Three universality classes for reaction fronts in disordered flow

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The effect of fluid flows on active interface motion are relevant to a wide variety of dynamical processes, including population dynamics in biology, flame propagation in combustion, solidification fronts or marine ecology systems.

Traveling chemical wave fronts provide an example which exhibits a complex dynamics when coupled to a disordered flow field. Generated by an autocatalytic reaction, the balance between molecular diffusion and the nonlinear chemical kinetics leads to a solitary wave like behavior, i.e in the absence of the flow the reaction fronts propagate with a constant velocity and keep a stationary concentration profile.

Their interaction with a heterogeneous flow in a porous medium leads to the formation of self-affine rough fronts and to two distinct depinning transitions when the mean flow velocity is varied. Intriguingly, this system exhibits a frozen steady state in a certain range of flow rate, leading to sawtooth shape pattern formation.

We have performed experiments over a wide range of mean flow rates, in both directions relatively to the chemical reaction direction. The measured spatial and temporal fluctuations are consistent with three distinct universality classes in d=1+1, and controlled by a single parameter, the mean flow velocity.

Fast advancing or receding fronts exhibit the Kardar-Parisi-Zhang (KPZ) class scaling laws. When the mean flow velocity almost cancels the reaction rate, the fronts propagate transitorily and are characterized by the quenched Kardar-Parisi-Zhang class (positive-qKPZ) for advancing fronts, and the negative-qKPZ equation for receding fronts. The latter two exhibit a depinning transition with distinct features in agreement with theoretical predictions.