INTERMITTENT PROPERTIES OF FLOW IN POROUS MEDIA

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ABSTRACT

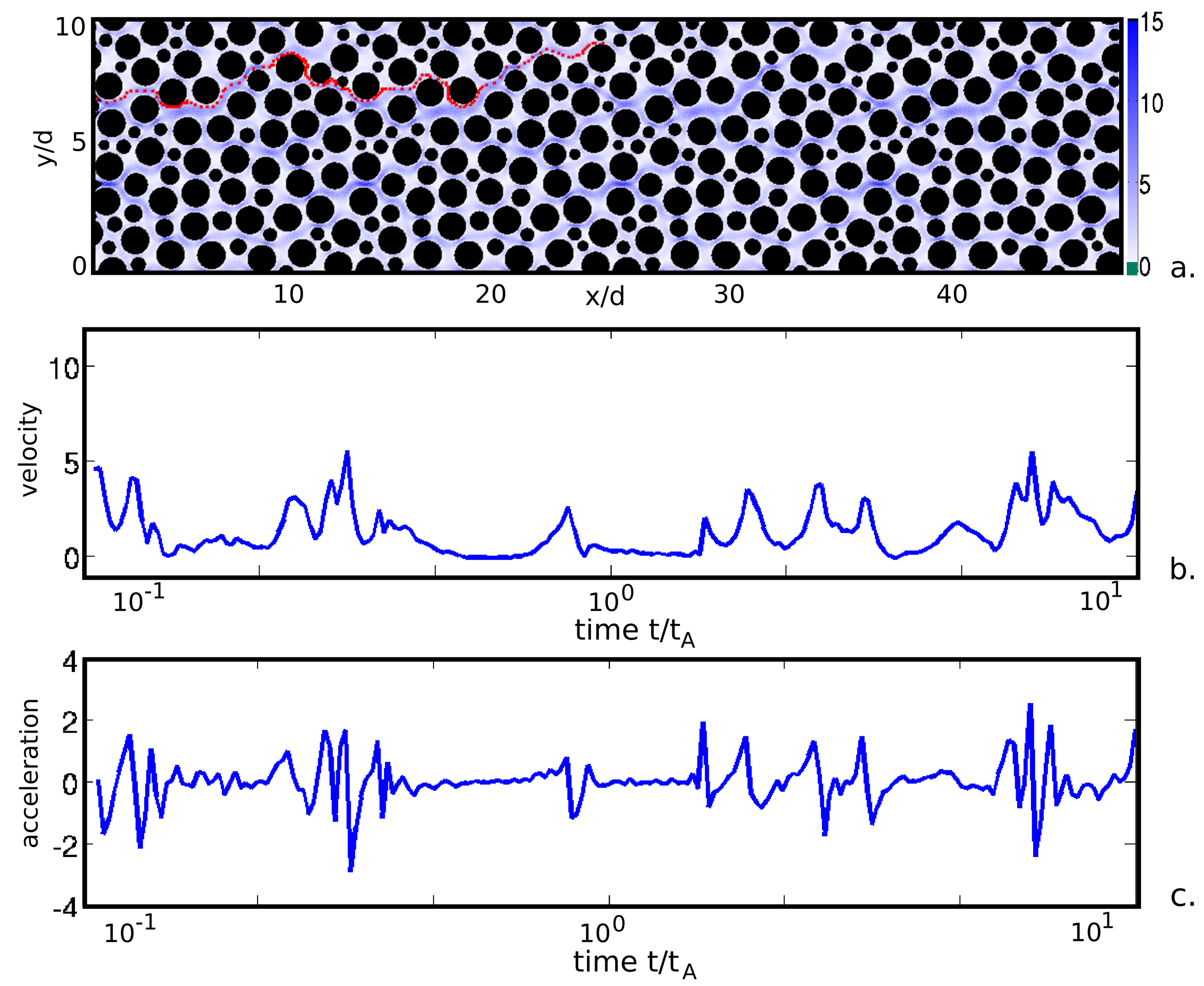
Using data from numerical simulations of pore-scale flow in porous media, we demonstrate the existence of an intermittent-like behavior of Lagrangian accelerations similar to the one observed in turbulent flows. This phenomenon, characterized by non-Gaussian distributions of Lagrangian velocity increments and long-range correlation of Lagrangian accelerations, is at the origin of the breakdown of classical upscaled models. For transport in porous media this manifests itself as anomalous scaling of the temporal evolution of the characteristic dispersion length, called anomalous dispersion. Long range correlation is related to the existence of low velocity regions and localized high velocity channels.

While for turbulence, intermittency of Lagrangian velocities can be represented in a multifractal framework, for porous media we show that the dynamical picture is different and that this process is well captured by a **correlated Continuous Time Random Walk** approach. In this framework the correlation of successive transit times is a key property which is a consequence of micro scale flow conservation.

Similar correlation properties found in a variety of fields, including financial market dynamics, biological and human motion pattern, and earthquake occurrences, have recently motivated a series of theoretical developments on correlated CTRW models showing that their scaling properties are different from the uncorrelated case.

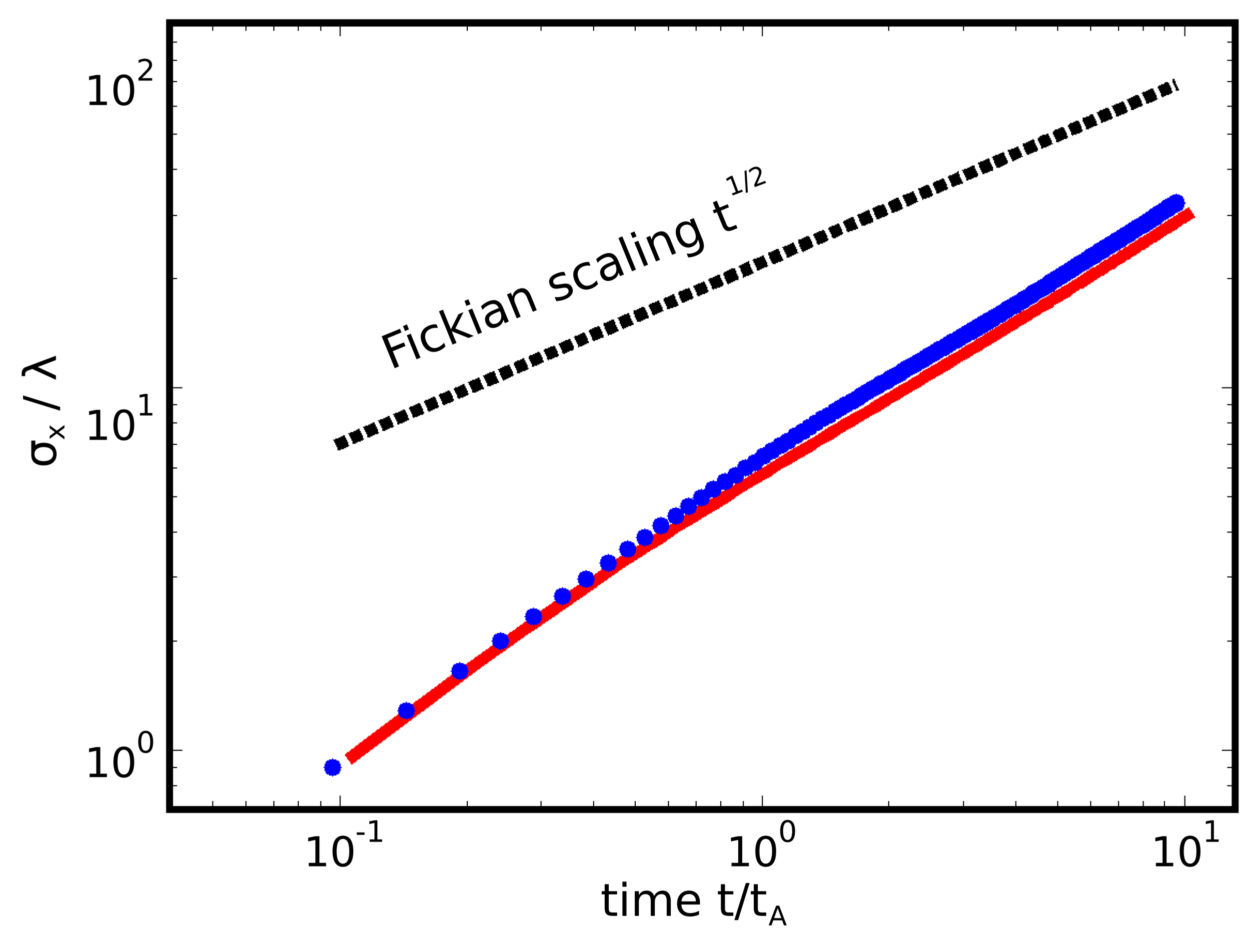
1. PORE SCALE 2d FLOW IN AN HETEROGENEOUS POROUS MEDIUM (LAGRANGIAN SPH SOLUTION)

PORE SCALE 2d FLOW



a) The amplitude of the pore scale velocity field normalized by the average Lagrangian velocity $\overline{v}$. Space is rescaled with respect to the average pore size d. The trajectory of a Lagrangian particle is shown with red dots at equidistant time increments $\Delta t = 6 \cdot 10^{-2} t_A$. Time is rescaled with respect to $t_A = d/\overline{v}$. b) and c) are respectively the time series of the Lagrangian velocity and acceleration for the particle trajectory displayed in red.

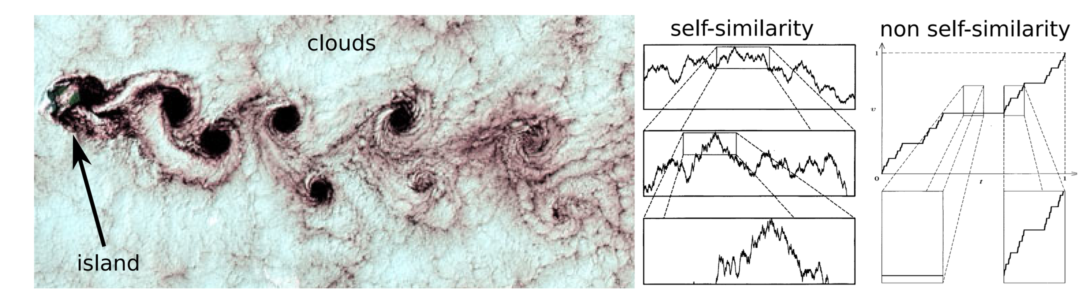
ANOMALOUS SPREADING OF ADVECTED PARTICLES



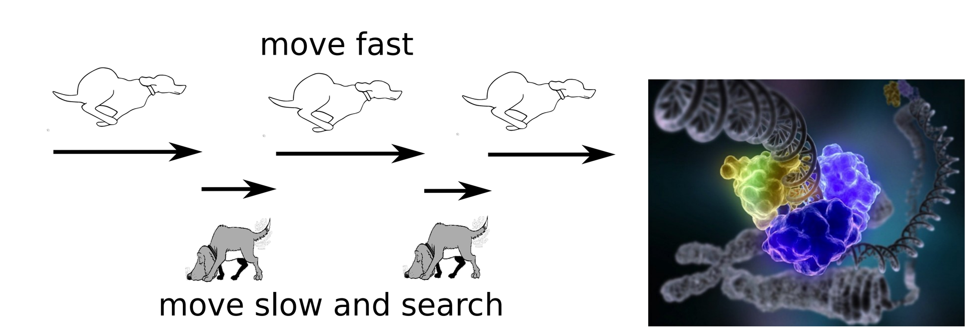
Purely advective hydrodynamic dispersion is characterized by the mean-squared longitudinal displacement σ_x^2 of of passive tracer: $\sigma_x^2 = \langle[\Delta x(t) - \langle\Delta x(t)\rangle]^2\rangle$, where $\Delta x(t) = x(t) - x(0)$. σ_x^2 is found to be anomalous, this means, σ_x^2 does not evolve linearly with time.

INTERMITTENT PROPERTIES? SOME EXAMPLE IN NATURE

TURBULENCE:
a central assumption of the classical Kolmogorov theory (K41) is the self-similarity of random velocity field. Intermittency represent a breakdown of classical K41 theory.



SEARCH PROCESSES:
A fast movement is known to significantly degrade perception abilities, the forager must search slowly. But forager have also to relocate as fast as possible in order to explore a previously unscanned space.



animals looking for food — DNA reading

IMBIBITION:
velocity of a viscous fluid interface during forced-flow imbibition in a disordered medium: the fronts display an intermittent behavior.

2. UPSCALING: CORRELATED CTRW

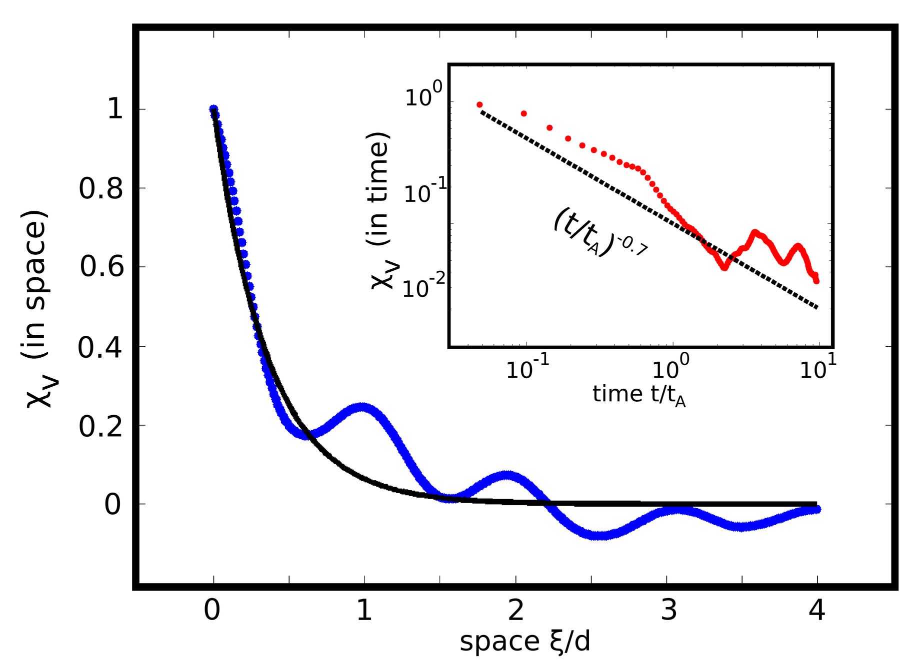
We consider a CTRW model for the motion of fluid particles in x–direction defined as:

$$x_{n+1} = x_n + \Delta x$$
$$t_{n+1} = t_n + \tau_n$$

where the transit time τ_n is a Markov process defined from the distribution $\phi(\tau)$ of transit time over a distance Δx and the conditional probability $\psi(\tau|\tau')$ of successive transit times. We define both from simulated particle trajectories at the pore scale. A non correlated CTRW can be defined from the distribution $\phi(\tau)$ of transit time.

Notice that neglecting the correlation of successive transit times in the CTRW model leads to underestimating particle dispersion and overestimating the probability of large velocity increments at small lag times.

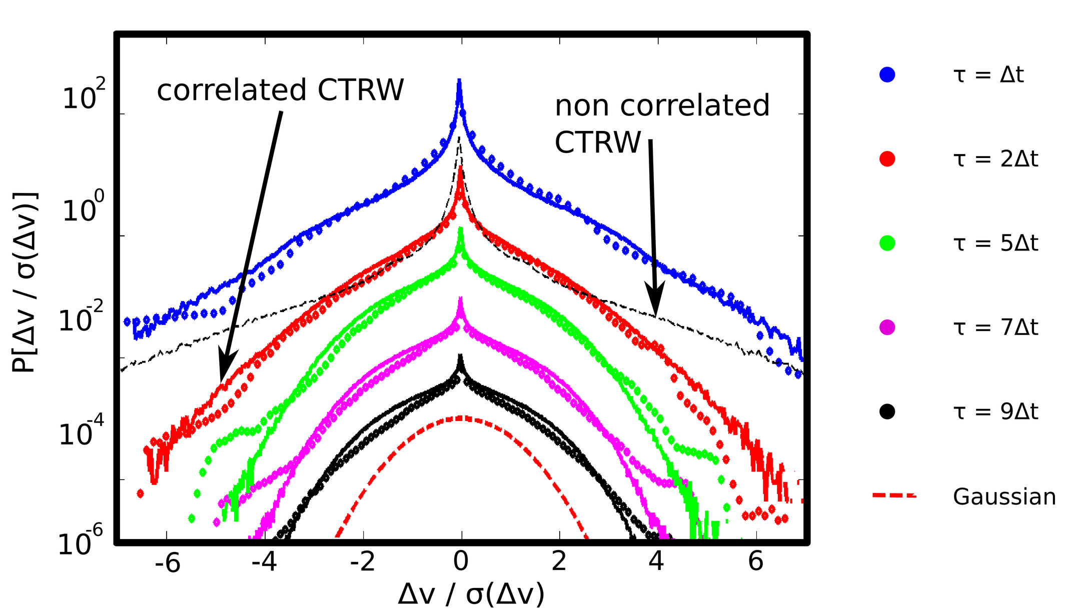
3. CORRELATION OF PORE SCALE VELOCITIES



The black solid line is an exponential fit: the associated characteristic correlation length is $\xi = 0.25d$: thus, for the correlated CTRW model we fix the distance $\Delta x = 0.25d$. $\chi_v(\xi) = \frac{\langle[v(x+\xi)-\langle v\rangle][v(x)-\langle v\rangle]\rangle}{\sigma_v^2}$

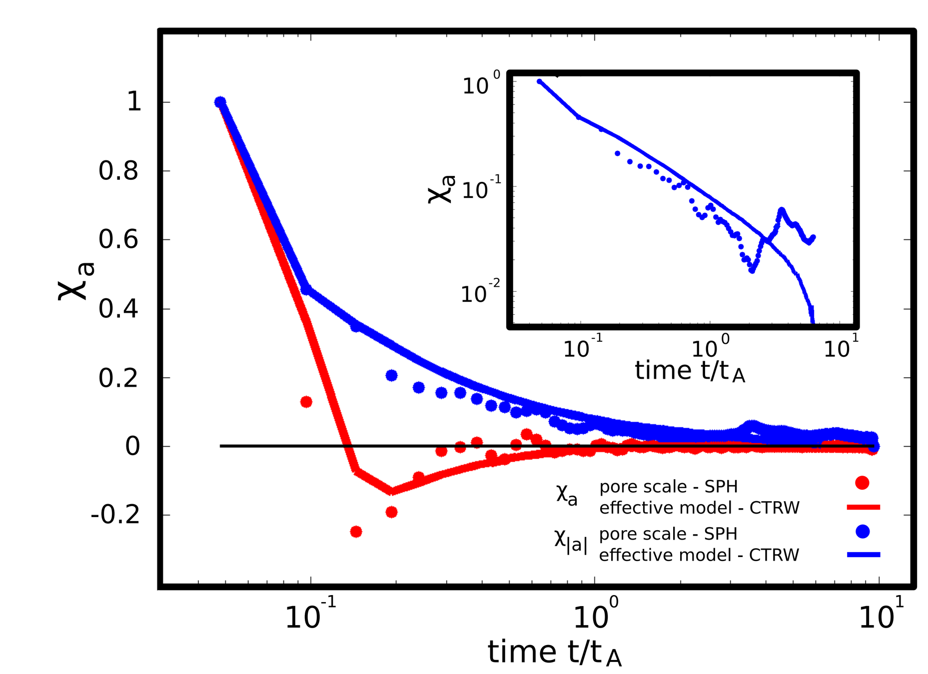
4. PDF OF VELOCITY INCREMENTS

$\Delta_\tau v = v(t+\tau) - v(t)$



Dots represent the SPH pore scale simulations, solid lines the correlated CTRW upscaled effective model. The dashed black line represent the result of non correlated CTRW for the case $\tau = 2\Delta t$. Curves are shifted for clarity.

5. CORRELATION OF ACCELERATIONS



Red and blue represent respectively the correlation of the Lagrangian accelerations and of its absolute value. Dots represent the SPH pore scale simulations and lines the correlated CTRW upscaled model.

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