Effective Viscosity in Plasmas

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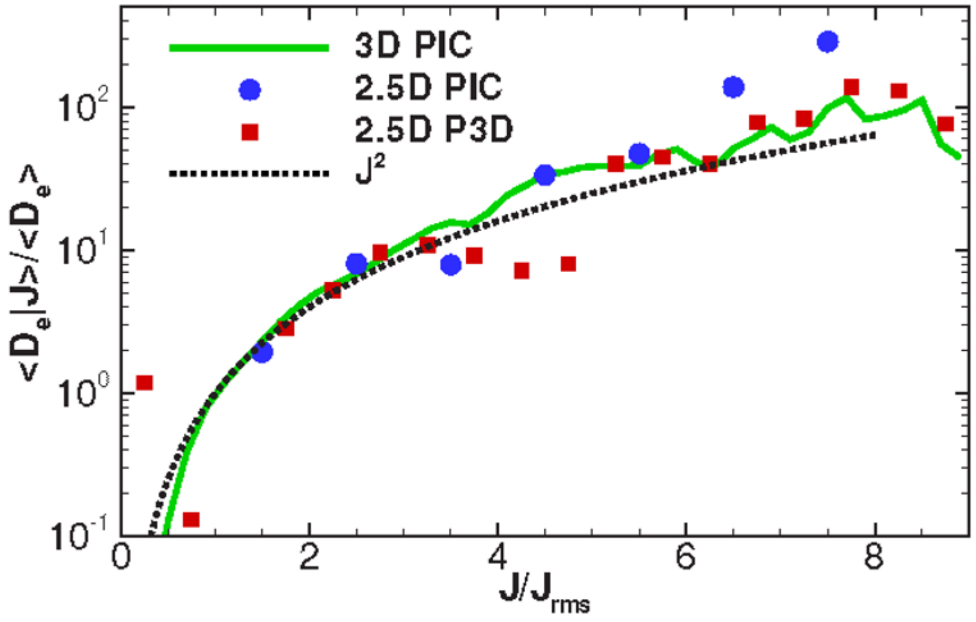
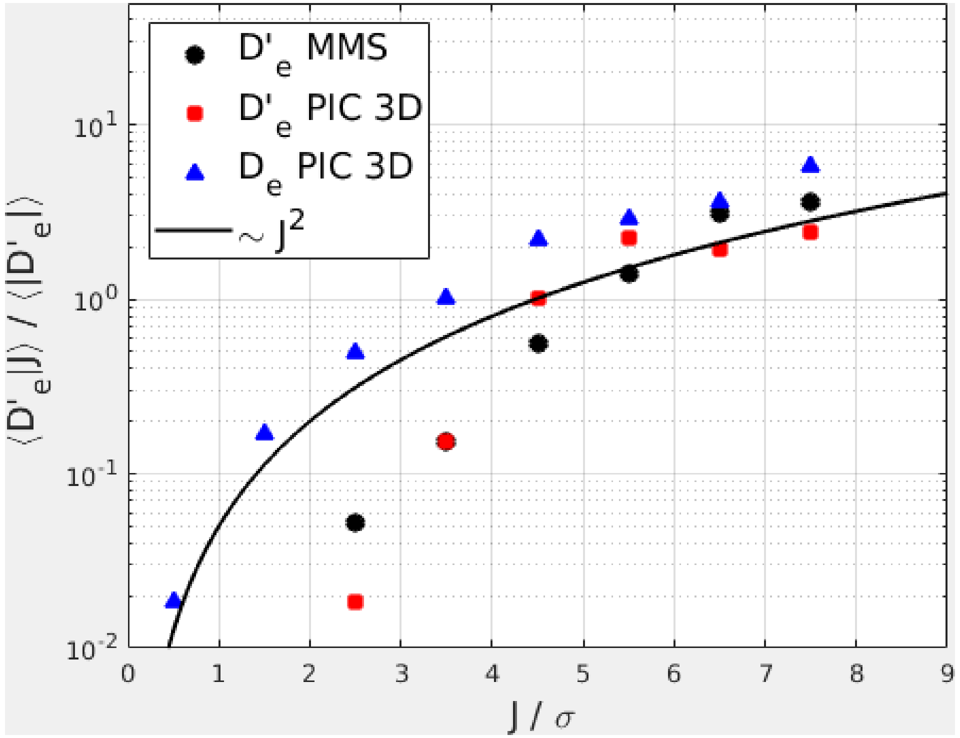
Background

- In collisional media (MHD), viscosity (ν) and resistivity (μ) dissipate.
- $J = \mu E$; $J.E \sim J^2$
- Similarly, $\Pi_{ij} = \nu D_{ij}$; $\Pi_{ij}\, D_{ij} \sim DijD_{ij}$
- What about (weakly-collisional) plasmas?

J.E in Plasmas



Wan et al. (2016) PoP



Chasapis et al. (2018) ApJL

Pi-D

$$\partial_t f_\alpha + \boldsymbol{v} \cdot \boldsymbol{\nabla} f_\alpha + \frac{\mathbf{F}}{m_\alpha} \cdot \boldsymbol{\nabla}_{\boldsymbol{v}} f_\alpha = 0$$

← Assume Vlasov

Dist. func.

α = proton, electron, ...

$$\partial_t \mathcal{E}^f_\alpha + \nabla \cdot (\mathcal{E}^f_\alpha \mathbf{u}_\alpha + \mathbf{P}_\alpha \cdot \mathbf{u}_\alpha) = (\mathbf{P}_\alpha \cdot \nabla) \cdot \mathbf{u}_\alpha + n_\alpha q_\alpha \mathbf{E} \cdot \mathbf{u}_\alpha. \quad (1)$$

$$\partial_t \mathcal{E}^{th}_\alpha + \nabla \cdot (\mathcal{E}^{th}_\alpha \mathbf{u}_\alpha + \mathbf{h}_\alpha) = -(\mathbf{P}_\alpha \cdot \nabla) \cdot \mathbf{u}_\alpha. \quad (2)$$

$$\partial_t \mathcal{E}^m + \frac{c}{4\pi} \nabla \cdot (\mathbf{E} \times \mathbf{B}) = -\mathbf{E} \cdot \mathbf{J} \quad (3)$$

Caveat: Ignore collisions

Add internal energy: dissipation

$$\partial_t \langle E^f_\alpha \rangle = \langle (\boldsymbol{P}_\alpha \cdot \nabla) \cdot \boldsymbol{u}_\alpha \rangle + \langle n_\alpha q_\alpha \boldsymbol{E} \cdot \boldsymbol{u}_\alpha \rangle,$$

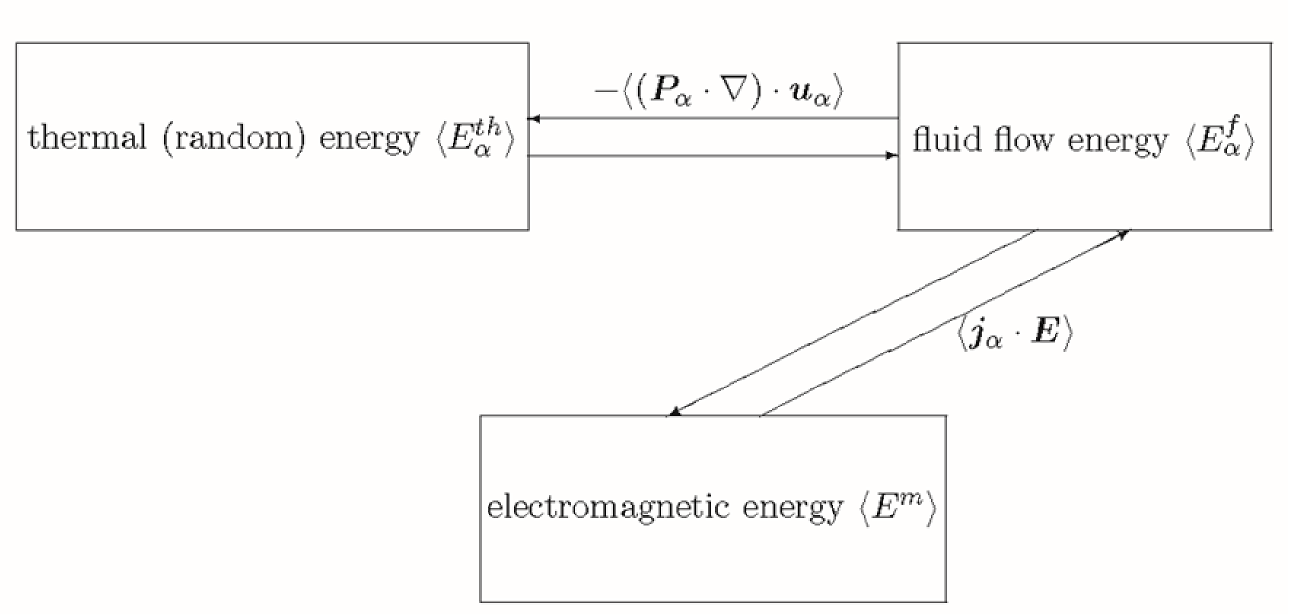
$$\partial_t \langle E^{th}_\alpha \rangle = -\langle (\boldsymbol{P}_\alpha \cdot \nabla) \cdot \boldsymbol{u}_\alpha \rangle, \longleftarrow \text{Heating!}$$

$$\partial_t \langle E^m \rangle = -\langle \boldsymbol{E} \cdot \boldsymbol{j} \rangle.$$

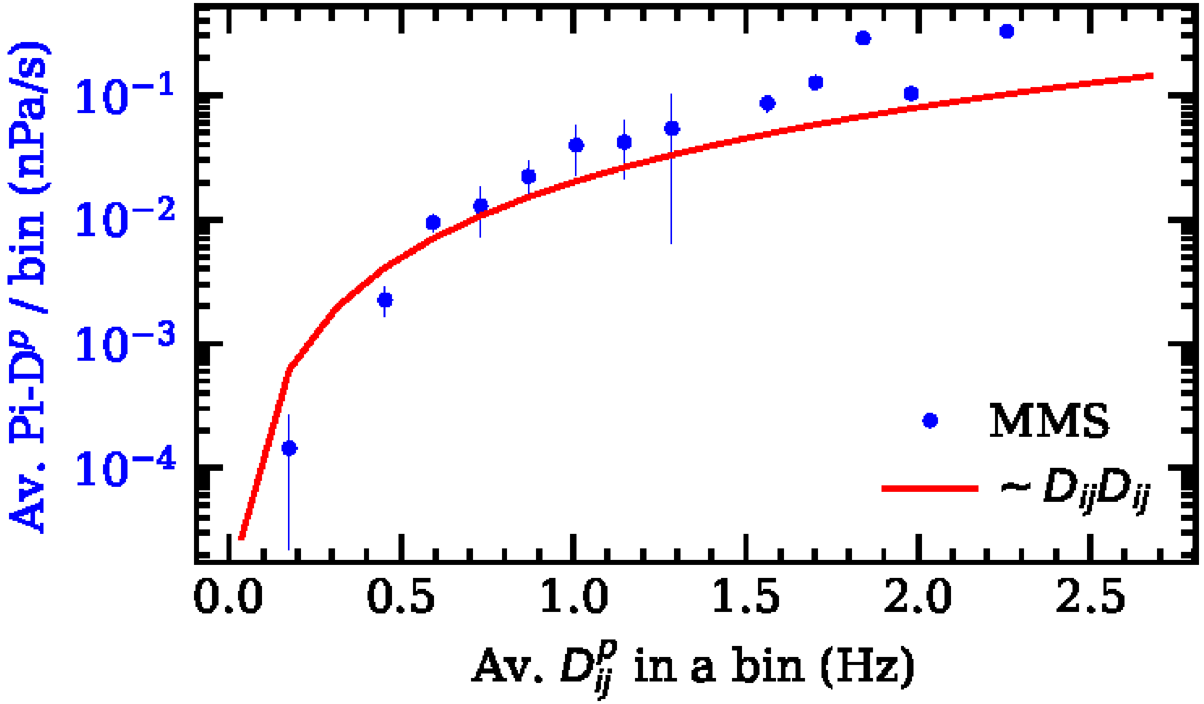
J.E and Pi-D measure somewhat different stages of energy conversion (dissipation)

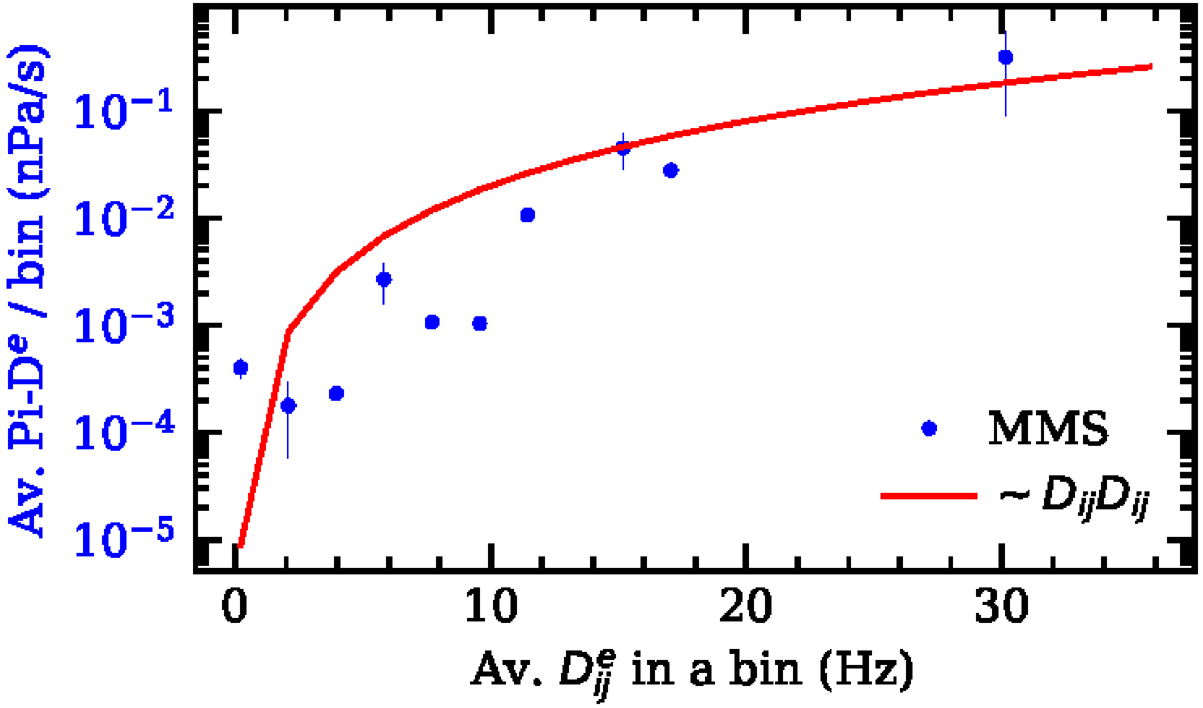
- Integrate conservation eqns over arbitrary volume: transport on surface (or may vanish)

- Triangle diagram describes energy conversion



Pi-D in MMS

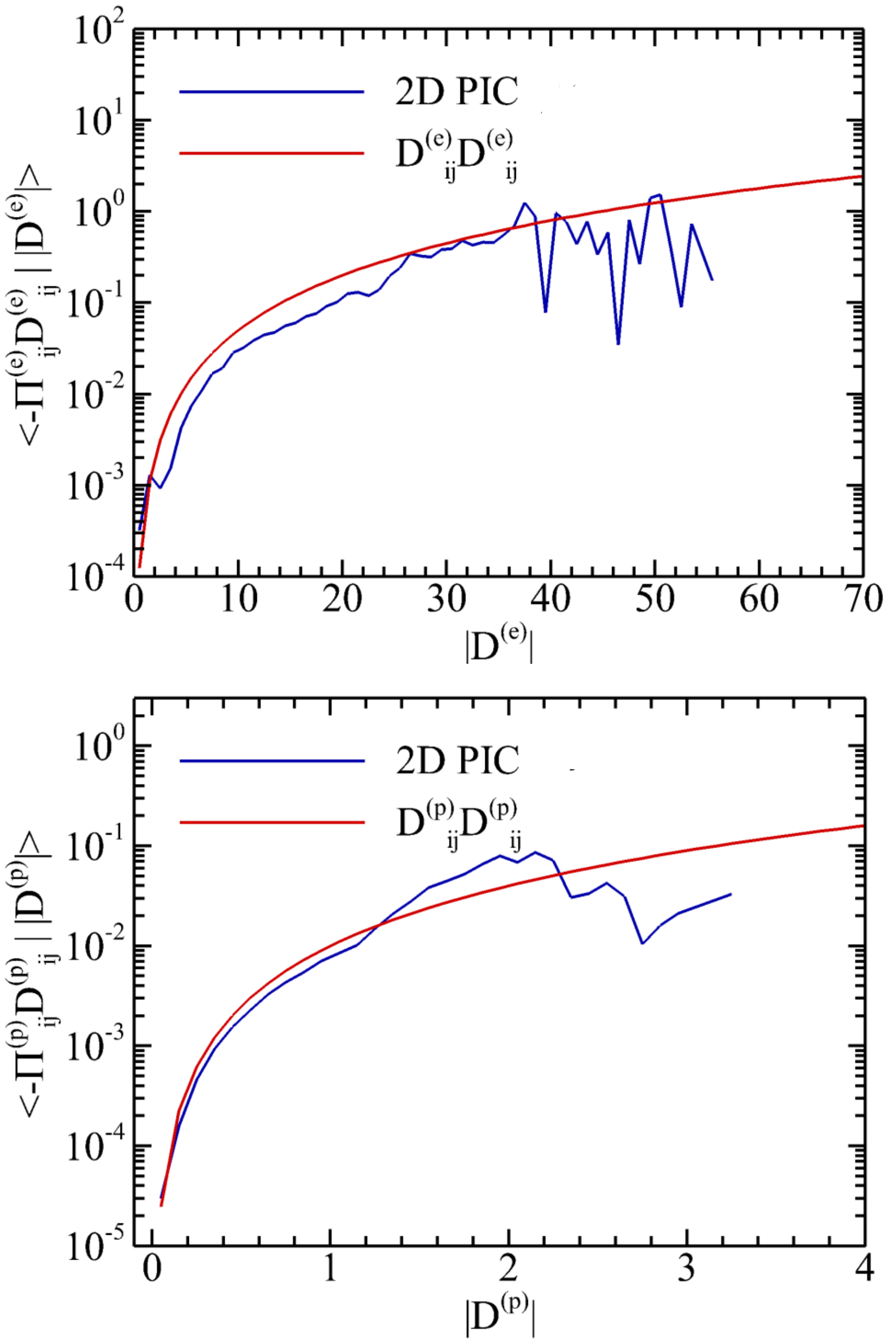




Bandyopadhyay et al. (2021) in prep.

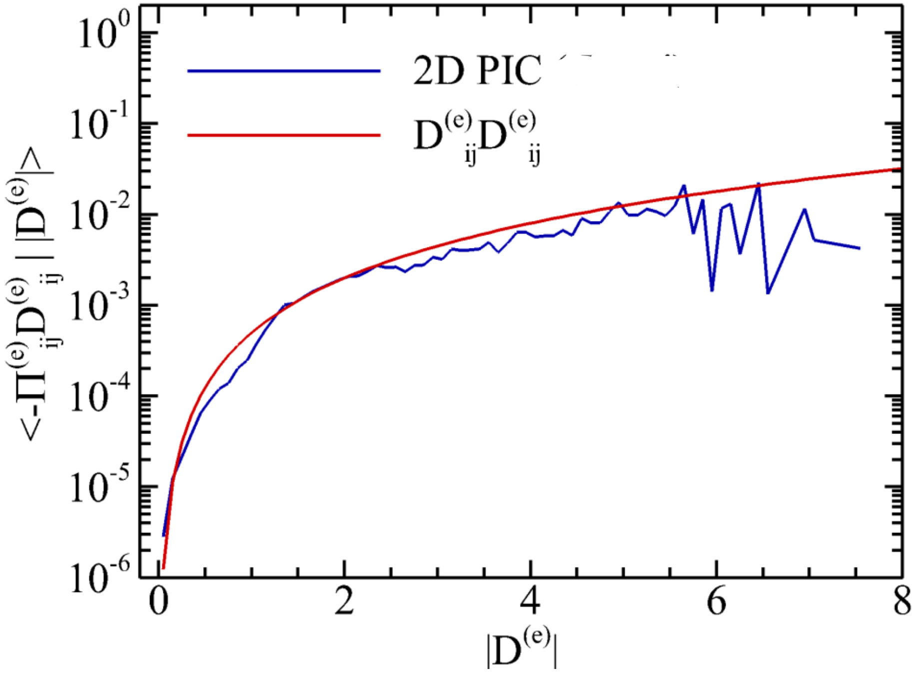
Pi-D in 2.5D PIC: I

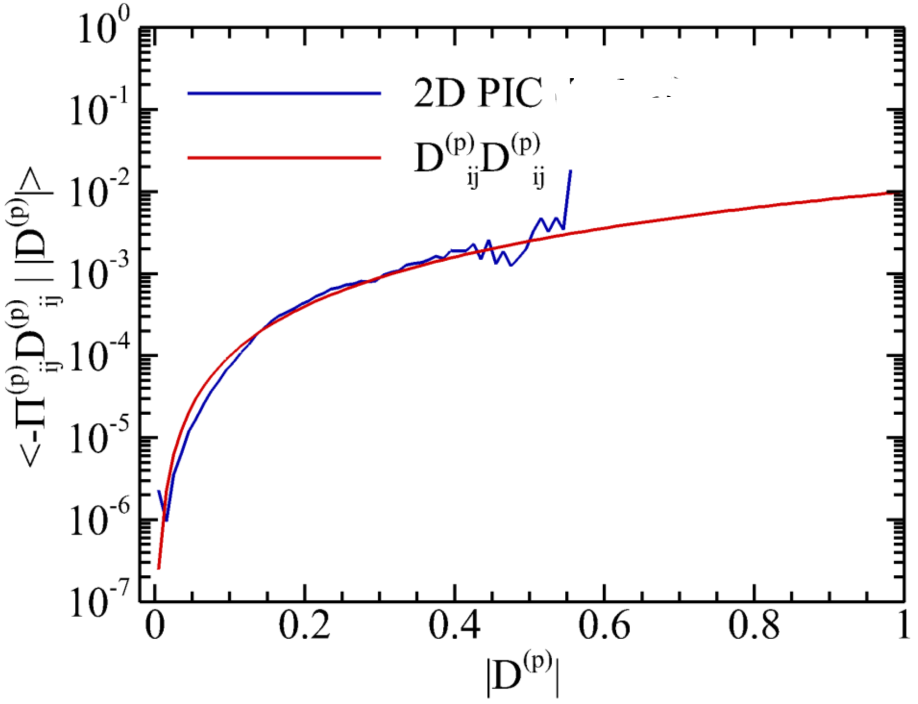
Dim	L	Grid	m_i/m_e	B_0	ppg
2.5D	$102.4d_i$	8192^2	25	5.0	300



Pi-D in 2.5D PIC: II

Dim	L	Grid	m_i/m_e	B_0	ppg
2.5D	$149.6d_i$	4096^2	25	1.0	3200

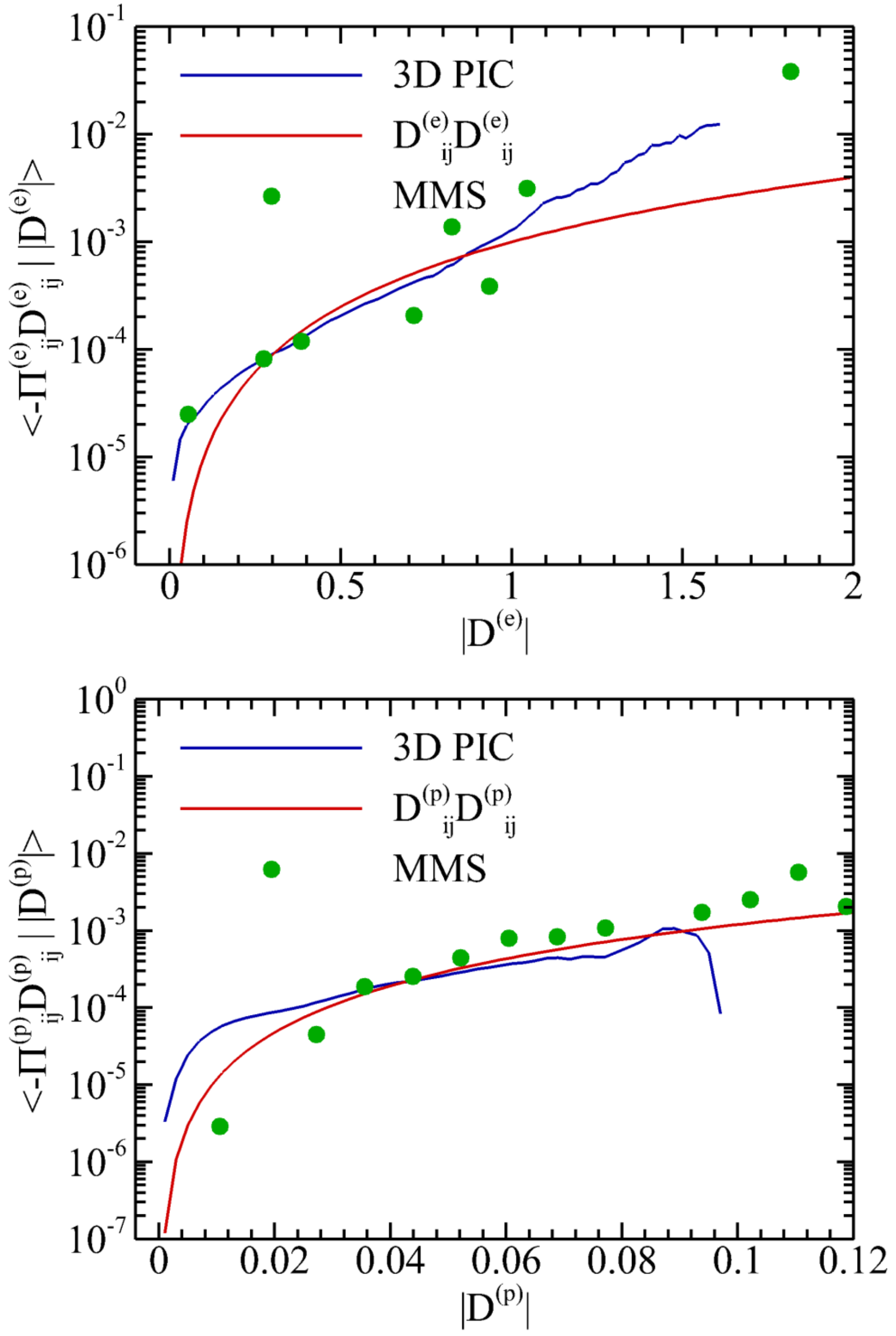




Pi-D in 3D PIC

Dim	L	Grid	m_i/m_e	B_0	ppg
3D	$41.9d_i$	2048^3	50	0.5	100

Roytershteyn et al. (2015) RSPTA



Summary

- Even in plasmas J.E ~ J^2 and Π_{ij} D_{ij} ~ DijD_{ij}
- Evaluate ν, μ for natural systems?

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