Rayleigh-Bénard thermal convection in concentrated emulsions: a plethora of dynamical regimes

Francesca Pelusi*, Andrea Scagliarini†, Mauro Sbragaglia‡, Massimo Bernaschi† and Roberto Benzi§,‡

Emulsions are widely used in numerous interdisciplinary fields, yet their behavior in buoyancy-driven thermal flows remains poorly understood. This study comprehensively characterizes the dynamical regimes of thermal convection in emulsions via lattice Boltzmann simulations[1]. Emulsions are prepared with different volume fractions (ϕ), ranging from dilute systems with Newtonian rheology to jammed systems exhibiting non-Newtonian yield-stress behavior. Our study focuses on the Rayleigh-Bénard (RB) thermal convection, i.e., we consider emulsions confined between two parallel walls at different temperatures, undergoing buoyancy forces whose impact can be encoded in the dimensionless Rayleigh number (Ra). We identify the emergence of distinct convection dynamical regimes by systematically varying ϕ and Ra. In a previous work[2], we observed that sustained convection in jammed emulsions is accompanied by intermittent transient dynamics leading to emulsion phase inversion. However, as Ra increases, many structural transformations such as droplet breakup, coalescence, and phase inversion may affect the emulsions (see Fig.1), significantly altering their rheological properties. For low-to-moderate values of ϕ, the dominant mechanism at high values of Ra is droplet breakup, while for high values of ϕ, phase inversion prevails. In both cases, the droplet size distribution is influenced by Ra, and scaling laws for the average droplet size are derived and quantified[3]. Furthermore, these structural changes also affect the behavior of the average heat transfer as a function of Ra, confirming a continuous transition from conductive to convective state for low values of ϕ but evidencing a sharp transition in the phase inversion regime due to the rupture of the original jammed emulsion in favor of the diluted inverted one[3]. These findings detail the various dynamic regimes in thermal convection and their connection to structural changes in emulsions. The study sheds light on the complex interplay between thermal forces, emulsion structure, and rheology, offering valuable insights into the behavior of emulsions under buoyancy-driven thermal flows.

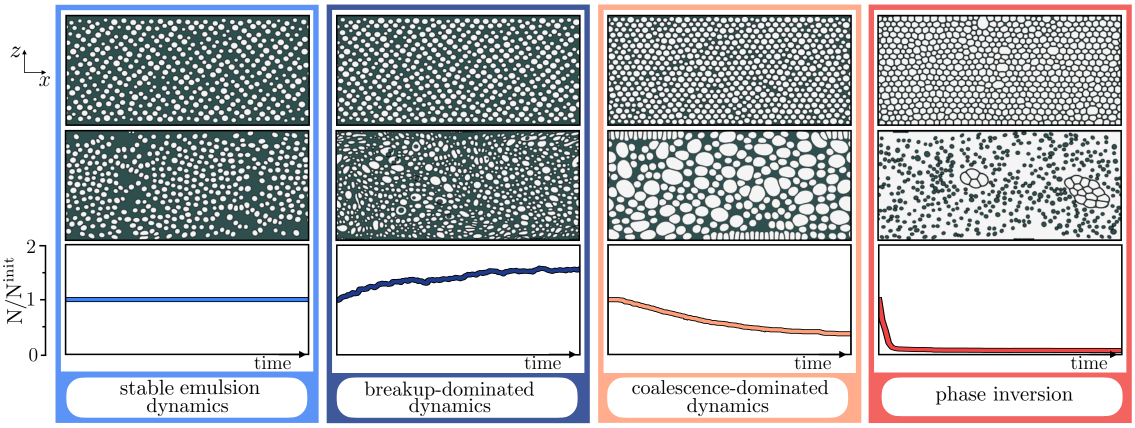

Figure 1: Pictorial view of dynamical regimes of thermally convective emulsions under RB thermal convection, resulting from different combinations of ϕ and Ra. The distinction is based on the behavior in the number of droplets N with respect to its initial value N^{init}. Top panels: initial conditions. Middle panels: steady-state configurations. From left to right: *stable* convective regime, with no variation of N; *breakup-dominated* dynamics, with an increase of N due to breakup events; *coalescence-dominated* dynamics, with a N decrease caused by coalescence events; *phase-inverted* emulsion.

*Istituto per le Applicazioni del Calcolo, CNR, Via Pietro Castellino 111, 80131 Naples, Italy
†Istituto per le Applicazioni del Calcolo, CNR, Via dei Taurini 19, 00185 Rome, Italy
‡Department of Physics & INFN, Tor Vergata University of Rome, Via della Ricerca Scientifica 1, 00133 Rome, Italy
§Sino-Europe Complex Science Center, School of Mathematics Northwestern University of China, Shanxi, Taiyuan 030051, China
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[2] F. Pelusi et al., *Physical Review Letters* **133**, 244001 (2024).
[3] F. Pelusi et al., *under review*, `https://arxiv.org/html/2411.11553v1` (2024).