Clustering of heavy particles and ions in MHD turbulence

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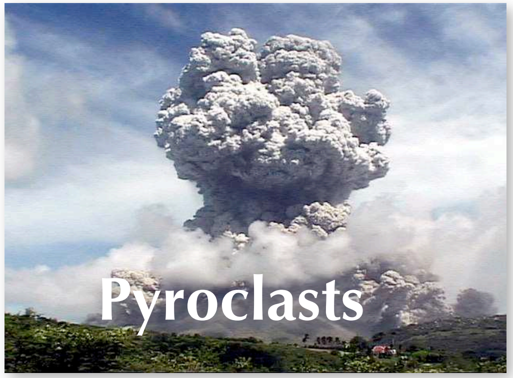
Particle laden flows



- **Finite-size** and **mass** impurities transported by turbulent flow

Heavy particles

- Charged or uncharged spherical particles much smaller than the Kolmogorov scale η, much heavier than the fluid.

$$\begin{cases} \dfrac{d\vec{X}}{dt} = \vec{V} \\ \dfrac{d\vec{V}}{dt} = -\dfrac{1}{\tau_s}[\vec{V} - \vec{v}(\vec{X}(t), t)] + q\vec{V} \times \vec{B} \end{cases}$$

$$\tau_s = 2\rho_p a^2/(9\rho_f \nu)$$

$$\mathrm{St} = \frac{\tau_s}{\tau_\eta}$$

$\vec{B} = 0$ $\vec{v}$ solution of Navier-Stokes

$\vec{B} \neq 0$ $\vec{v}$ and $\vec{B}$ solutions of the equations of incompressible MHD

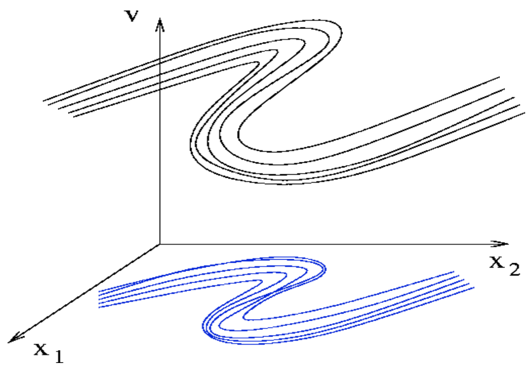
- **Aims:**
  - Understand differences with hydrodynamical flows (structures where particles cluster or are ejected from).
  - Understand the effect of charge on the particle concentration properties

Clustering

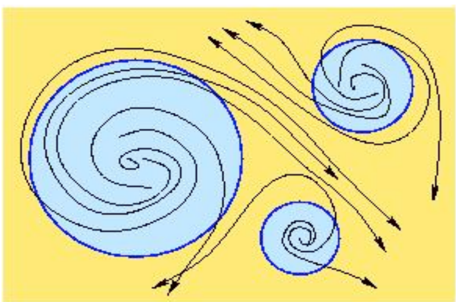
- **Important for**
  - ∗ the rates at which particles interact (collisions, chemical reactions, gravitation…)
  - ∗ the fluctuations in the concentration of a pollutant
  - ∗ the possible feedback of the particles onto the fluid

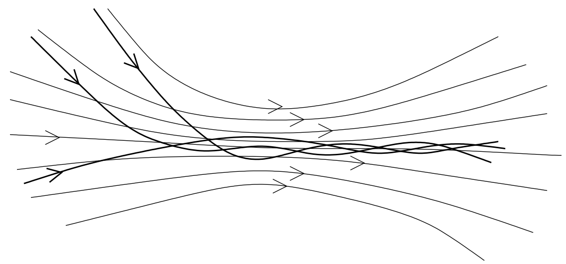
- **Phenomenology:** different mechanisms

Dissipative dynamics
⇒ **attractor**



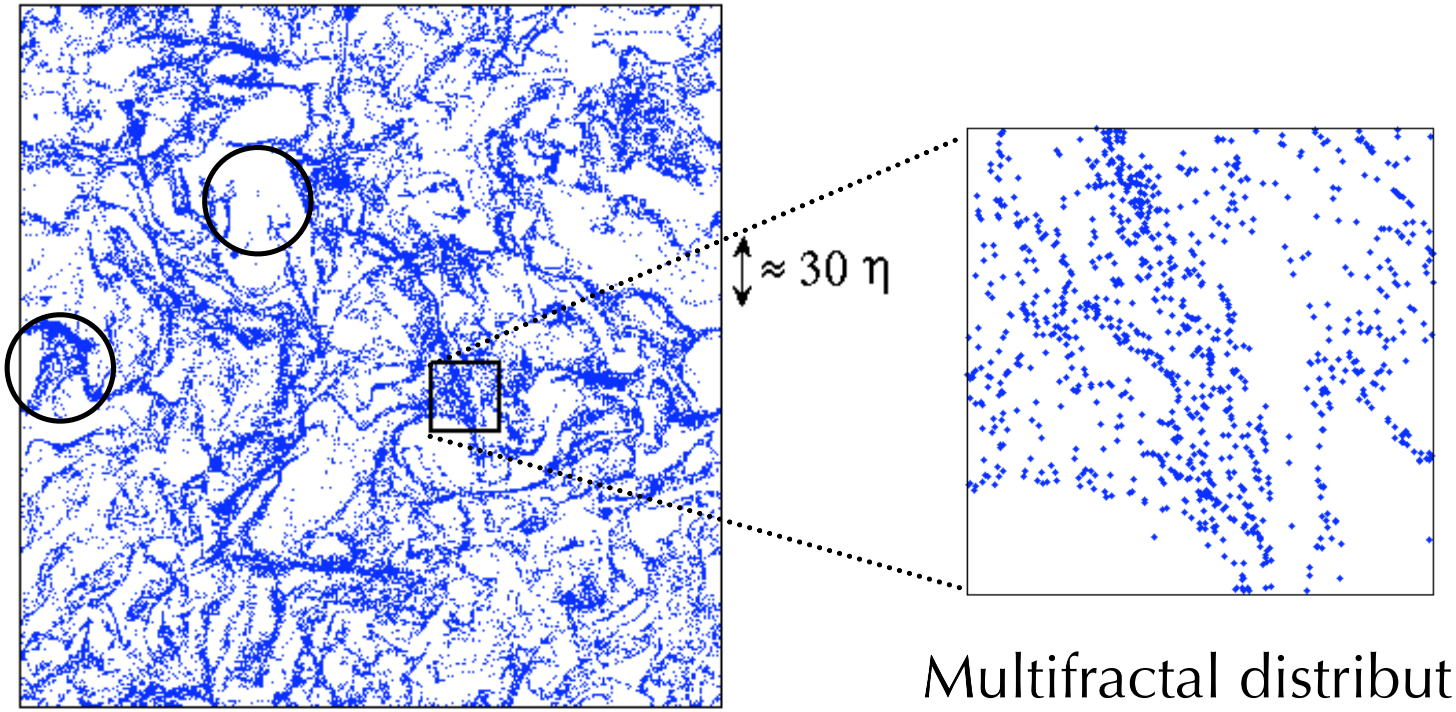
Ejection from **eddies** by centrifugal forces





⇒ concentration in **straining regions**

Clustering in hydrodynamics



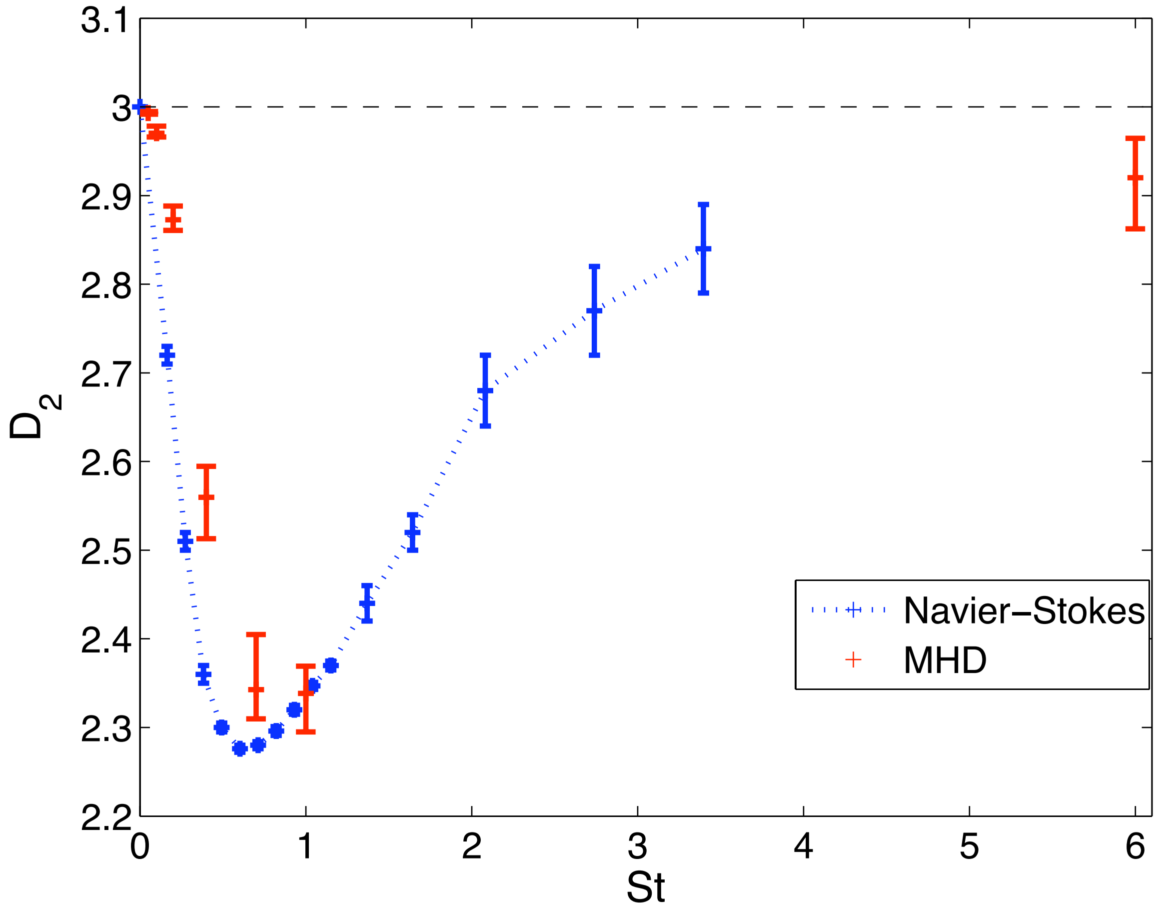
Inertial-range clusters and voids

Multifractal distribution at dissipative scales

Small-scale clustering

- $P_2(r)$ = Probability that two particles are within a distance r

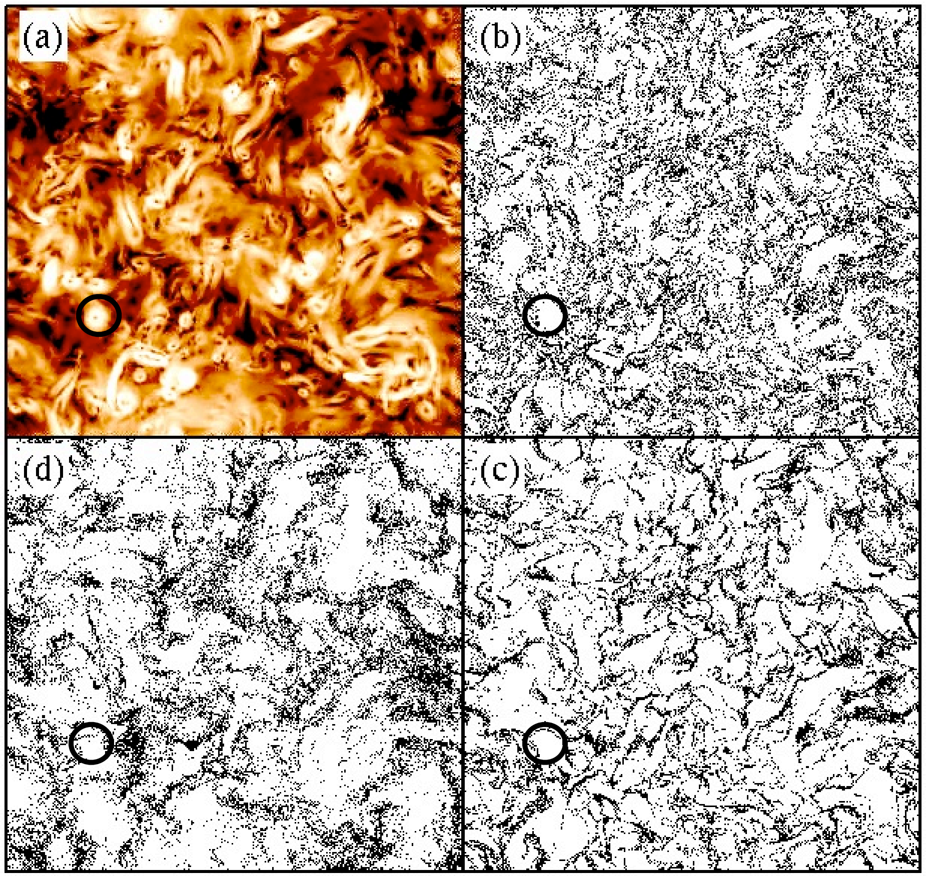
Correlation dimension $\mathcal{D}_2 = \lim_{r \to 0} d_2(r), \quad d_2(r) = \dfrac{\mathrm{d} \ln P_2(r)}{\mathrm{d} \ln r}$



Inertial-range concentrations

Real flow have structure and particle distribution correlates with the acceleration field

Modulus of acceleration



$\mathrm{St} = 0.16$

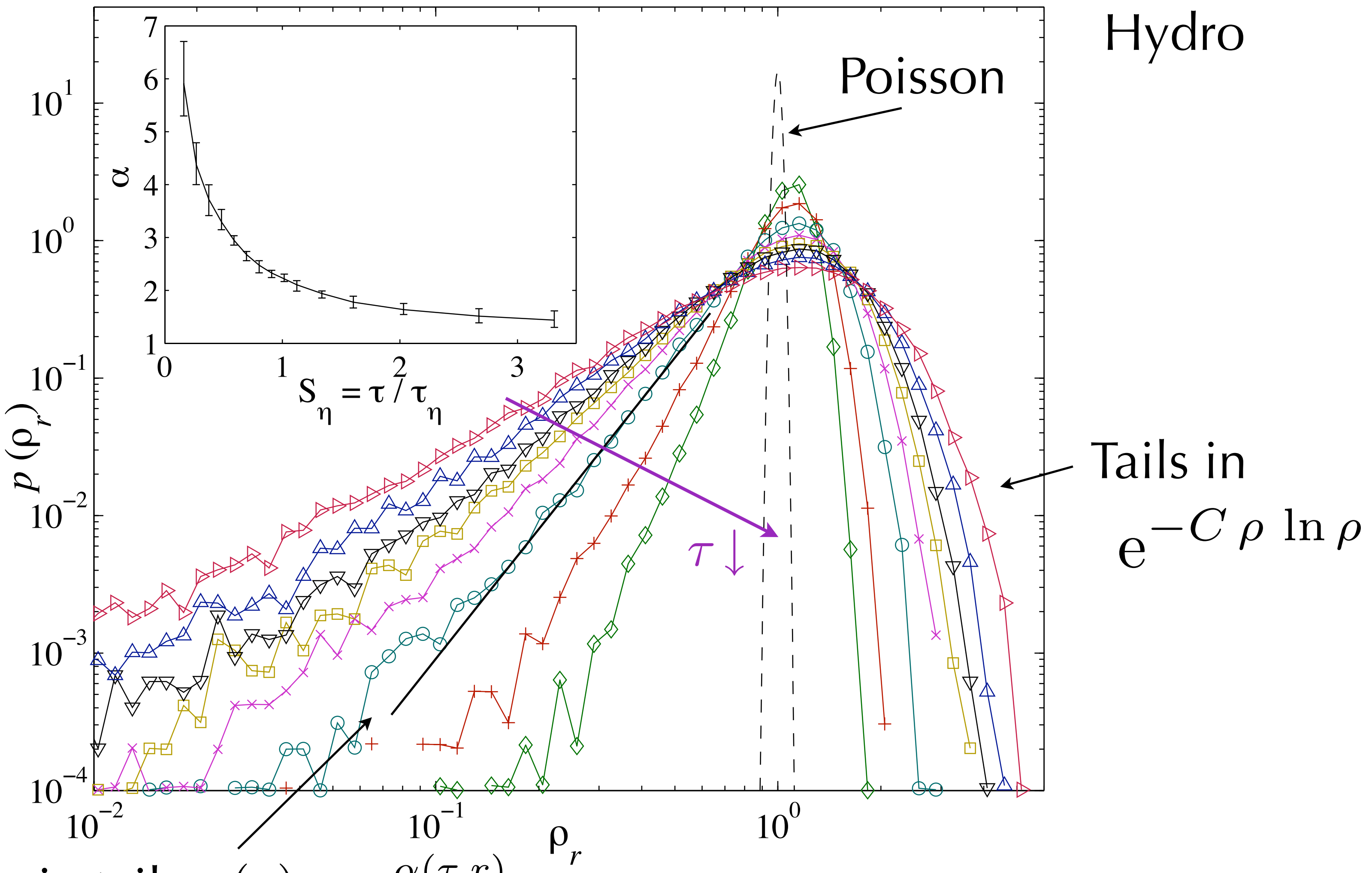
Hydro

$\mathrm{St} = 3.3$

$\mathrm{St} = 0.8$

Consequence of Maxey's approximation $\dot{X} \approx v(X,t) - \tau_s \, \mathrm{D}_t v(X,t)$

Coarse-grained density

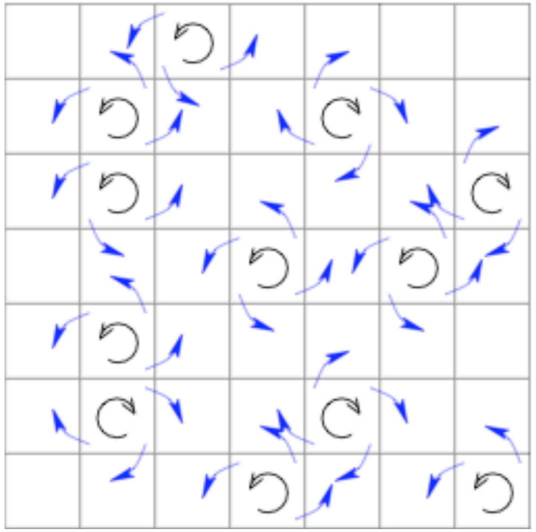


Algebraic tails $p(\rho) \propto \rho^{\alpha(\tau,r)}$
(signature of voids)

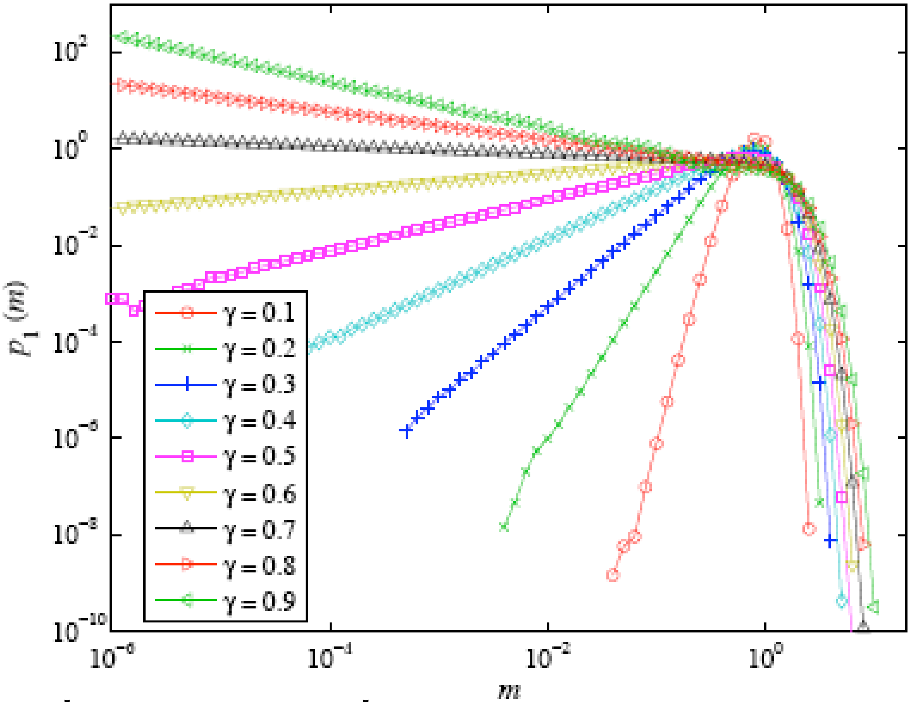
JB, L. Biferale, M. Cencini, A. Lanotte,
S. Musacchio, and F. Toschi, PRL 2007

Ejection dominates

- **Model**: at each time step some (randomly chosen with probability p) cells eject a fraction of their mass to their neighbors. Parameter = γ ejection rate



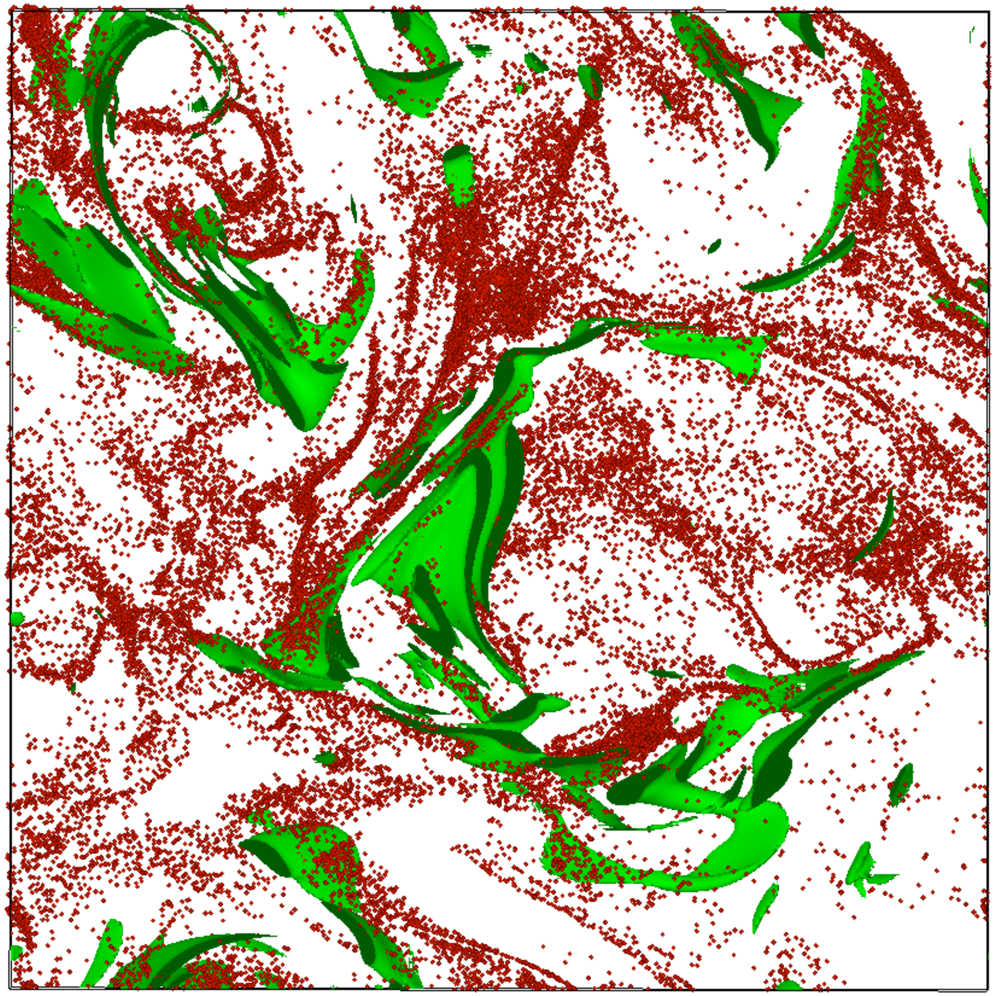
JB, R. Chétrite, New J. Phys. 2007



- This model gives (analytically) the same tails

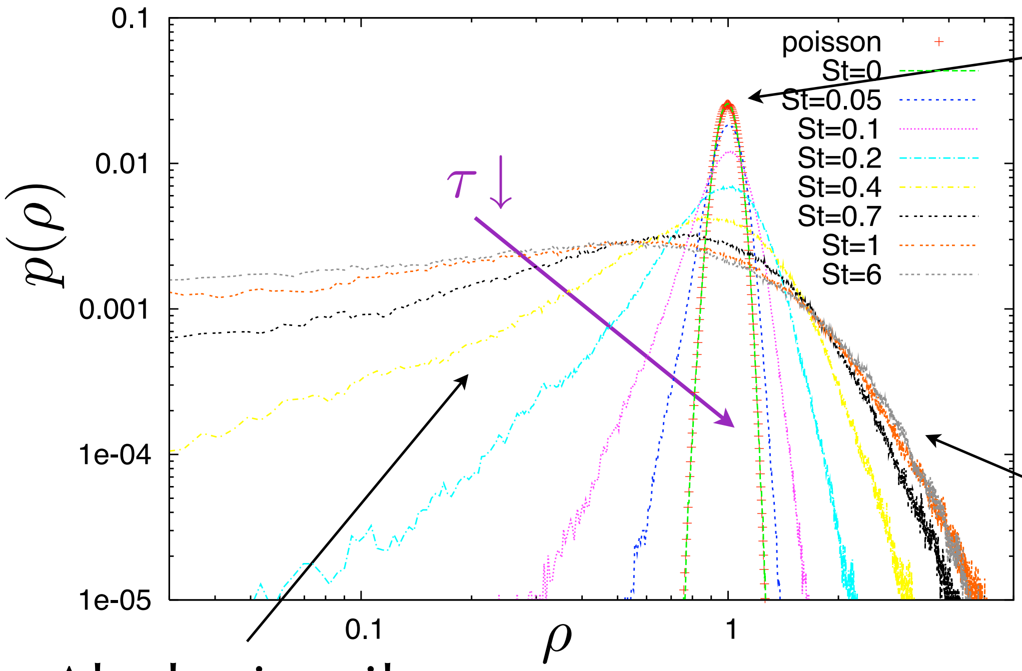
$$p(\rho) \propto \begin{cases} \rho^{\alpha(\gamma)} & \rho \to 0 \\ e^{-C(\gamma)\rho \ln \rho} & \rho \to \infty \end{cases}$$

Inertial-range distributions in MHD



- Uncharged particles concentrate in the neighborhood of current sheets

Coarse-grained density

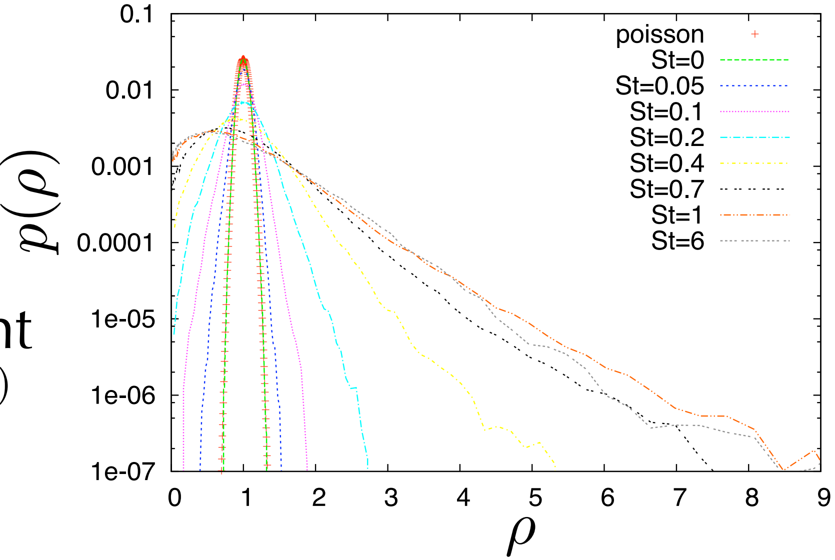


Poisson

MHD

Exponential tails

Algebraic tails

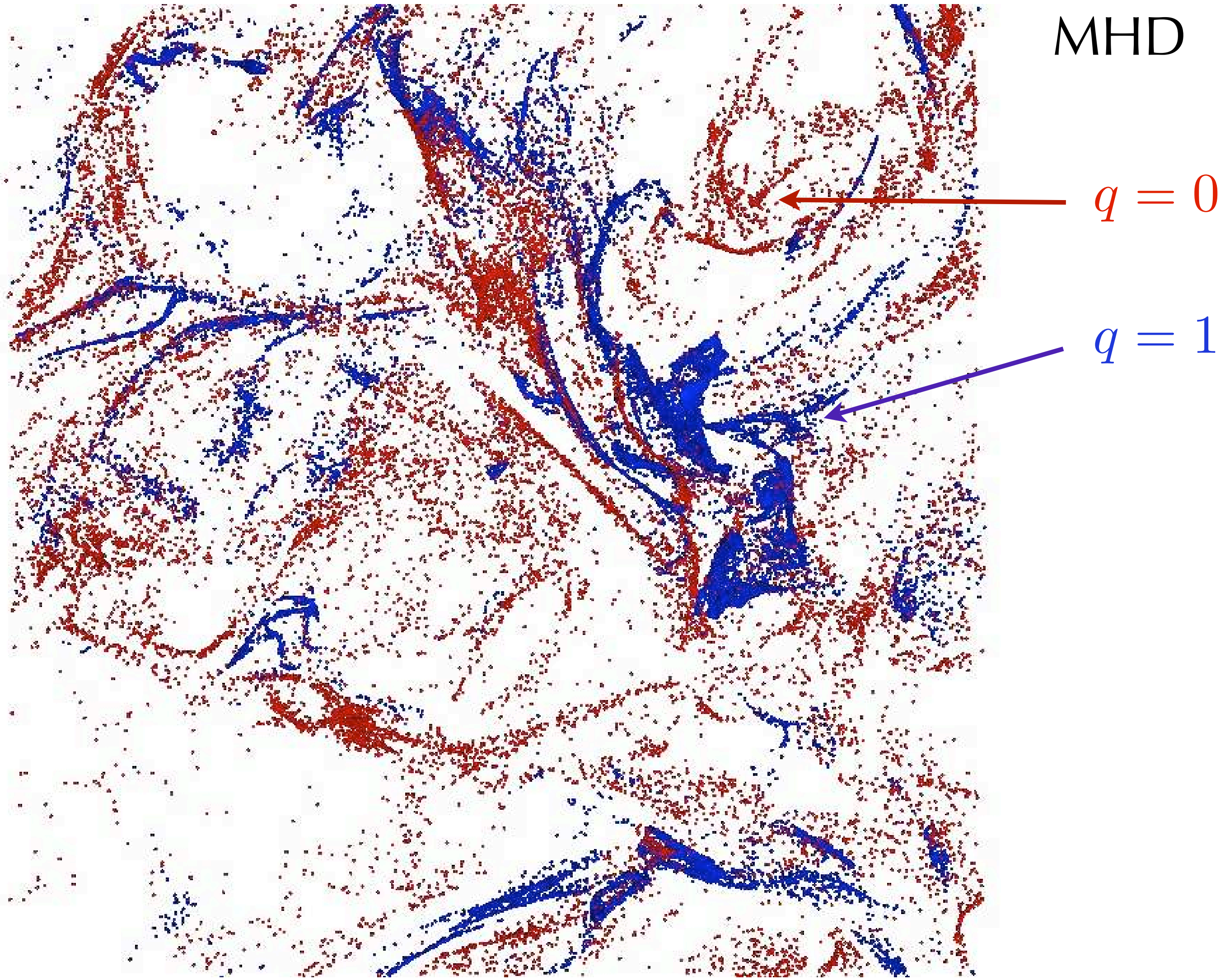


A clustering mechanism is present

(not only fluctuations in an ejection process)

Effect of charge

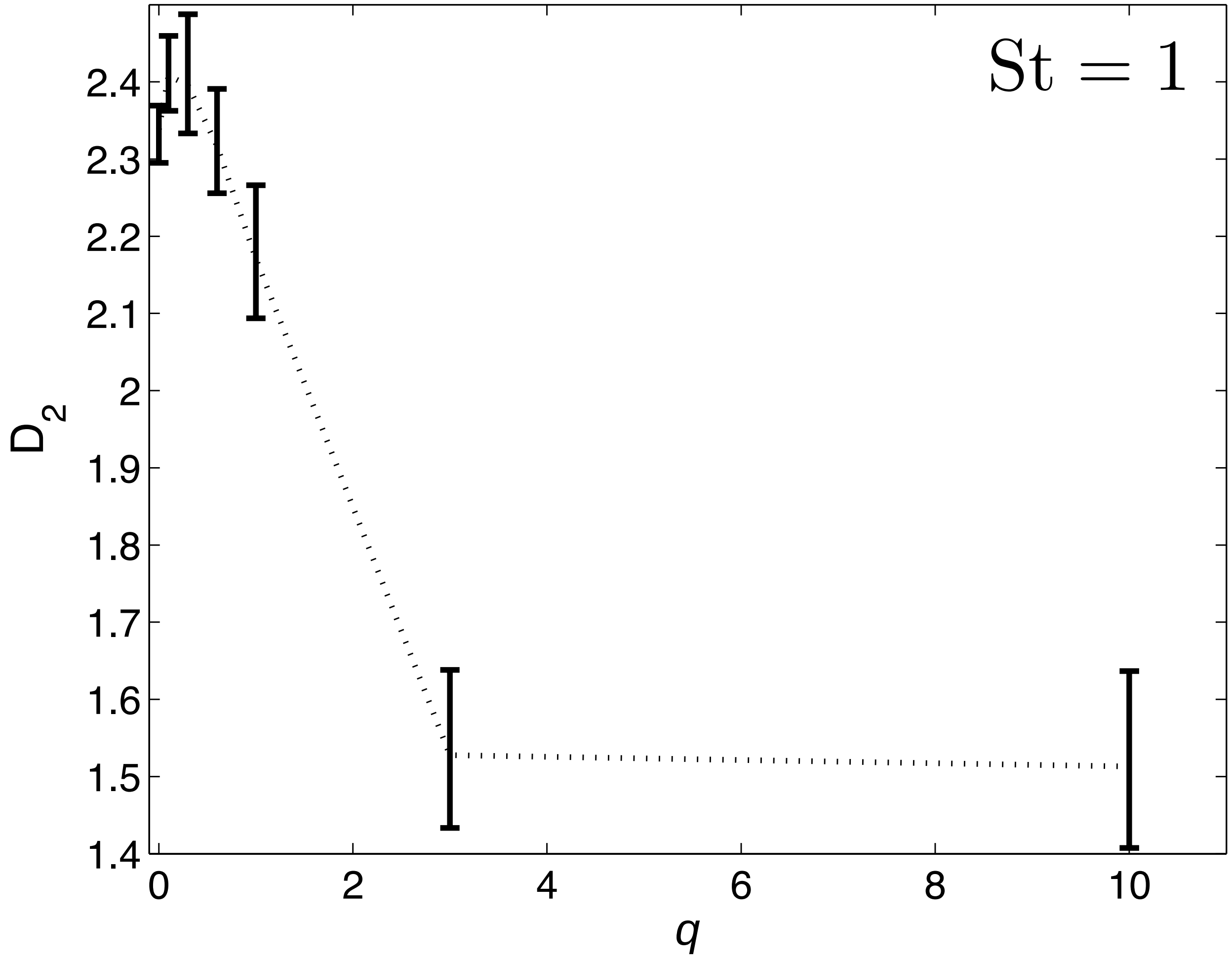
$\mathrm{St} = 1$



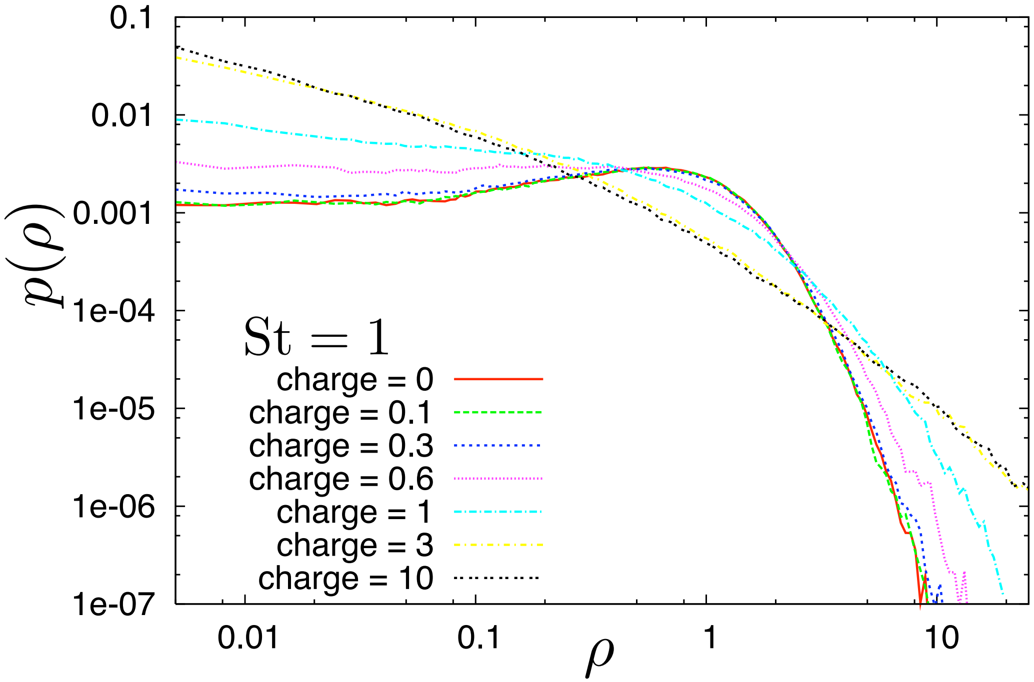
Effect of charge

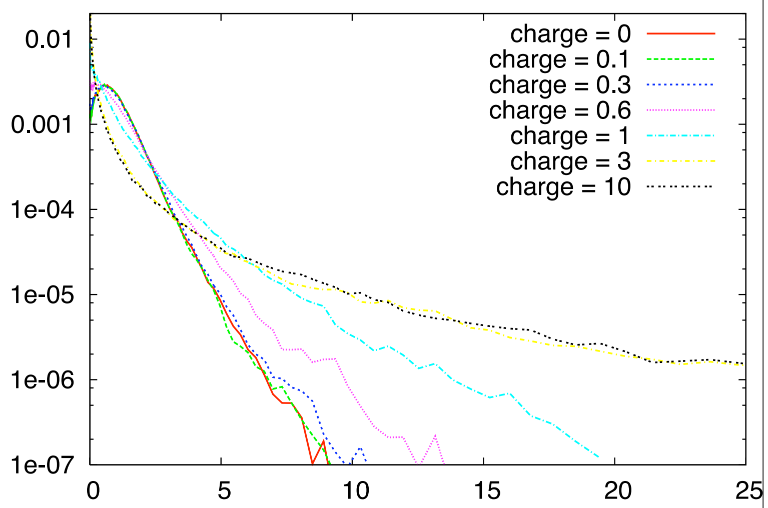
- **Correlation dimension**

MHD



Inertial-range mass distribution

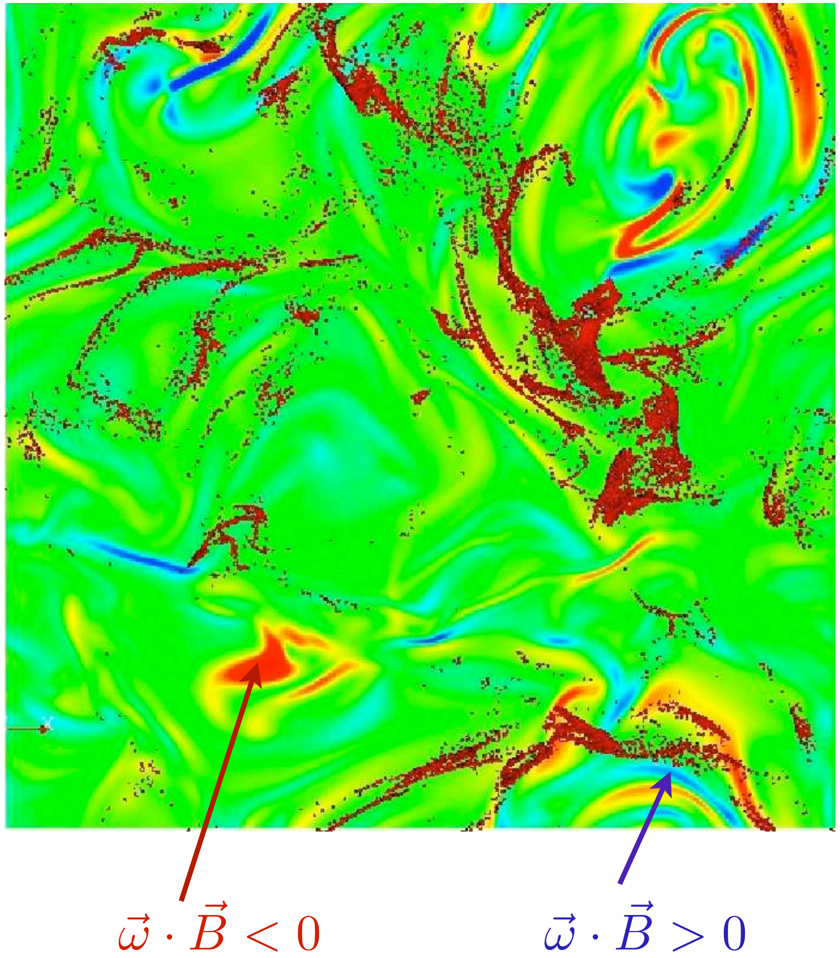




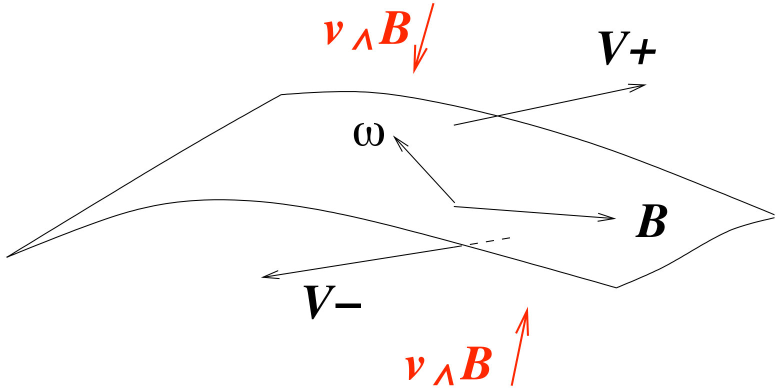
Right tail seems faster than exponential

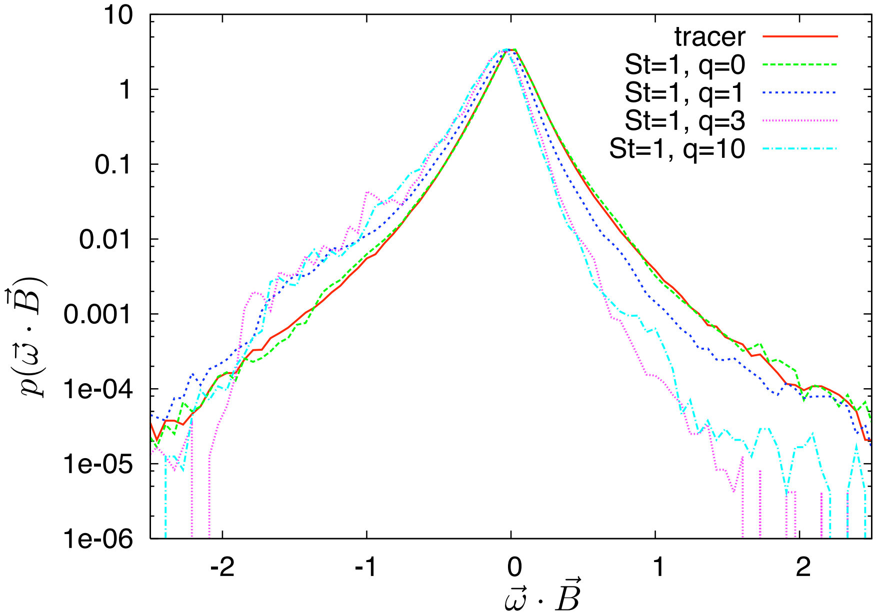
Left algebraic tails can have a negative exponent = finite probability to have a completely empty cell

Correlation with the fields



Charged particles concentrate near the sheets where $\vec{\omega}\cdot\vec{B} < 0$





Conclusions and Perspectives

- Strong correlation between the particle distribution and the more violent structures of the flow. Can be used to give insight on the flow structure?

- Understand the mechanisms responsible for large mass fluctuations in MHD. Simple models?

- Rescaling of the mass distribution in MHD as a function of τ_s and r, as that observed in Navier-Stokes?

- Effect of electrical interaction between the charged particles?