Interstellar Turbulence and Magnetic fields

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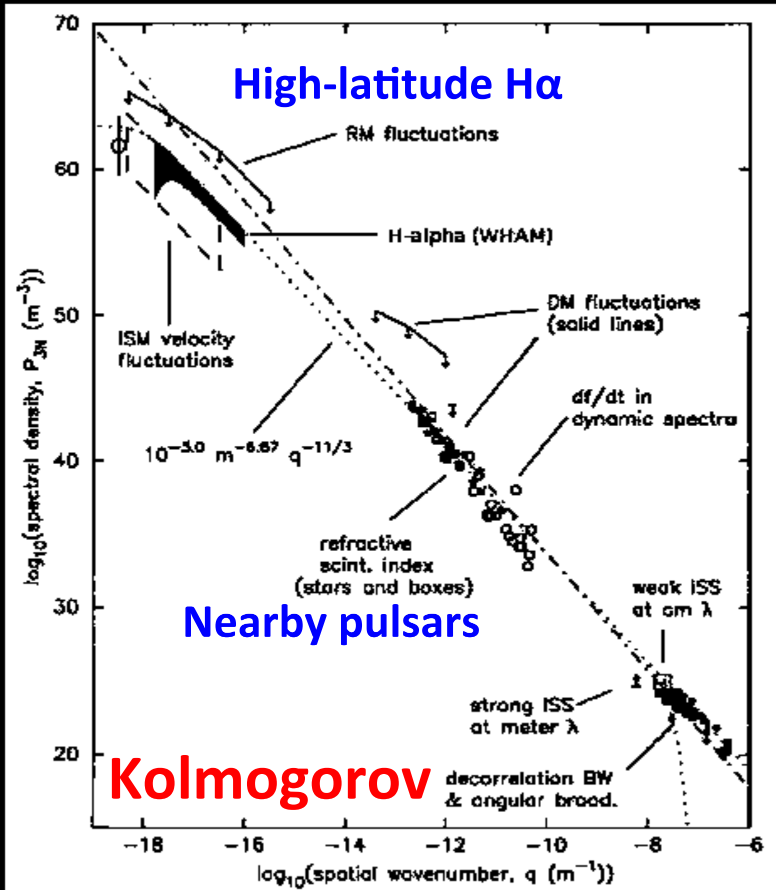
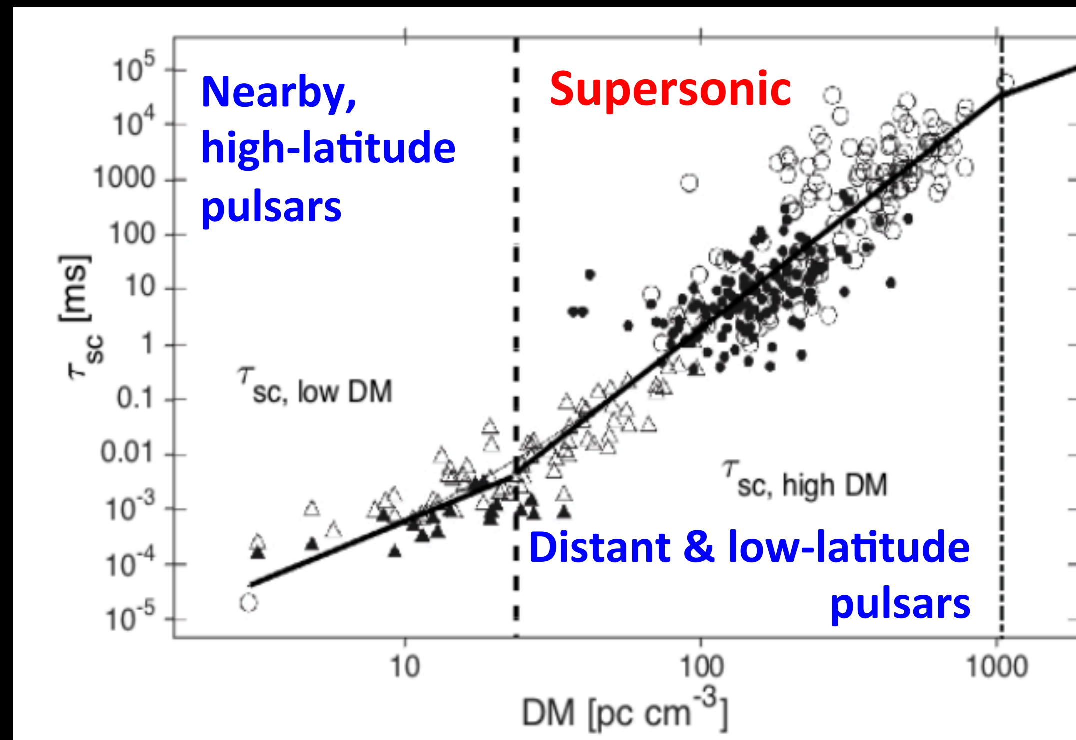
Alex Lazarian UW-Madison

Density spectra of interstellar turbulence

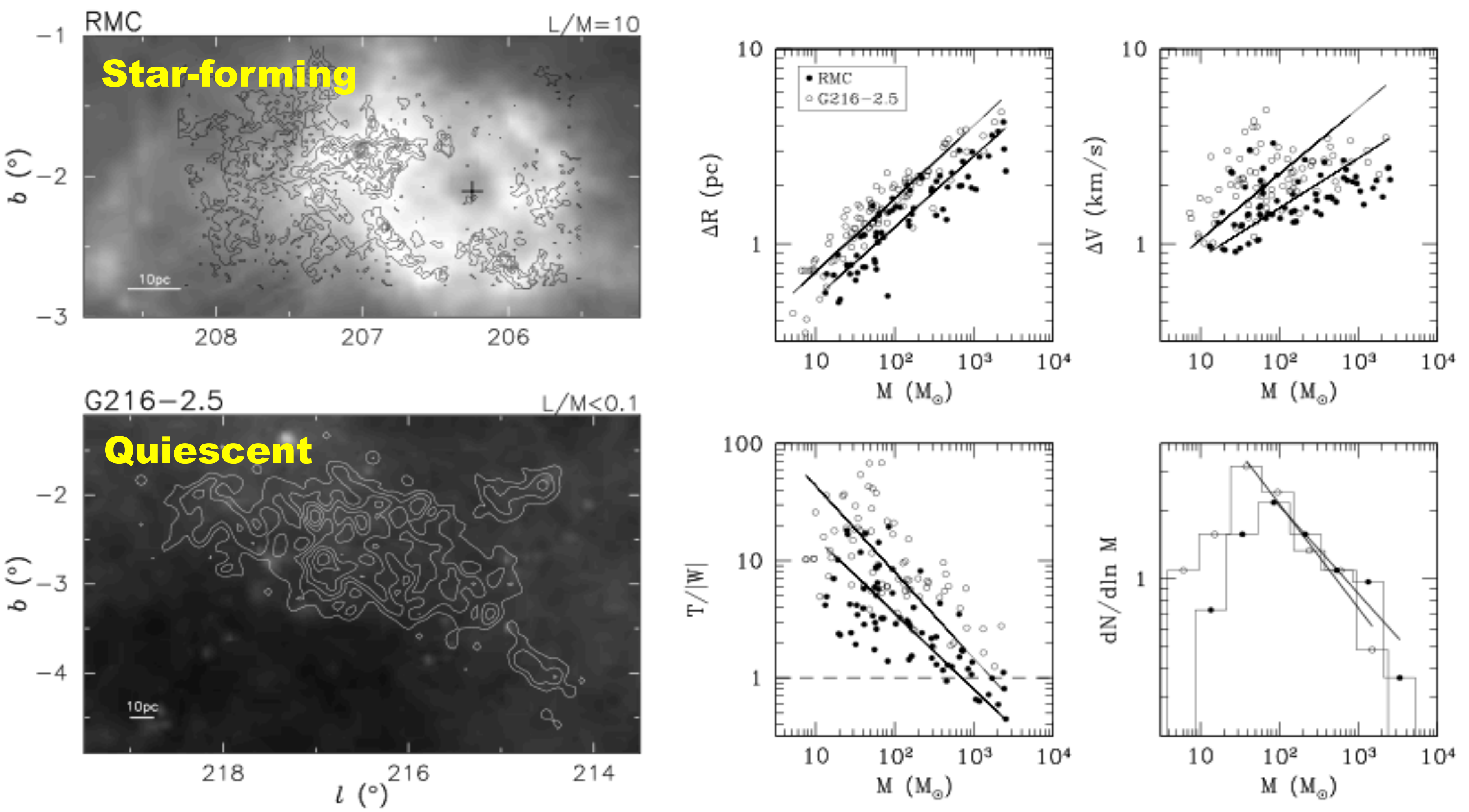


Armstrong et al. 1995;
Chepurnov & Lazarian 2009



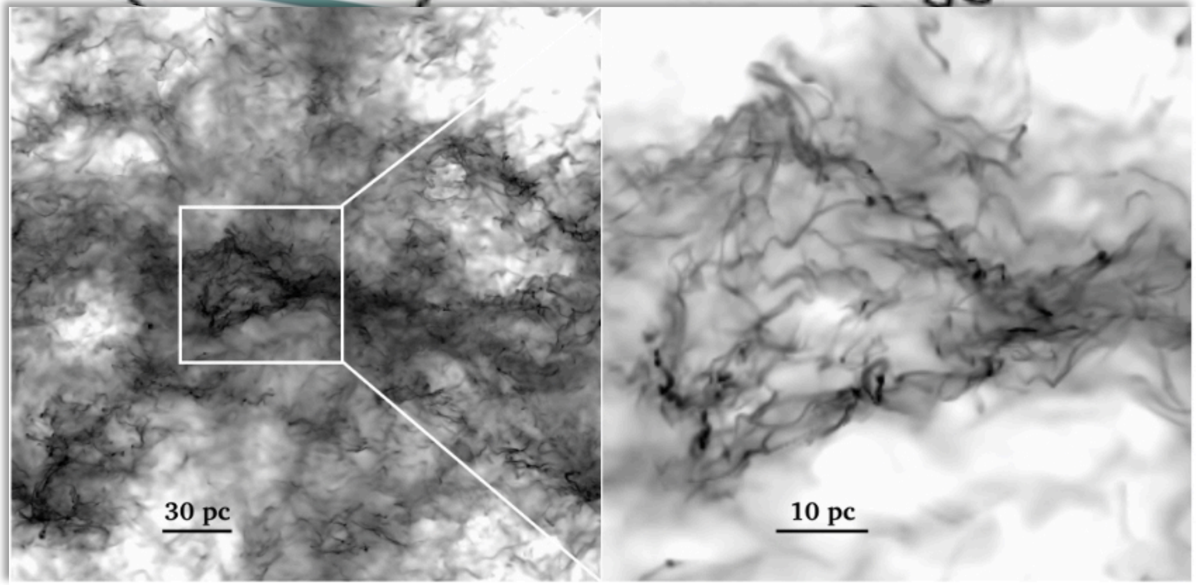
Xu & Zhang 2017, ApJ, 835, 2

Universal self-similarity in density distributions



Williams et al. 2000

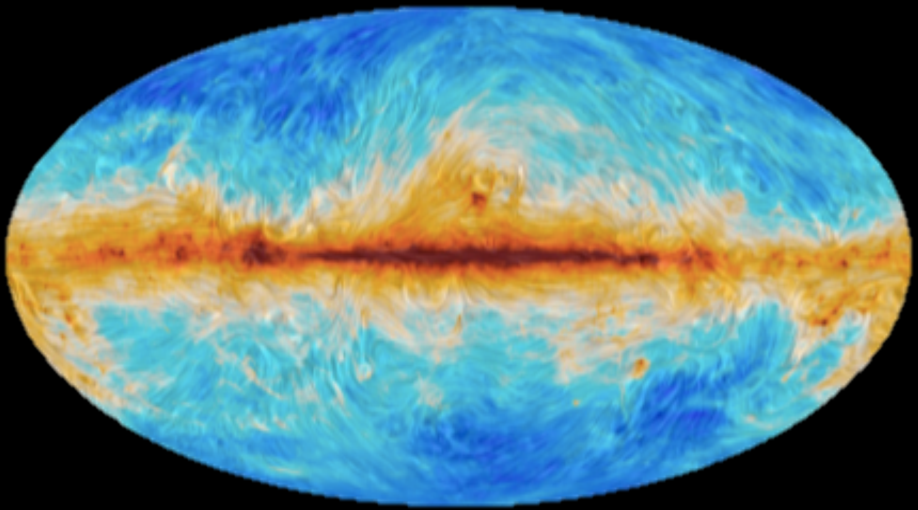
Supernova driving of the interstellar turbulence



Padoan et al. 2016

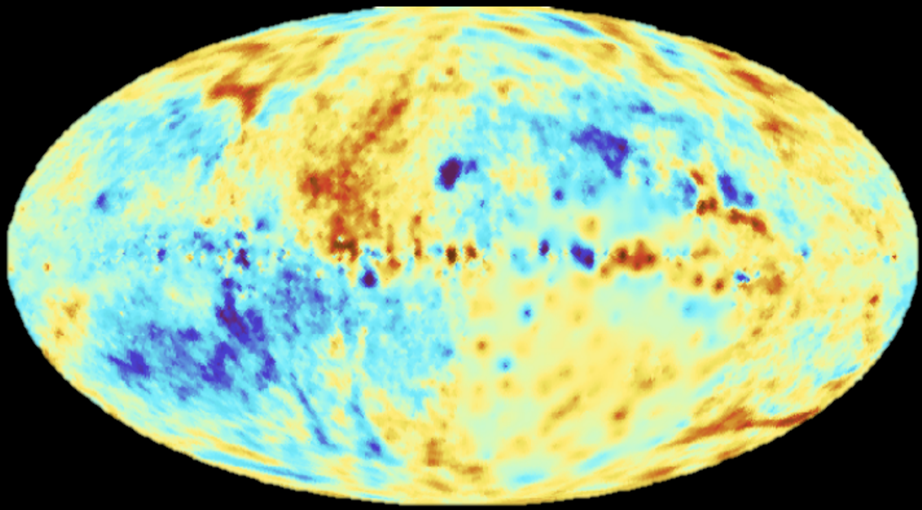
Turbulent magnetic fields in the ISM

$B_\perp$



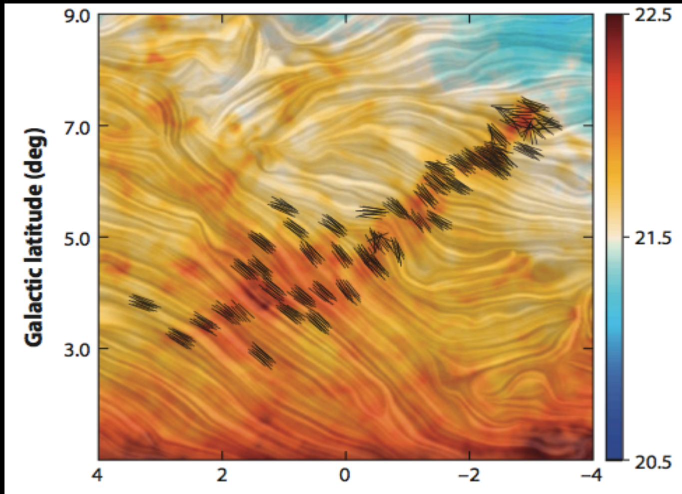
ESA/Plank Collaboration

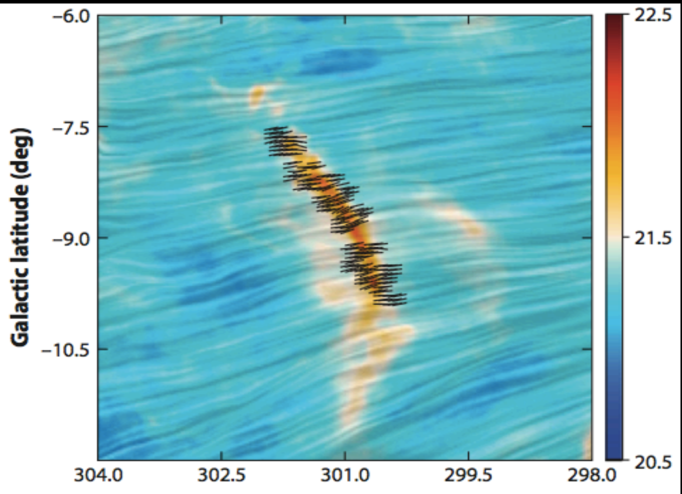
$B_{//}$



Galactic Faraday sky

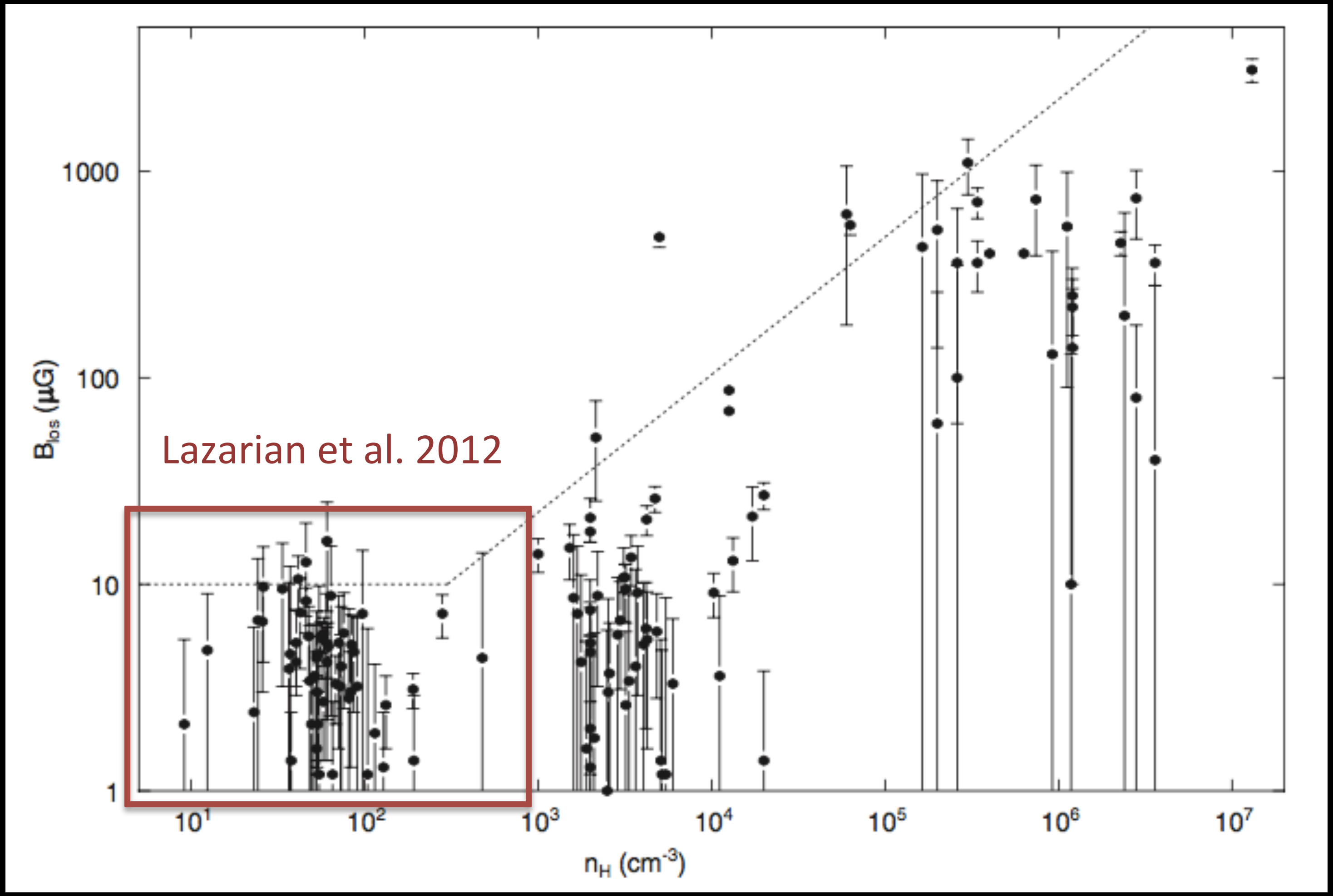
Oppermann et al. 2012





Soler et al. 2016

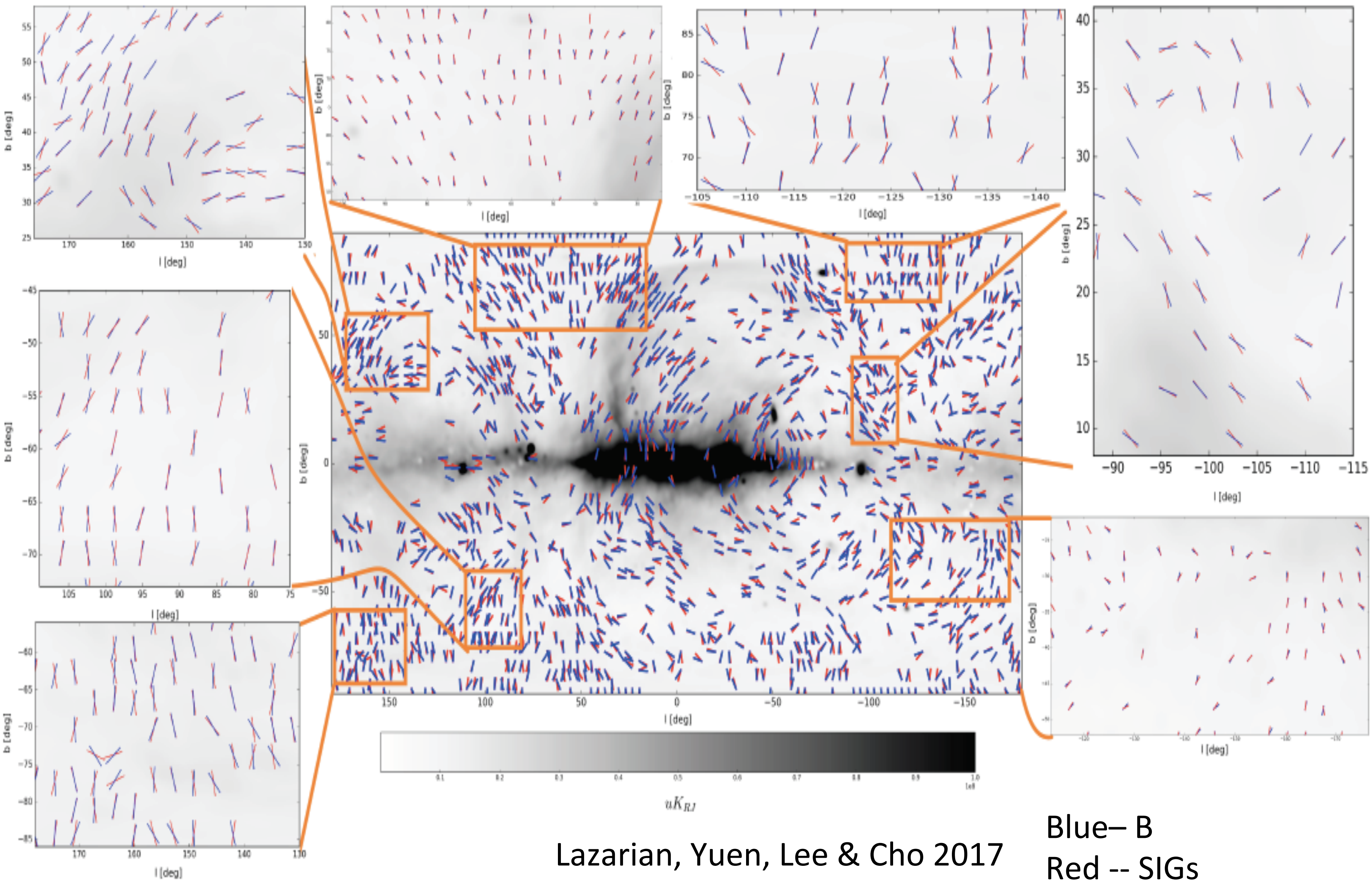
Turbulent magnetic fields in the ISM



Crutcher et al. 2010

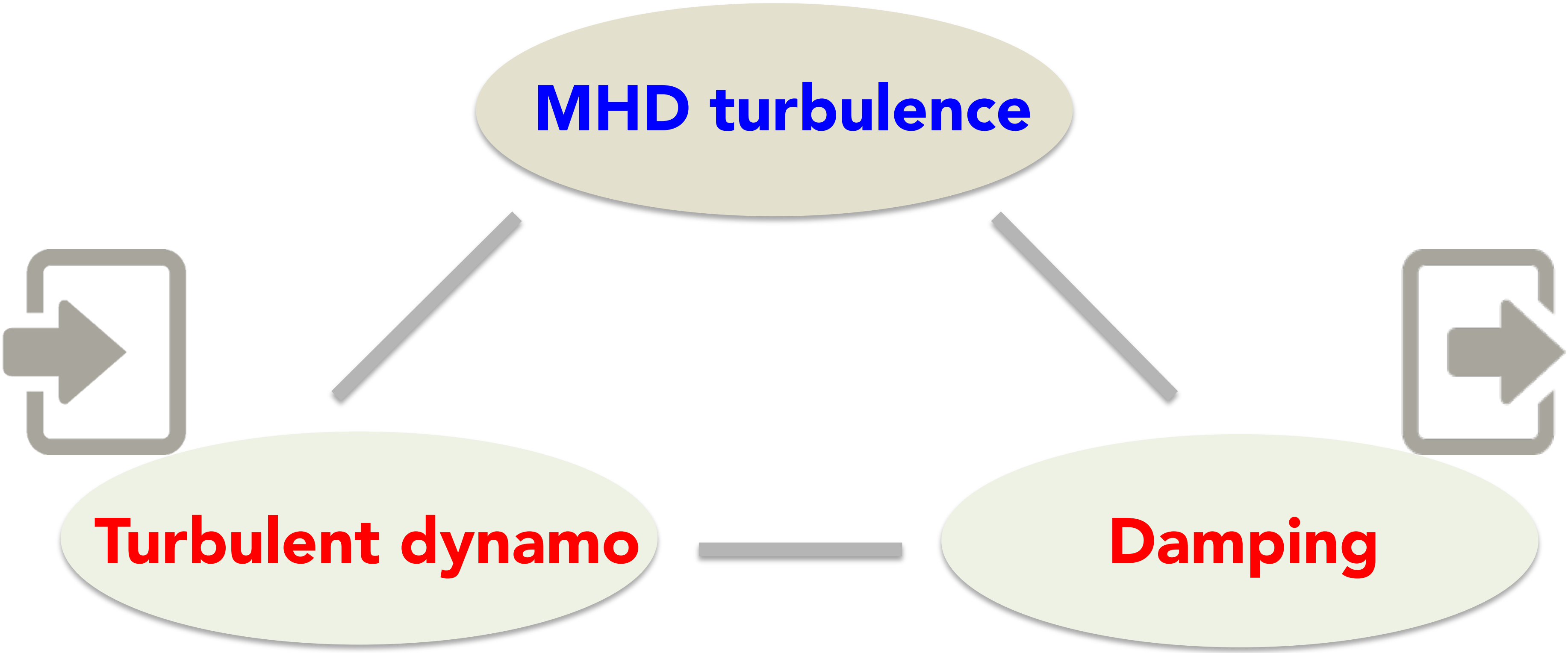
MHD turbulence

Synchrotron Intensity Gradients provide a new way to study B



Lazarian, Yuen, Lee & Cho 2017

Blue– B
Red -- SIGs



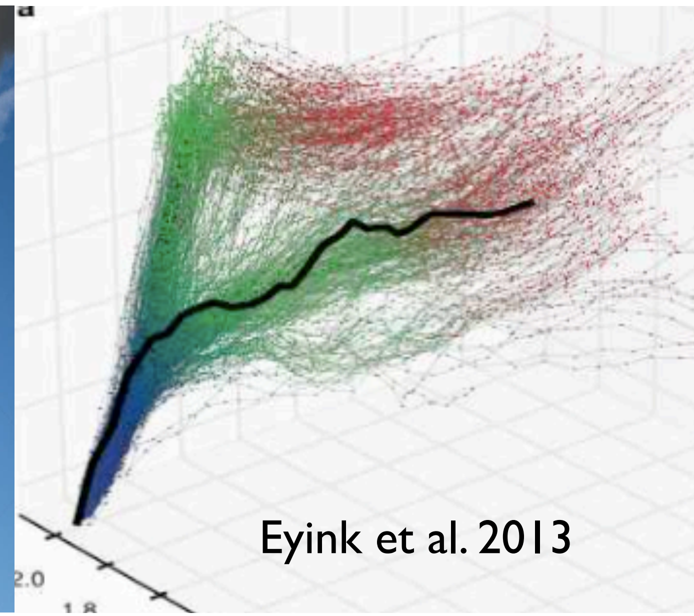
MHD turbulence
Turbulent dynamo
Damping

Turbulent dynamo

Stretching vs. Diffusion

Turbulent diffusion

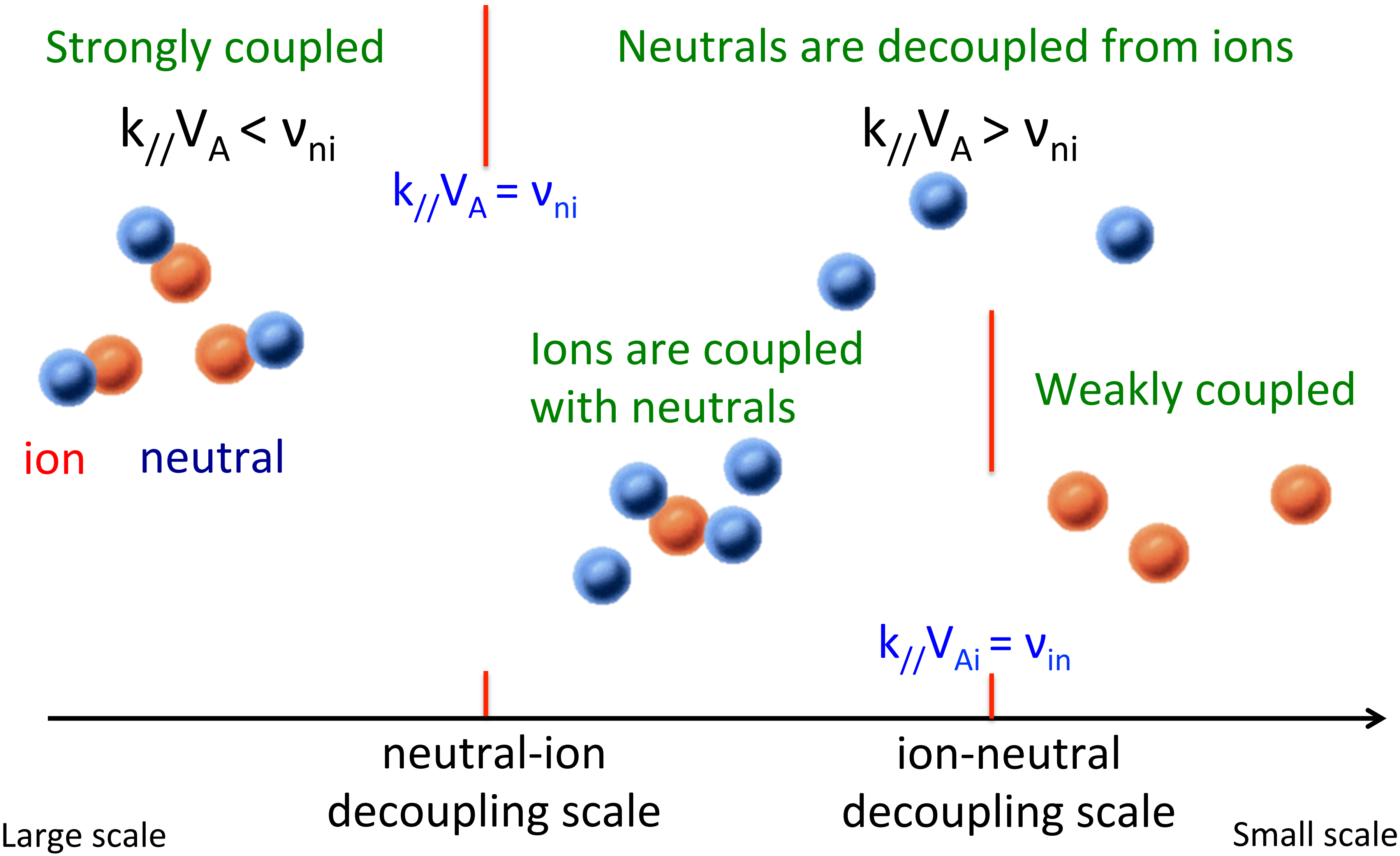
✧Turbulent reconnection & reconnection diffusion



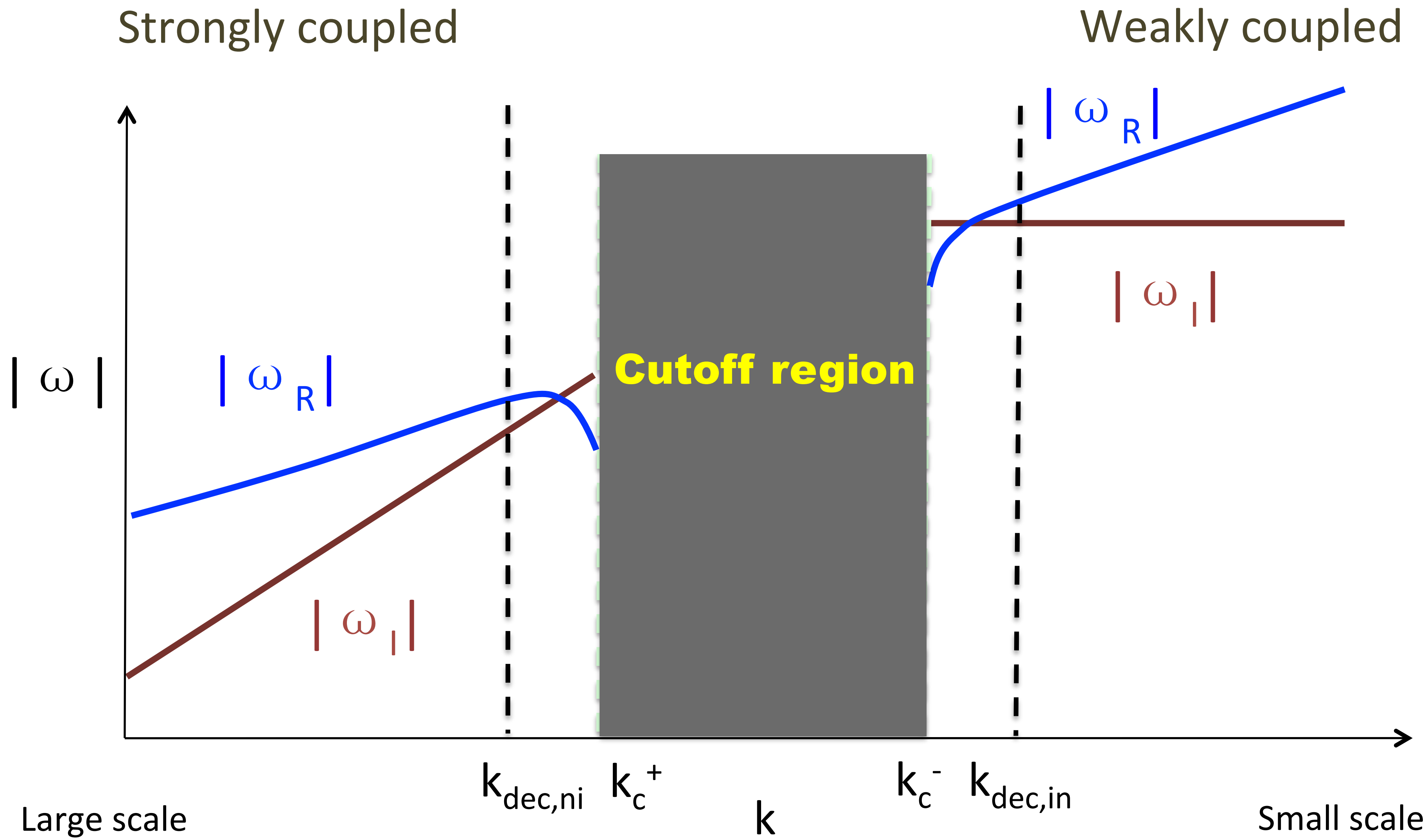
$$\langle l(t)^2 \rangle \sim \varepsilon\, t^{3}$$

Lazarian & Vishniac 1999

Microscopic diffusion



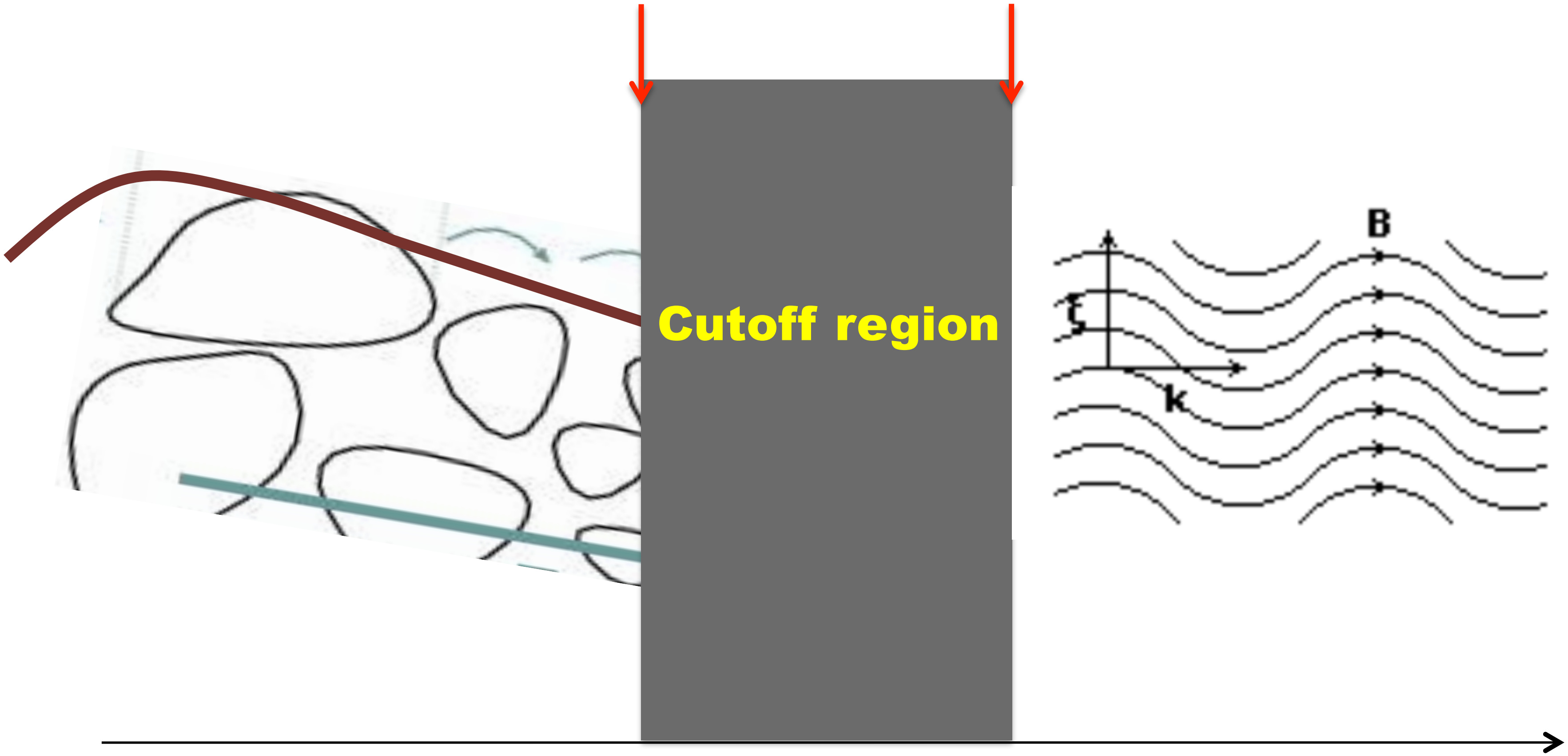
Damping in partially ionized gas



Damping in partially ionized gas

Damping
of turbulence

Damping
of waves (plasma instabilities)

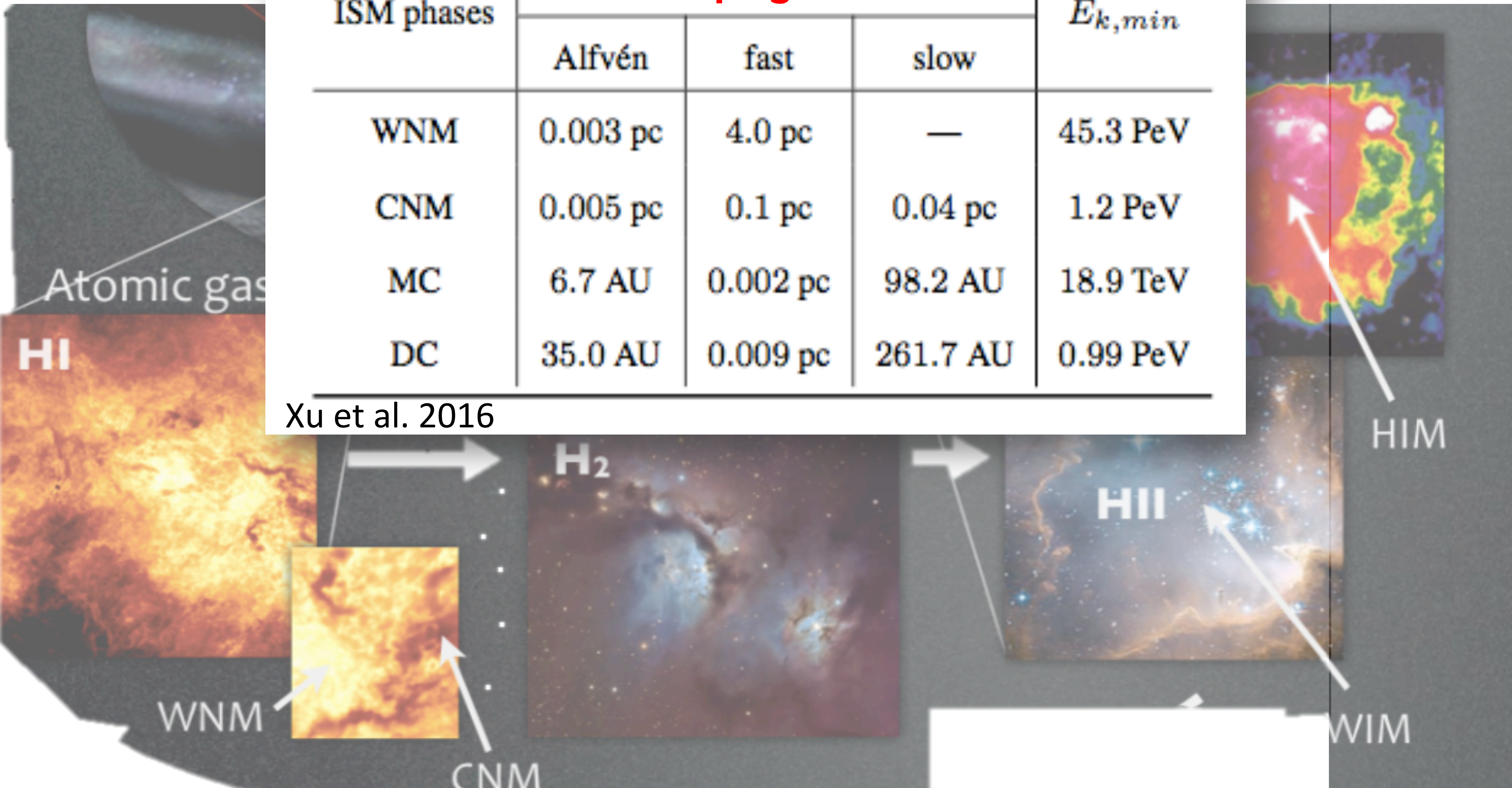


k

Damping in partially ionized gas

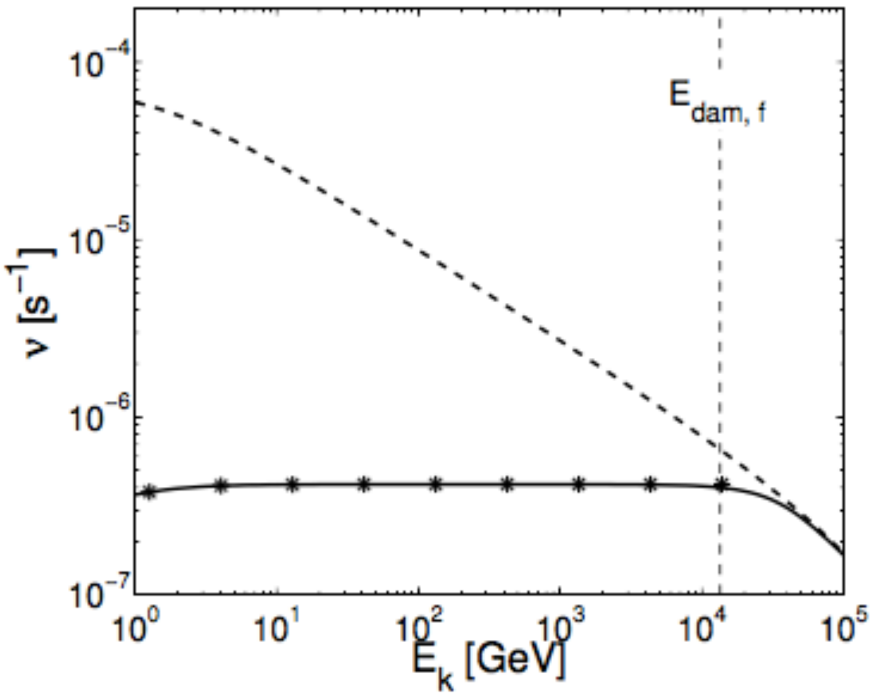
ISM phases	Damping scale			$E_{k,min}$
	Alfvén	fast	slow	
WNM	0.003 pc	4.0 pc	—	45.3 PeV
CNM	0.005 pc	0.1 pc	0.04 pc	1.2 PeV
MC	6.7 AU	0.002 pc	98.2 AU	18.9 TeV
DC	35.0 AU	0.009 pc	261.7 AU	0.99 PeV

Xu et al. 2016

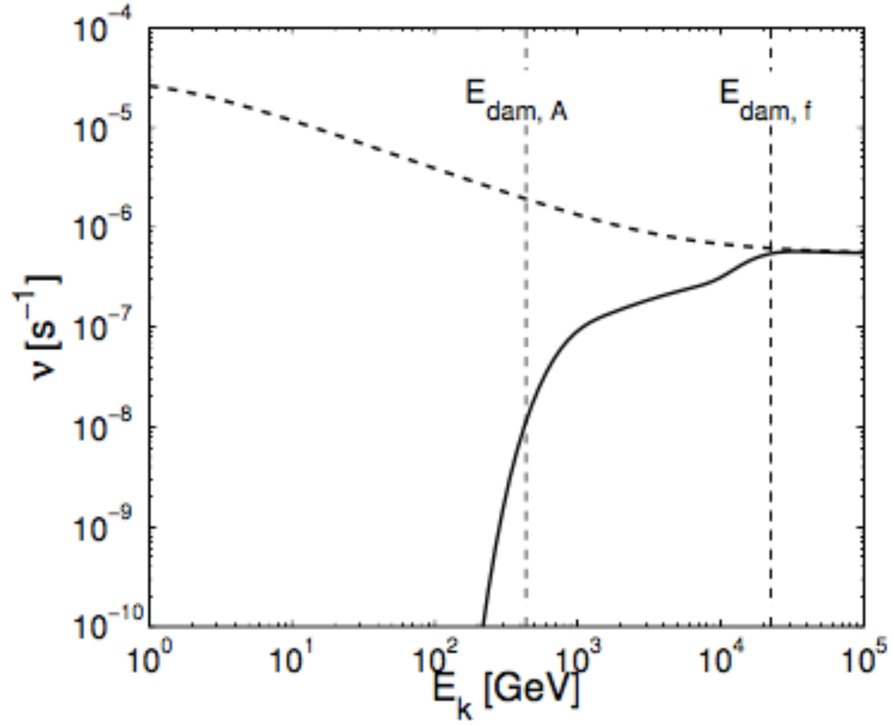


CR propagation in the damped MHD turbulence

Scattering of CRs in the presence of damping



Transit-time damping

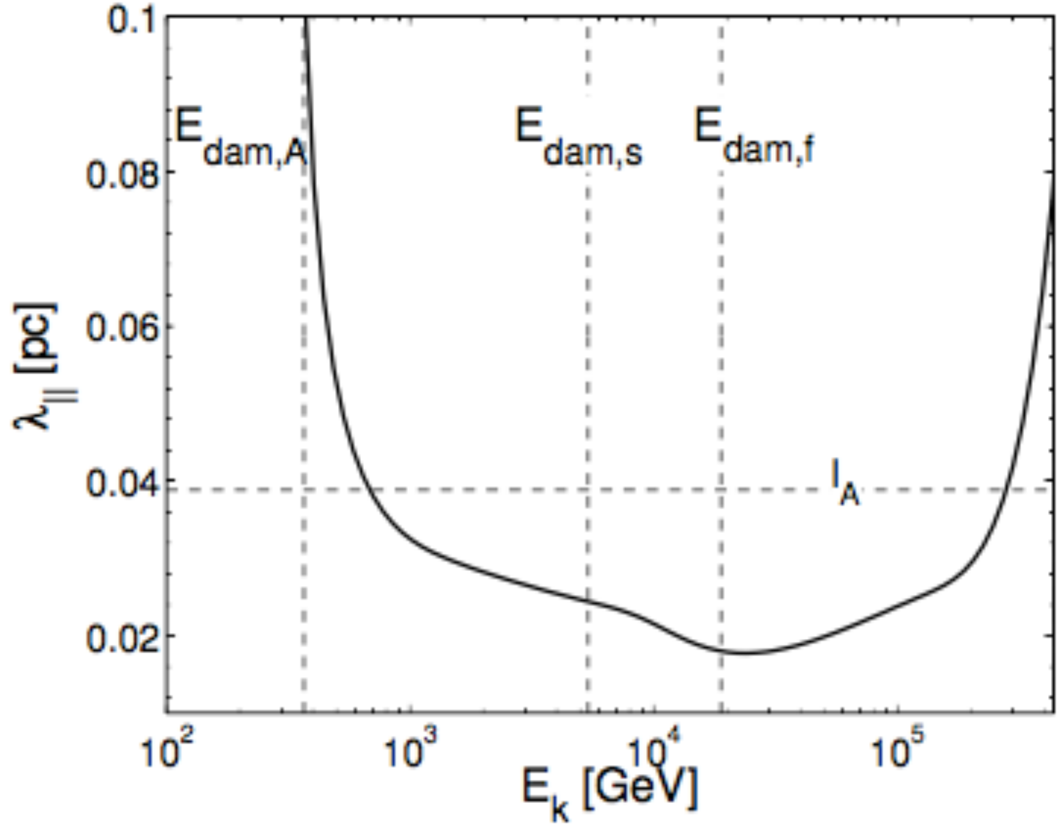


Gyroresonance

Xu et al. 2016

CR propagation in the damped MHD turbulence

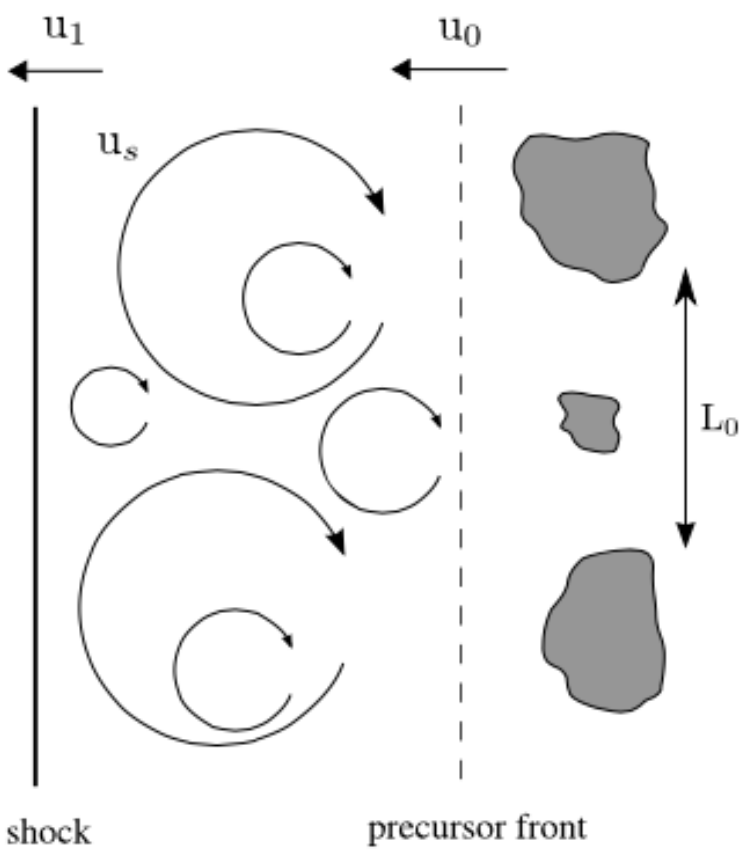
Parallel mean free path of CRs in the presence of damping



Xu et al. 2016

Turbulent dynamo in supernova remnants (SNRs)

Preshock



$$V_L \sim \frac{\Delta \rho}{\rho} v_{\rm sh}$$

Weakly ionized preshock medium

	$n_H\,[\mathrm{cm}^{-3}]$	n_e/n_H	T [K]	$B_0\,[\mu\,\mathrm{G}]$
CNM	30	10^{-3}	100	5
MC	300	10^{-4}	20	5

Beresnyak et al. 2009

Draine 2011

Turbulent dynamo in supernova remnants (SNRs)

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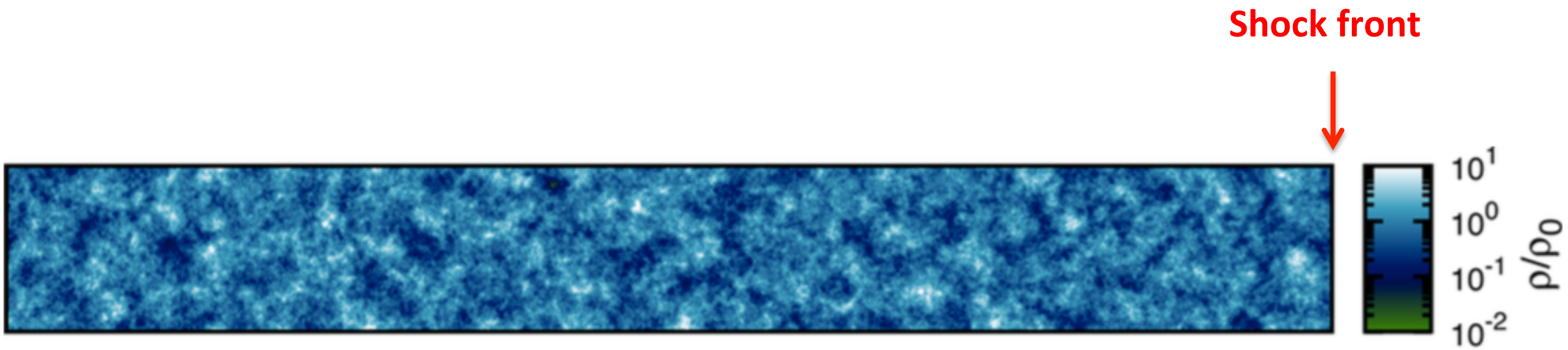
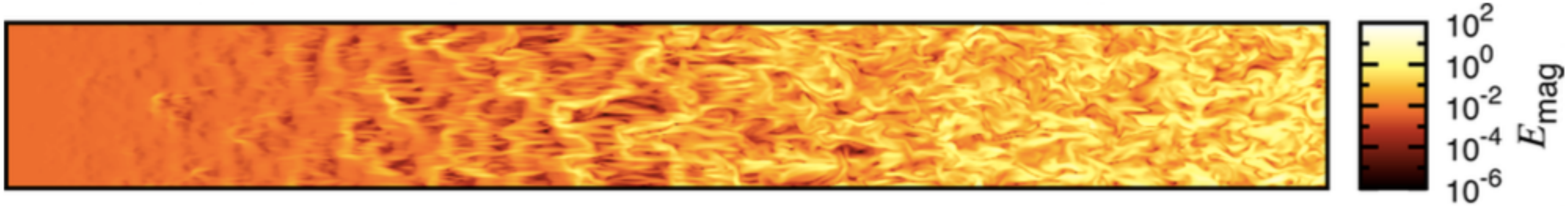


Initial density distribution

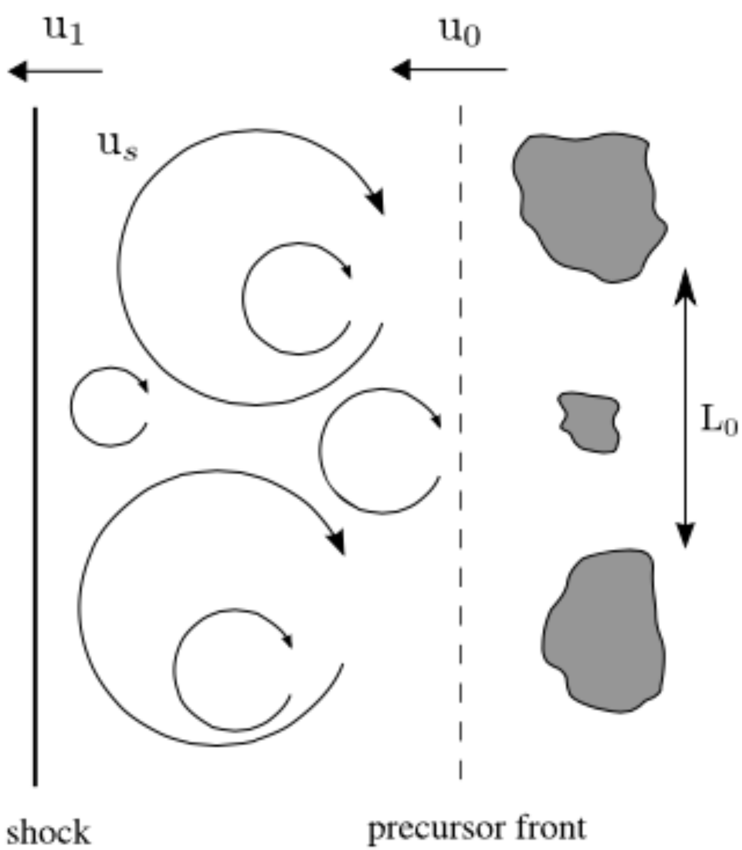


Final distribution of the magnetic energy

del Valle et al. 2016

Turbulent dynamo in supernova remnants (SNRs)

Preshock



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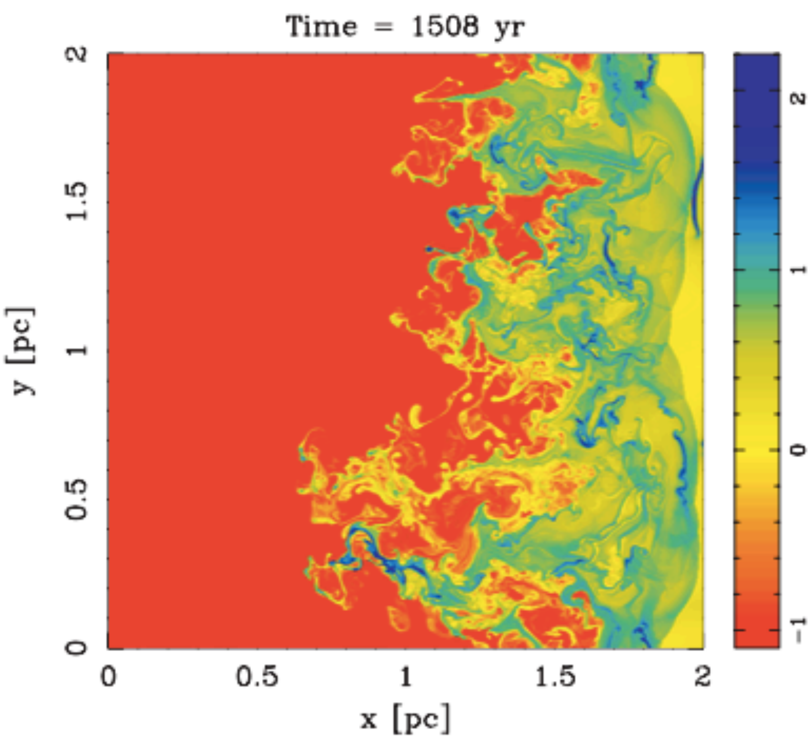
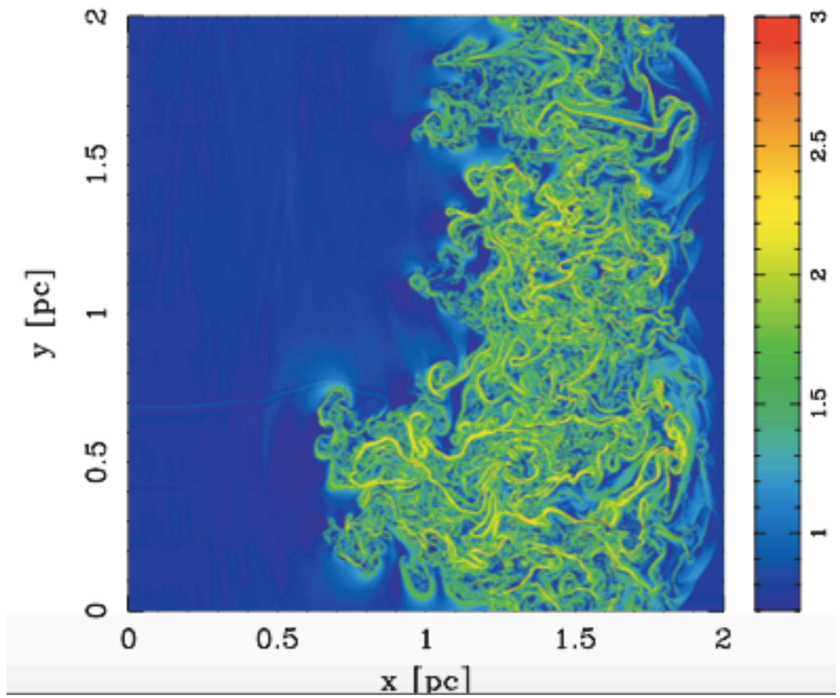
Turbulent dynamo in SNRs

Postshock



Density



Magnetic field

Inoue et al. 2009

Turbulent dynamo in SNRs

Preshock

- **Damping kinematic dynamo**

Severe IN collisional damping

Ambipolar diffusion

Linear-in-time growth of B

$$B \sim \frac{3}{23} C^{-\frac{1}{2}} L^{-\frac{1}{2}} V_L^{\frac{3}{2}} t$$

✧ new dynamo regime

Postshock

- **Nonlinear dynamo**

Equipartition between E_B and E_K

Turbulent diffusion

Linear-in-time growth of E_B

$$E_B \sim \frac{3}{38} L^{-1} V_L^3 t$$

consistent with

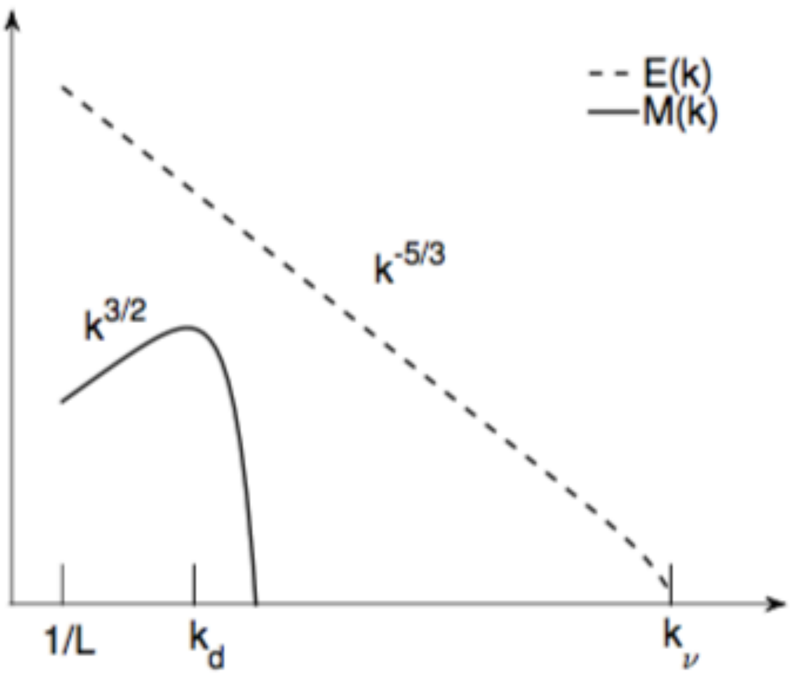
e.g. Cho et al. 2009; Beresnyak 2012

Xu & Lazarian submitted

Turbulent dynamo in SNRs

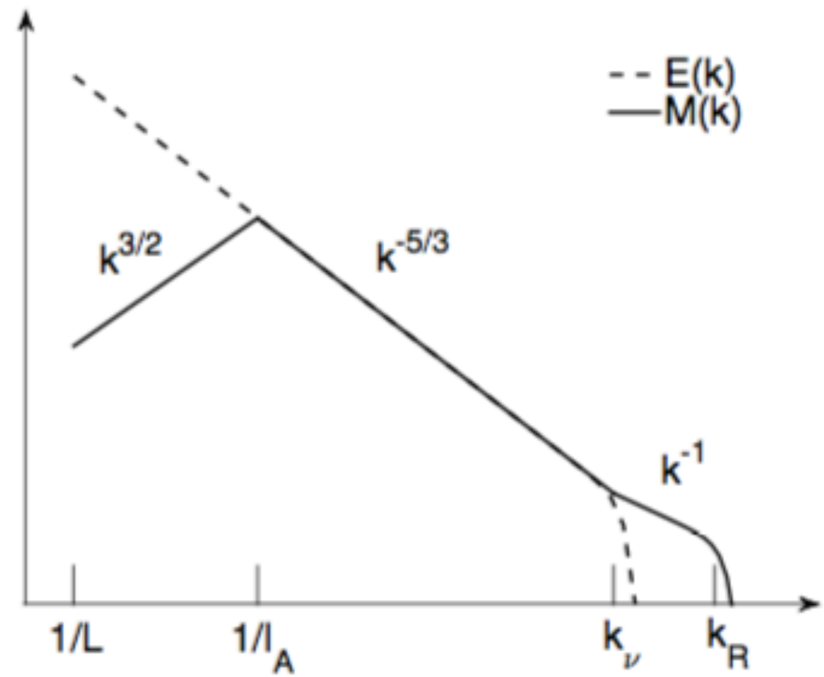
- **Damping kinematic dynamo**

Energy spectra



- **Nonlinear dynamo**

Energy spectra

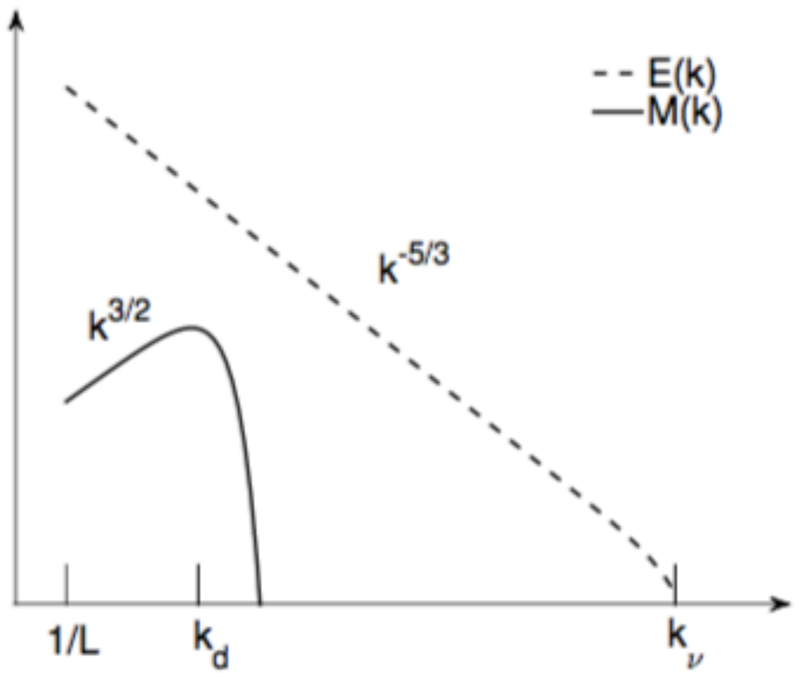


Xu & Lazarian submitted

Turbulent dynamo in SNRs

- **damping kinematic dynamo**

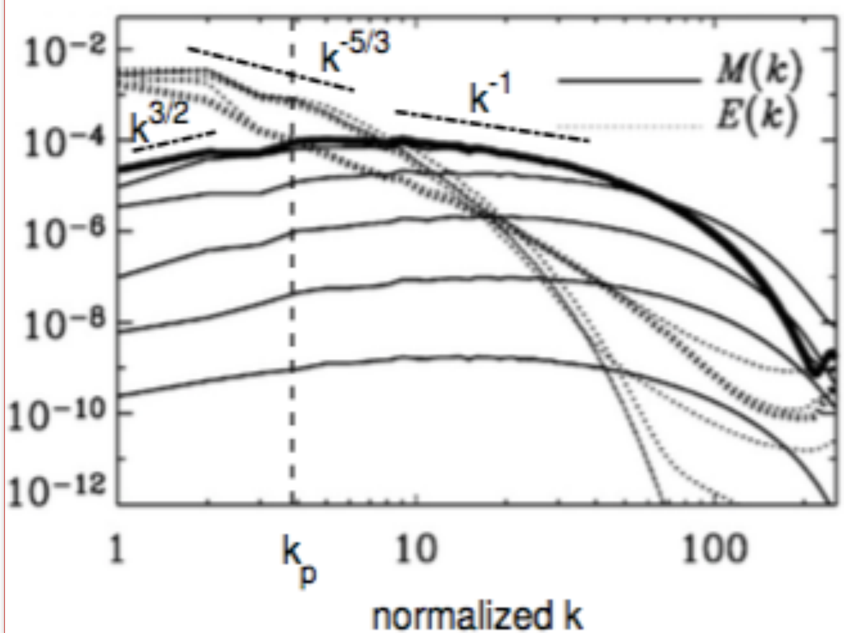
Energy spectra



Xu & Lazarian submitted

- **nonlinear dynamo**

Energy spectra

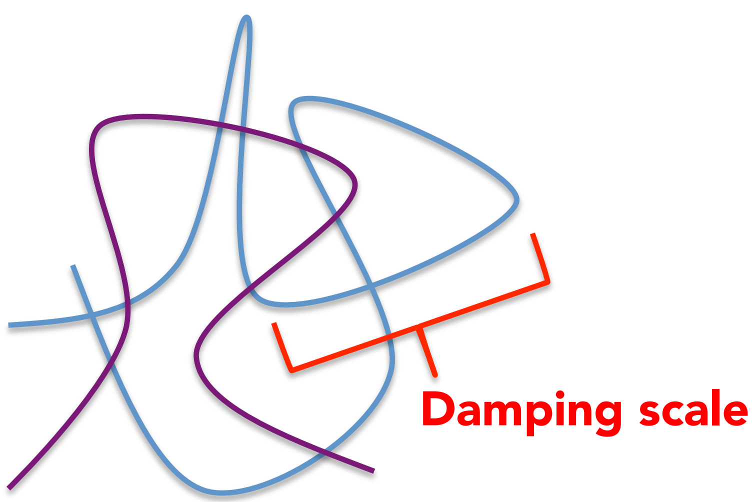


Brandenburg & Subramanian 2005

Turbulent dynamo in SNRs

Preshock

	$n_H\,[\mathrm{cm}^{-3}]$	n_e/n_H	T [K]	$B_0\,[\mu\,\mathrm{G}]$	k_ν^{-1} [pc]	k_{d0}^{-1} [pc]	t_{dyn} [yr]	$B_{\mathrm{dyn}}\,[\mu\,\mathrm{G}]$
CNM	30	10^{-3}	100	5	1.3×10^{-7}	1.2×10^{-4}	741.9	452.6
MC	300	10^{-4}	20	5	1.7×10^{-8}	1.6×10^{-6}	749.7	7.7×10^{3}



$$E_{\mathrm{CR,\,max}} = eB_{\mathrm{dyn}}L$$

4.2×10^{16} eV in the CNM

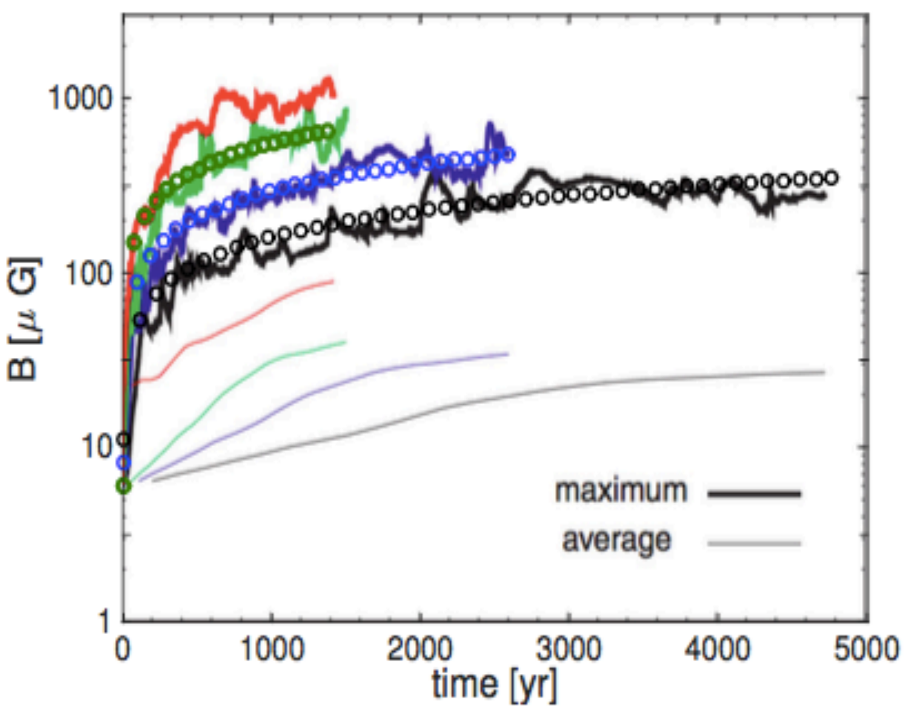
7.1×10^{17} eV in the MC

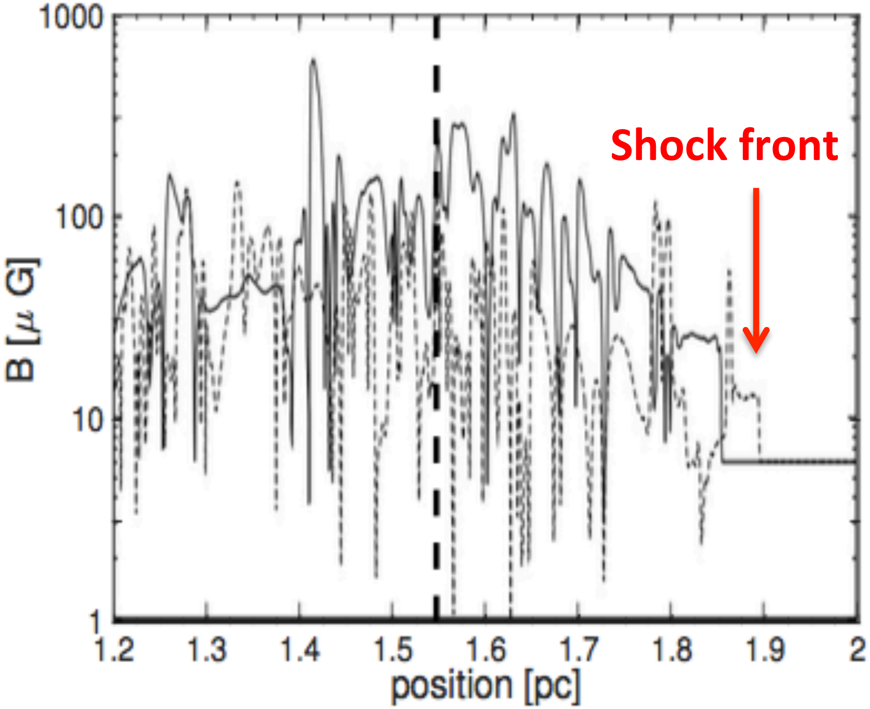
Xu & Lazarian submitted

Turbulent dynamo in SNRs

Postshock

Comparison between our analysis & simulations (Inoue et al. 2009)



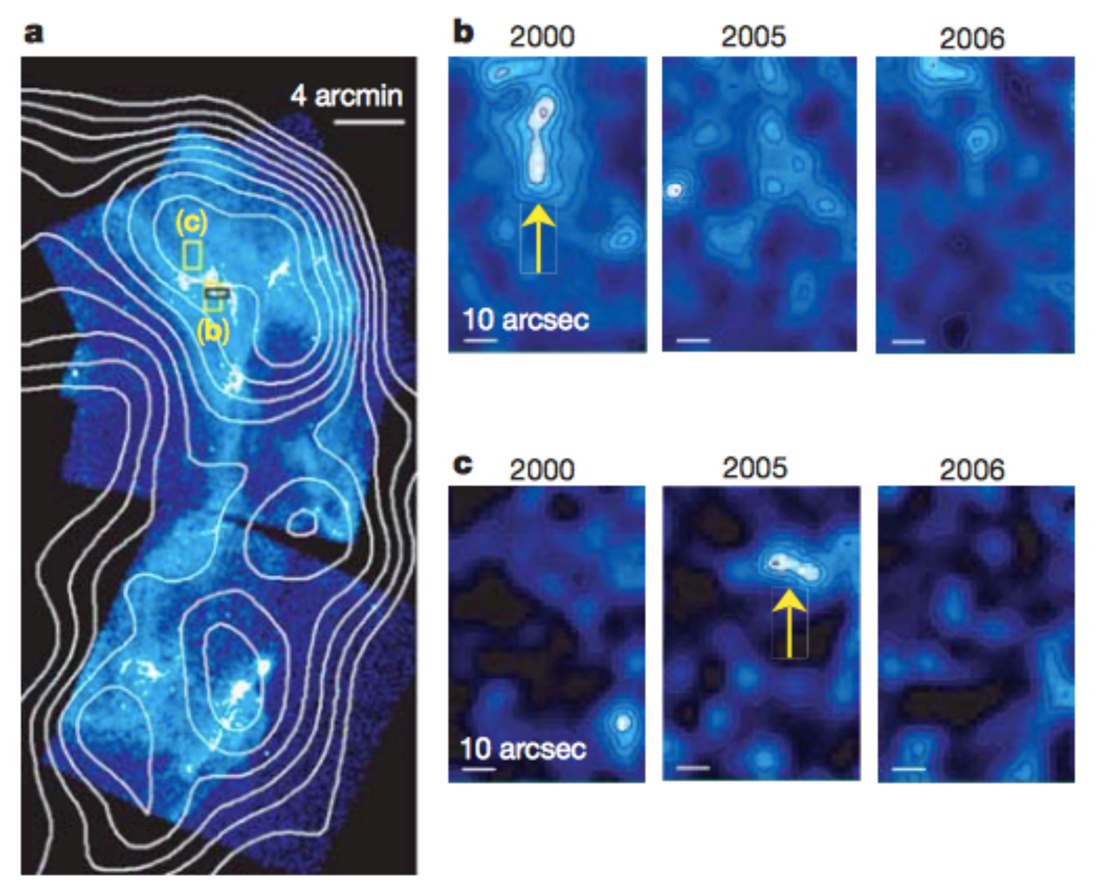


Xu & Lazarian submitted

Turbulent dynamo in SNRs

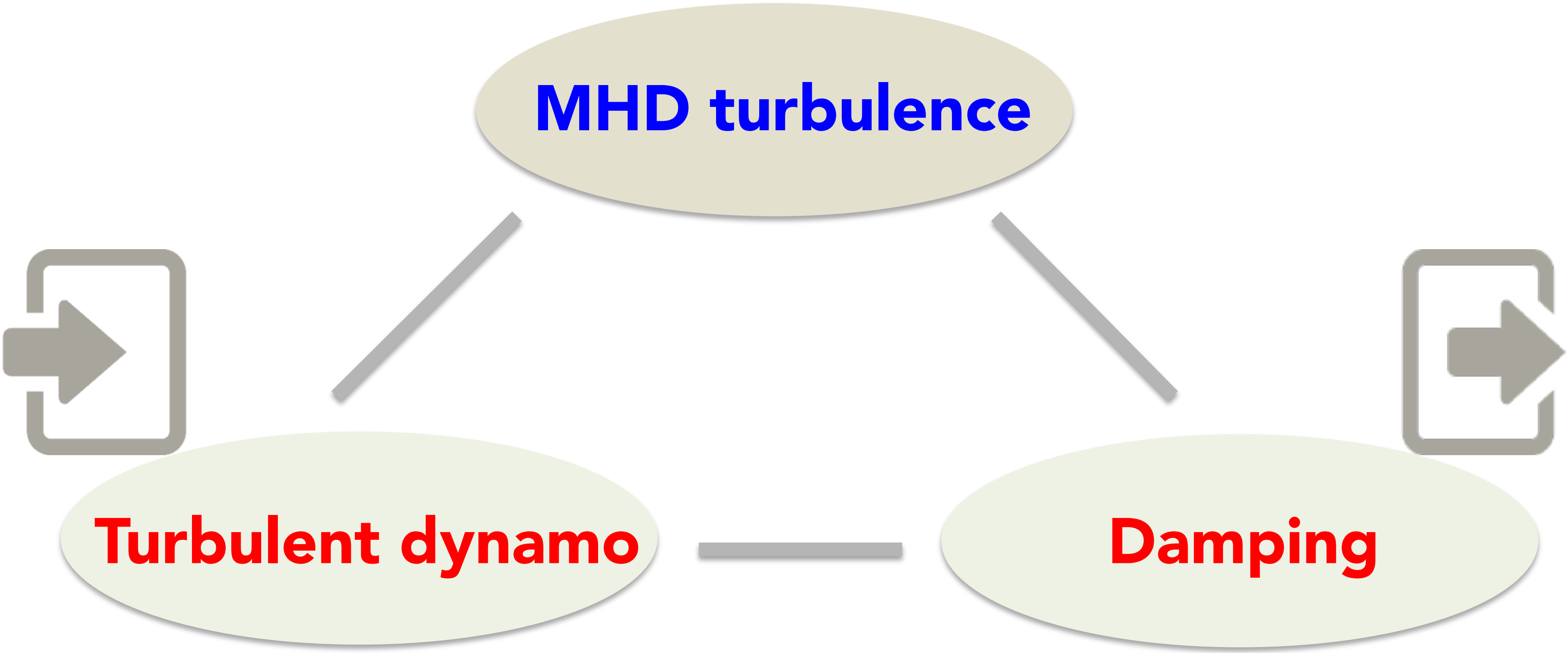
Comparison between our analysis & observations

Chandra X-ray images of the western shell of SNR RX J1713.723946.



- Amplification of the magnetic field by a factor of more than 100 (~ mG).
- The X-ray hot spots observed is located at more than 0.1 pc behind the shock front.

Uchiyama et al. 2007


MHD turbulence
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Damping