Mixing in viscous flows

The inhibiting role of phase space structures at the walls

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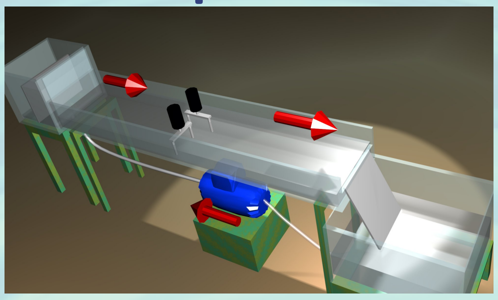
Mixing of viscous fluids: motivations and approach

- Mixing is ubiquitous in industry: food processing, microfluidics, glass melting
- Framework = chaotic advection: chaotic trajectories ⇒ good mixing. Phase space = real space !

How fast can you mix ?

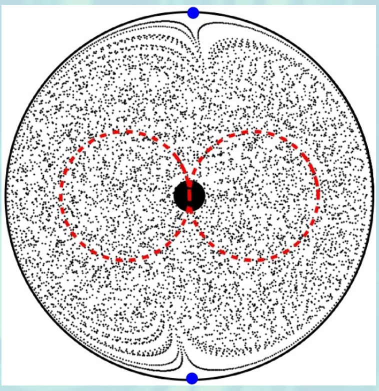
Quantitative dye mixing experiments

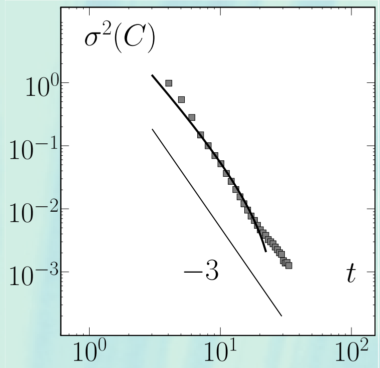
Closed and open flows



Closed flows: phase portrait at the wall determines mixing dynamics

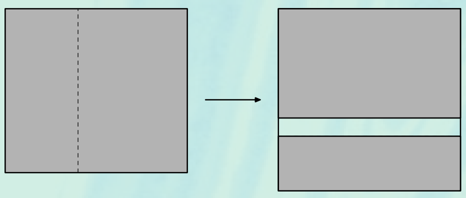
Full chaotic region: walls ⇒ algebraic mixing



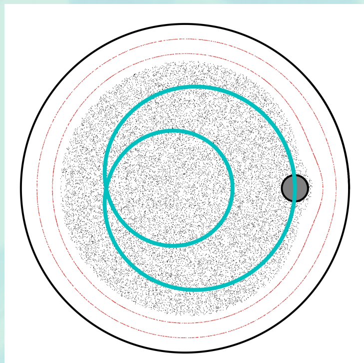


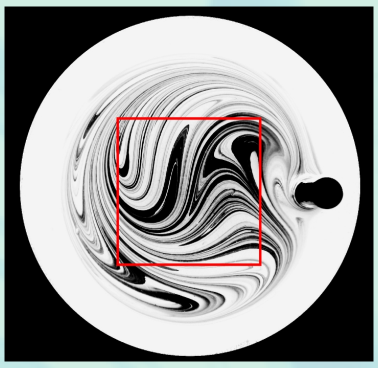
- Full chaotic region
- Stagnation (parabolic) point on the wall
- No-slip condition ⇒ poorly-mixed fluid slowly reinjected in the bulk.

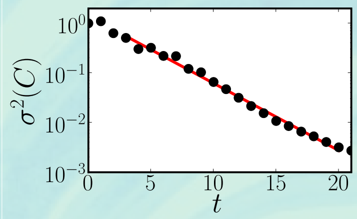
1-D model



Can we "protect" the chaotic region ?





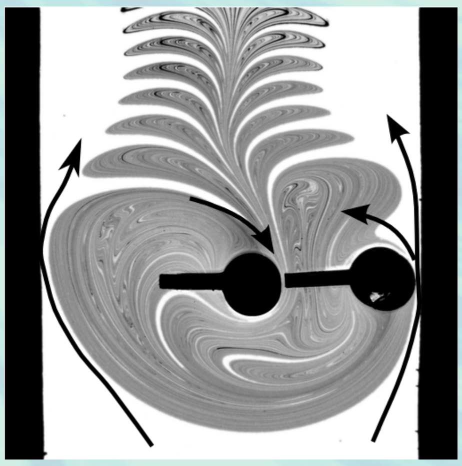


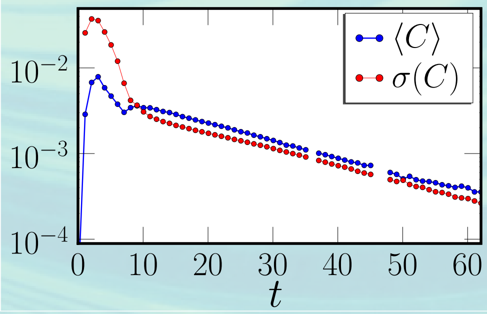
- Exponential mixing
- Permanent pattern: eigenmode

Open flows: different residence-time distributions . . .

. . . for different phase portraits

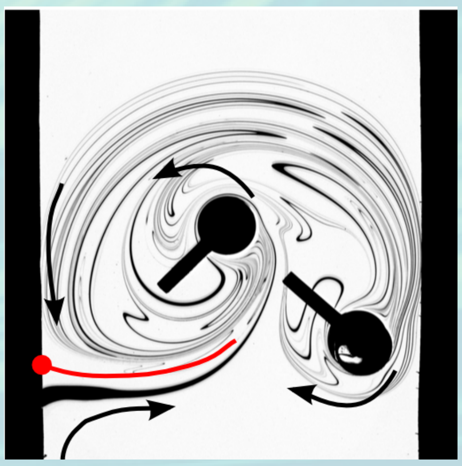
Butterfly protocol

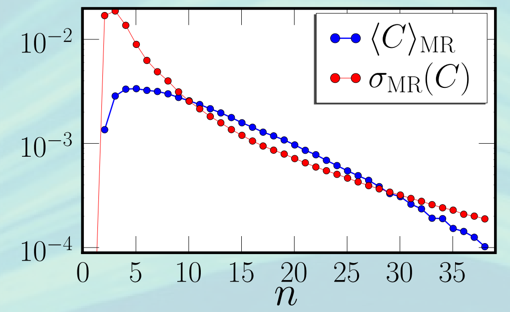




- Chaotic region protected from the walls
- Parallel exponential evolution for all moments: eigenmode

Breaststroke protocol





- Stagnation points on walls
- Deviation from the eigenmode: long residence times (walls).

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