8th KAW

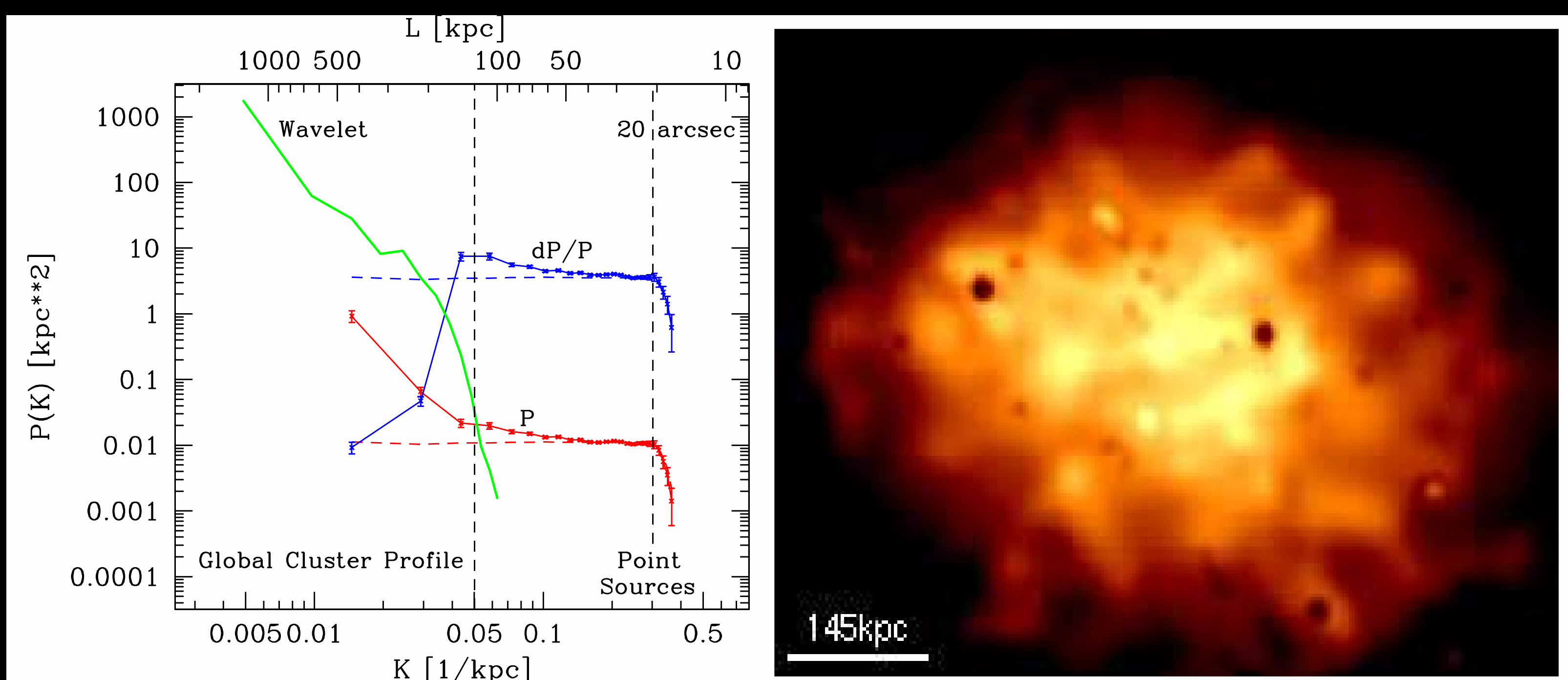
Nov. 12 2014

EFFECTS OF MULTIPLE-SCALE DRIVING ON TURBULENCE STATISTICS

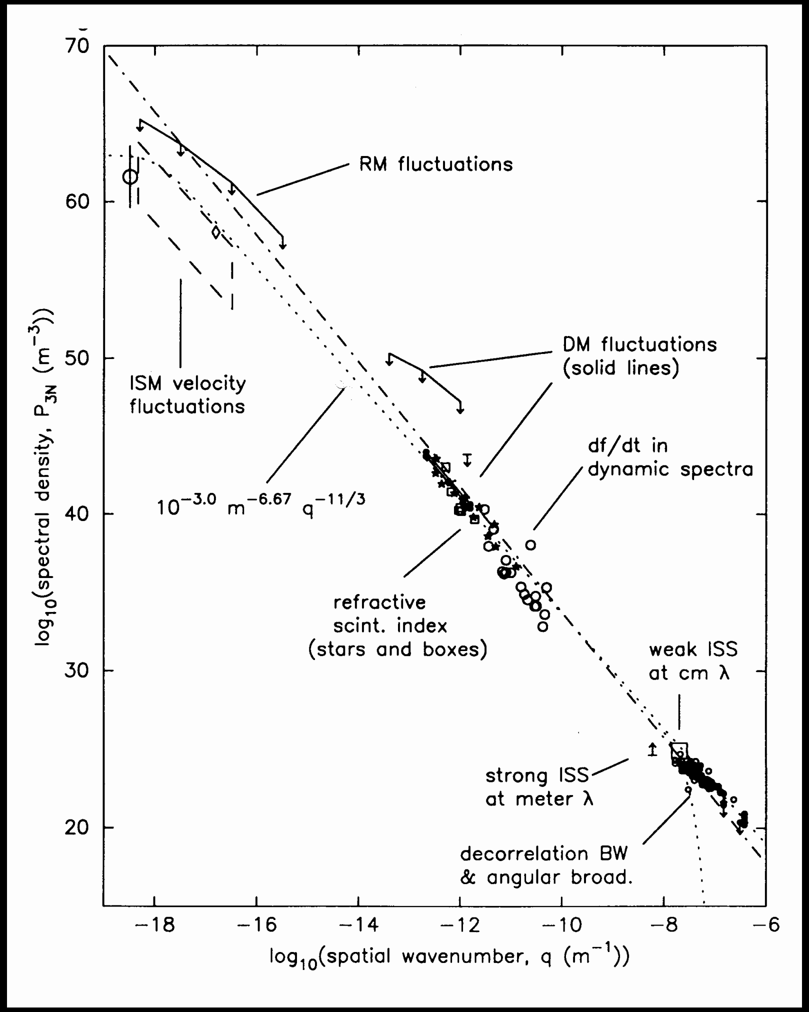
HYUNJU YOO, JUNGYEON CHO
CHUNGNAM NATIONAL UNIVERSITY
hyunju527@gmail.com

INTRODUCTION

* Astrophysical fluids
  - Magnetized & Turbulent
    (e.g Intracluster medium (ICM), Interstellar medium (ISM), solar winds)



ICM turbulence (Schuecker+04)

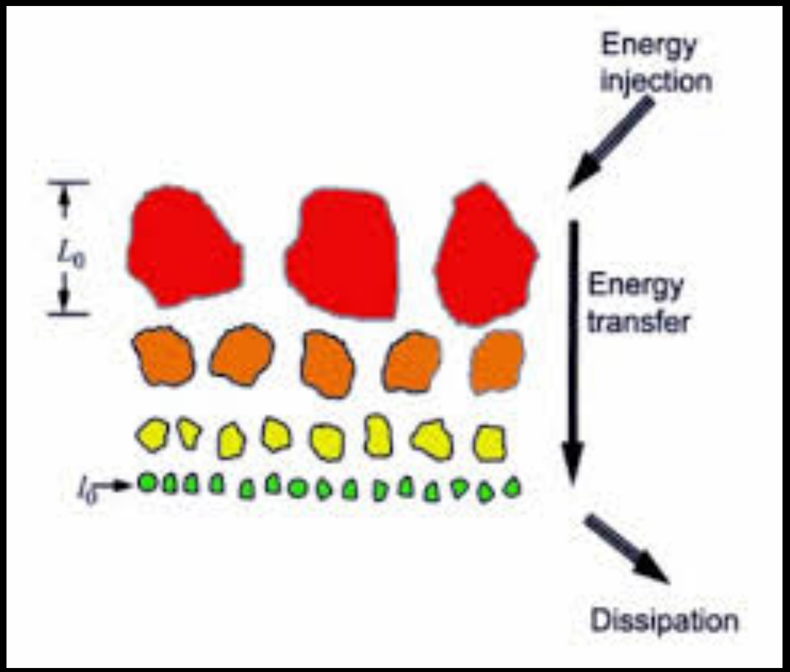


ISM turbulence (Armstrong+95)

INTRODUCTION

* Astrophysical fluids
  - Magnetized & **Turbulent**
    (e.g Intracluster medium (ICM), Interstellar medium (ISM), solar winds)

* Energy cascade of turbulence
  - Energy injection (driving) is required



INTRODUCTION

Magnetized

Turbulent

fluids

Energy injection

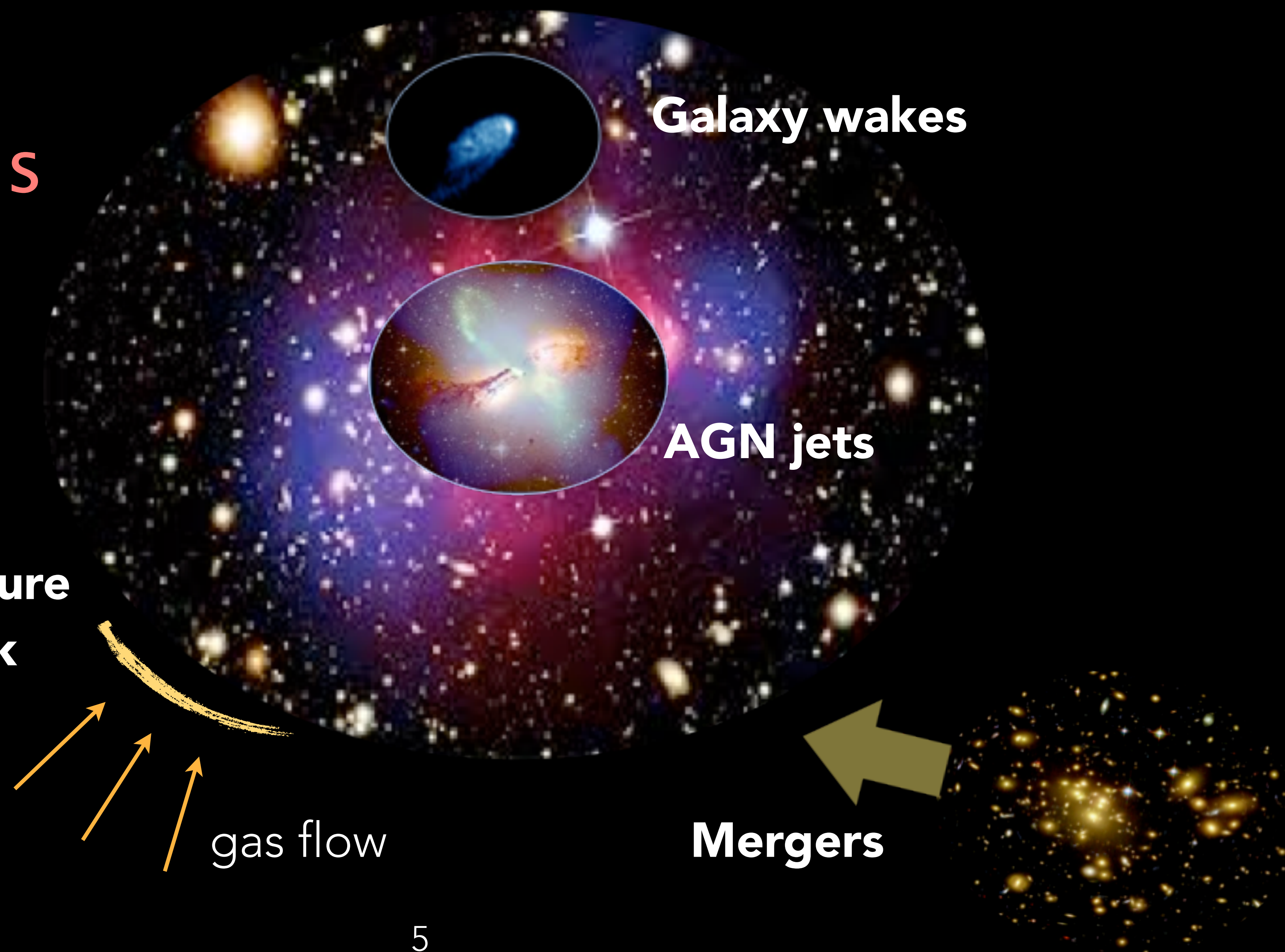
Numerical simulations of driven MHD turbulence

INTRODUCTION

* Various energy injection scales in ICM turbulence

tens of kpc ~ hundreds of kpc

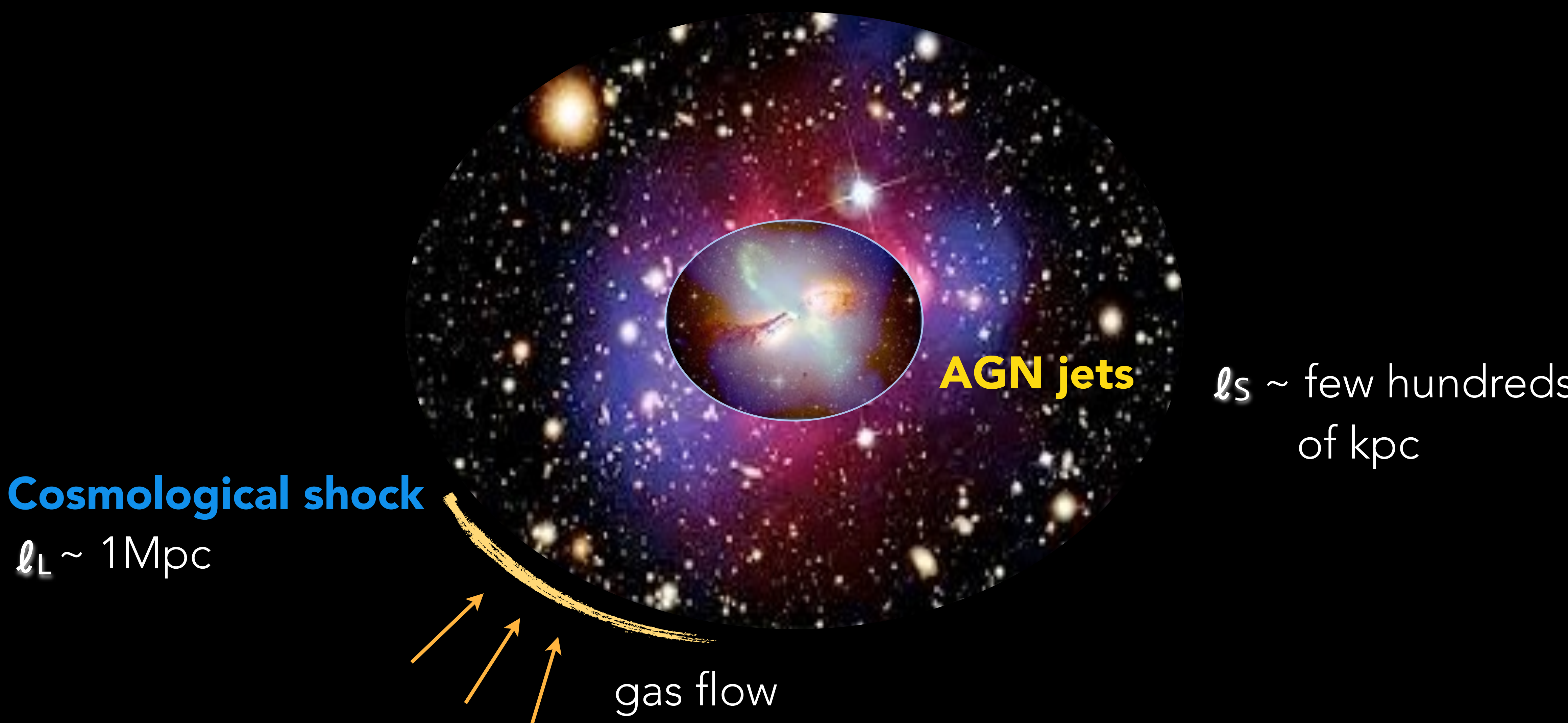
Simultaneous effect



NUMERICAL METHOD

* Assumption (two-scale driving on ICM turbulence)

- Weakly magnetized medium
- Scale difference ~ order of magnitude
- Driving is dominant at small-scale ($\epsilon_S >> \epsilon_L$)



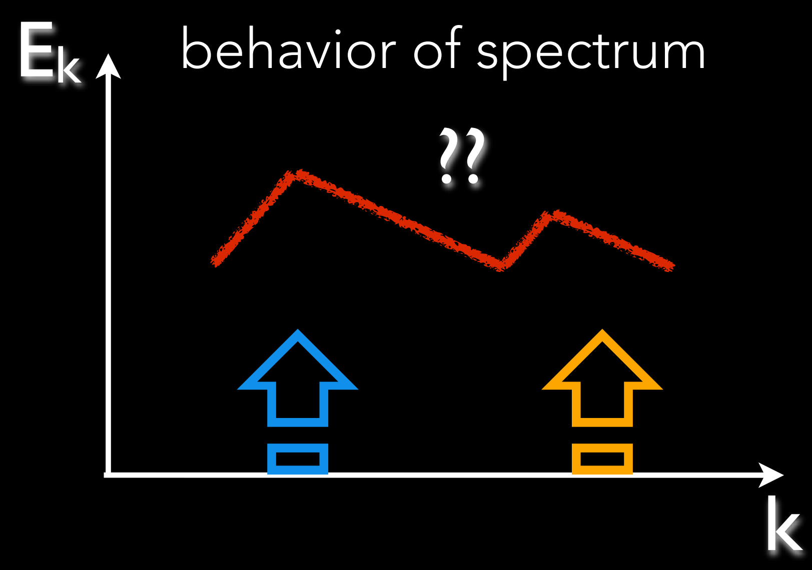
NUMERICAL METHOD

* Incompressible MHD turbulence simulations

- Pseudo-spectral code
- Resolution : 256^3 grids
- External magnetic field B_0=0.001 (weak) (in the same unit as the Alfven speed)

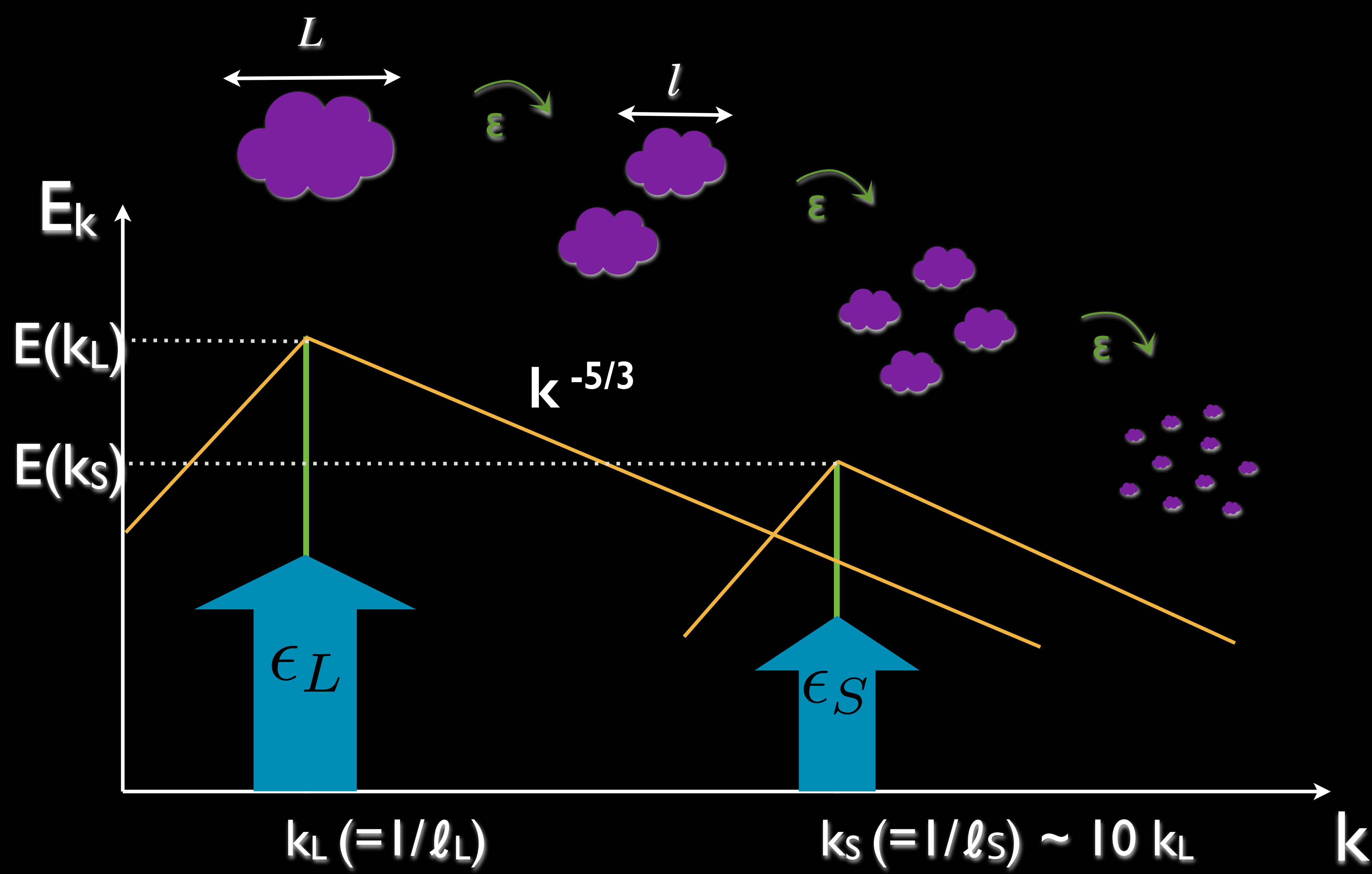
* Driving (injecting energy)

- Driven at two ranges in Fourier space
  - large-scale random forcing in $2<k<\sqrt{12}$
  - small-scale random forcing in $15<k<26$



NUMERICAL METHOD

* Spectrum of turbulence model driven at two scales



ANALYTIC EXPECTATION

* Expected scaling relation

According to Kolmogorov's theory (Kolmogorov 1941)

$$v = (\epsilon l)^{\frac{1}{3}} \;\; \& \;\; k \sim 1/l \quad \Longrightarrow \quad \frac{v_L}{v_S} = \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{1}{3}} \left(\frac{l_L}{l_S}\right)^{\frac{1}{3}} = \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{1}{3}} \left(\frac{k_S}{k_L}\right)^{\frac{1}{3}}$$

An approximation,

$$v \approx \sqrt{kE(k)} \quad \Longrightarrow \quad \frac{v_L}{v_S} \approx \frac{\sqrt{k_L E(k_L)}}{\sqrt{k_S E(k_S)}} = \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{1}{3}} \left(\frac{k_S}{k_L}\right)^{\frac{1}{3}}$$

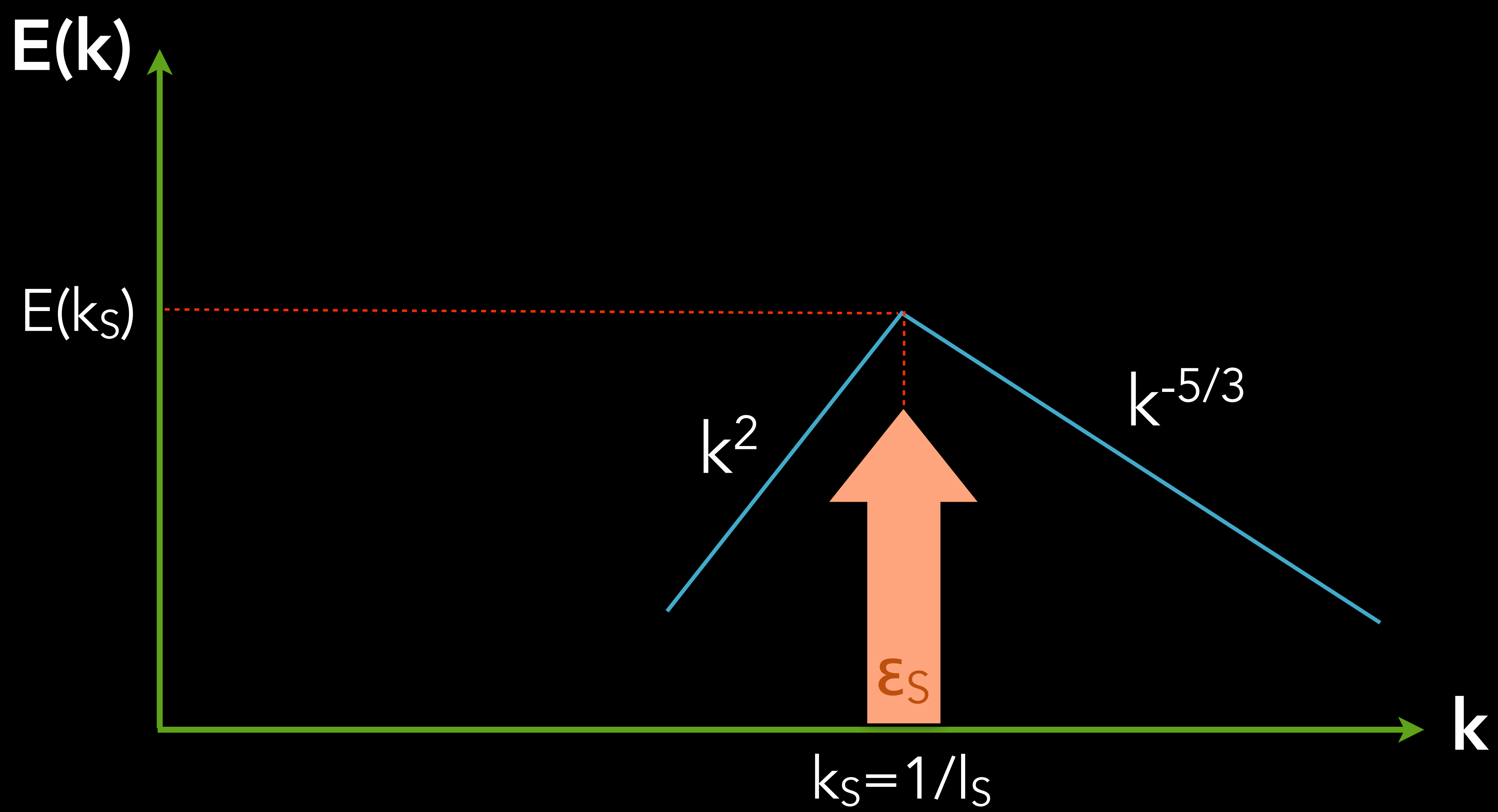
$$\frac{E(k_L)}{E(k_S)} = \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{2}{3}} \left(\frac{k_S}{k_L}\right)^{\frac{5}{3}} \quad \Longrightarrow \quad \frac{E(k_L)}{E(k_S)} = 32 \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{2}{3}}$$

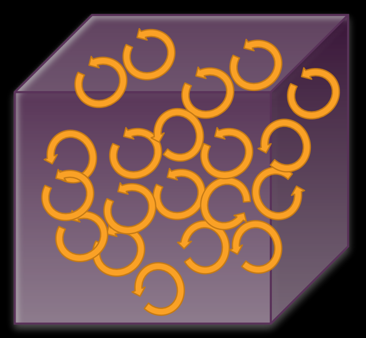
for our cases

$$\left(k_S \,/\, k_L = 8 \right)$$

OUR APPROACH

* Turbulence driven at one scale (small-scale driving)



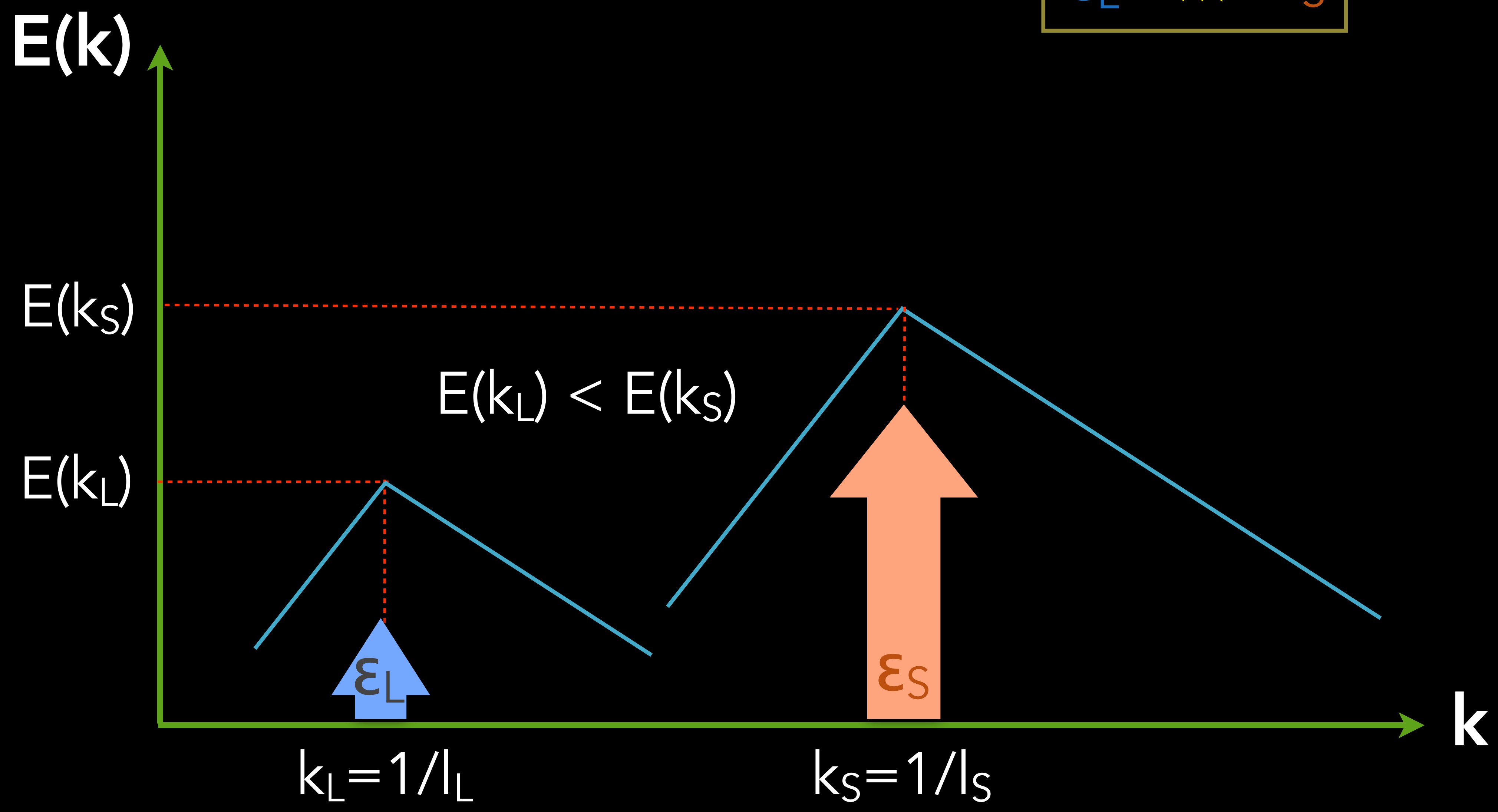


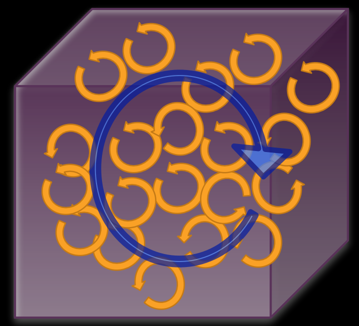
* *k_S ~ 20* for our simulations

OUR APPROACH

* Turbulence driven at two scales (large & small scale driving)

$\varepsilon_L \lll \varepsilon_S$



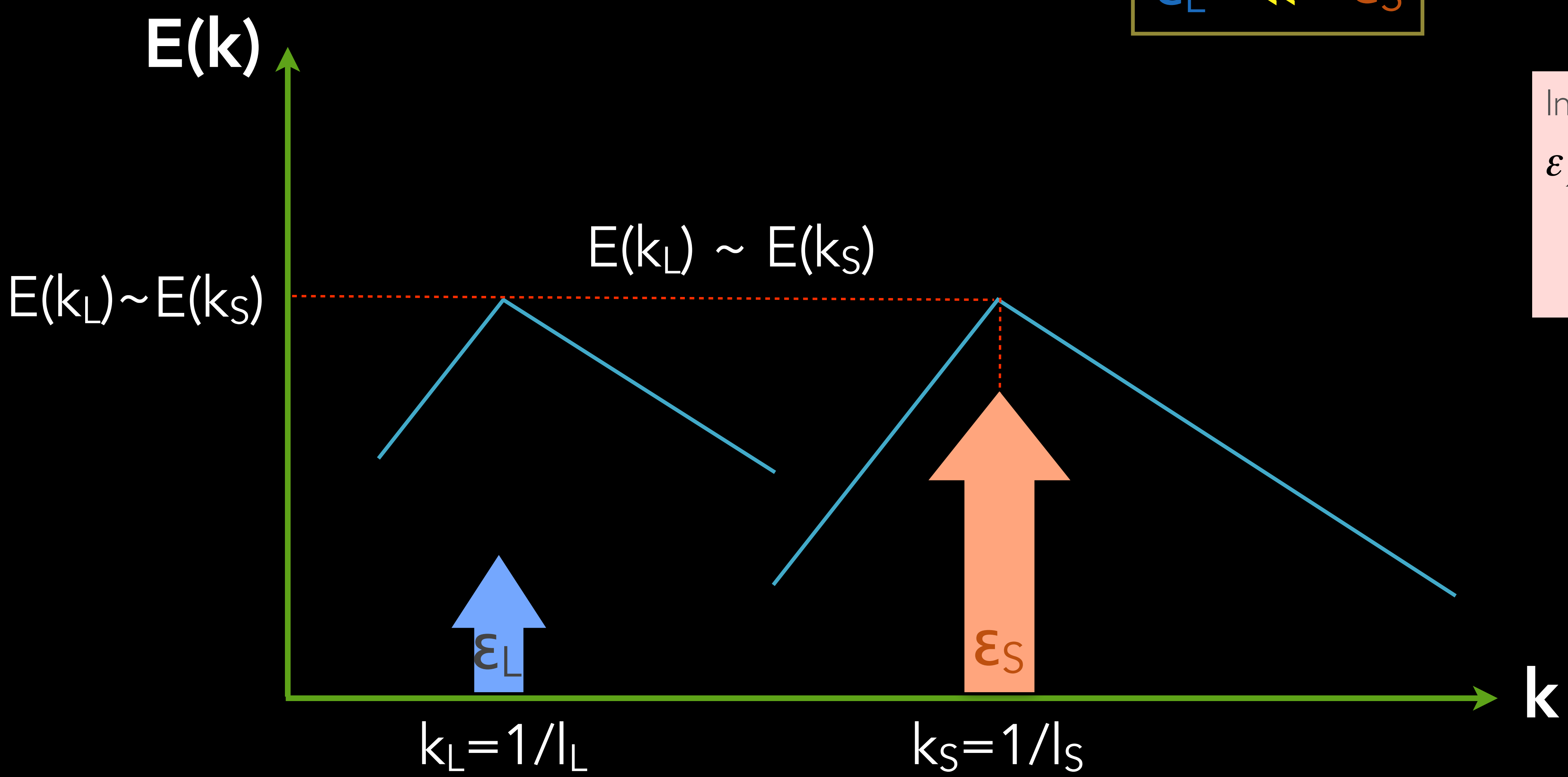


* $k_S \sim 20$, $k_L \sim 2.5$ } for our simulations

OUR APPROACH

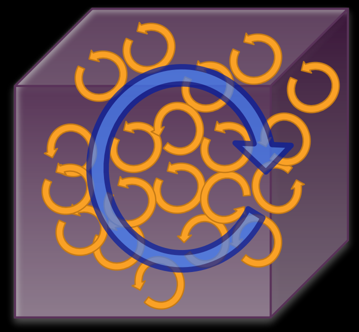
* Turbulence driven at two scales (large & small scale driving)

$\varepsilon_L \ll \varepsilon_S$



In our cases,

$$\varepsilon_L / \varepsilon_S \sim (k_L / k_S)^{2.5}$$
$$\sim (1/180)$$
$$\sim 0.0056$$

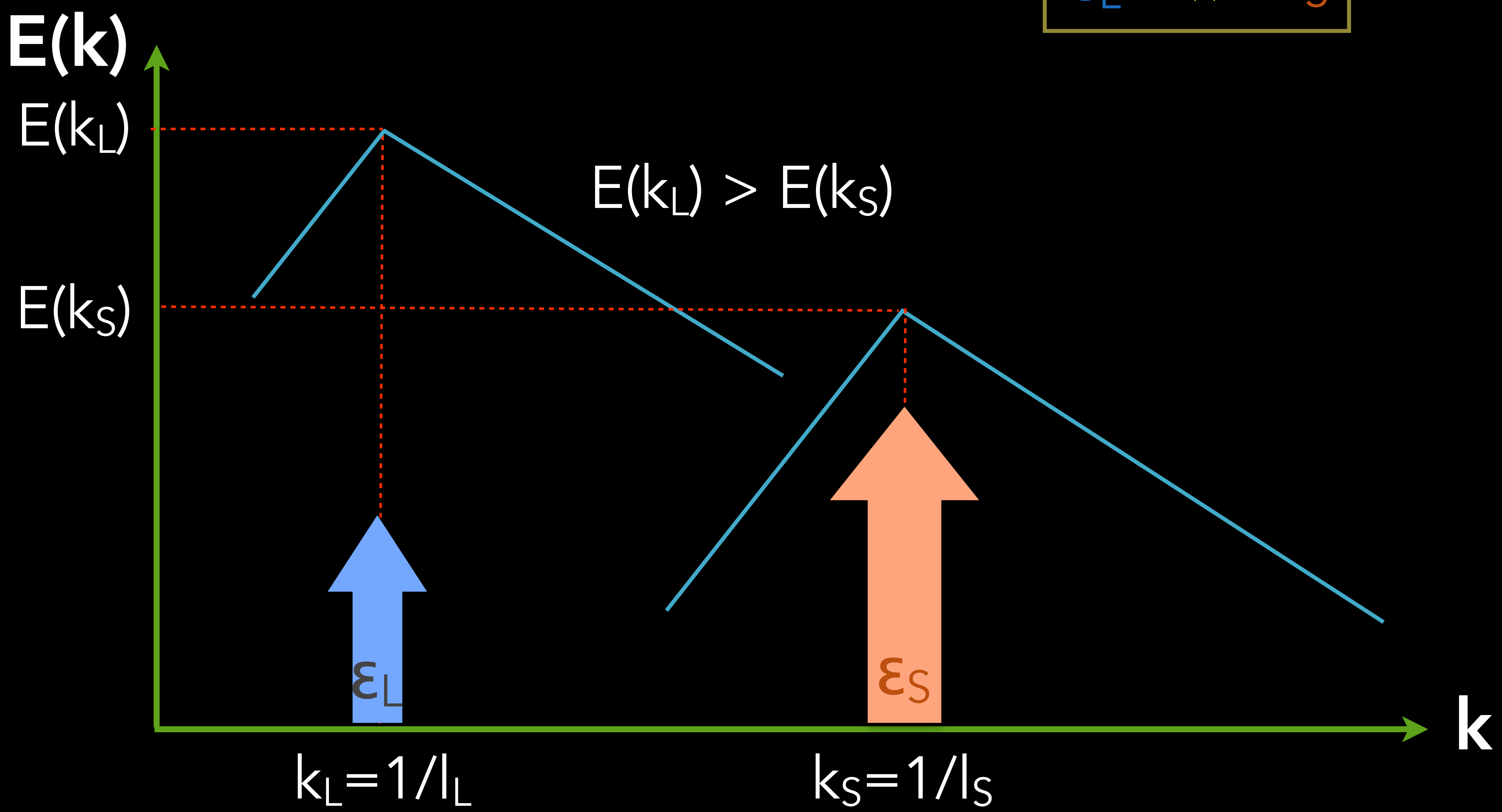


* $k_S \sim 20$, $k_L \sim 2.5$ } for our simulations

OUR APPROACH

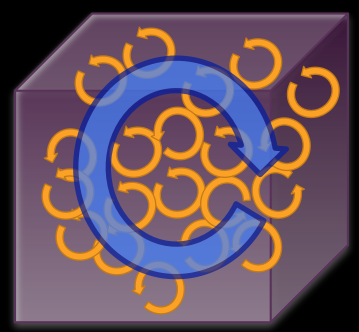
* Turbulence driven at two scales (large & small scale driving)

$\varepsilon_L \ll \varepsilon_S$



In our cases,

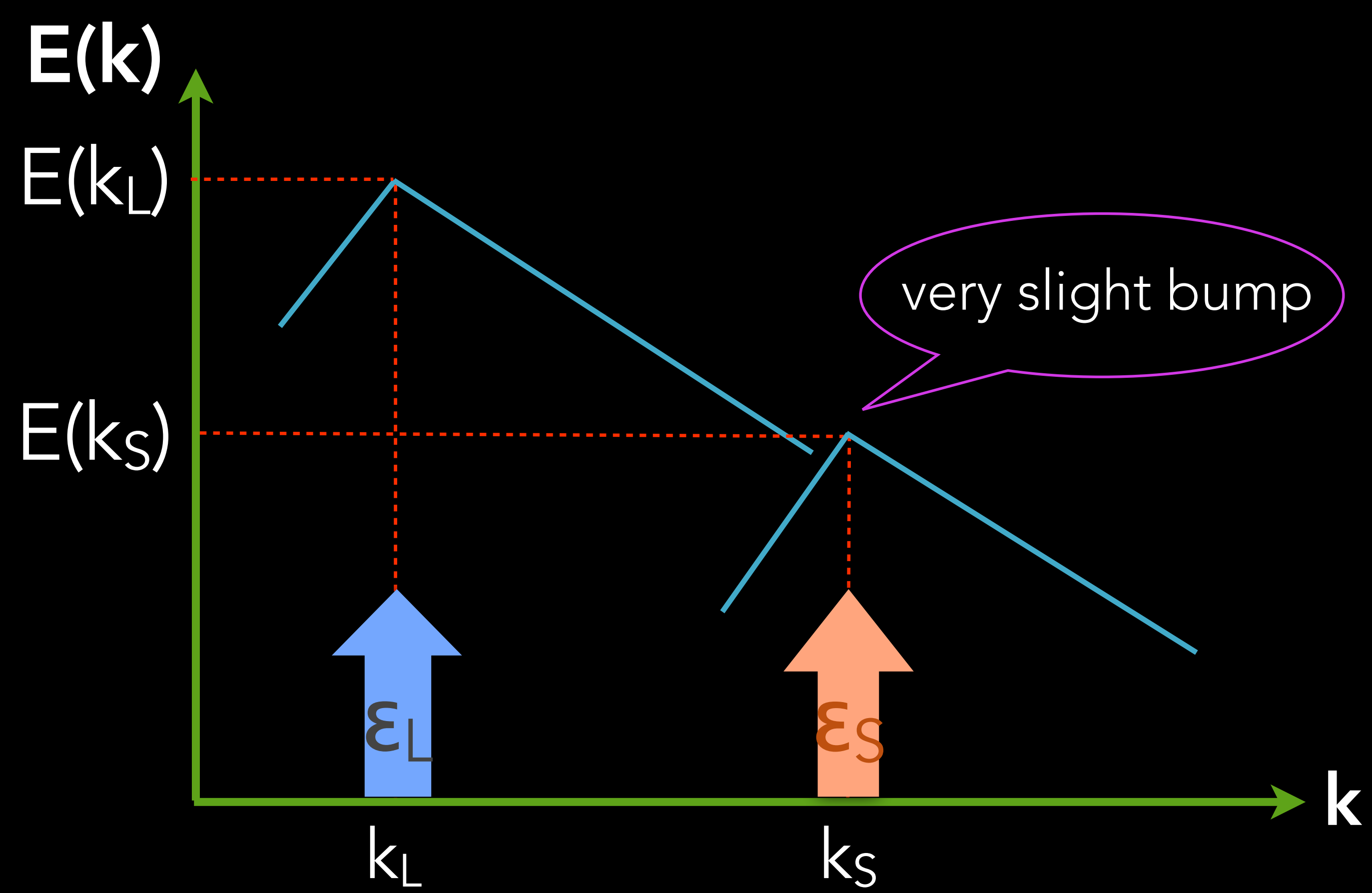
$\varepsilon_L / \varepsilon_S \geq 0.0056$



* $k_S \sim 20$
$k_L \sim 2.5$ } for our simulations

OUR APPROACH

* Turbulence driven at two scales (large & small scale driving)



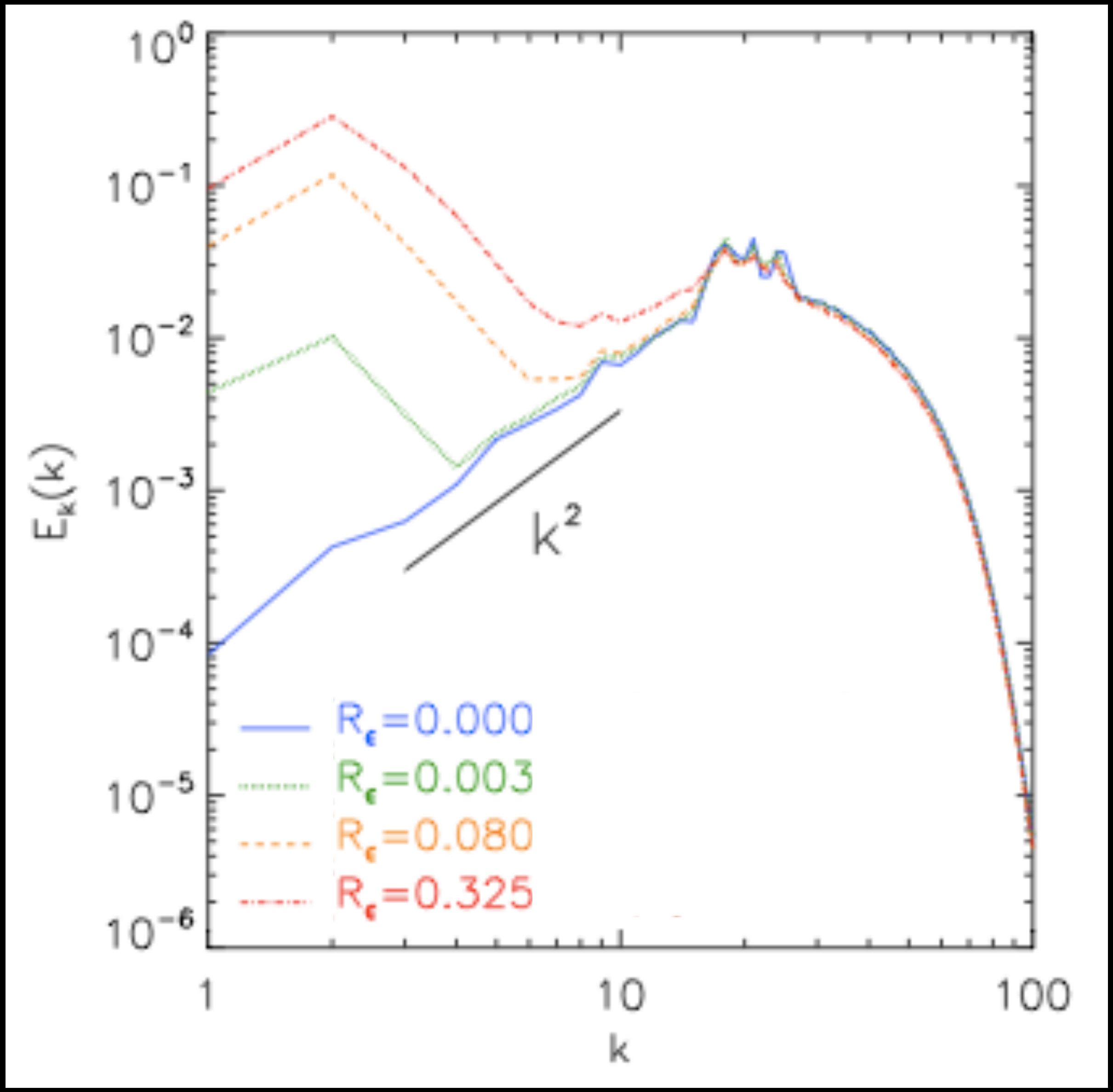
$\varepsilon_L \approx \varepsilon_S$

* If $\varepsilon_L > \varepsilon_S$, small-scale peak → invisible

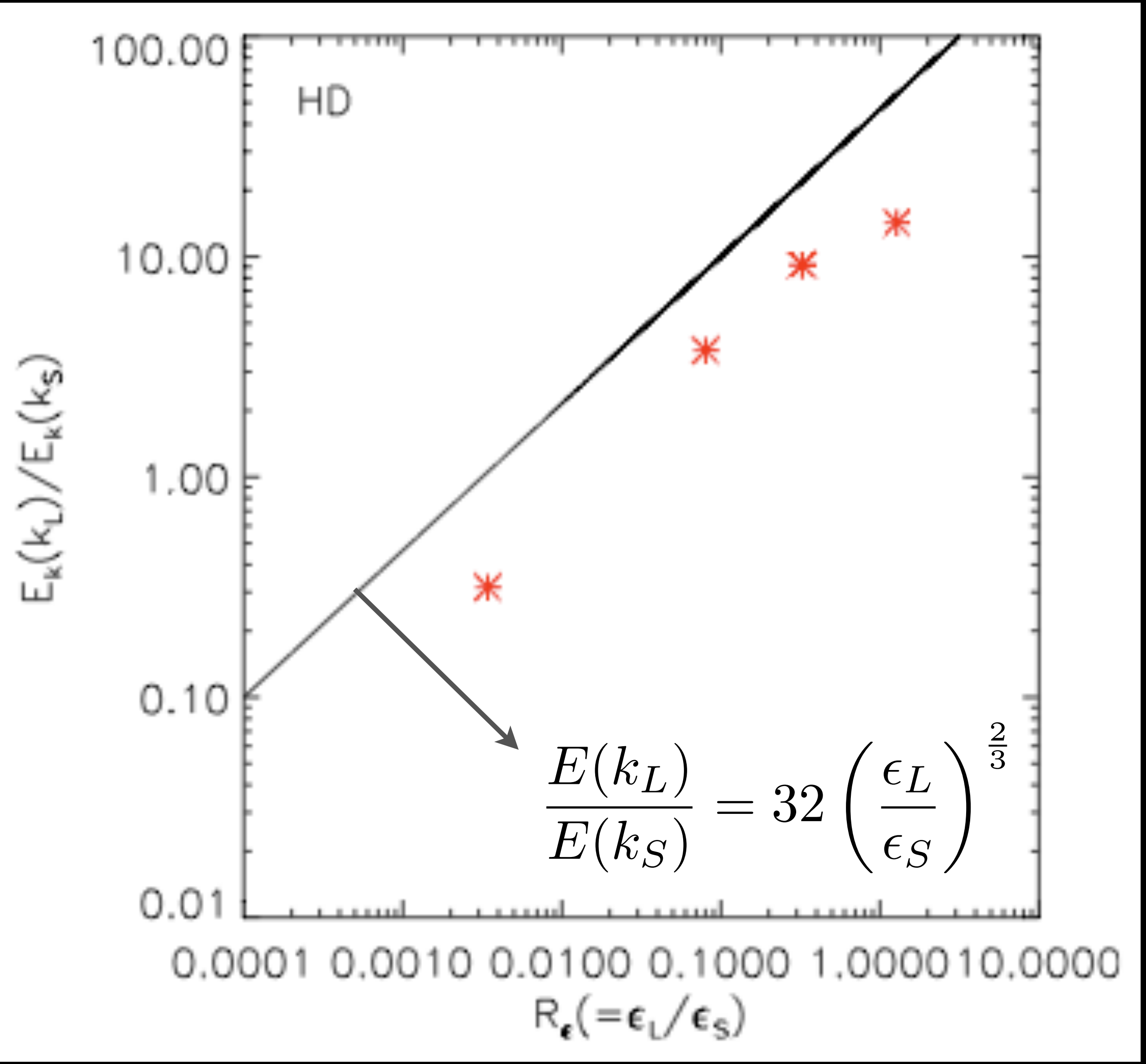
RESULTS

* Incompressible HD test

Kinetic spectra



Scaling relation for $E_k(k)$



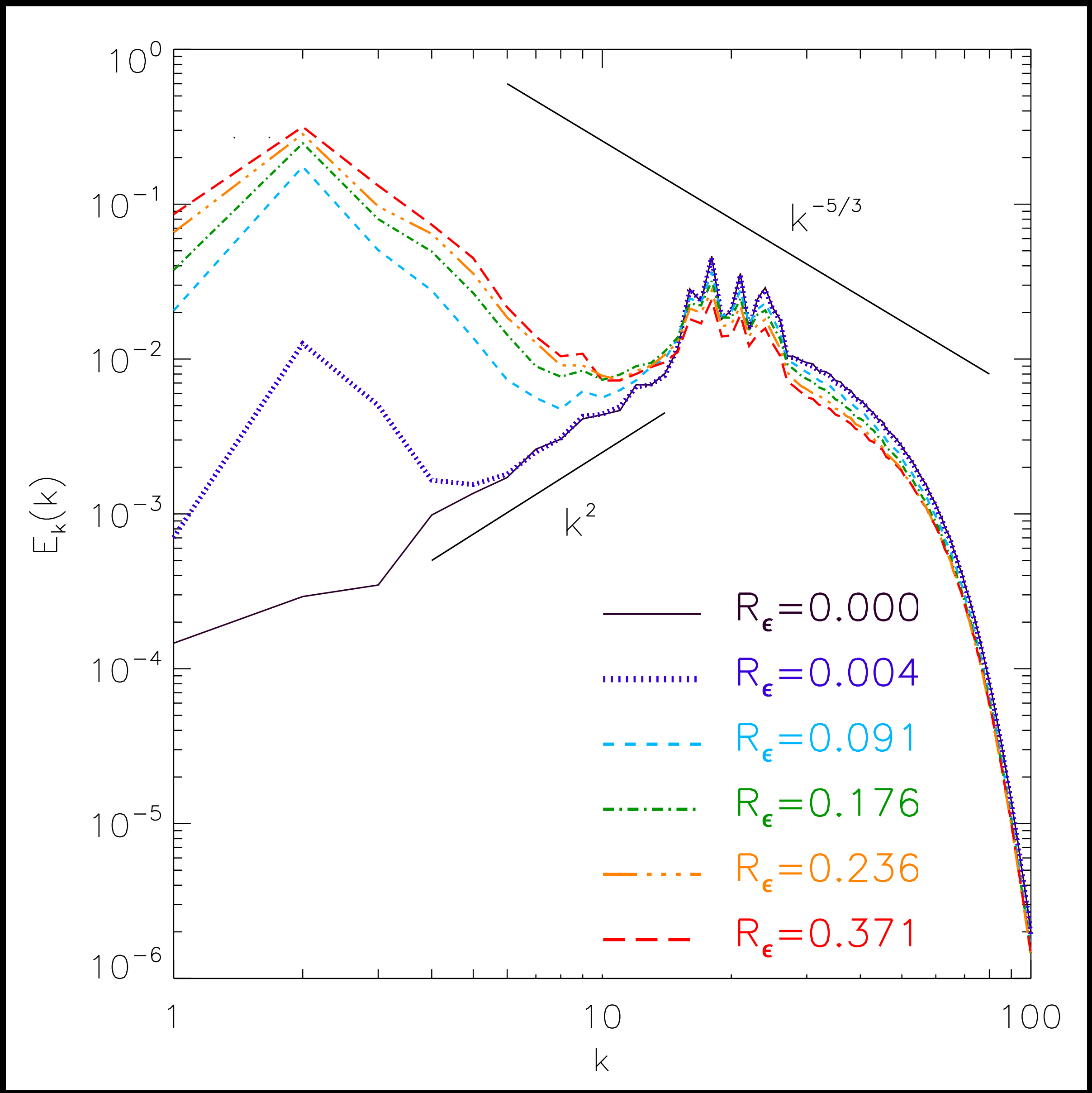
$R_\varepsilon = \varepsilon_L/\varepsilon_S$

Yoo & Cho 2014

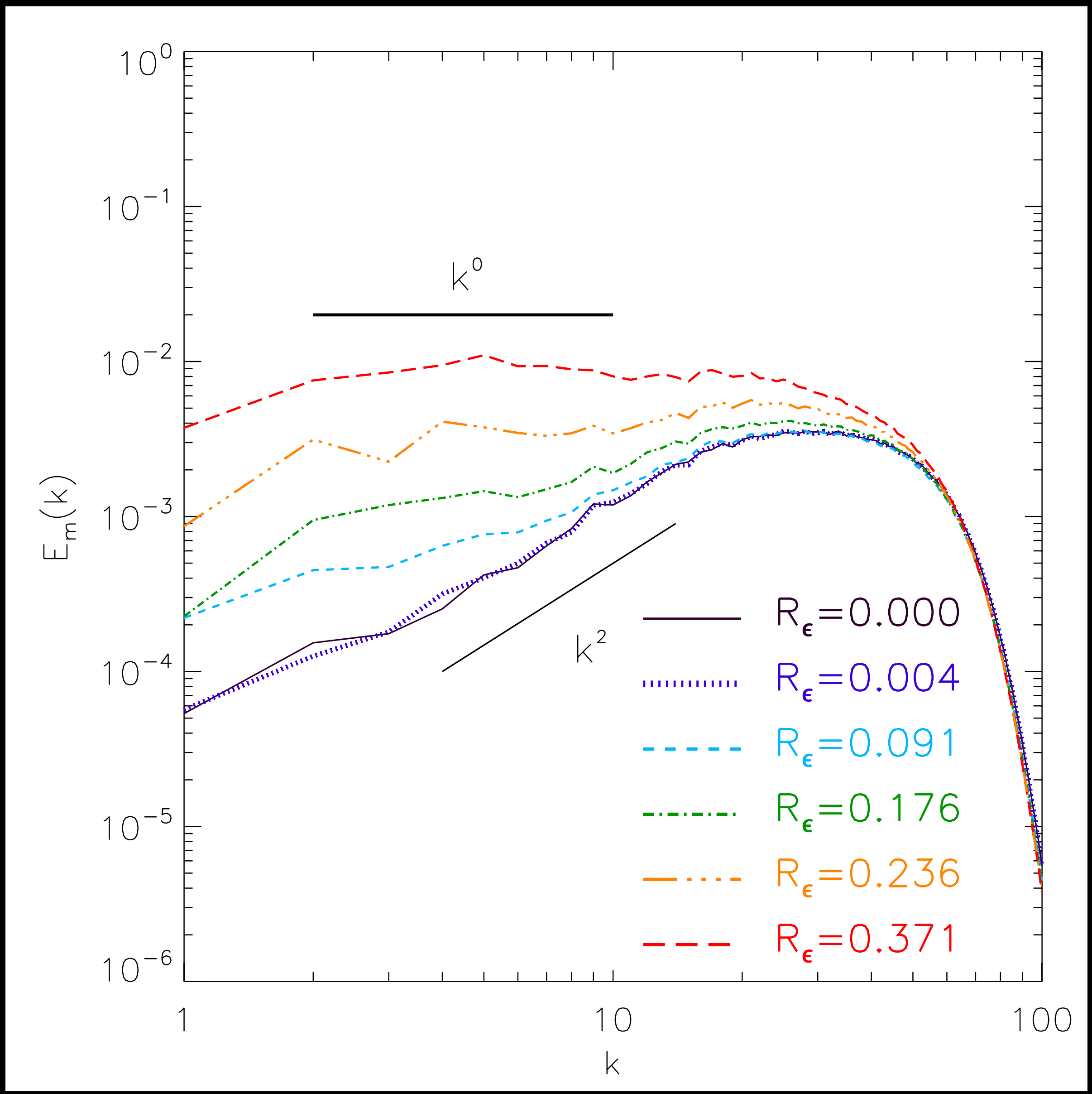
RESULTS

* Weakly-magnetized incompressible MHD simulations

Kinetic spectra



Magnetic spectra



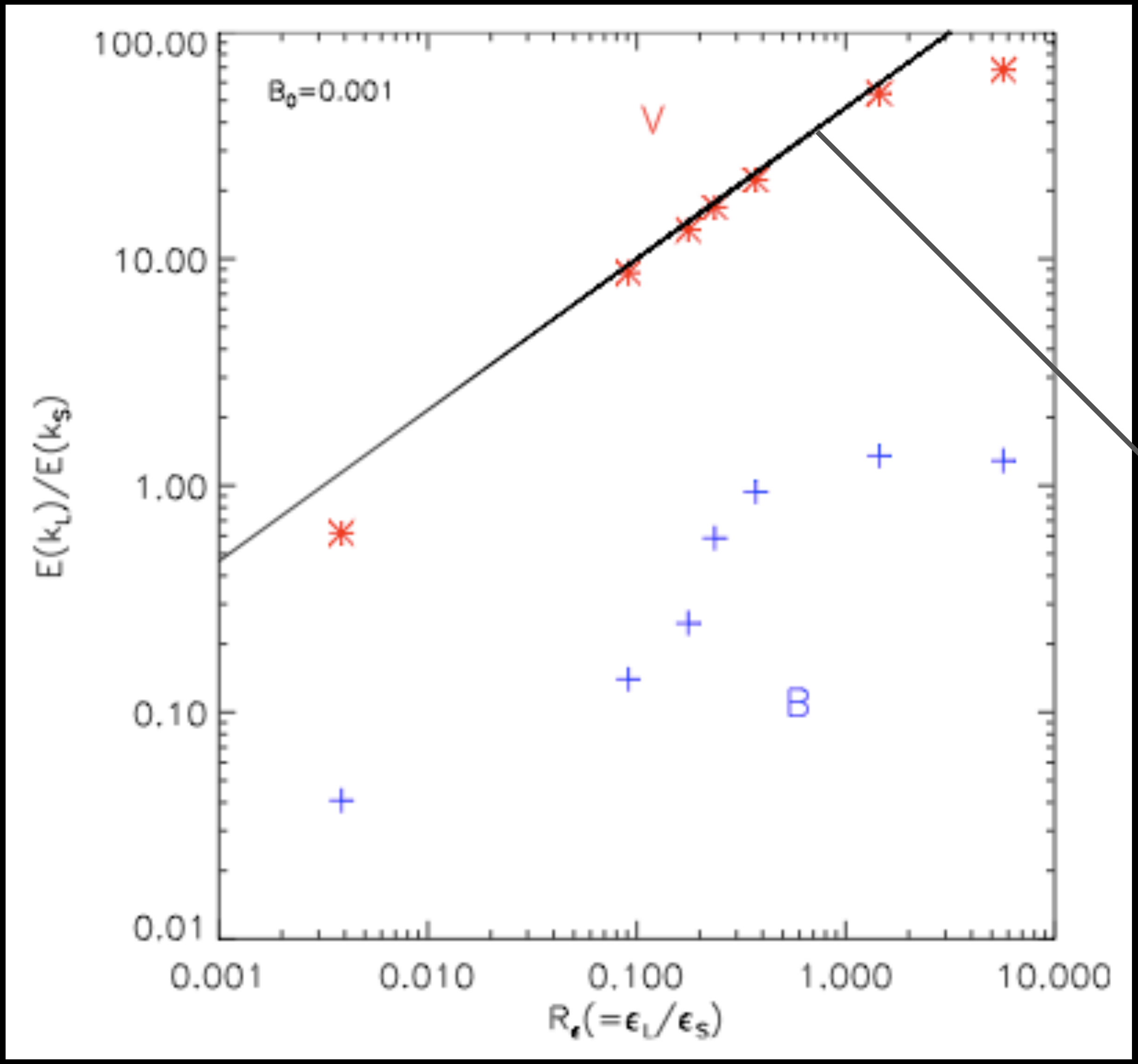
$R_\varepsilon = \varepsilon_L/\varepsilon_S$

Yoo & Cho 2014

RESULTS

* Weakly-magnetized incompressible MHD simulations

Scaling relation for $E_k(k)$ and $E_m(k)$



$R_\varepsilon = \varepsilon_L/\varepsilon_S$

Yoo & Cho 2014

$$\frac{E(k_L)}{E(k_S)} = \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{2}{3}} \left(\frac{k_S}{k_L}\right)^{\frac{5}{3}}$$

* k_S ~ 20, k_L ~ 2.5 } for our simulations

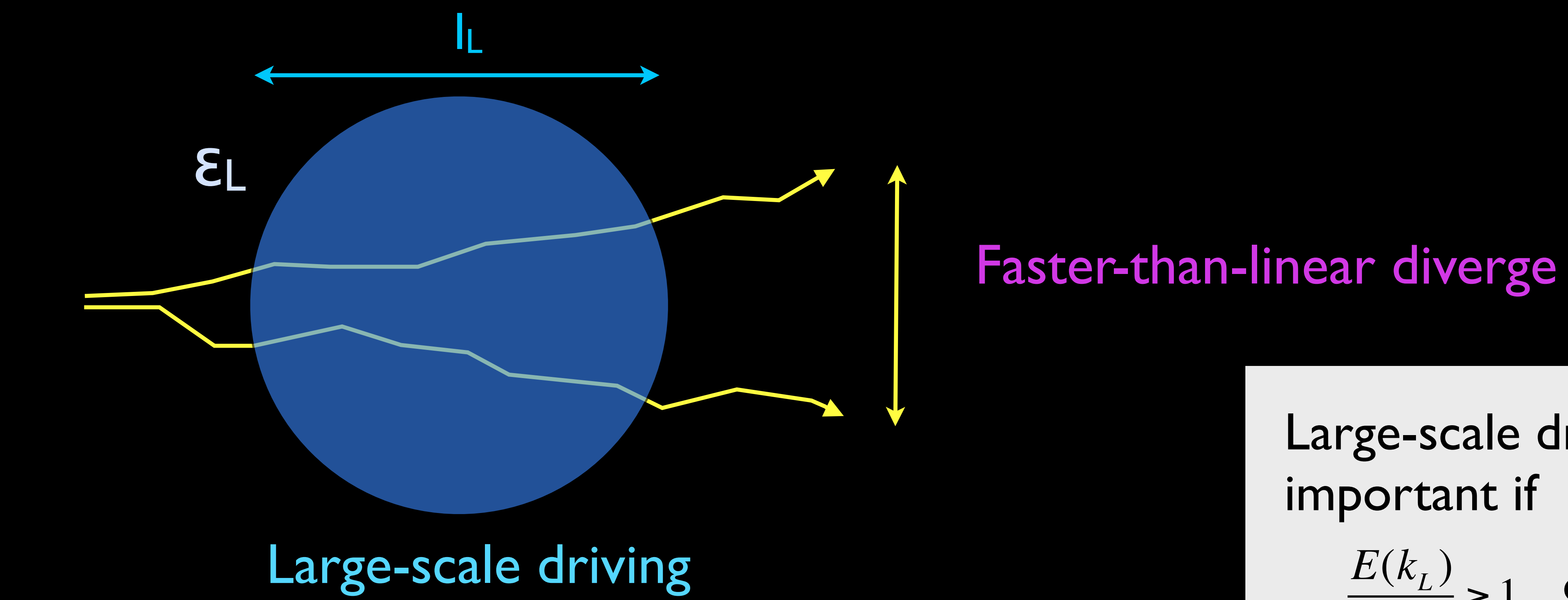
$$\frac{E(k_L)}{E(k_S)} = 32 \left(\frac{\epsilon_L}{\epsilon_S}\right)^{\frac{2}{3}}$$

∗ : for kinetic energy spectrum

+ : for magnetic energy spectrum

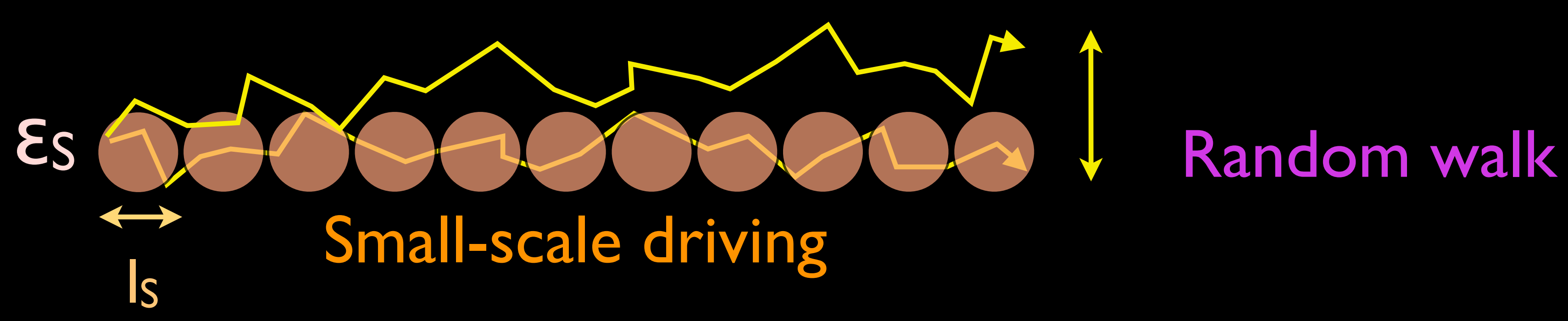
DISCUSSION

* Magnetic field-line divergence



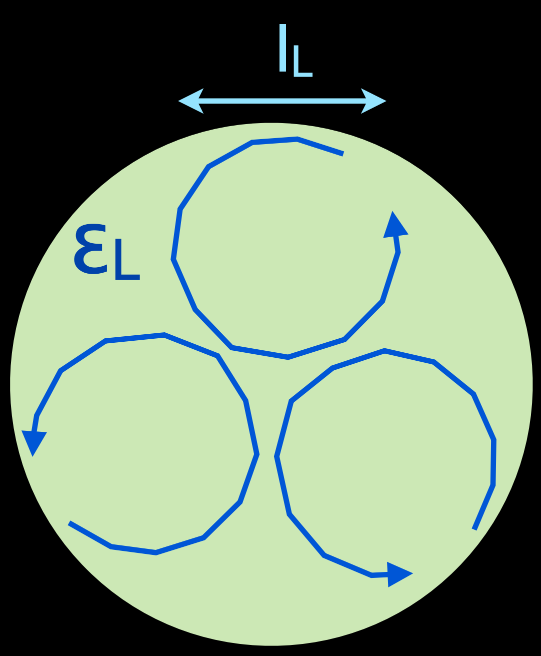
Large-scale driving is more important if

$$\frac{E(k_L)}{E(k_S)} \geq 1 \quad \text{or} \quad \frac{\varepsilon_L}{\varepsilon_S} \geq \left(\frac{l_S}{l_L}\right)^{5/2}$$

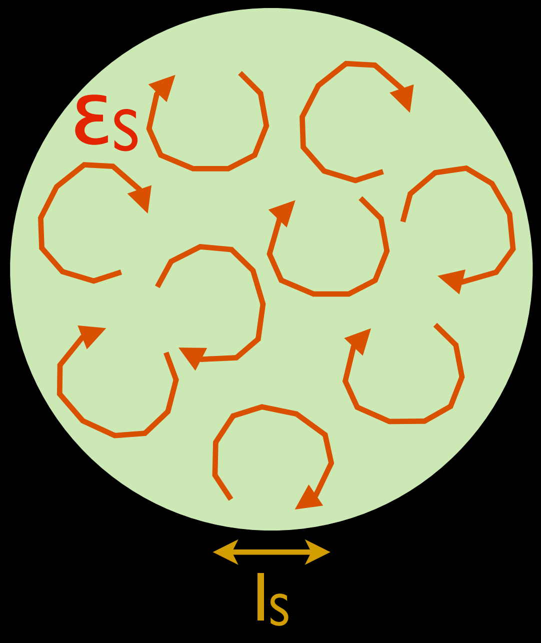


DISCUSSION

* Turbulence diffusion



Large-scale driving



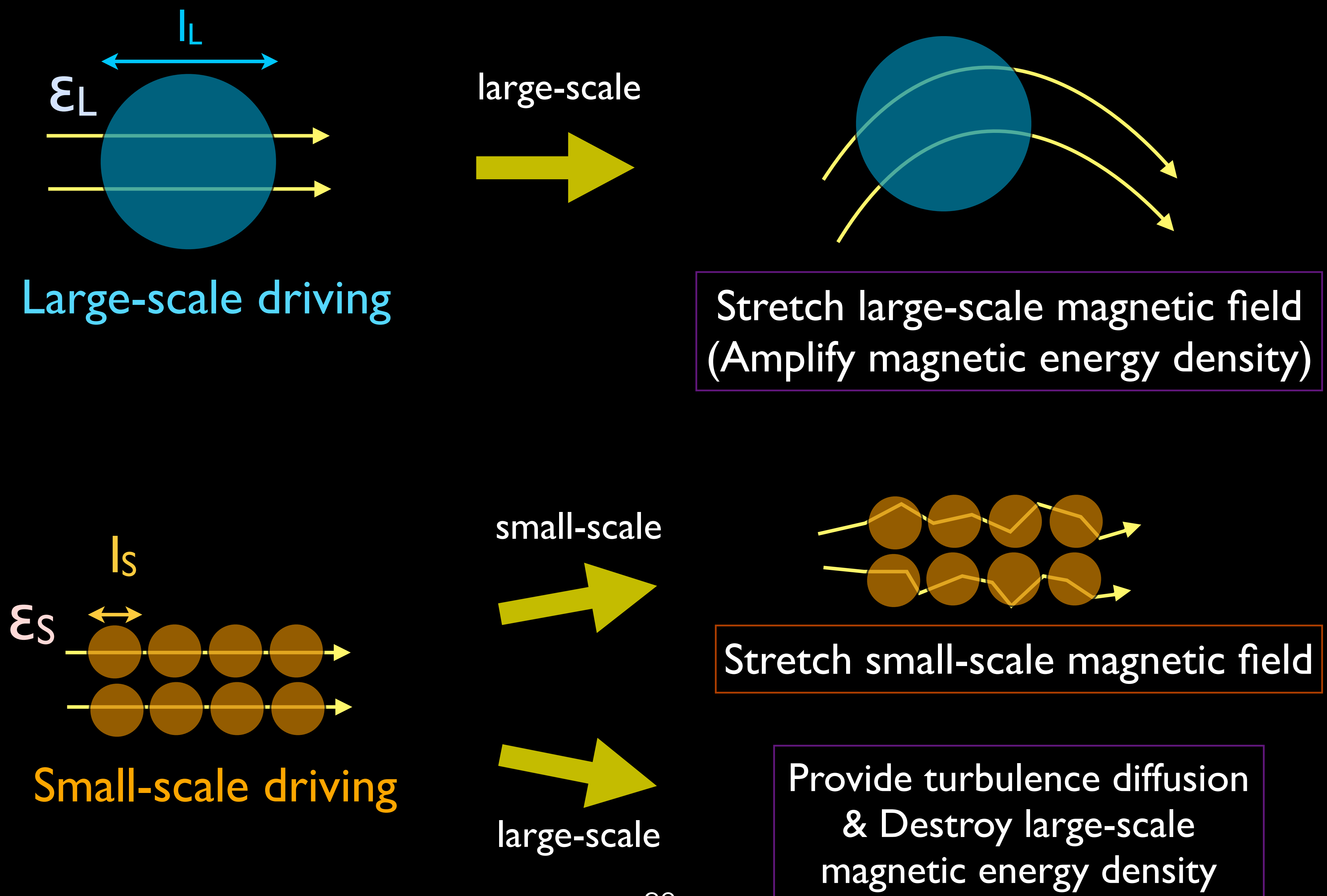
Small-scale driving

Large-scale driving is more important if

$$\frac{\varepsilon_L}{\varepsilon_S} \geq \left(\frac{l_S}{l_L}\right)^4$$

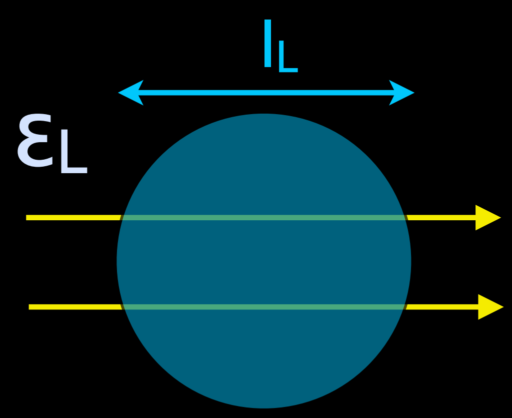
DISCUSSION

* Turbulence dynamo



DISCUSSION

* Turbulence dynamo



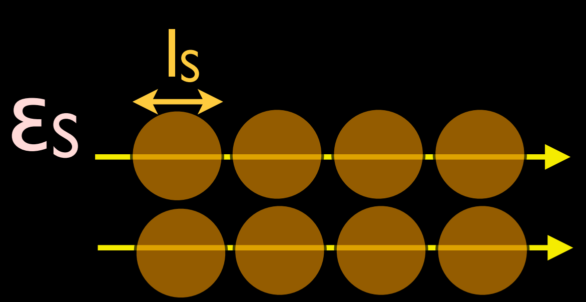
Large-scale driving

amplification rate of large-scale magnetic energy density by large-scale driving

$$\sim C v_L b_L^2 / l_L$$

Large-scale driving is more important if

$$\frac{v_L}{v_S} \geq \frac{l_S}{l_L} C^{-1} \quad \text{or} \quad \frac{\varepsilon_L}{\varepsilon_S} \geq \left(\frac{l_S}{l_L}\right)^4 C^{-3}$$



Small-scale driving

destroy rate of large-scale magnetic energy density by small-scale driving

$$\sim (l_S v_S) b_L^2 / l_L^2$$

CONCLUSION

- We studied the effects of two-scale driving

- Kinetic energy spectrum shows two peaks

  ⇒ $E(k_L) \gtrsim E(k_S)$, even if $\epsilon_L \ll \epsilon_S$

- Two-scale driving affect several physical properties

  (e.g. magnetic field-line divergence, turbulence diffusion and turbulence dynamo)

  ⇒ Large-scale driving can be more important, even if $\epsilon_L \ll \epsilon_S$

- More detailed results are presented in Yoo & Cho 2014 ApJ, 178, 99

  (including compressible simulations & large-scale driving dominant cases)

THANK YOU :)