Turbulence and Origin of Cosmic Magnetic Fields

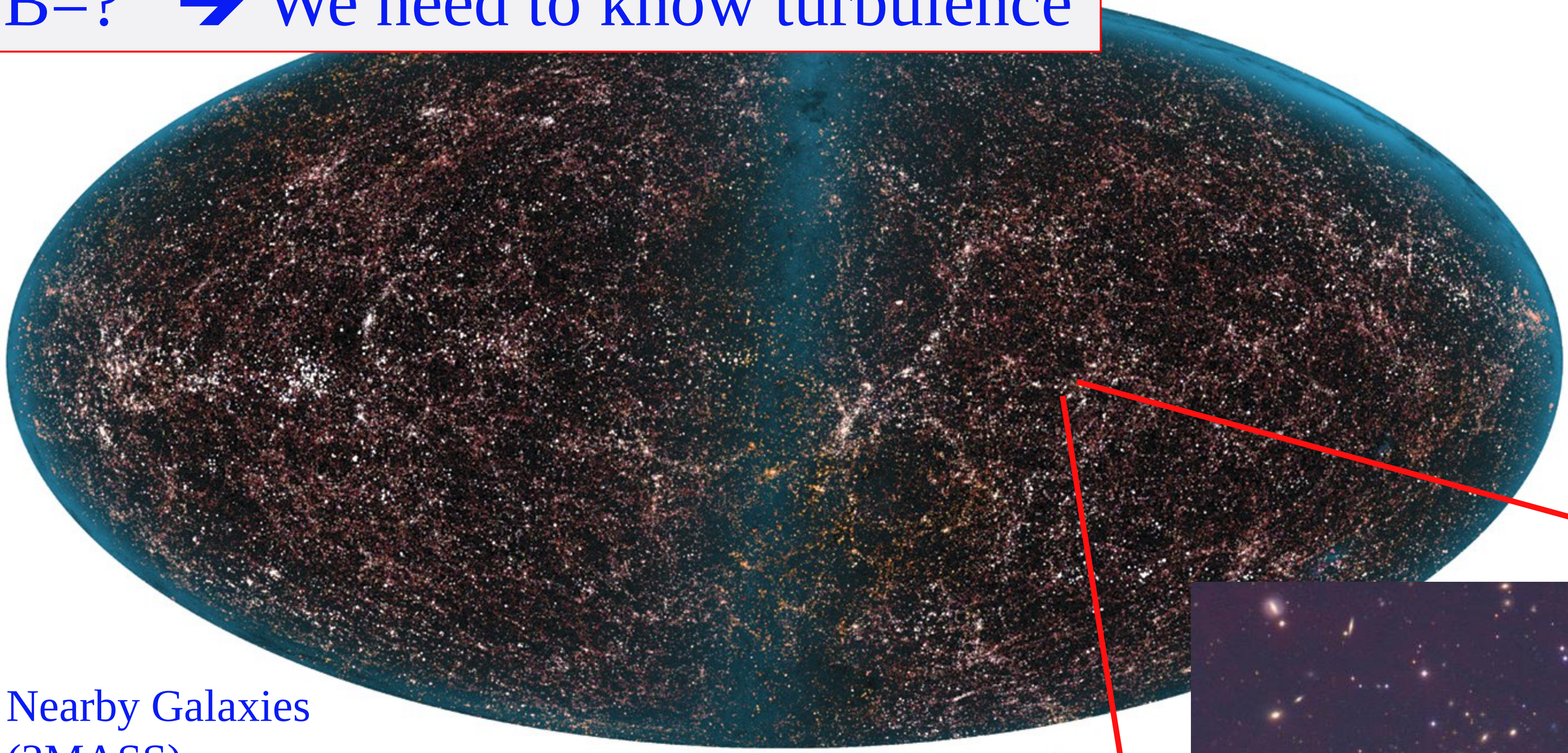
<Turbulence dynamo in clusters and filaments>

Jungyeon Cho (趙, 政衍)

(CNU, South Korea)

Cho, Vishniac, Beresnyak, Lazarian, & Ryu 2009
Cho & Yoo (2012; ApJ)
Cho (2013; PRD)
Cho (2014; submitted)

B=? ➔ We need to know turbulence



Nearby Galaxies
(2MASS)

Weak seed field ➔ Strong B

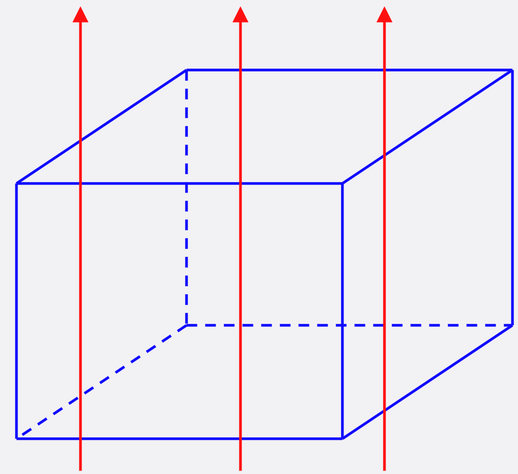
↑

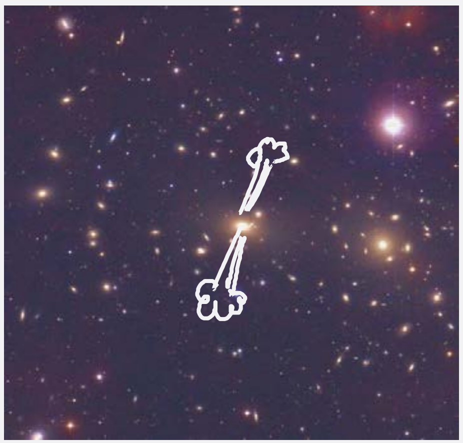
Turbulence

Origin of cosmic seed magnetic fields is uncertain.

Primordial?

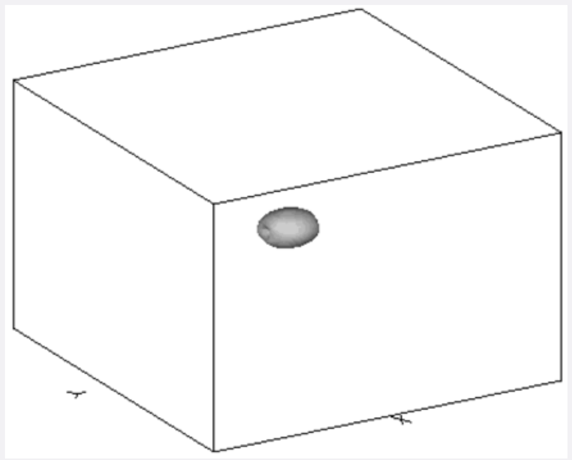
Weak uniform seed field





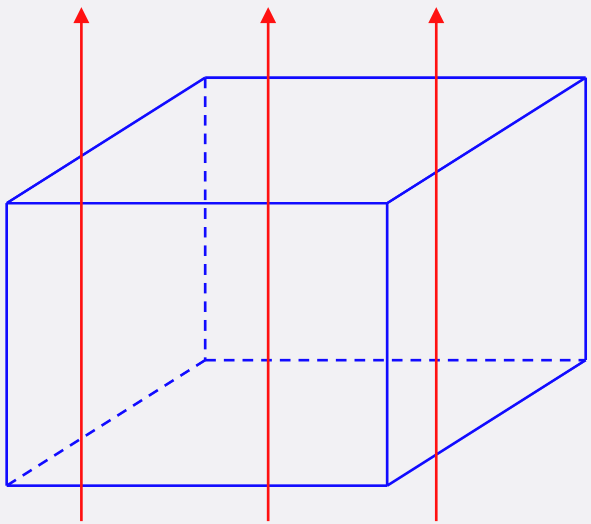
Astrophysical?

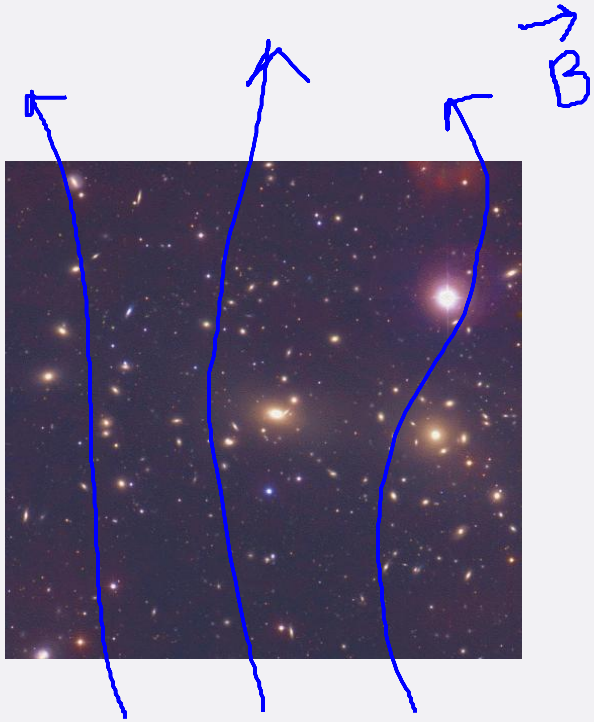
Weak localized seed field



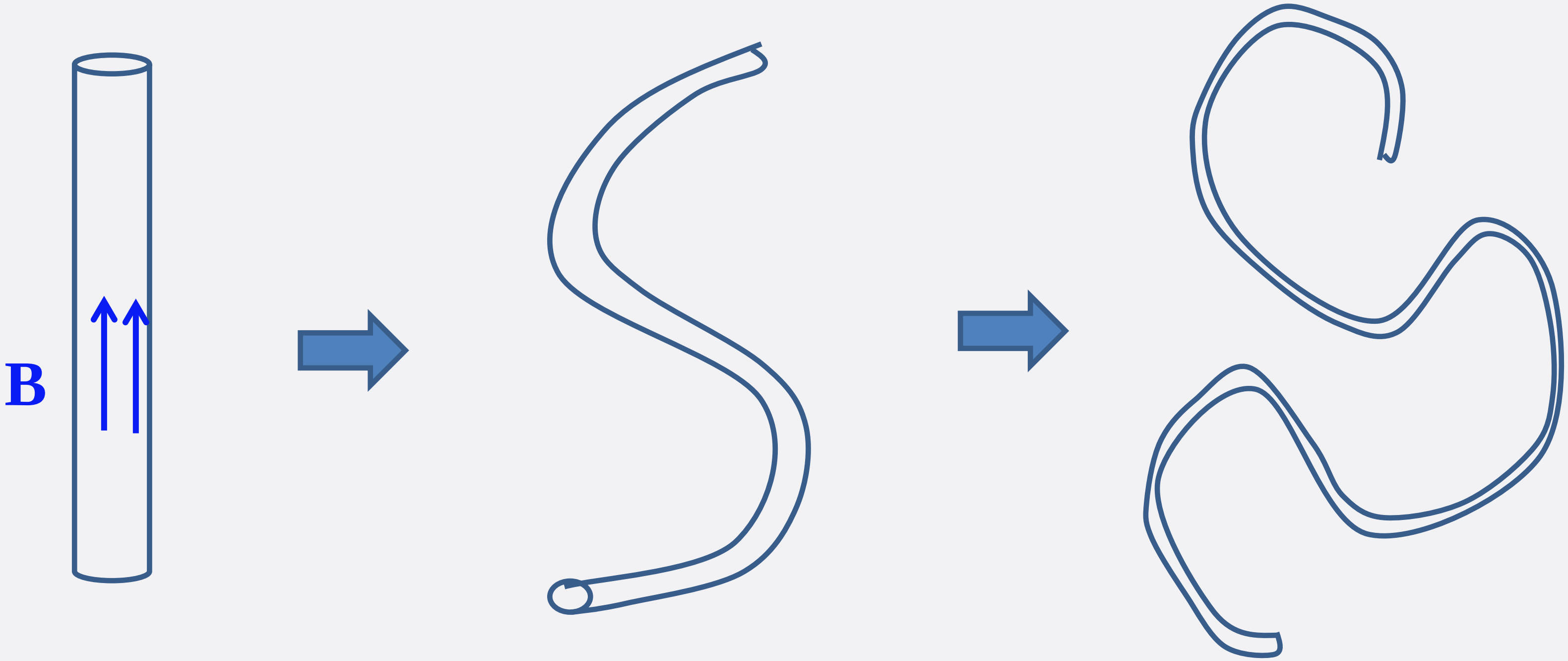
Topic 1. Amplification of a uniform seed field in turbulence

Weak seed field (B_0)





Key Process = Stretching!

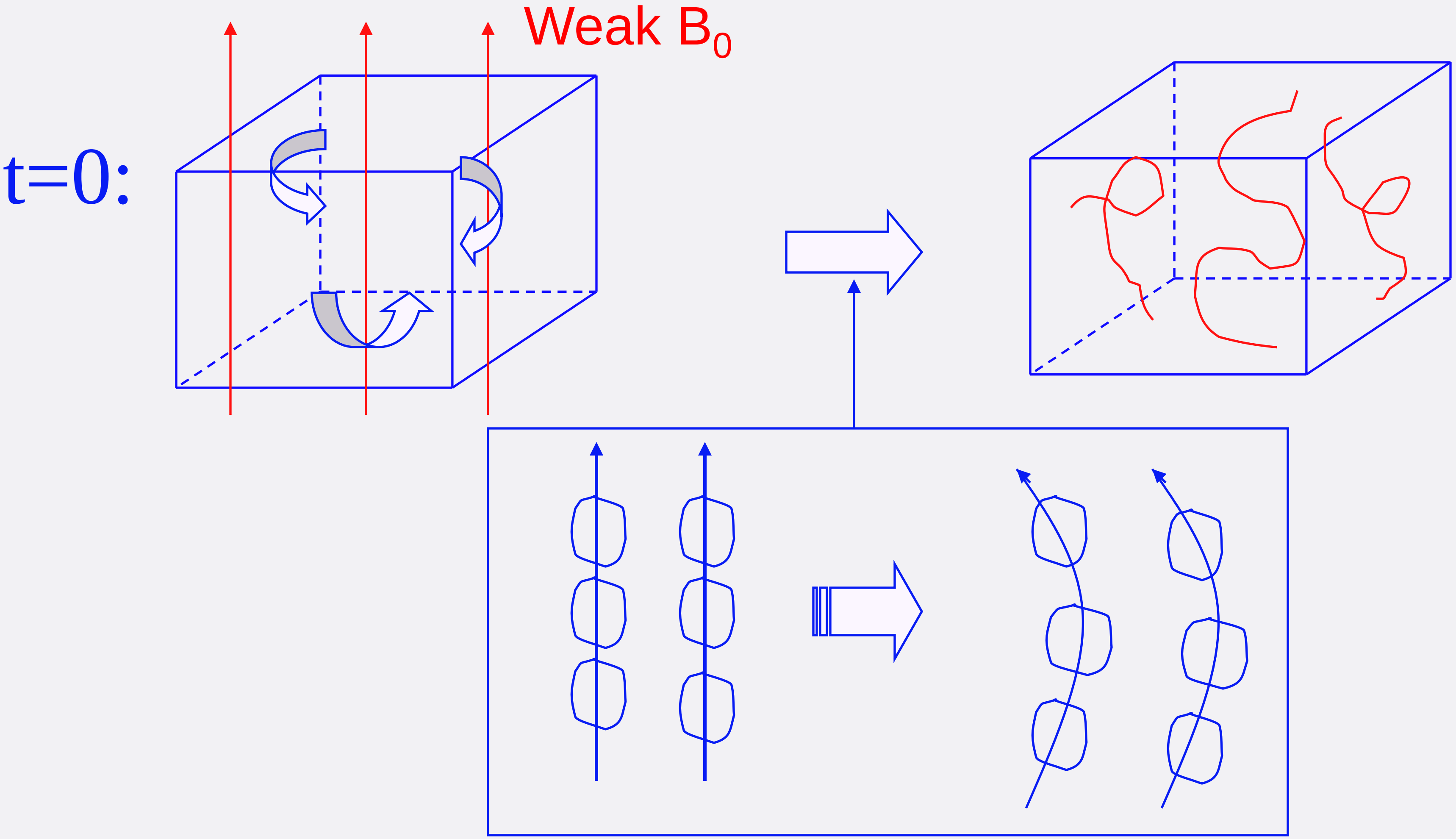


Magnetic flux tube

⇨ B(t) ∝ length

*In this talk, I'll assume incompressibility

Stretching of field lines

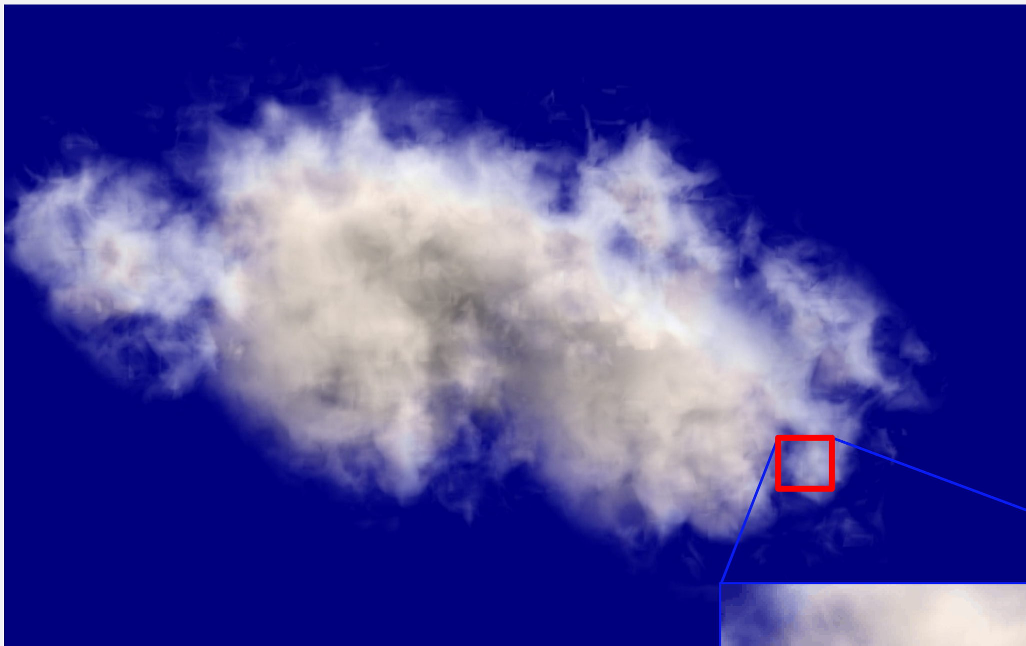


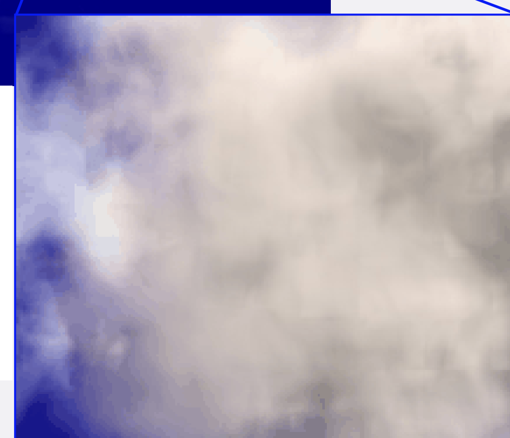
Fluid elements and field lines move together

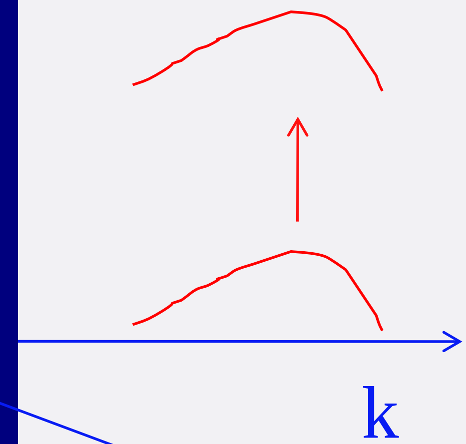
*Back reactions are negligible if $E_{mag} < E_{kin}$

Expectations:

Stretching on the dissipation scale will occur first because eddy turnover time is shortest there





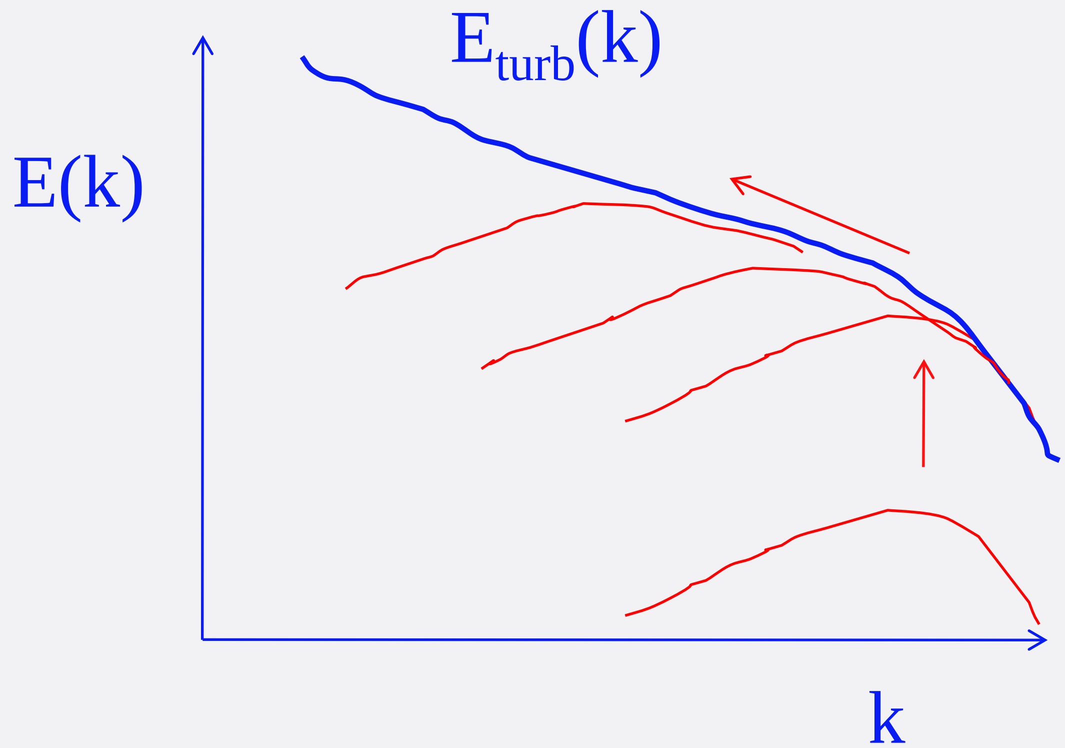


growth

1950)

Small-scale structures change faster

Expectations:



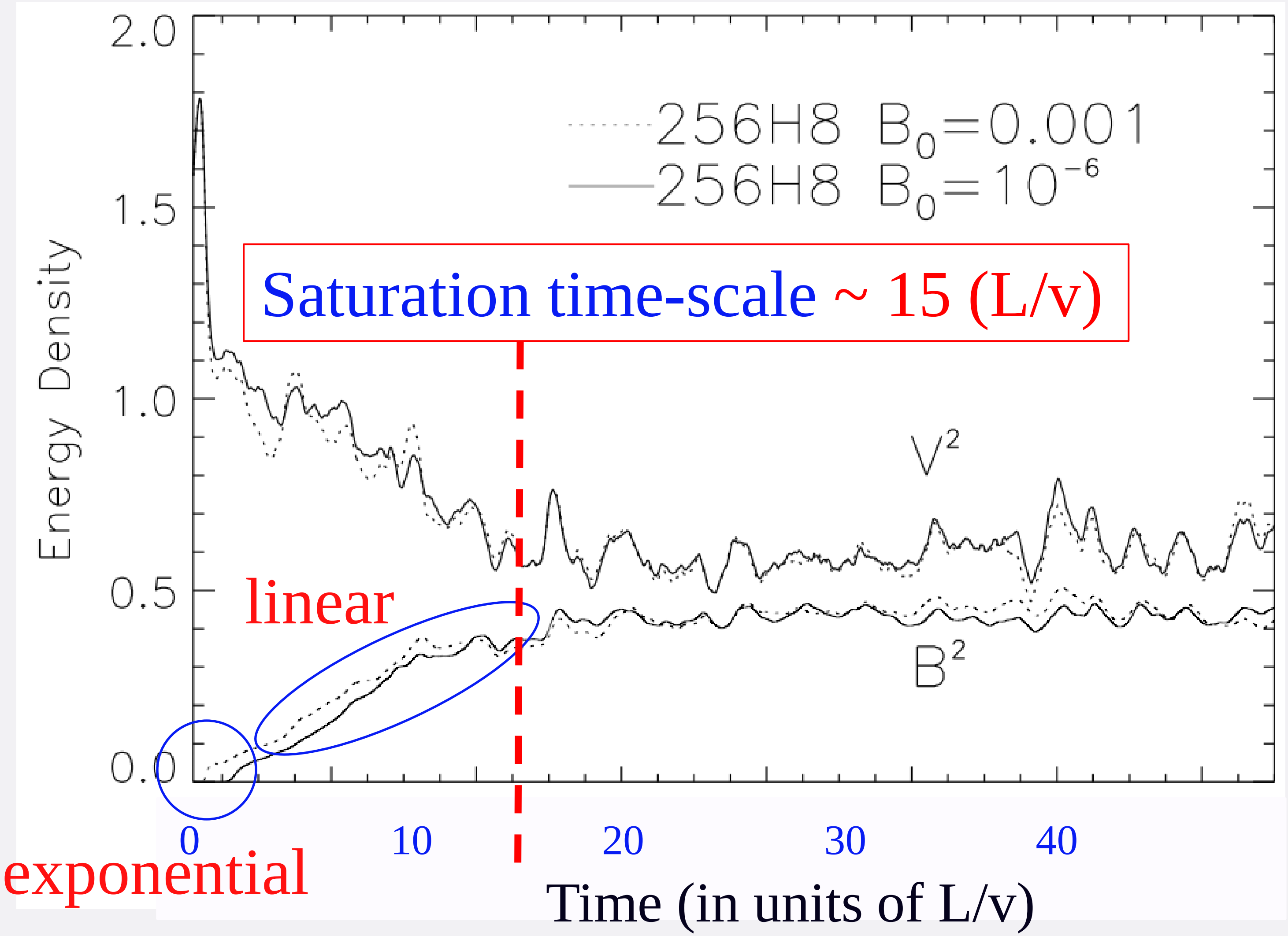
What will happen when $E_{turb} \sim E_{mag}$ on the dissipation scale?

➔ Exponential growth stage will end!

➔ Stretching scale gradually moves to larger scales.

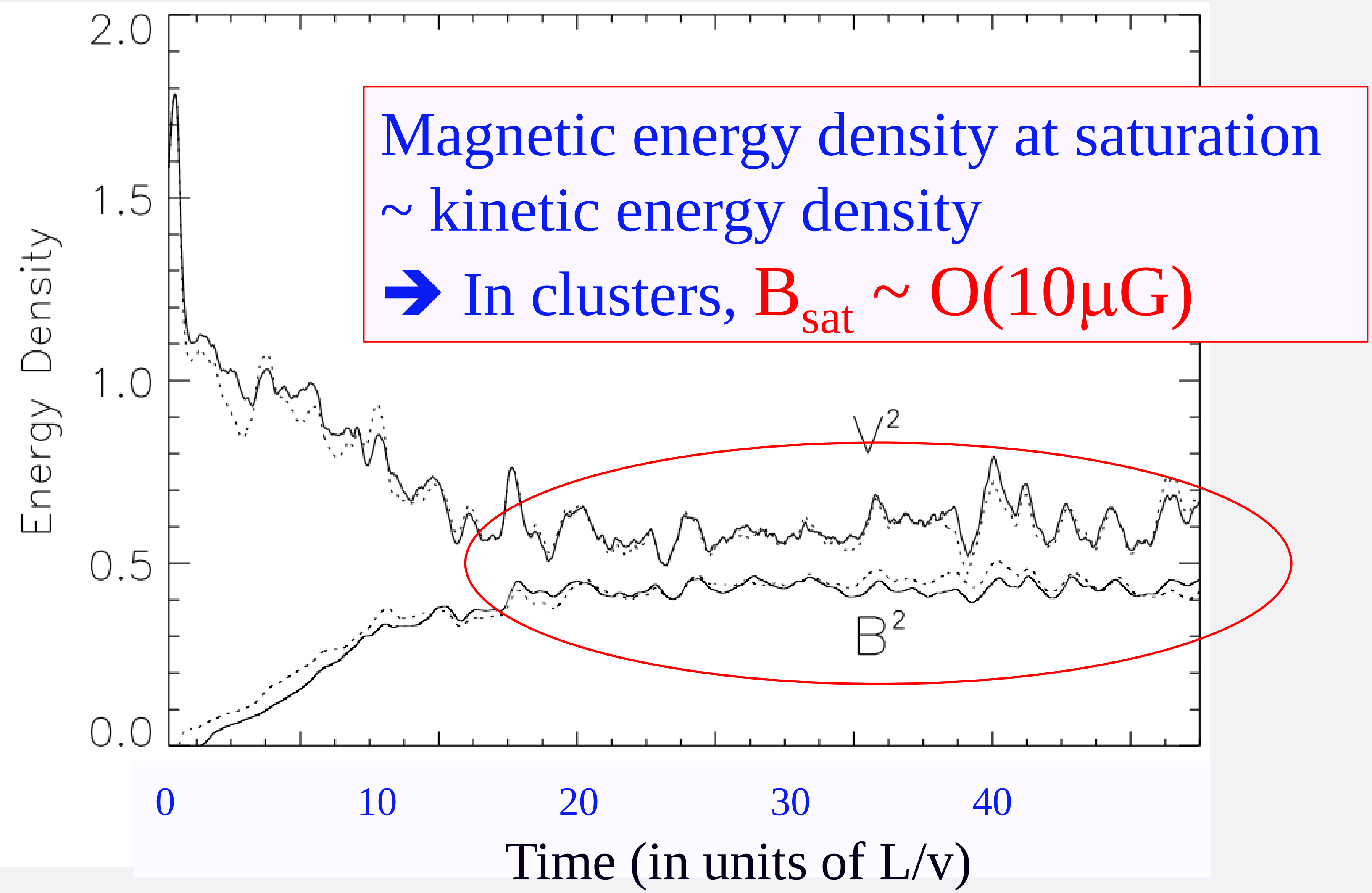
(see, for example, Cho & Vishniac 2000)

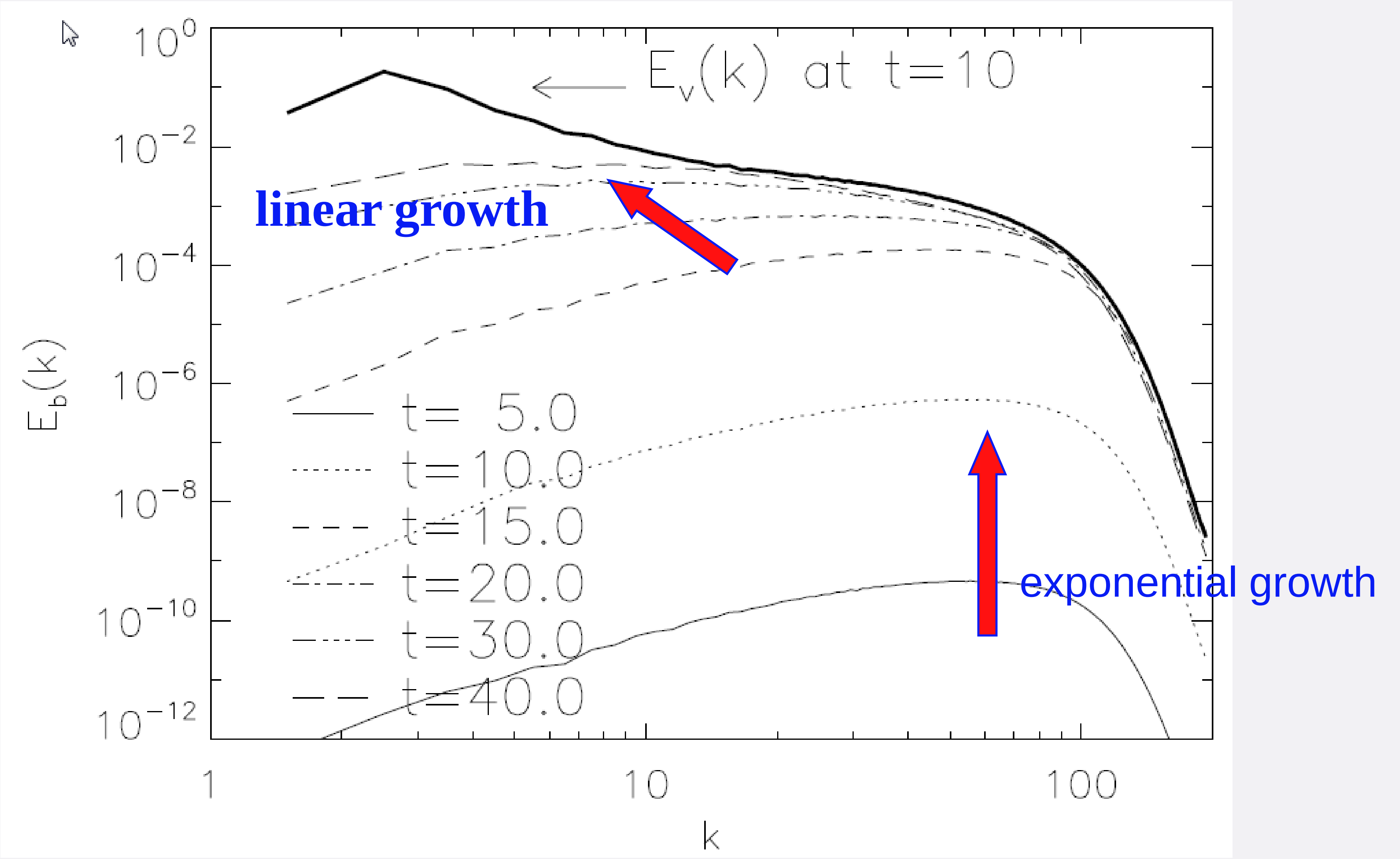
Results of simulations



Ryu+2008; Cho+ (2009);
See also Schlueter & Bierman (1950)

Results of simulations





Cho et al. (2009)

* See also Cho & Vishniac (2000); Schekochihin et al (2006)

Conclusions for Topic 1

-Turbulence can amplify uniform weak seed B fields
-Two stages of amplification: exp. and linear
-Saturation time-scale ~15 (L/v)

Example)
Cluster with a driving scale (L) of 300kpc & v~300km/s

➔ (L/v) ~ 1 billion years!

➔Growth of B takes ~ 15(L/v) ~ 15 billion years!

➔ Present-day B ~ close to B_{sat} ~ a few μG

(see Ryu et al (2008) for better estimates)

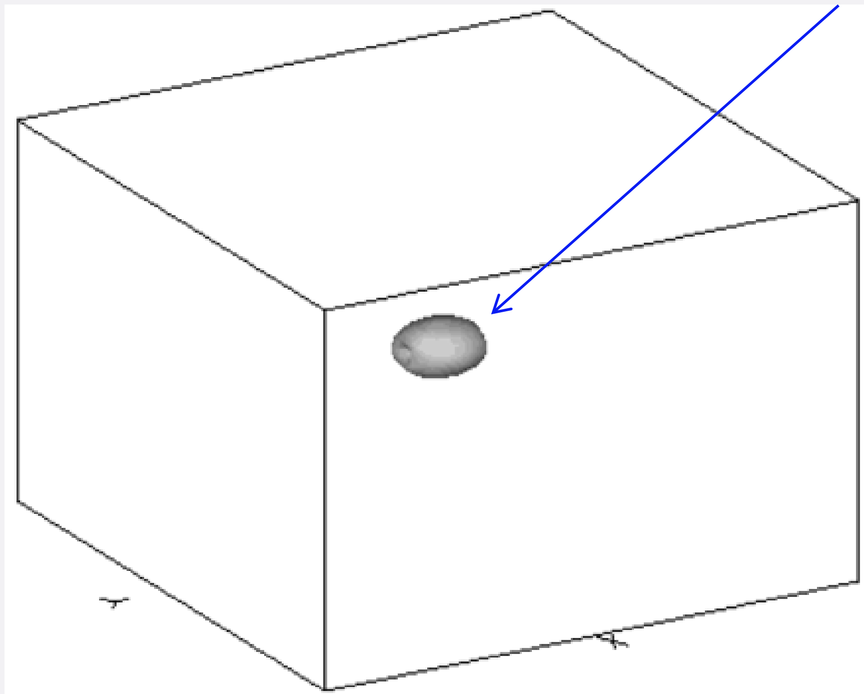
TABLE 1 Cluster magnetic fields

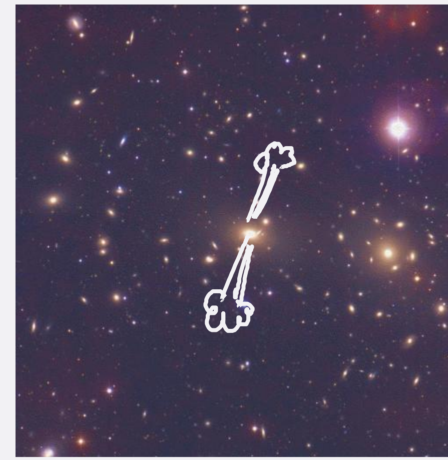
Method	**Strength μG**	**Model parameters**
Synchrotron halos	0.4–1	Minimum energy, $k = \eta = 1$, $\nu_{\rm low} = 10$ MHz, $\nu_{\rm high} = 10$ GHz
Faraday rotation (embedded)	3–40	Cell size = 10 kpc
Faraday rotation (background)	1–10	Cell size = 10 kpc
Inverse Compton	0.2–1	$\alpha = -1$, $\gamma_{\rm radio} \sim 18000$, $\gamma_{\rm xray} \sim 5000$
Cold fronts	1–10	Amplification factor ~3
GZK	>0.3	AGN = site of origin for EeV CRs

Carilli & Taylor 2002

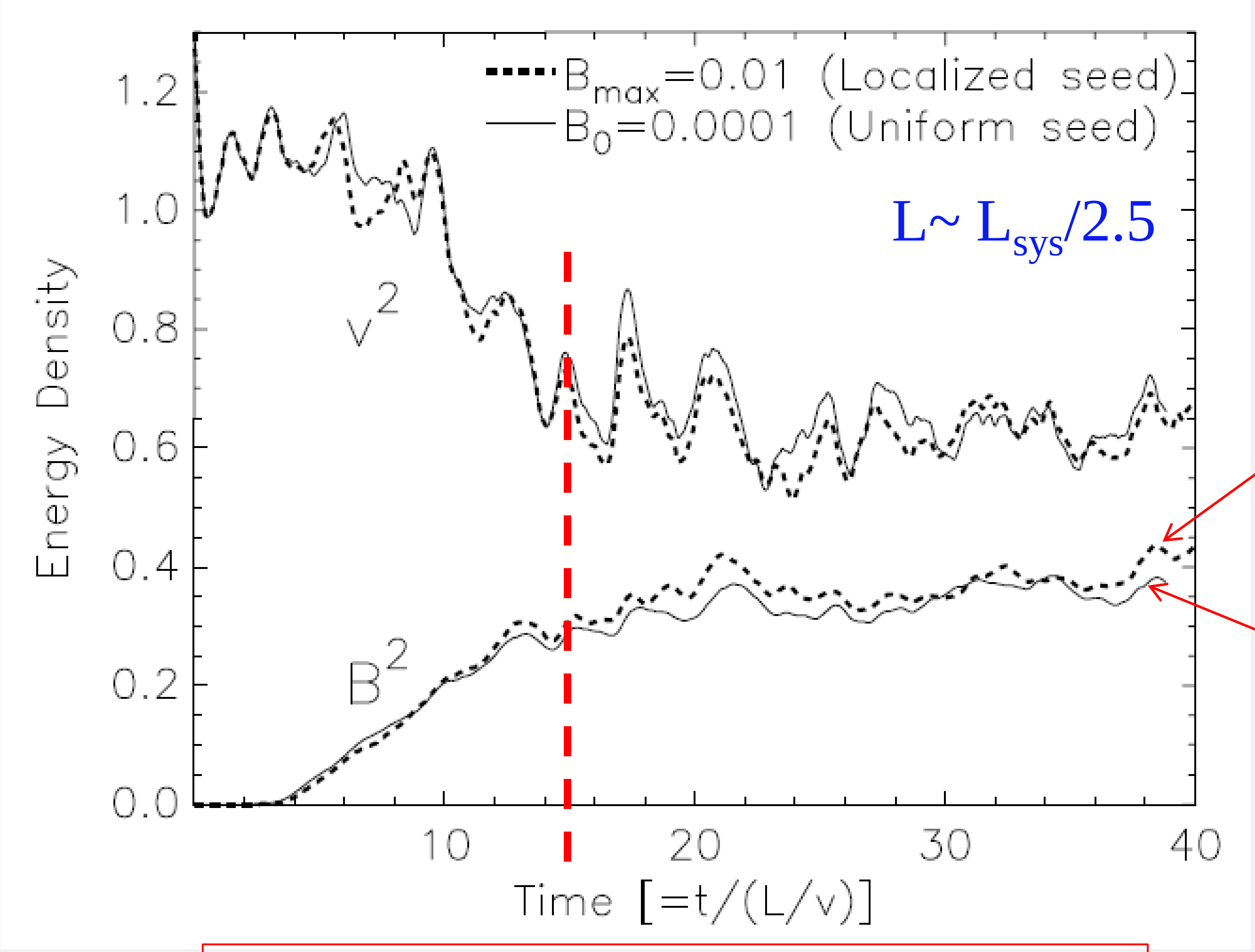
Topic 2: Growth of a localized seed field in turbulence

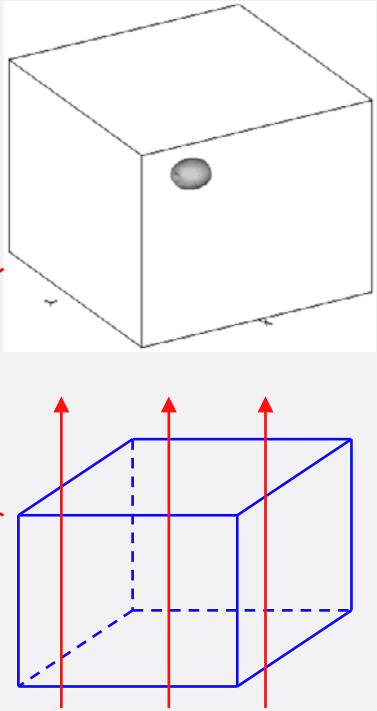
Weak localized seed field





Similar results for a localized seed & a uniform seed !



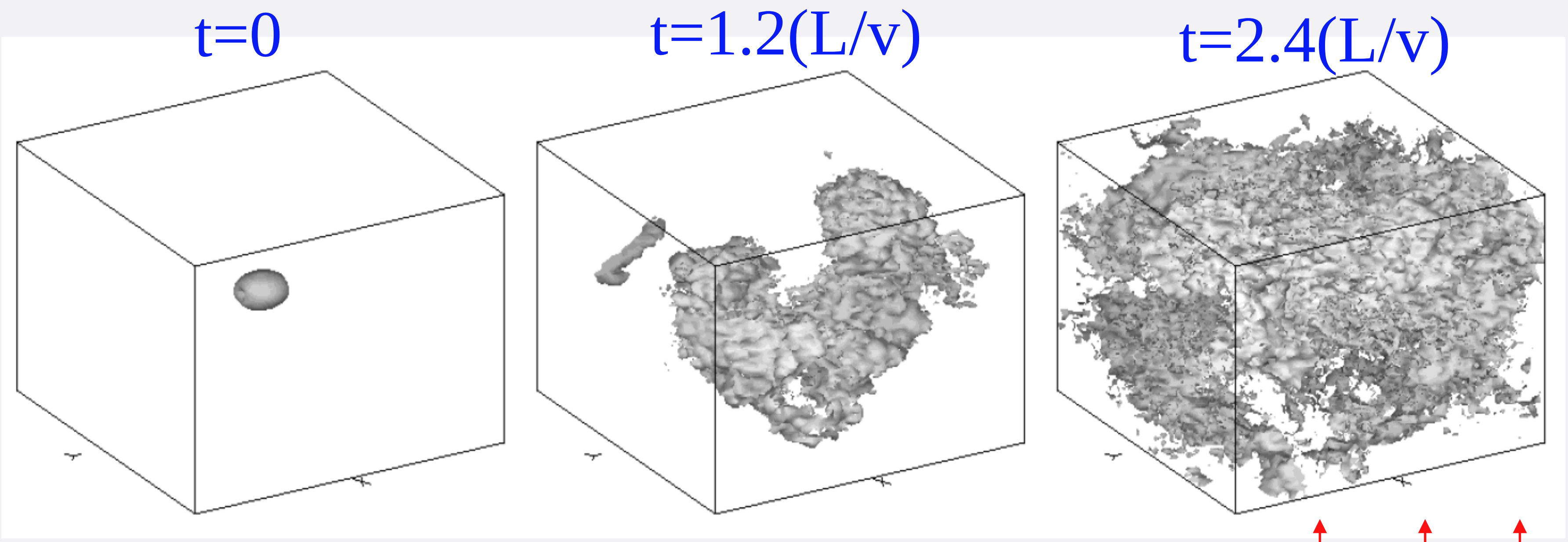


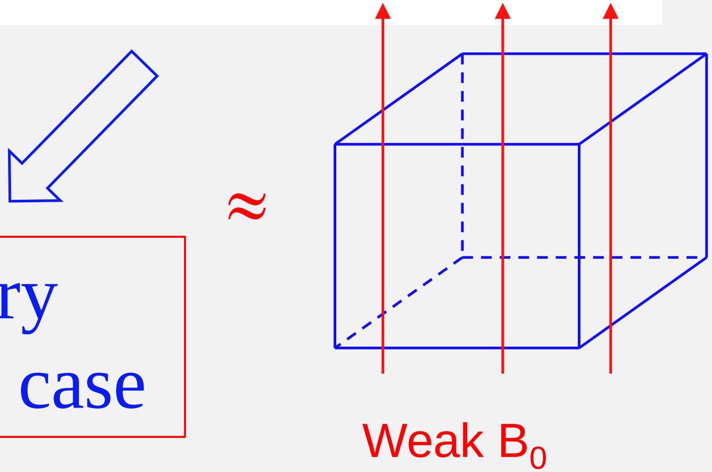
Saturation time-scale ~ 15 (L/v)

Cho & Yoo (2012)

Why are the results so similar?

➔ Answer: fast magnetic diffusion or fast homogenization!

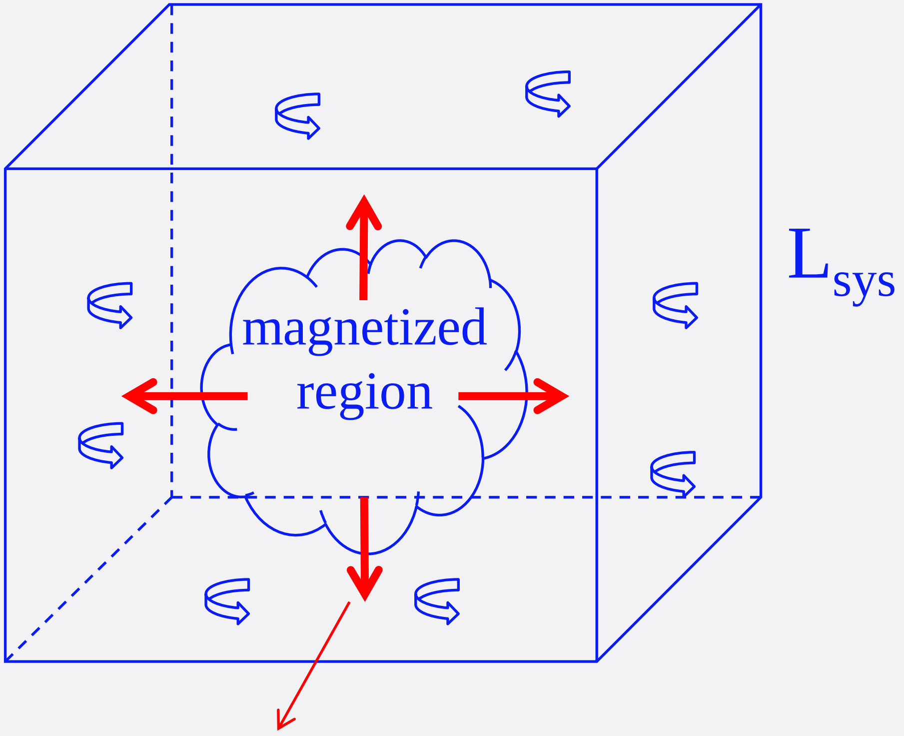




After this, the evolution should be very similar to that of a uniform seed field case

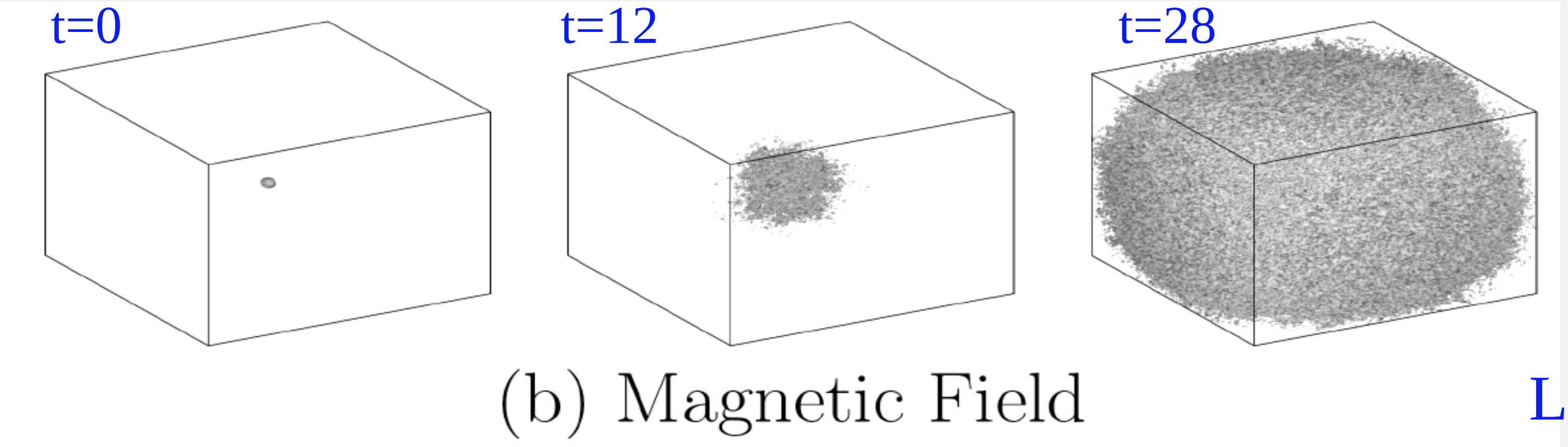
Fast homogenization followed by a usual turbulence dynamo is the key process!

➔What is the homogenization time in general?



The magnetized region expands ➔ What is the speed?

Homogenization time-scale?



$L \sim L_{sys}/20$

$V_{exp} \sim v$ ➔ Homogenization time ~ $L_{sys}/v = (L_{sys}/L)(L/v)$

Example) Cluster of size (L_{sys}) 1Mpc and v~300 km/s

➔ Homogenization time ~ 3 billion years

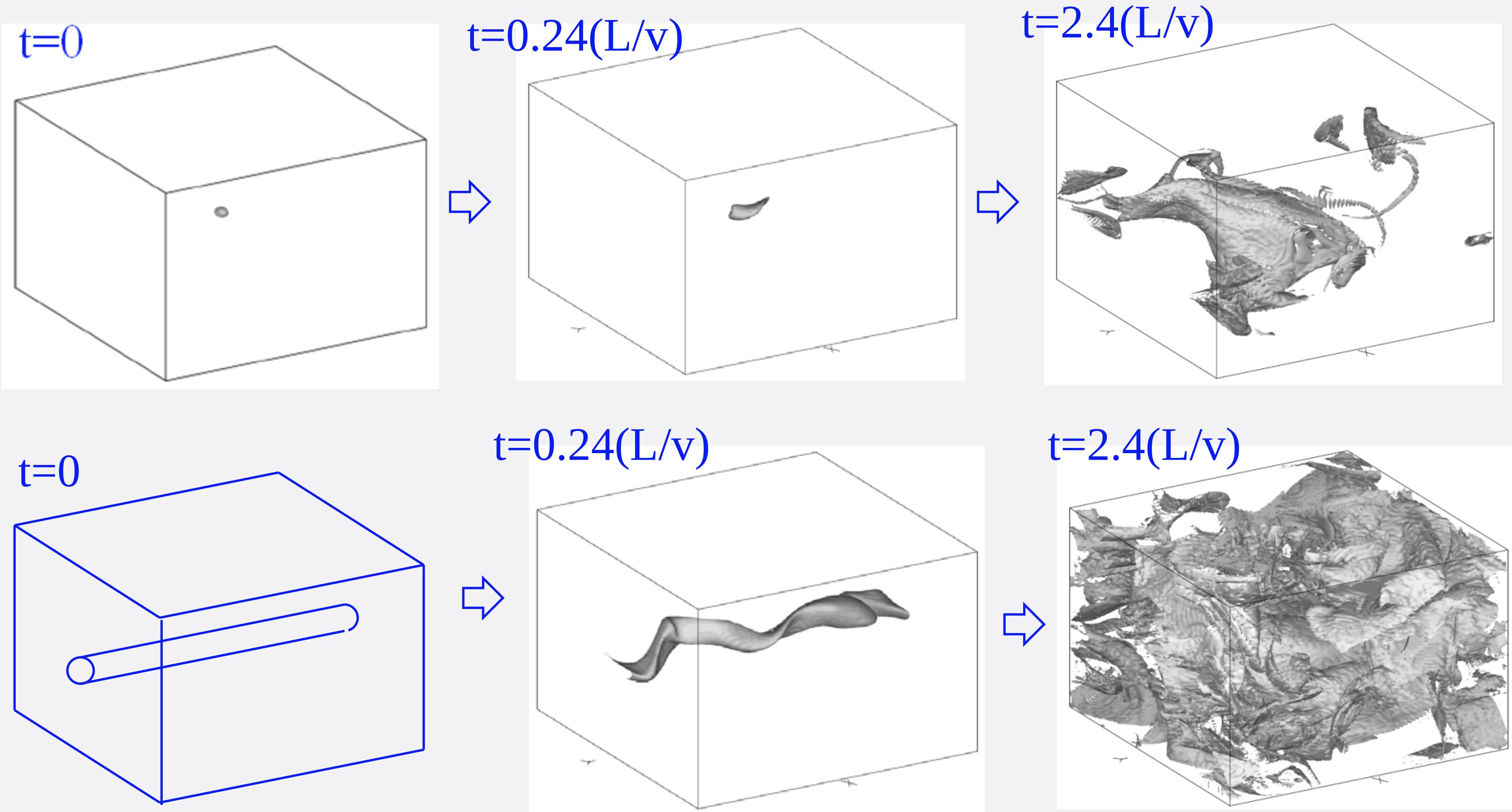
➔So, it is difficult to distinguish primordial and astrophysical origins

Cho (2013)

What if $\nu >> \eta$?

-The magnetic Prandtl number can be very large in the ICM (i.e. $\nu >> \eta$)

-Homogenization and growth of a localized seed field in a high-Pr,m fluid is also fast!



Cho (2014)

Implications for observations

- Homogenization time-scale (L_{sys}/v) is important
- For a cluster of size 1Mpc:
  - If $v > 75$ km/s, $L_{sys}/v <$ age of the universe

  ➔Regardless of the driving scale, the cluster is homogenized ➔ It is difficult to tell the origin.

- For a filament of size 4Mpc:
  - If $v > 300$ km/s, $L_{sys}/v <$ age of the universe
  - So, if $v<300$ km/s, B field in the filament can be inhomogeneous

  ➔ RM measurements for filaments will be useful!

Conclusions

- Turbulence can efficiently amply seed fields
- If the seed field is localized:

- Homogenization time-scale (L_{sys}/v) is important

- After homogenization, the usual turbulence dynamo follows!

- It is likely that clusters are already homogenized

- Filaments may not be homogenized yet if $v<300$km/s