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Three and Two dimensional turbulence in symmetric binary mixtures

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ERC Advanced Grant (N. 339032) "NewTURB"
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Three and Two dimensional turbulence in symmetric binary mixtures

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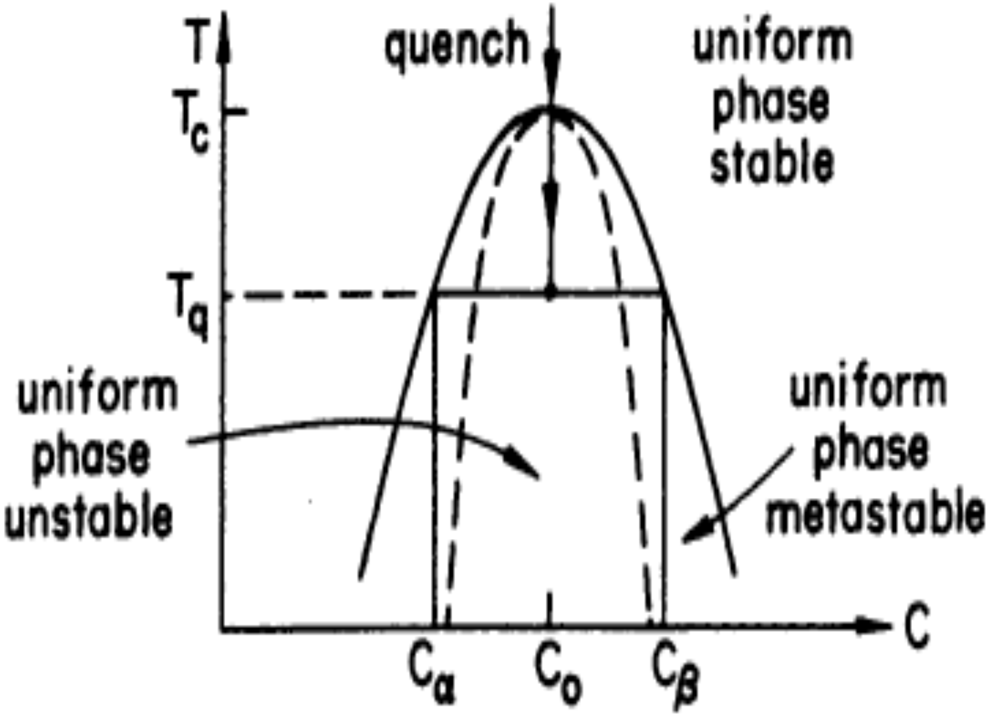
Outline

- Coarsening in binary mixture
- Coarsening arrest in 3d turbulence
- Coarsening arrest in 2d turbulence
    - ➢ Inverse cascade (this talk)
    - ➢ Forward cascade (initial results)

Symmetric liquid Binary mixture

- 50-50% binary mixture above critical temperature. Uniform stable phase
- When quenched (cooled) below T_c , the system phase separates.



Navier Stokes + Model-B

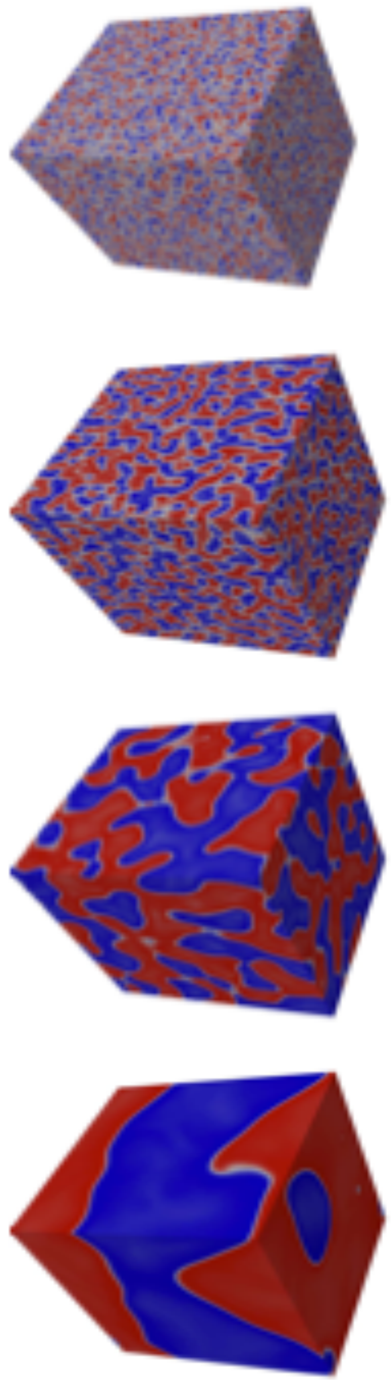
$$D_t u = \nu \nabla^2 u - \nabla p + \phi \nabla \mu$$

$$D_t \phi = M \nabla^2 \mu$$

$$\mu = -\phi + \phi^3 - \xi^2 \nabla^2 \phi$$

Coarsening

$$D_t u = \nu \nabla^2 u - \nabla p + \phi \nabla \mu$$
$$D_t \phi = D \nabla^2 \mu$$
$$\mu = -\phi + \phi^3 + \xi^2 \nabla^2 \phi$$



Dimensional Analysis

Initial time: u negligible $L(t) \sim t^{1/3}$

[I. Lifshitz and V. Slyozov, *J. Phys. Chem. Solids* **19**, 35 (1959).]

Intermediate times: Viscous scaling $L(t) \sim t$

[E.D.Siggia, *Phys. Rev. A* **20**, 595 (1979).]

Later times: Inertial scaling $L(t) \sim t^{2/3}$

[V.M. Kendon, *Phys. Rev. E* **61**, 6071 (2000).]

3D Turbulence + Coarsening

P. Perlekar, R. Benzi, H.J.H. Clercx, and F. Toschi, Phys. Rev. Lett., **112**, 014502 (2014).

Turbulence + Coarsening

Turbulence

- Effective mixing. Eddy diffusivity.
- Breaks large blobs into smaller ones.
- Cascade: Spectral transfer of energy flux from large to small scales.

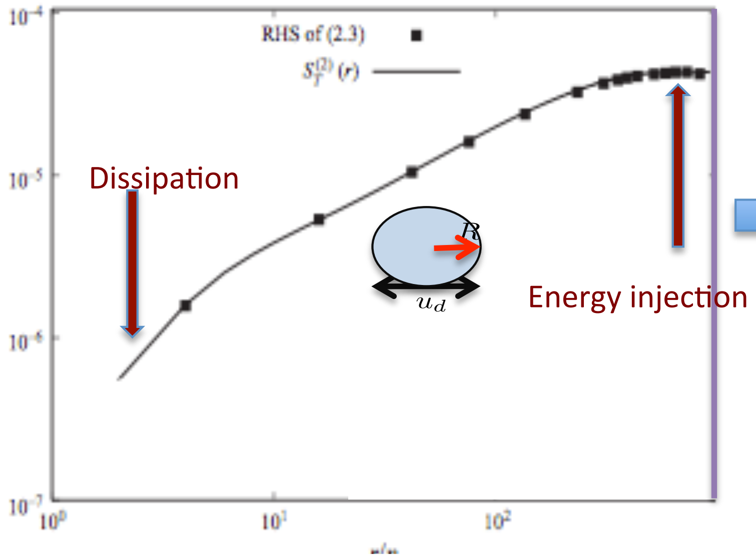
$$\langle [u(x+r) - u(x)]^p \rangle \sim \epsilon^{p/3} r^{p/3}$$

Coarsening

- Demixing
- Coarsening proceeds with different growth laws.
- Cascade: Spectral transfer from small to large scales.

Coalescence	$L(t) \sim t^{1/3}$
Viscous	$L(t) \sim t$
Inertial	$L(t) \sim t^{2/3}$

Arrest scale: phenomenology



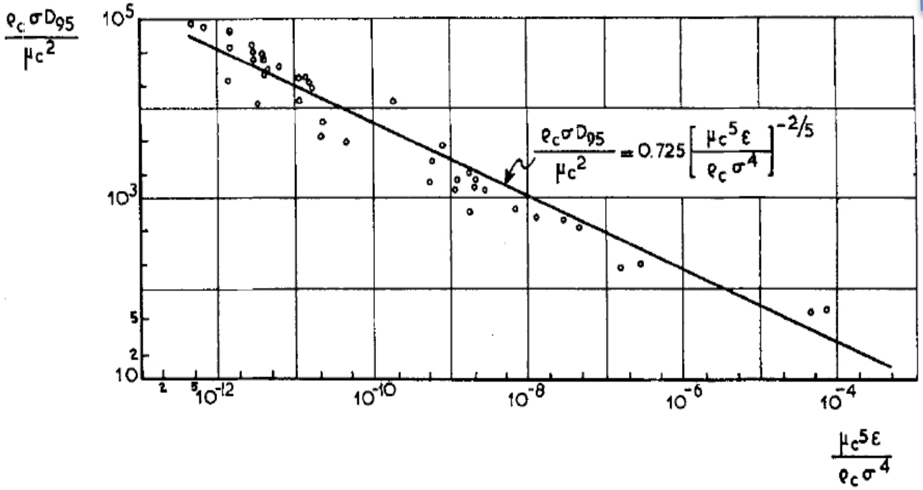


Fig. 6. Maximum drop size as a function of the energy input according to experimental data by Clay.

Maximum droplet diameter (d_{max}) that does not undergo breakup

Inertial force balances surface tension

Weber number:

$$We = \frac{\rho u_d^2 R}{\sigma}$$

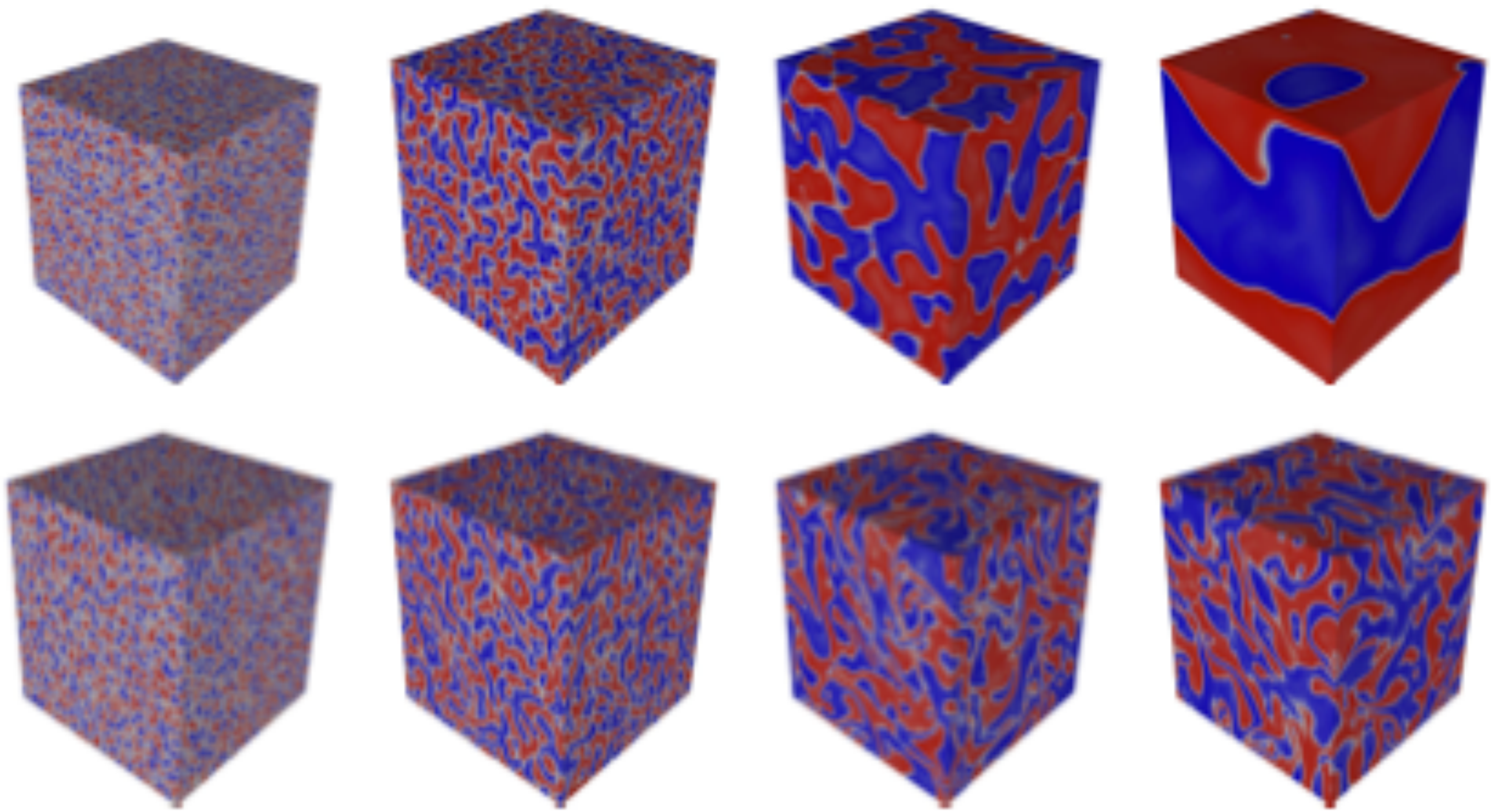
$$K41 : u^2 \sim d^{2/3} \epsilon^{2/3}$$

$$d_{max} = 0.725 \left(\frac{\rho}{\sigma}\right)^{-3/5} \epsilon^{-2/5}$$

J.O. Hinze, A.I.Ch.E, (1955)

Coarsening arrest

Without turbulence

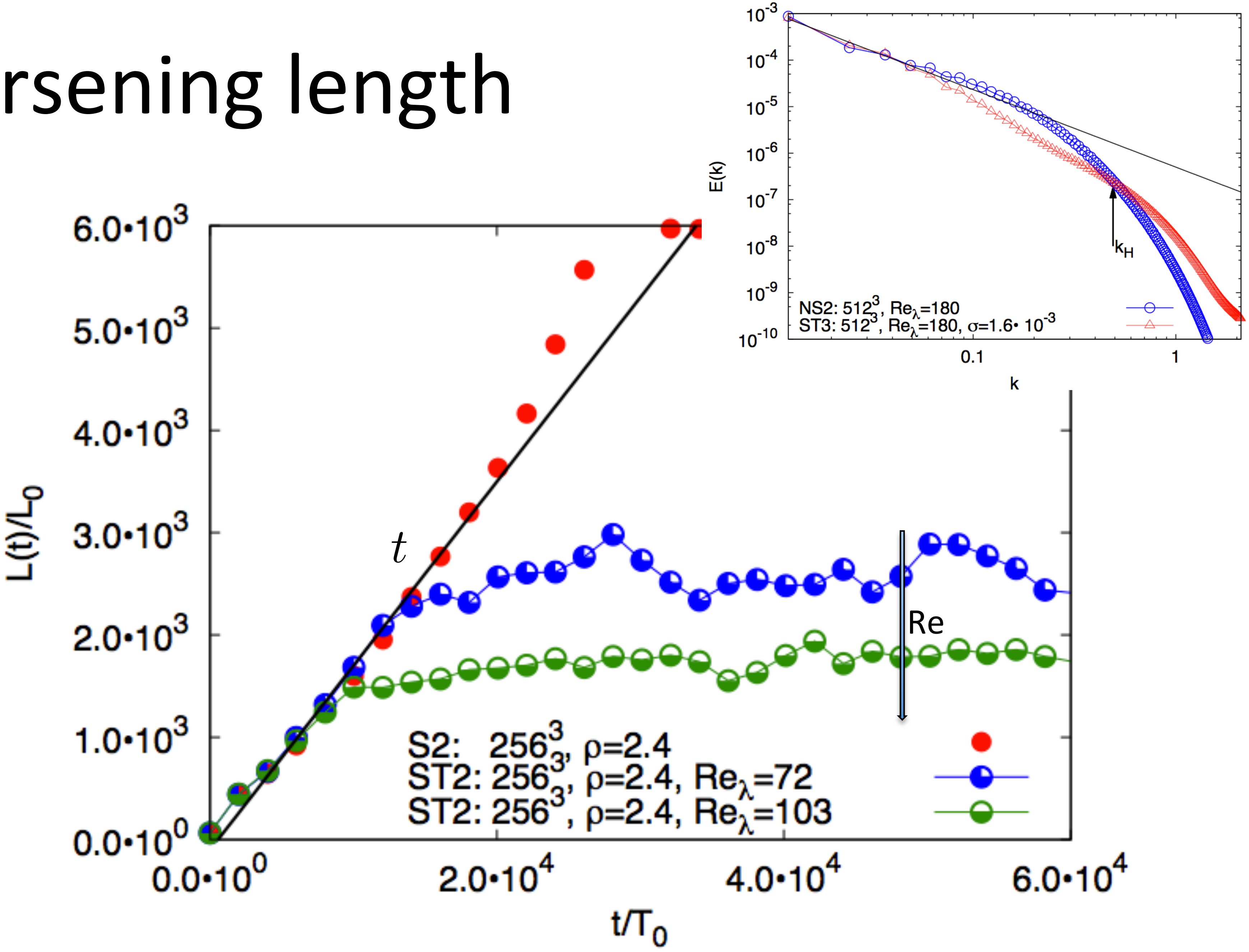


With turbulence

$Sc \sim 1$

Simulations using LBM

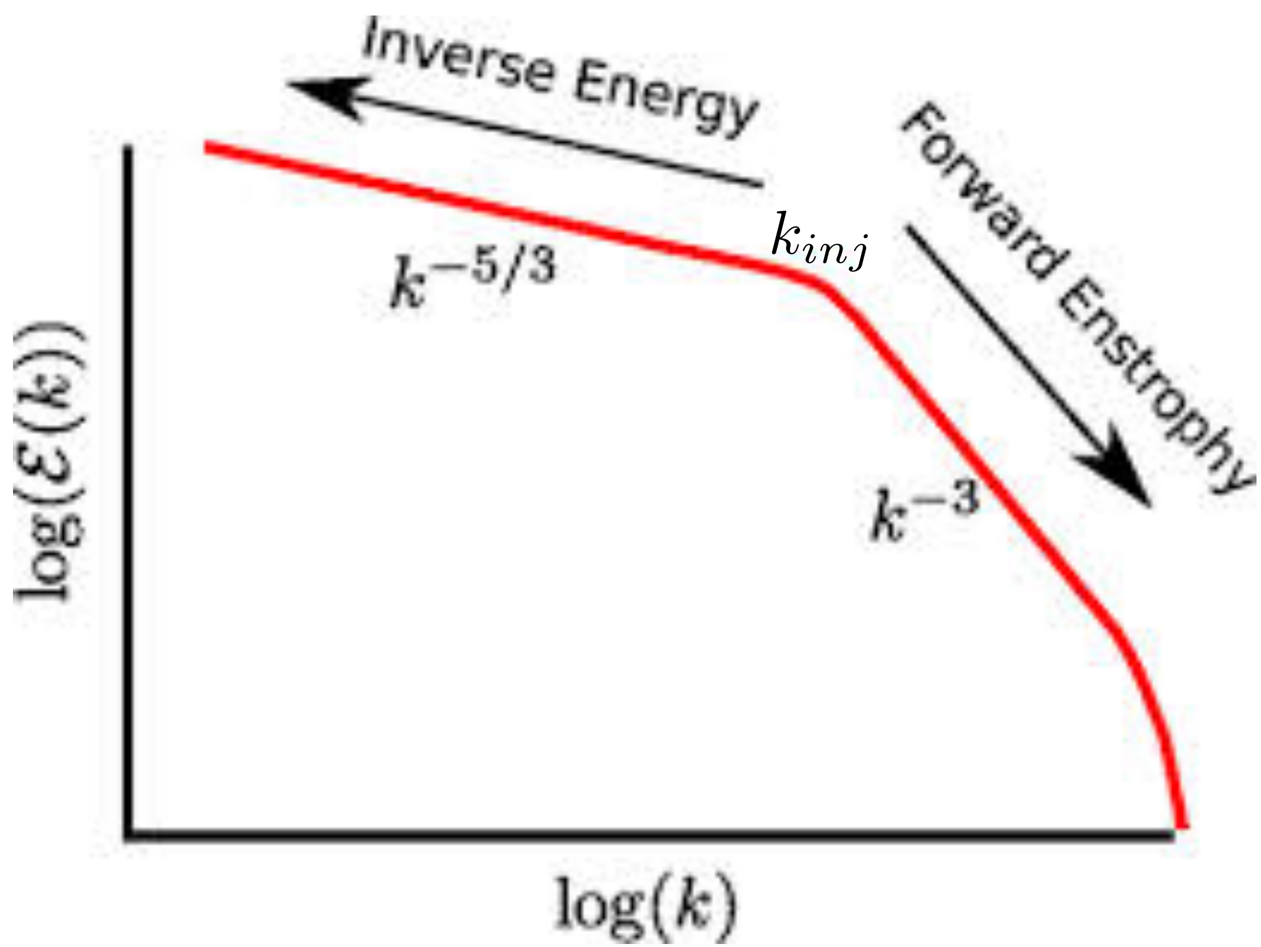
Coarsening length



2D Turbulence + Coarsening

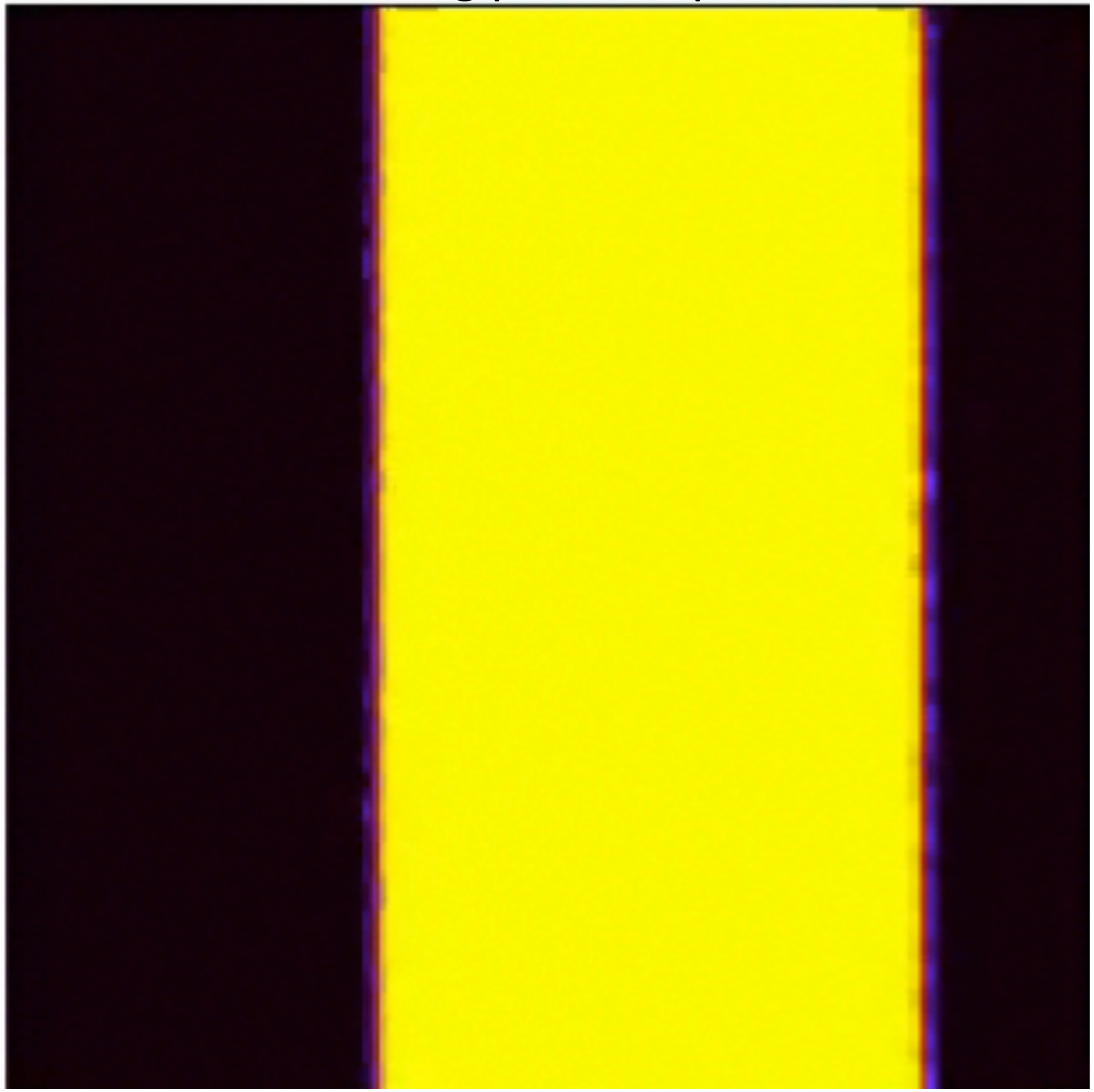
N. Pal, R. Pandit, and P. Perlekar, (in preparation).

2D Turbulence



Coarsening arrest in 2d

Simulations using pseudo-spectral method



Coarsening arrest: Earlier studies

Berti et al., PRL, **95**, 224501 (2005).

$$L^\star < \ell_f : \; L^\star \sim \gamma^{-1/3}$$

$$L^\star > \ell_f : \; \text{No scaling?}$$

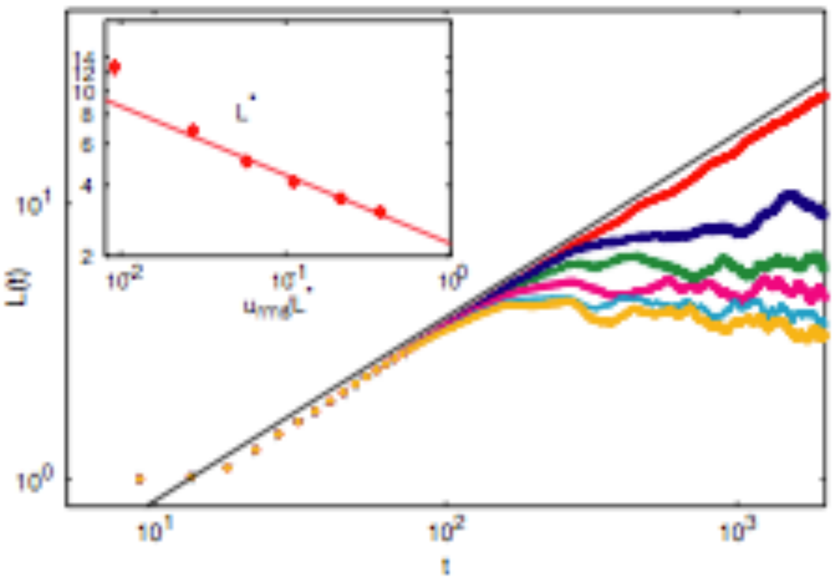
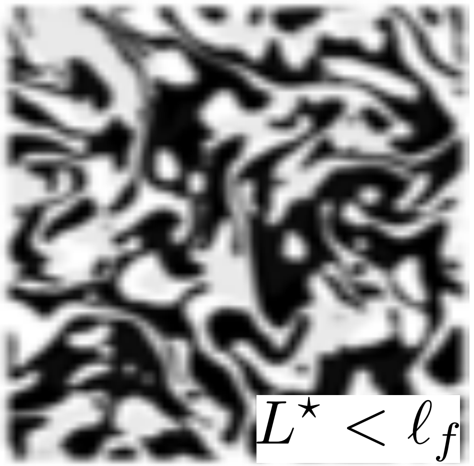


FIG. 3 (color online). L vs t at varying F, from top $F = 0$ (thick curve) and $F = 0.05, 0.10, 0.15, \ldots, 0.30$. Data refer to DNS with $\ell_f = 84\xi$ (the case with $\ell_f = 26\xi$ is qualitatively similar). The straight line displays the scaling $t^{2/3}$. Inset: L^* vs $u_{\rm rms}/L^*$; the straight line has slope -0.29 the point size is of the order of the statistical error.

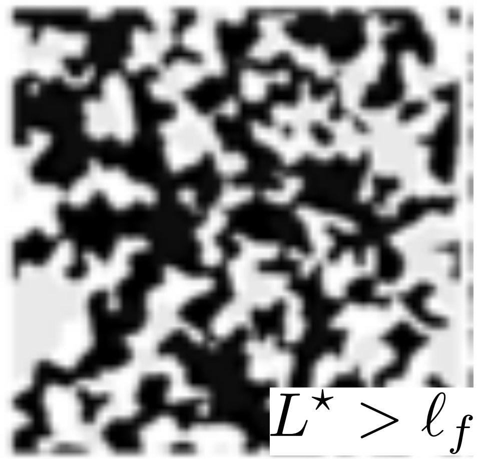
Arrest in forward vs inverse cascade

Berti et al., PRL, **95**, 224501 (2005).

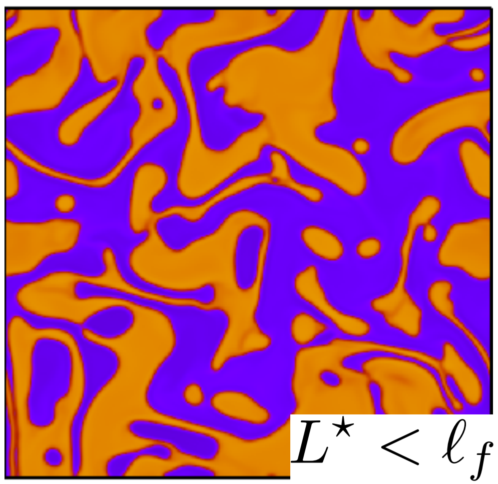
Forward enstrophy cascade

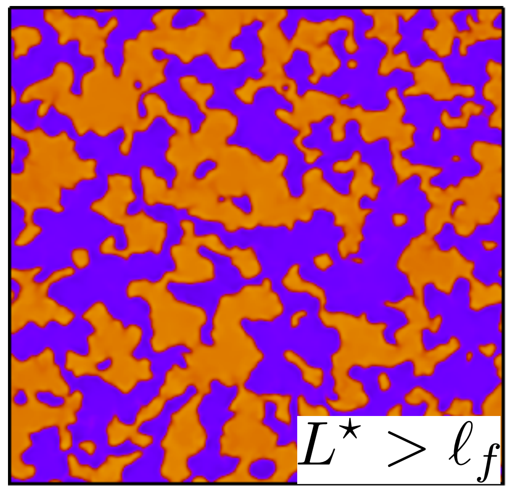


Inverse energy cascade



Our simulations:



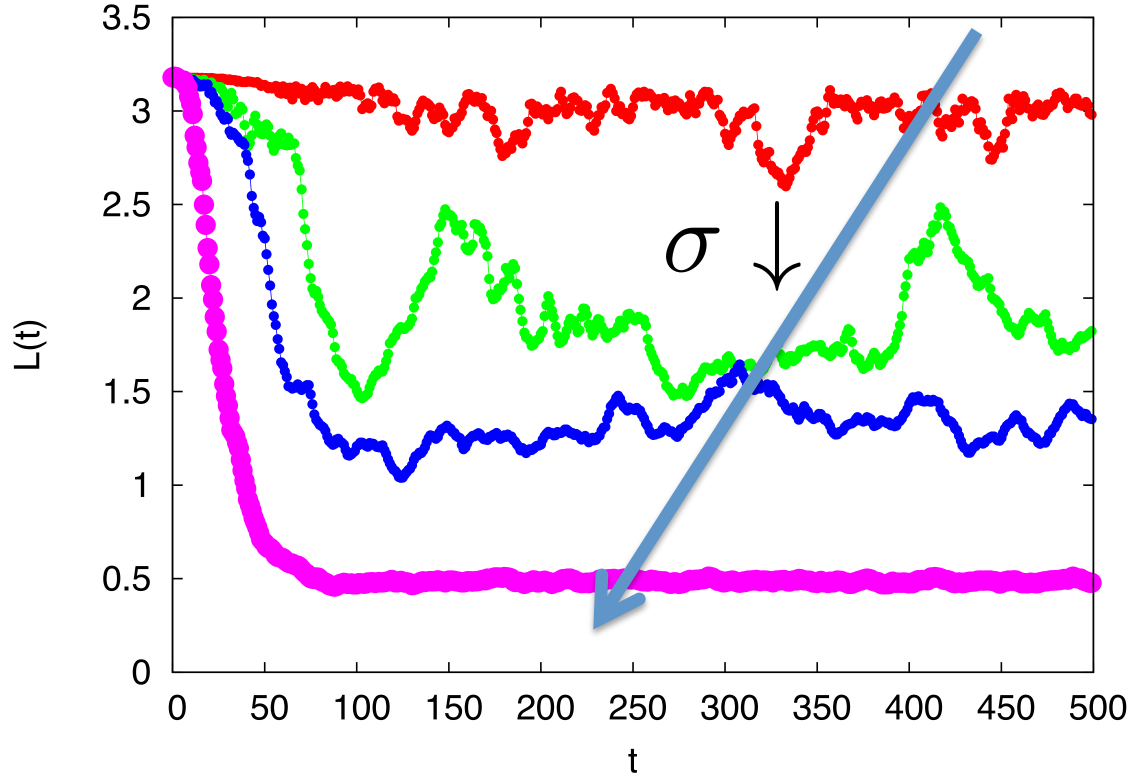


Coarsening arrest in inverse cascade

Coarsening arrest

$$L^\star > \ell_f$$

Initial configuration: Slab



$$We = \frac{\rho u_d^2 R}{\sigma}$$

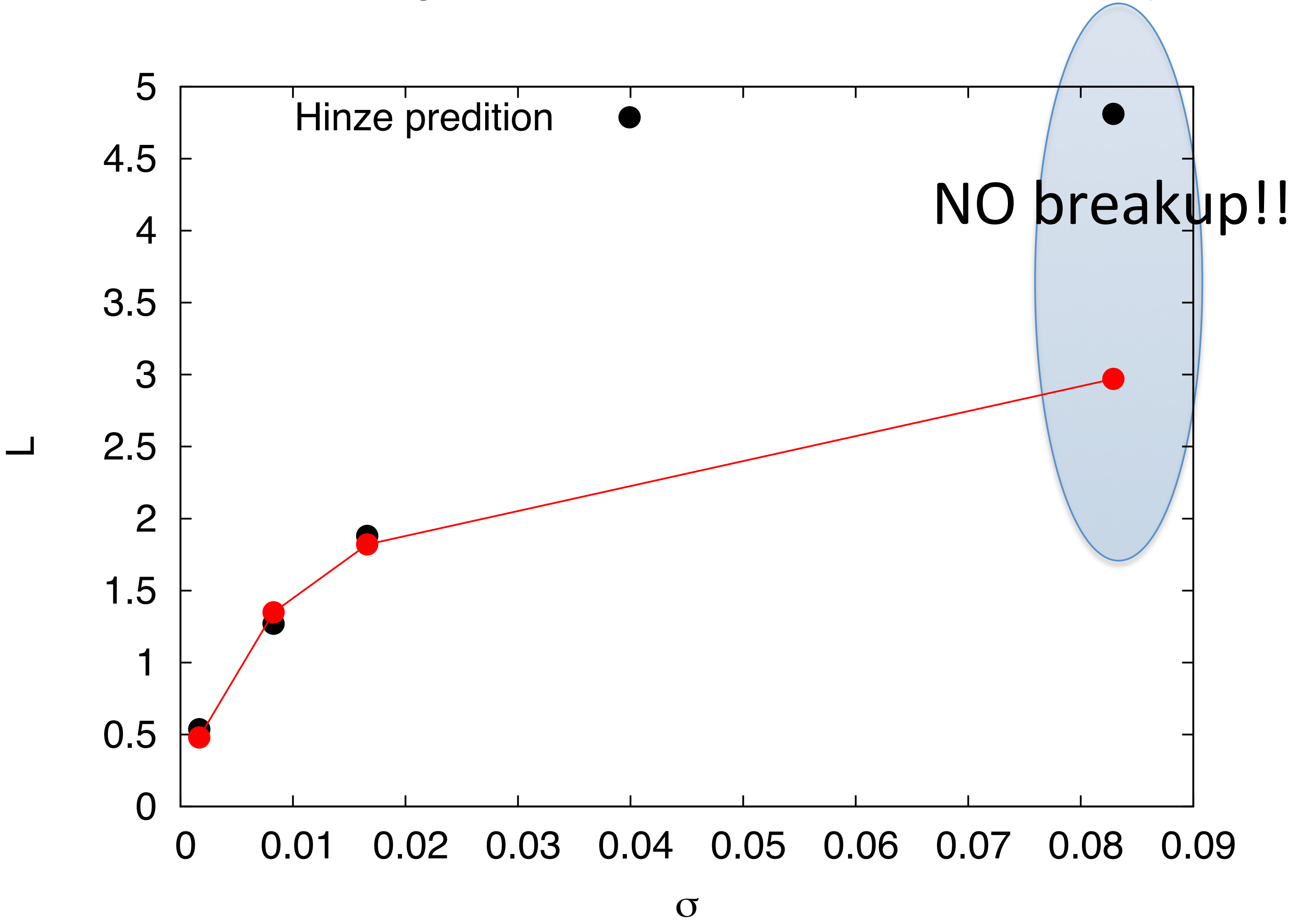
$$K41: u^2 \sim d^{2/3}\epsilon^{2/3}$$

$$L^\star = C\left(\frac{\rho}{\sigma}\right)^{-3/5}\epsilon^{-2/5}$$

$$k_c = \frac{\sum_k kS(k)}{\sum_k S(k)}$$

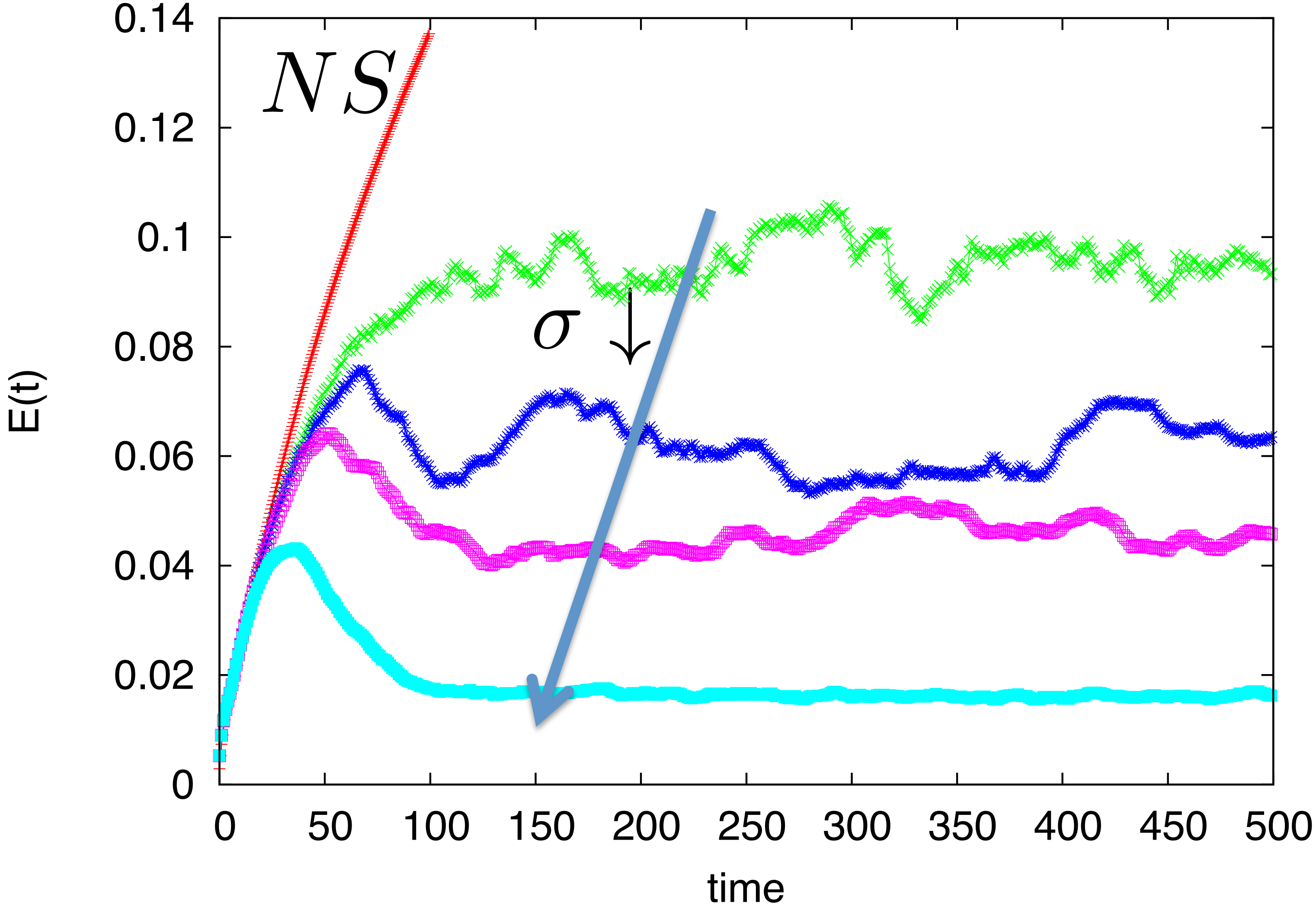
$$S(k) = \sum_{k-1/2<k'<k+1/2} |\phi_{k'}^2|$$

Hinze scale prediction $L^{\star} > \ell_f$



Smaller surface tension, more interface, more energy cost

Kinetic energy $L^\star > \ell_f$



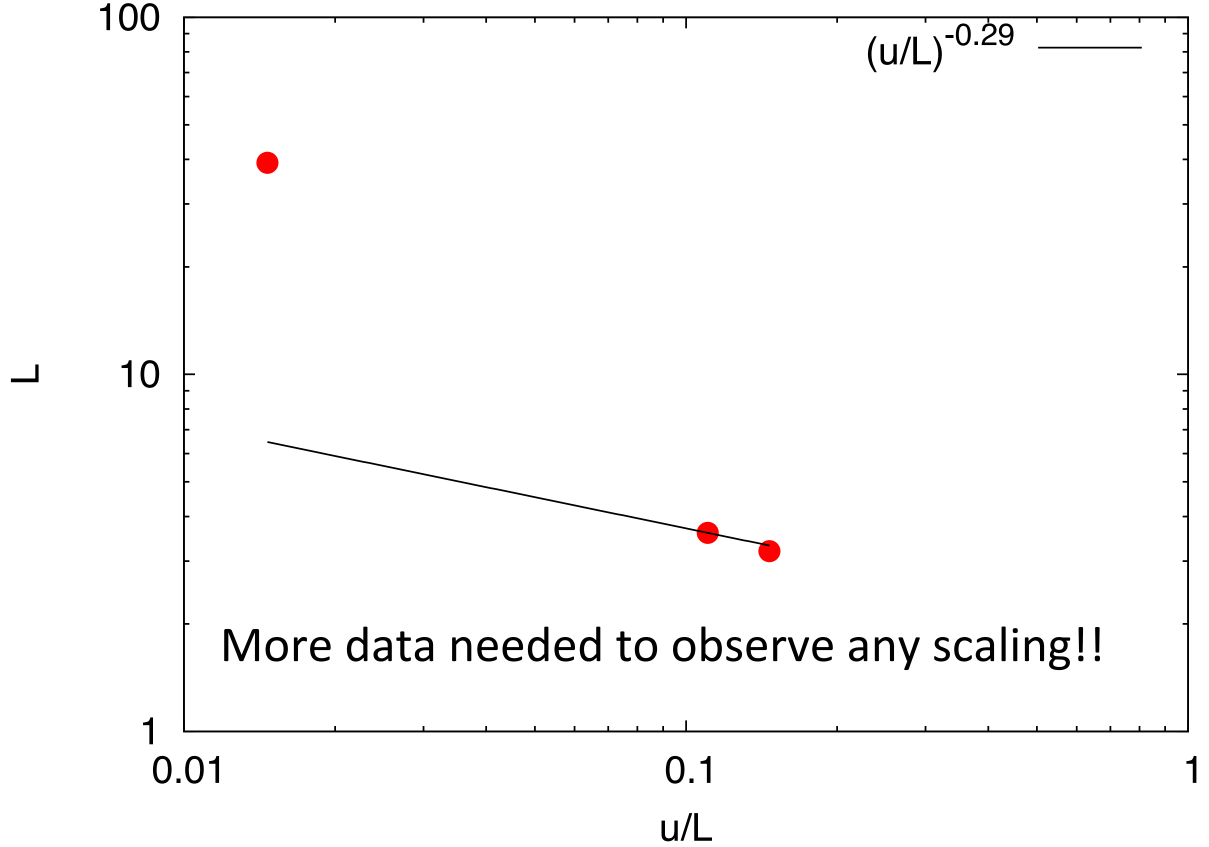
Smaller surface tension, more interface, more energy cost

Forward cascade

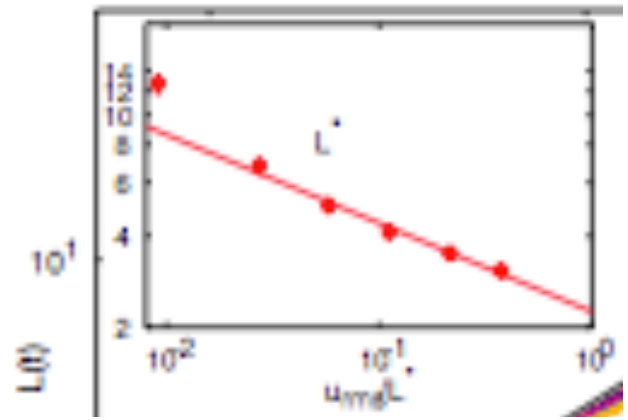
Coarsening arrest

$$L^\star < \ell_f$$

$$L^\star = \langle (1-\phi^2) \rangle^{-1}$$



Berti et al., op cit.



$$L \sim \gamma^{-0.29}$$

$$\gamma \equiv u/L$$

$$\beta : Enstrophy\ dissipation\ rate$$

Conclusion

- Coarsening arrest numerically verified for three and two dimensional turbulence homogeneous, isotropic turbulence

- Arrest scale determined by Hinze criterion in the 3d forward and 2d inverse cascade

- In 2d forward cascade simulations with interface give a decade long k^-3 slope. This is currently being investigated!!

❖ Future directions:
    1. Real mixtures (experiments) have large Schmidt number. Very high resolution.
    2. Asymmetric quenches.