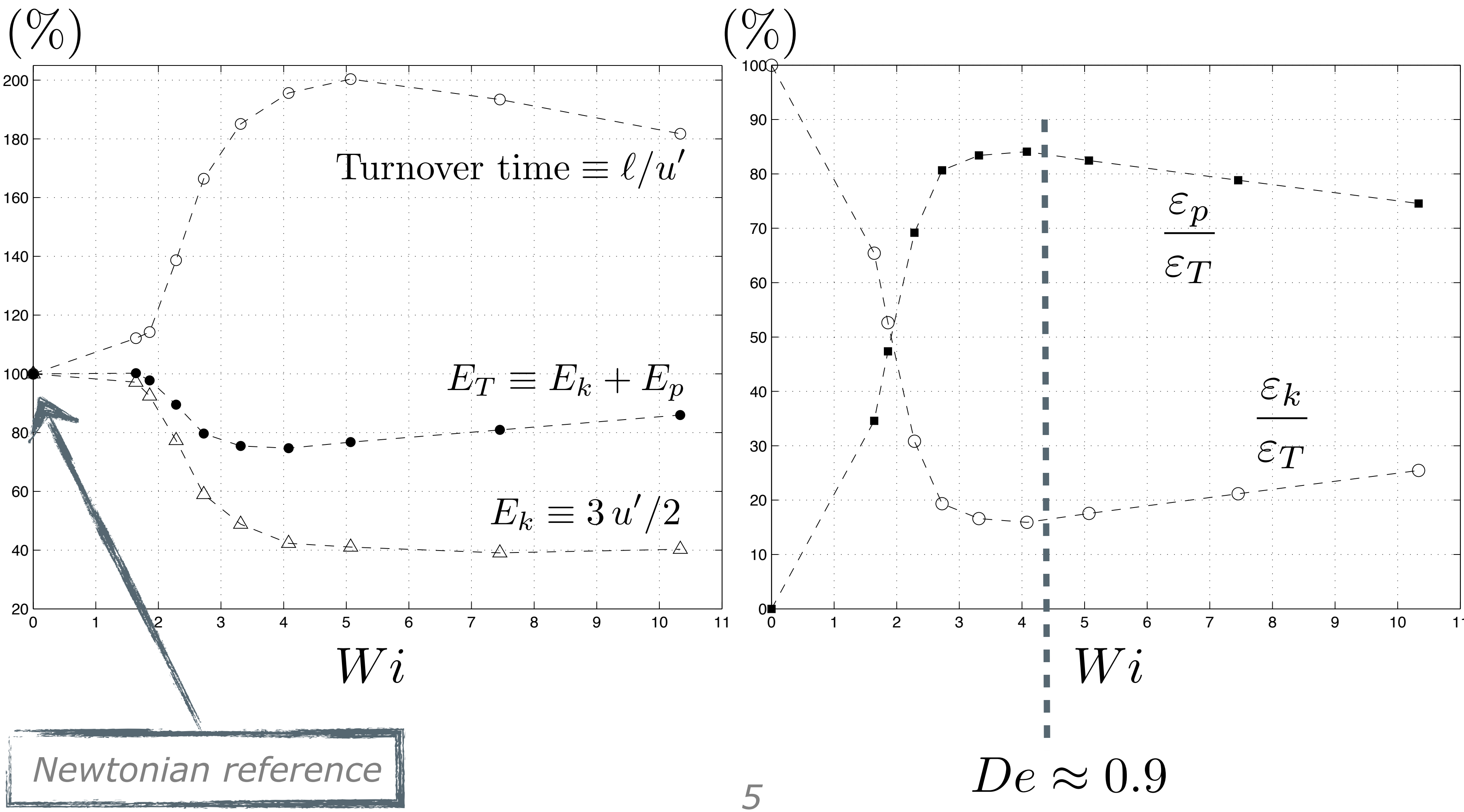
# Added dissipation due to polymer additives in forced HIT

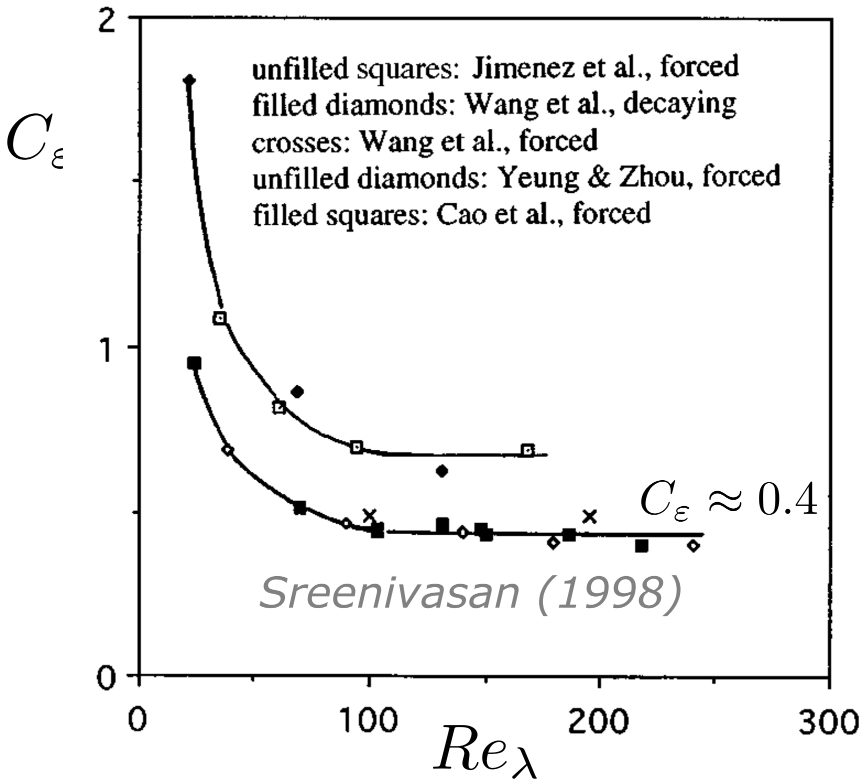
# Added dissipation due to polymer additives



# Added dissipation due to polymer additives - II

Recall: In Newtonian turbulent flows the rate of dissipation is inversely proportional to turnover time for a given turbulent kinetic energy

$$\varepsilon_k = C_\varepsilon u'^3/\ell \sim \frac{u'^2}{\ell/u'}$$

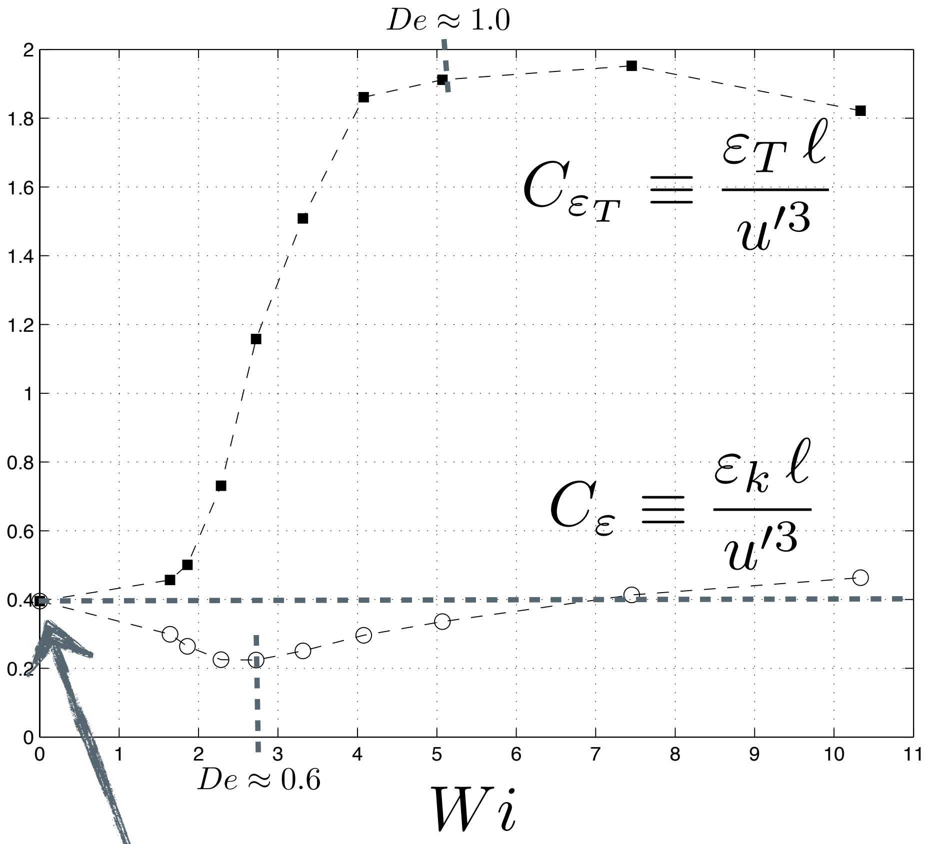



Sreenivasan (1998)

Previous slide:

- Decrease in kinetic energy
- Increase in turnover time
- Thus decrease in dissipation
- What about $C_\varepsilon$ ?

# Added dissipation due to polymer additives - III




Newtonian reference

- The polymer `hampers' the effectiveness of turbulence in dissipating kinetic energy
- However, the polymer additives efficiently transfer kinetic to elastic energy and dissipate it
- Overall there is <u>`drag' increase</u>

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# Effect of polymer additives on the turbulence energy cascade

# Effect of polymer additives on the energy cascade

Lin equation for statistically steady homogeneous viscoelastic turbulence

$$f(k) = -T(k) + T^{[p]}(k) + 2\nu^{[s]}k^2E(k)$$

*External force* — $f(k)$

*Non-linear transfer spectrum* — $T(k)$

*Kinetic to elastic energy transfer spectrum* — $T^{[p]}(k)$

*Dissipation spectrum* — $2\nu^{[s]}k^2E(k)$

$$\int_{k_{\min}}^{k_{\max}} f(k)\,dk = P_{\text{in}} \quad \left\{ \underbrace{\int_{k_{\min}}^{k_{\max}} T^{[p]}(k)\,dk}_{\varepsilon_p} + \underbrace{2\nu^{[s]}\int_{k_{\min}}^{k_{\max}} k^2E(k)\,dk}_{\varepsilon_k} \right.$$

$$\int_{k_{\min}}^{k_{\max}} T(k)\,dk = 0$$

# Effect of polymer additives on the energy cascade

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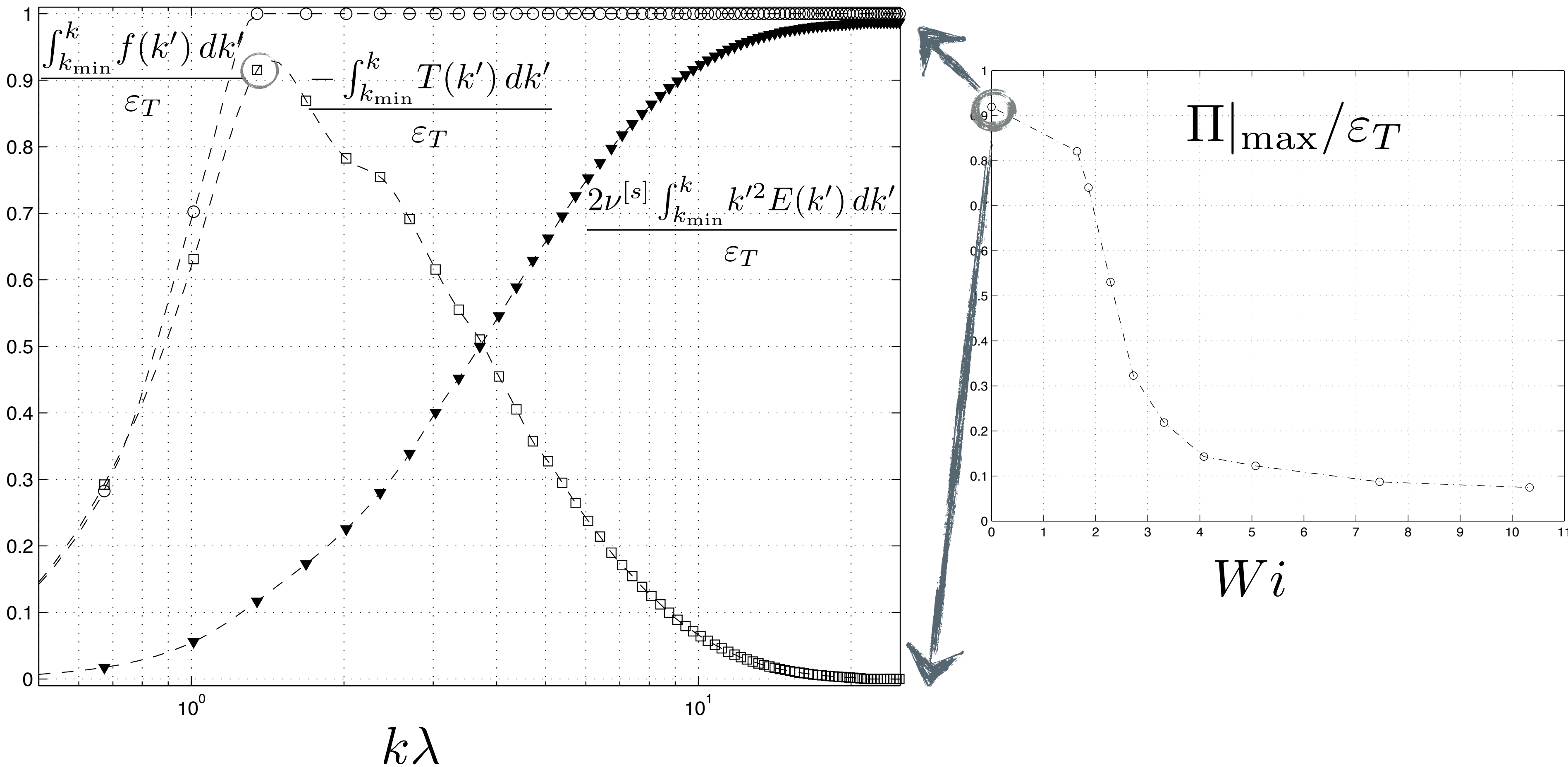

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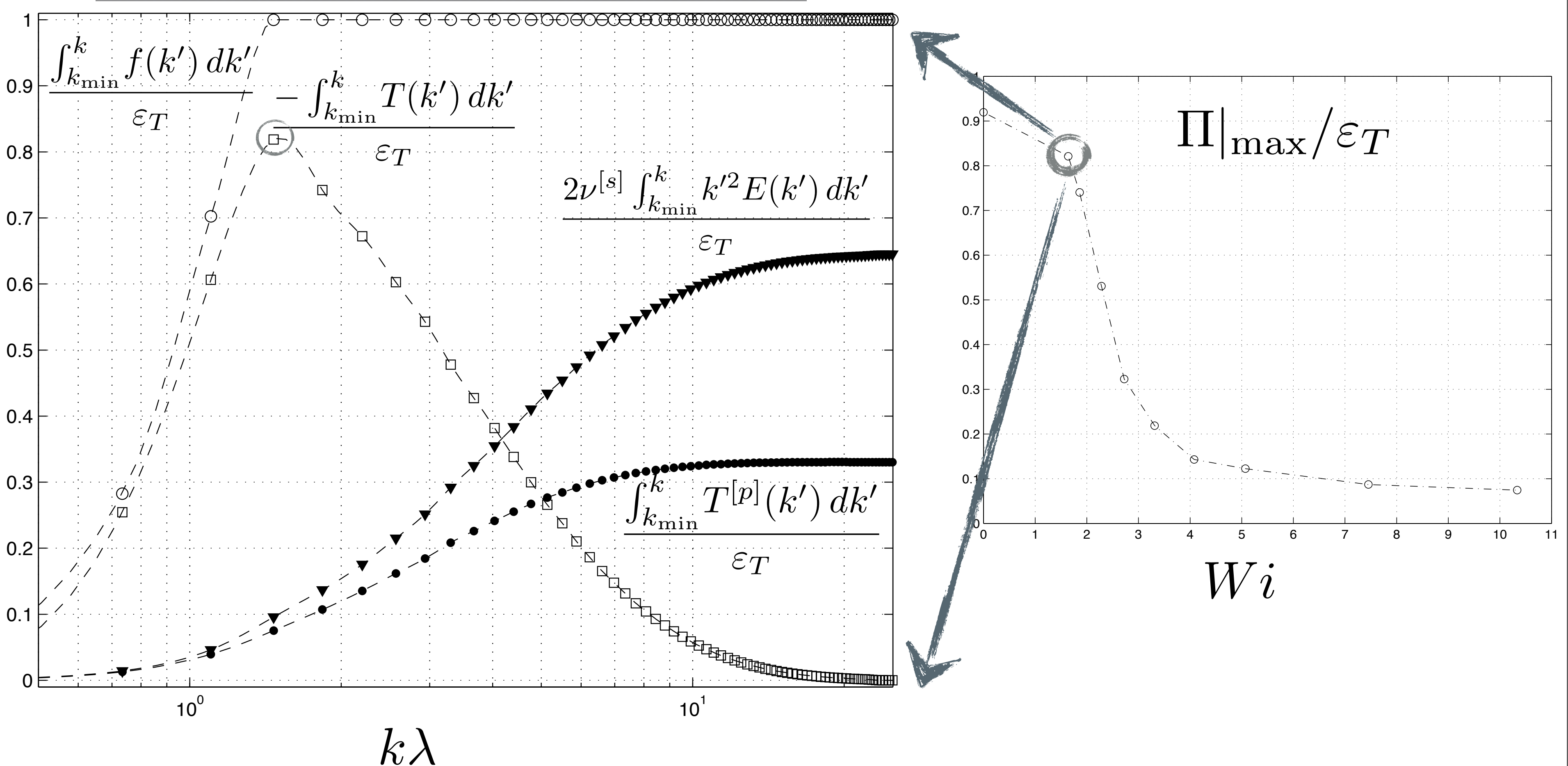

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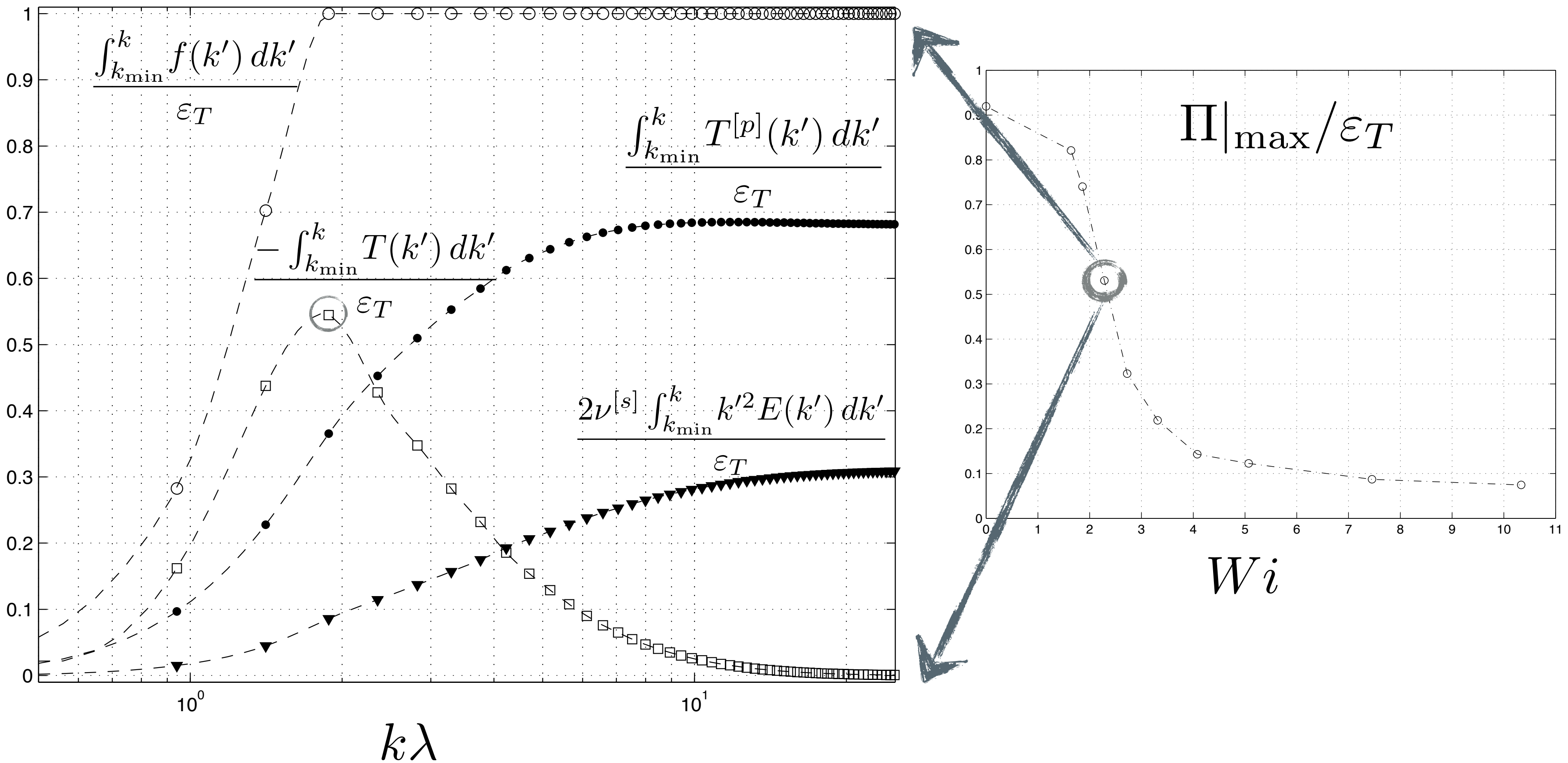

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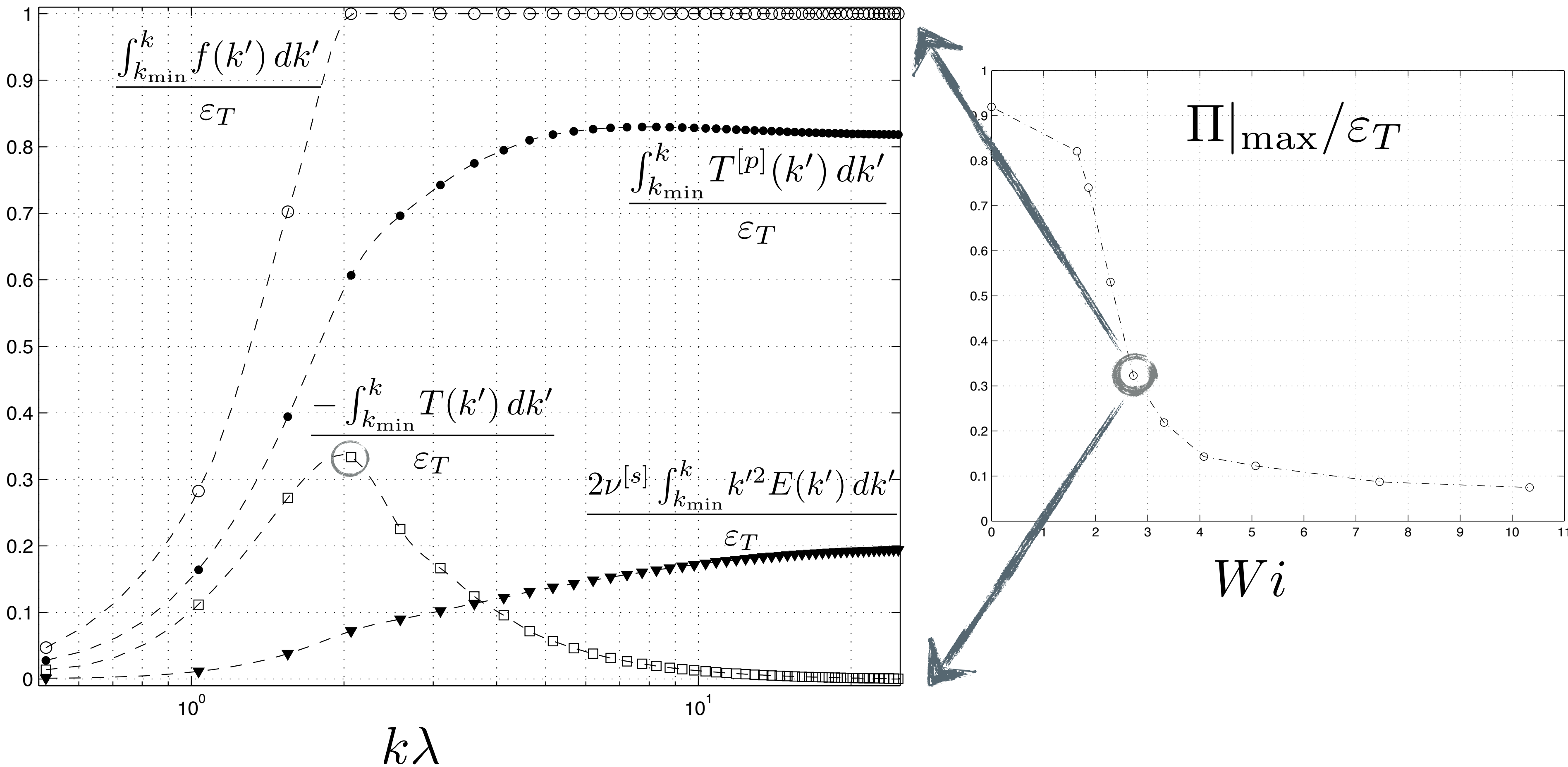

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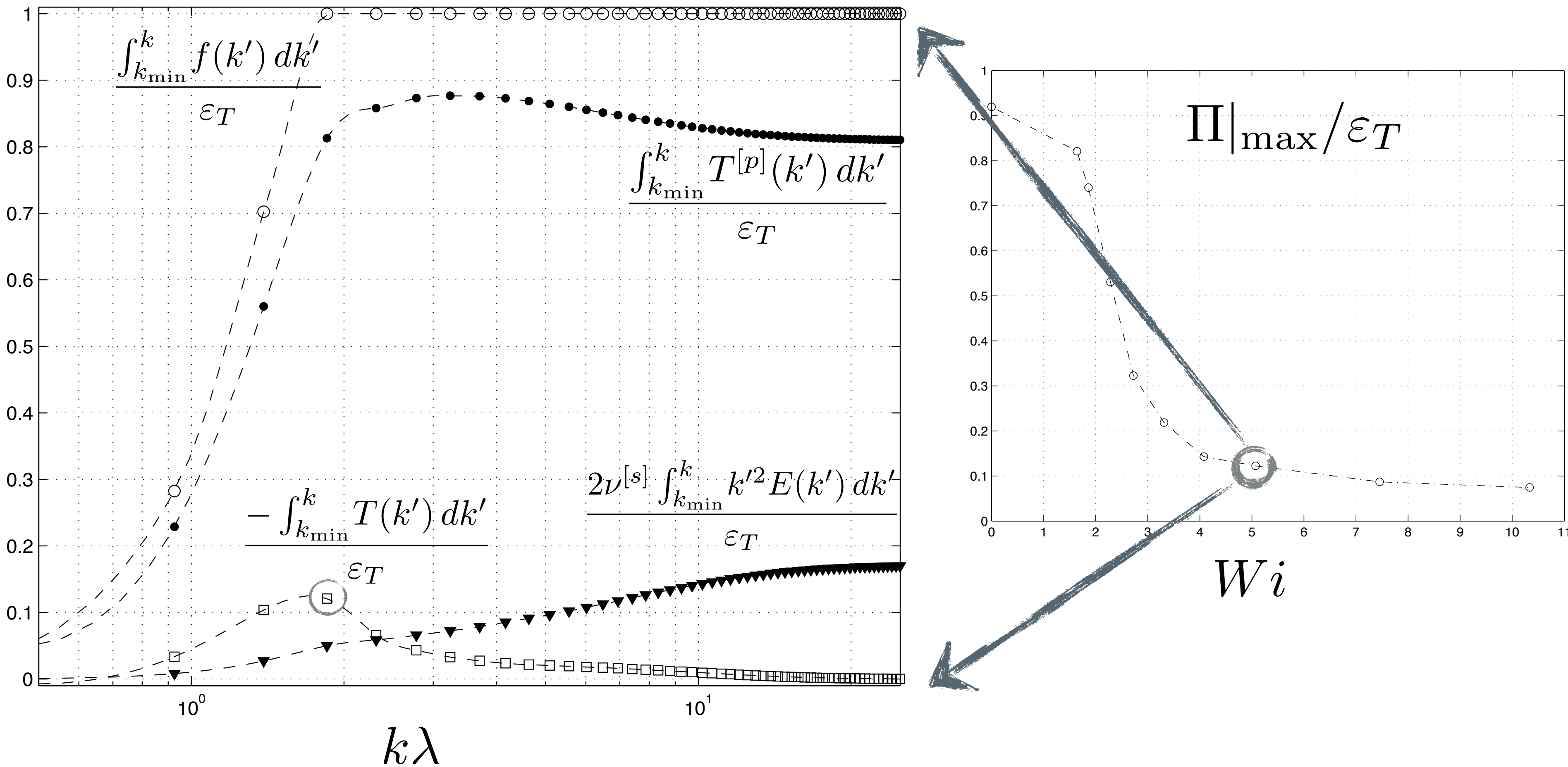

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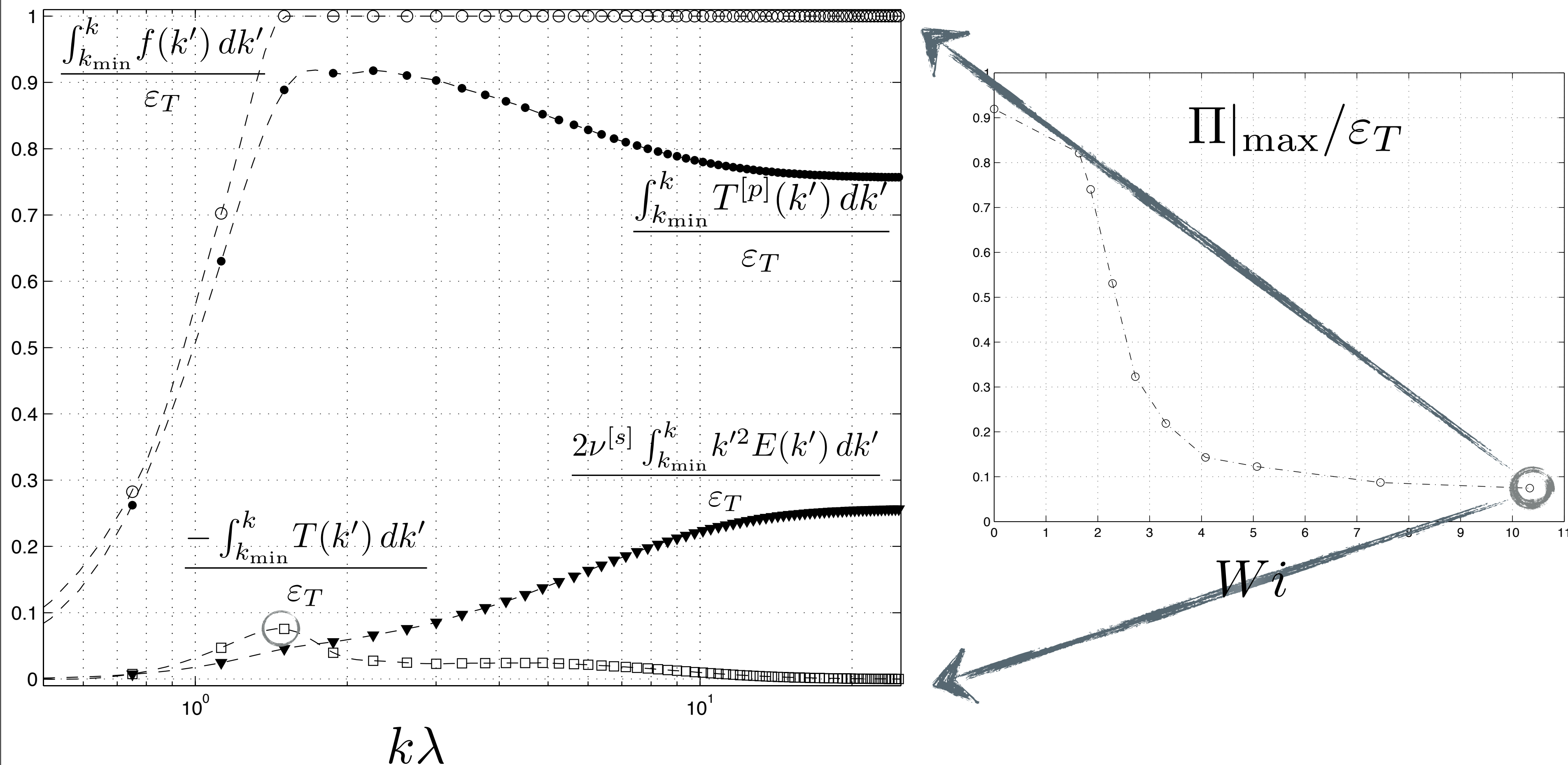
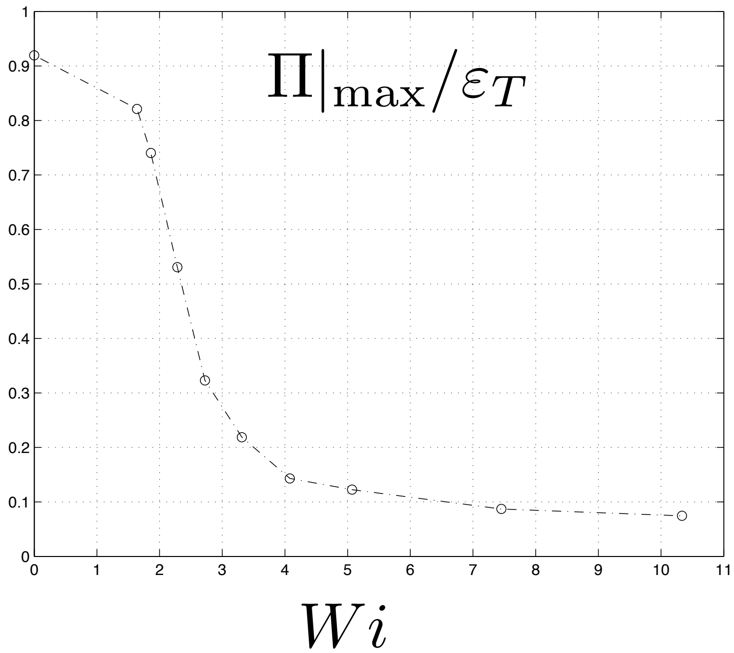
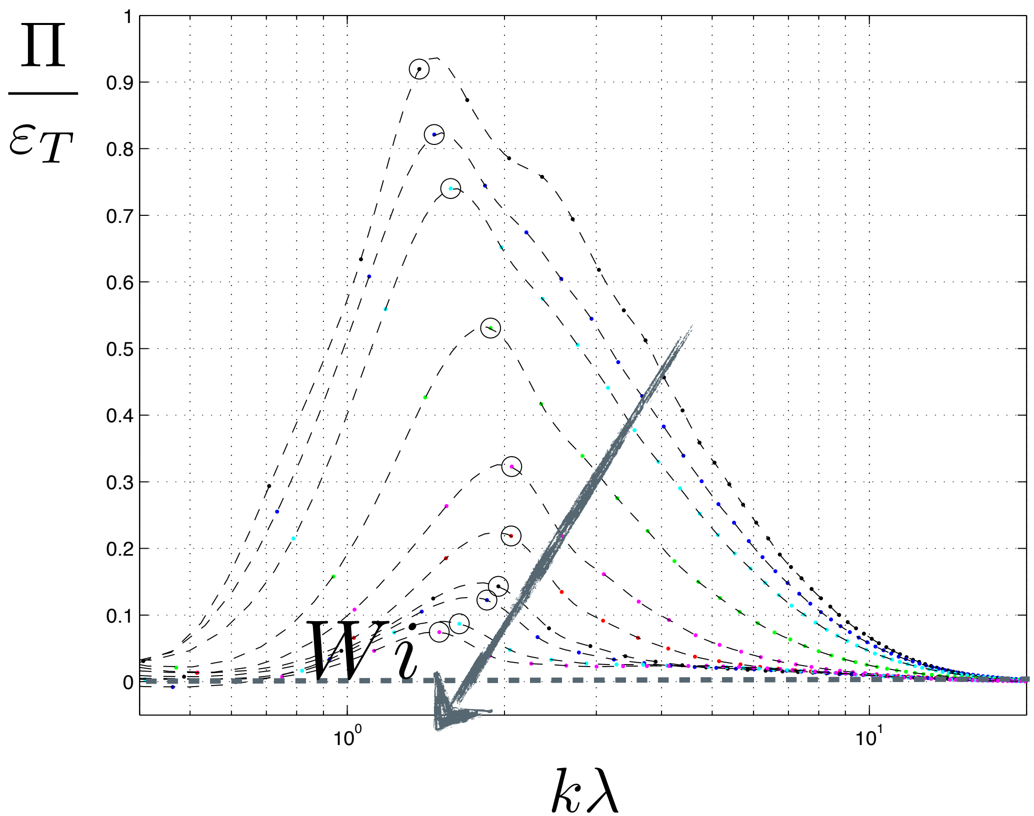


# Effect of polymer additives on the energy cascade

The non-linear transfer of energy decreases with increasing `Wi'

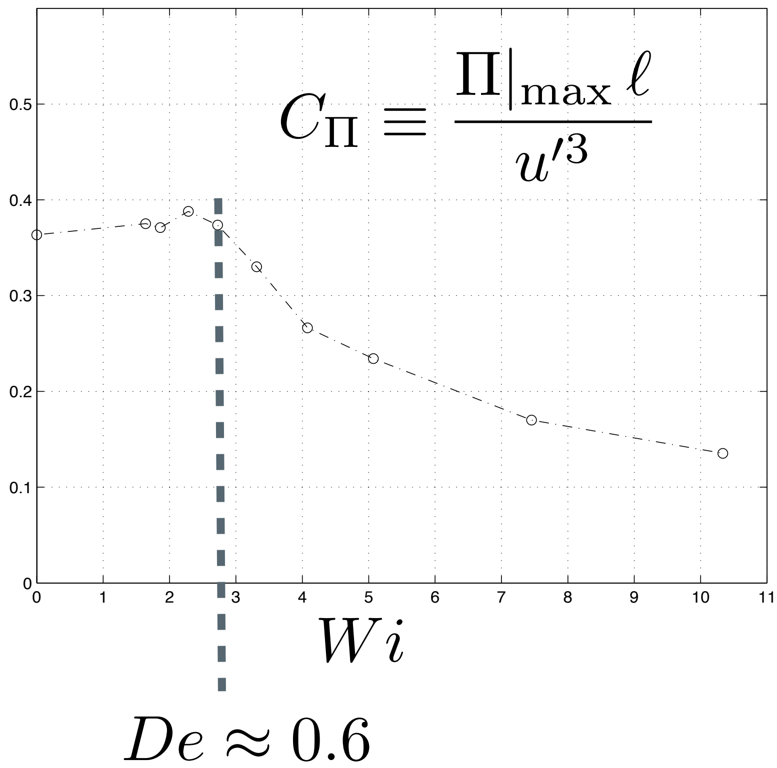
$$\Pi \equiv -\int_{k_{\min}}^{k} T(k')\,dk'$$

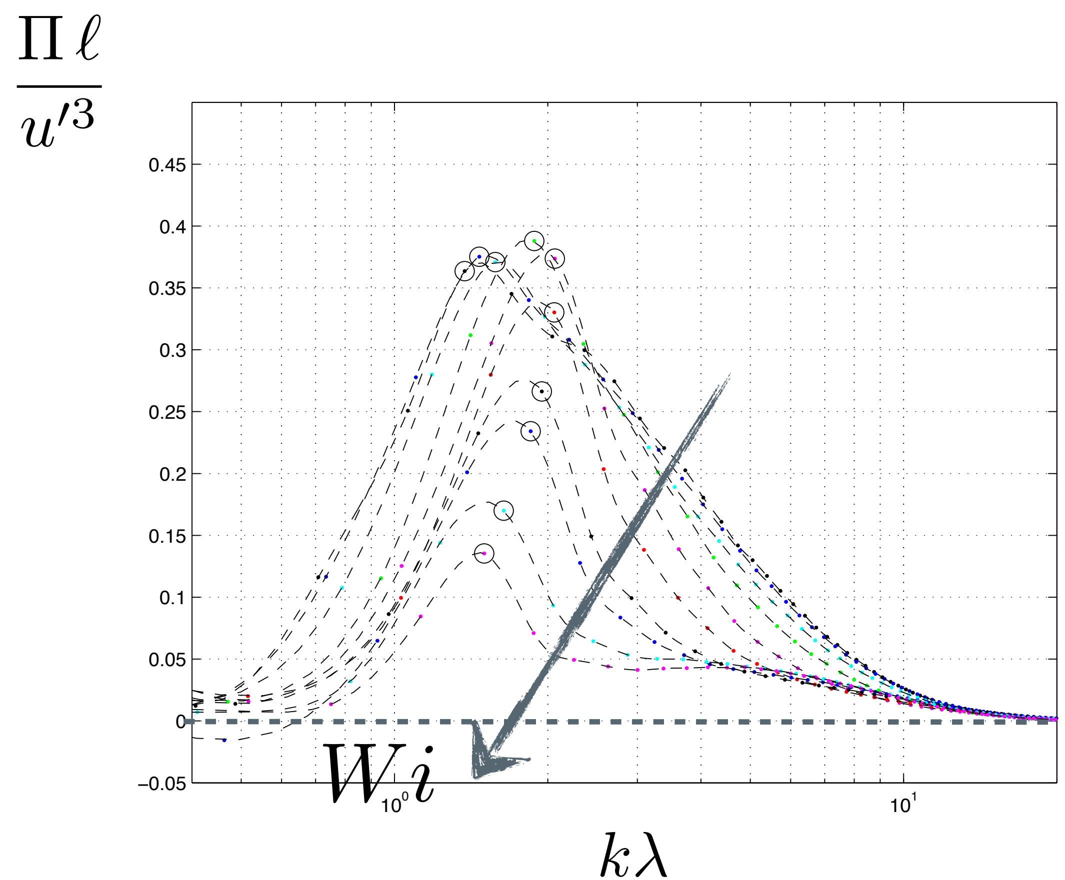


# Effect of polymer additives on the energy cascade

However ...



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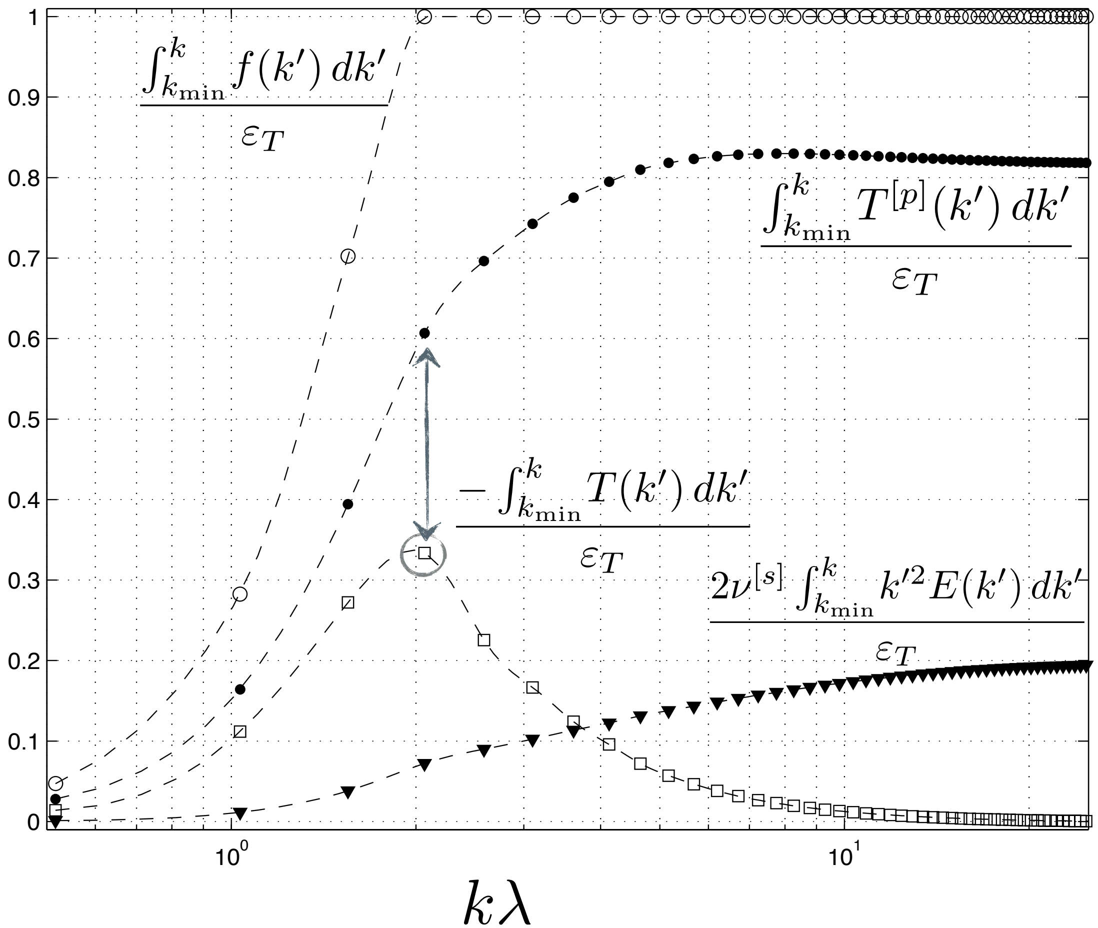
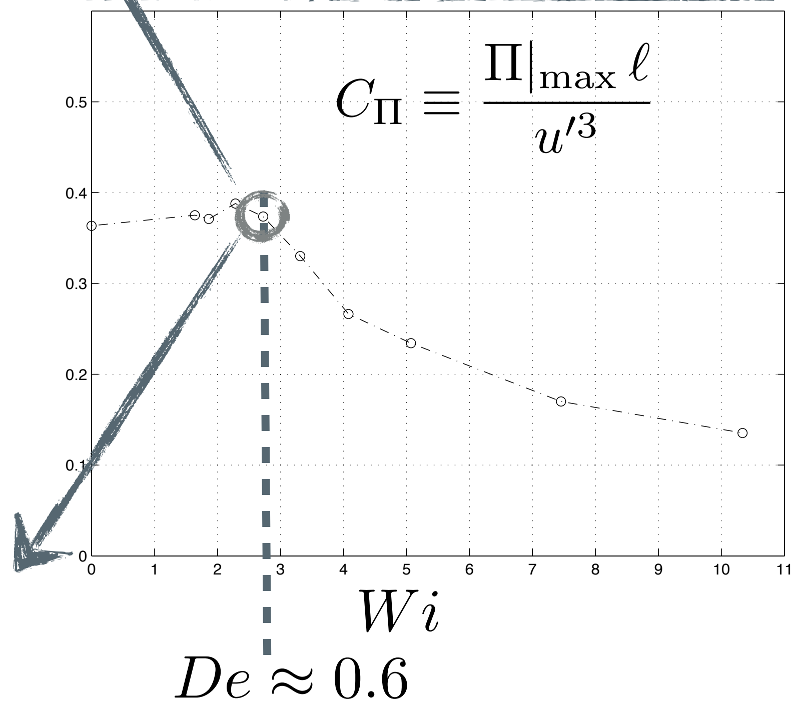


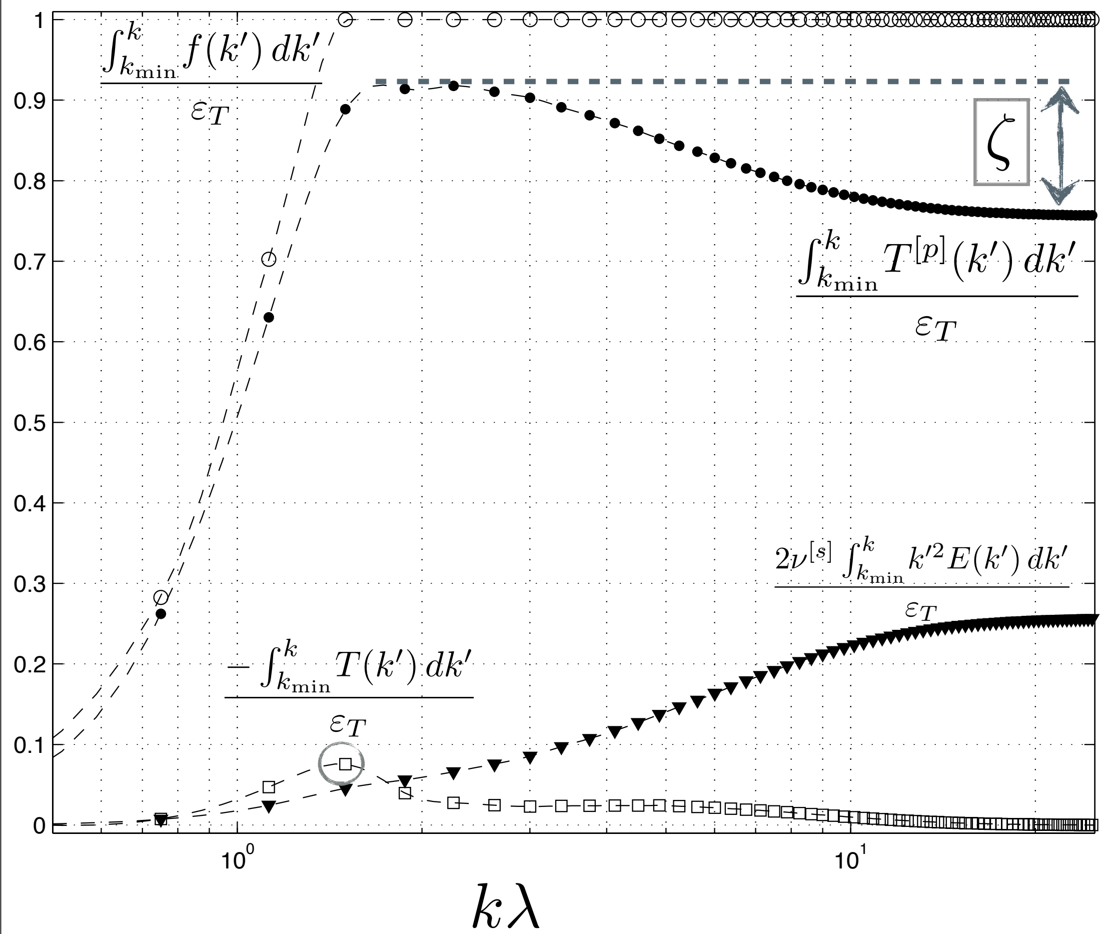

Kinetic -> Polymer transfer
<u>overwhelms</u>
Nonlinear energy transfer
by factor of **2**
but ***C*_Π** ≃ ***0.4***

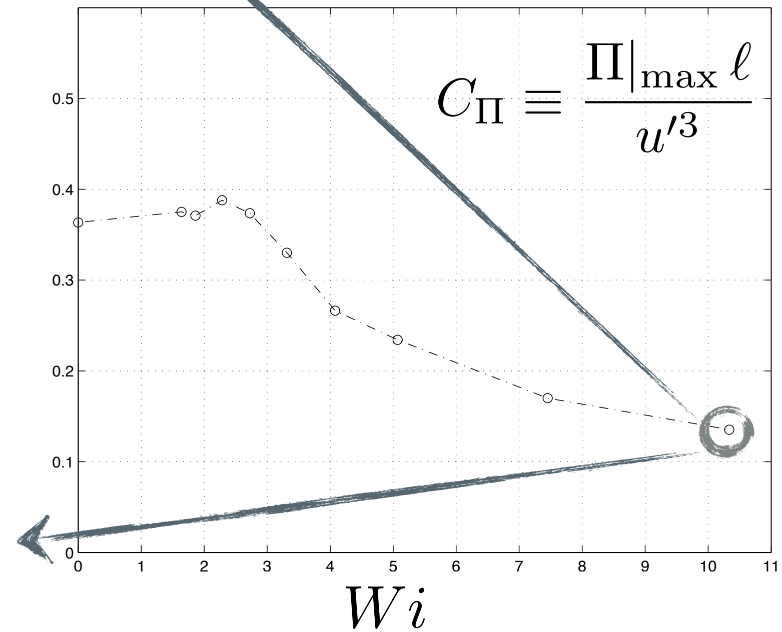


# The inter-scale energy cascade caused by the polymers

# Effect of polymer additives on the energy cascade

$\zeta$ - *represents*
*Polymer -> Kinetic energy*
*transfer* at high waveno.



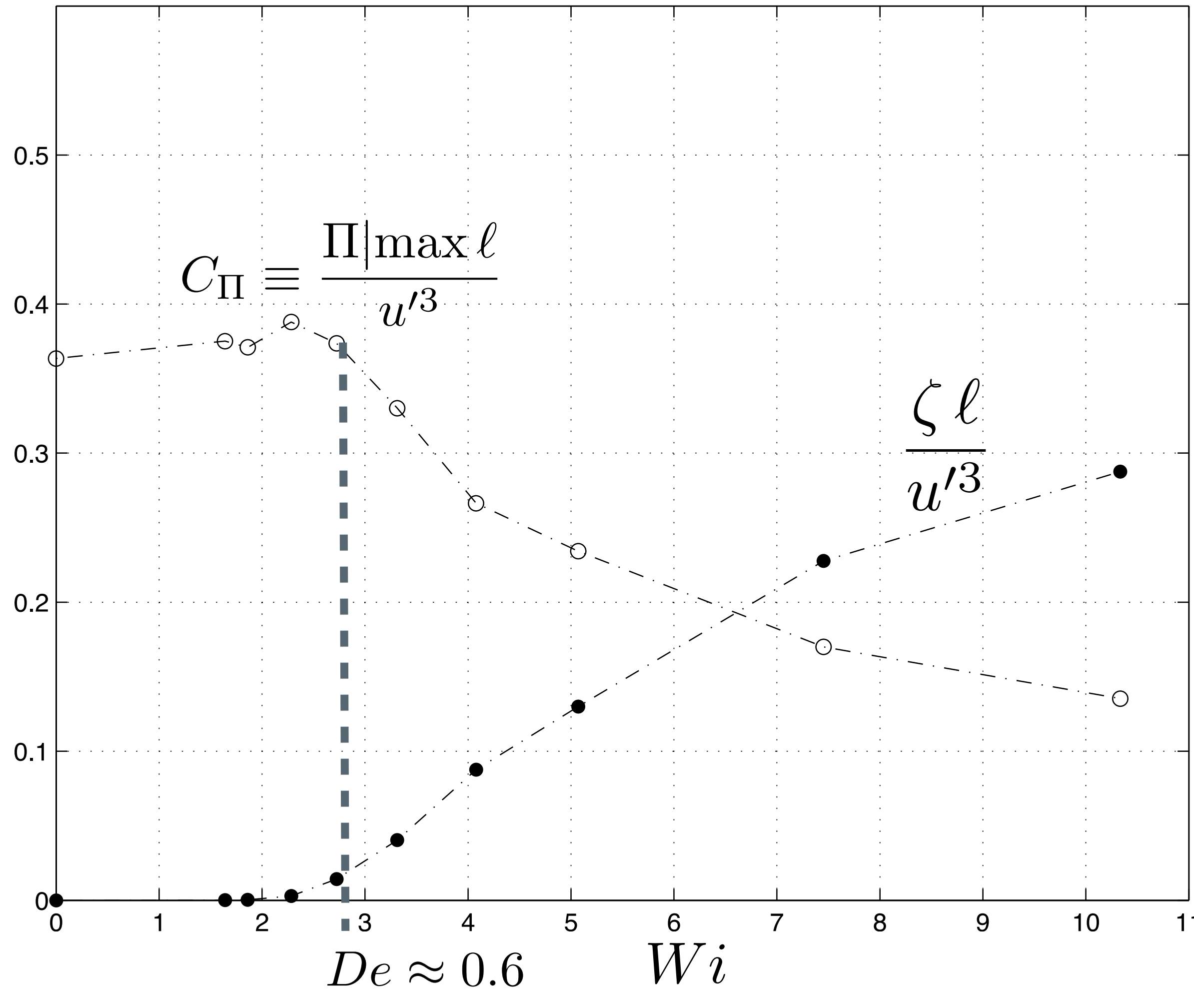



# The inter-scale energy transfer caused by the polymers

The tampering of the energy cascade

seems related to

small-scale polymer energy feedback



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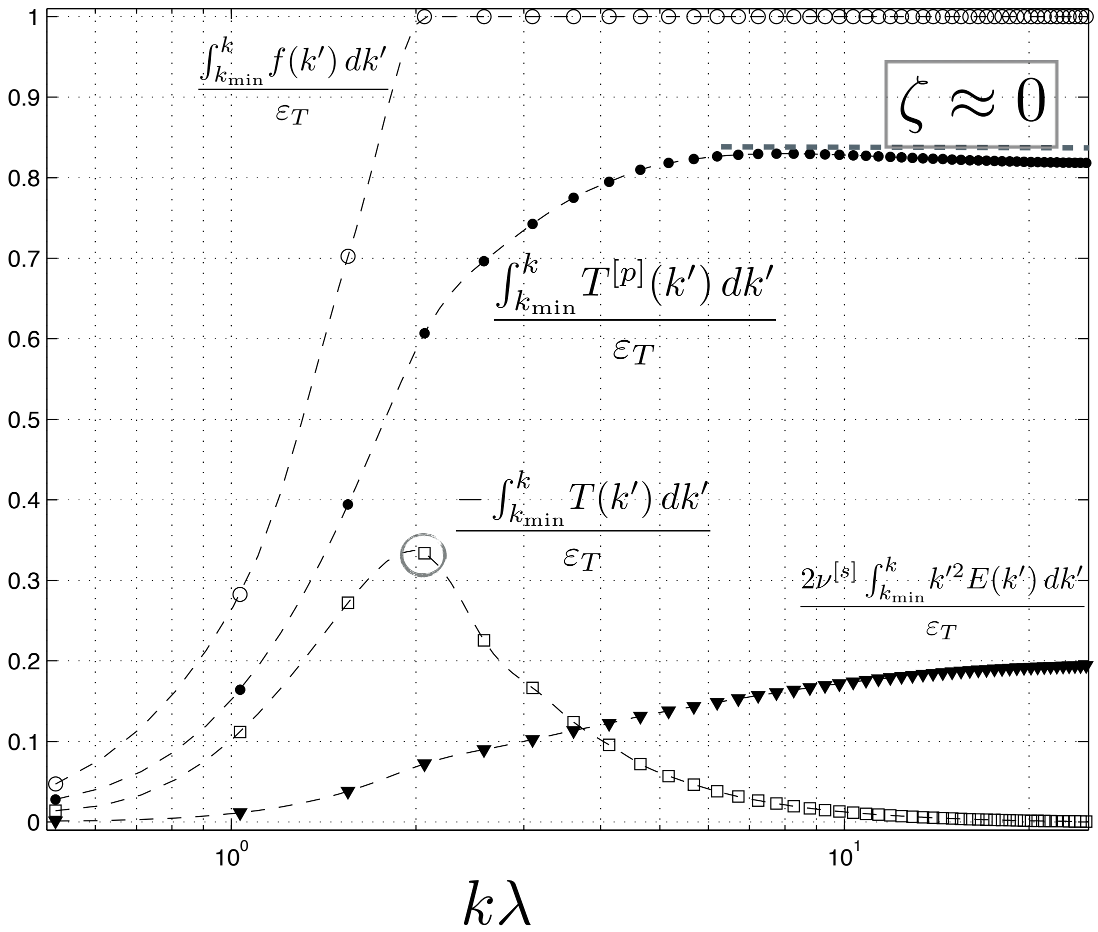
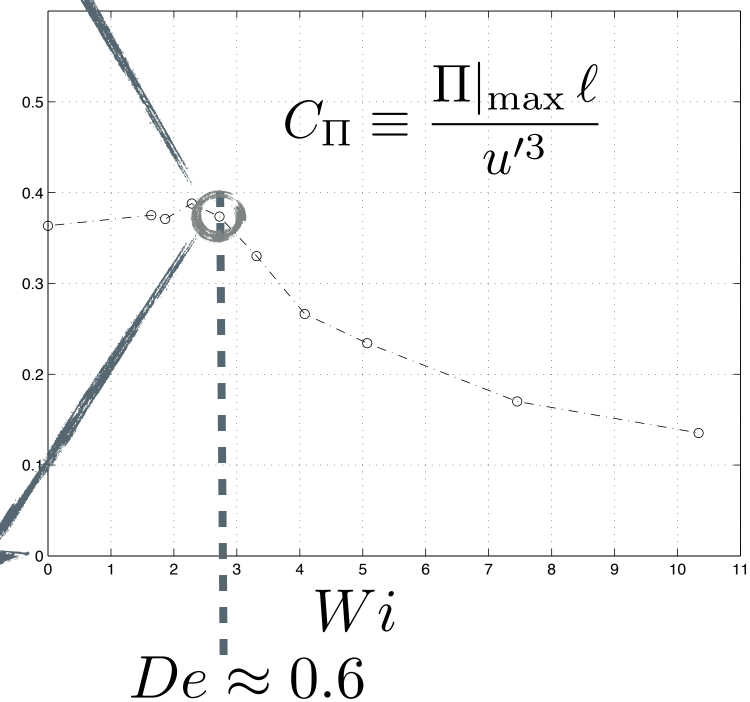



**Negligible**
Polymer -> Kinetic transfer

**Negligible** effect on
Nonlinear energy cascade



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# Summary

## Summary

- Polymers offer an additional energy dissipation mechanism causing <u>`drag increase'</u>
- Little change on energy cascade flux, w.r.t eddy turnover time even when polymers dissipate 80% of the total power input but no high waveno. energy feedback from polymers
- For higher Wi, polymers remove more energy at large scales than they dissipate and feedback the deficit at small scales
- Changes in cascade flux relative to turnover time seems to be closely related to high waveno. energy feedback from polymers