Regimes of intermittence in numerical ensembles of poorly-mixed chemical oscillators

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In this work we present a set of numerical results obtained from simulating a large ensemble of chemical oscillators that interact via a chemically active medium following the dynamics of the Belousov Zhabotinsky reaction, a paradigm for oscillating and synchronization phenomena. In well-mixed conditions, the stationary dynamic behaviors observed for this kind of oscillators usually range from full-synchronization (FS), oscillation death (OD) and super-synchronization (SS) [1], which refers to a phase and amplitude locking of the oscillators with the surrounding solution that couples them (which is another oscillator itself). In unmixed systems, the usual observed behavior is that of spiral waves [2] and in non-locally coupled oscillators there has been reported the possibility of chimera states [3]. Here, we direct our focus to a low, poorly-mixed diffusive configuration that corresponds better with a more realistic situation, as perfect mixing is almost never achieved. In the simulations, the oscillators are spatially distributed and are allowed to interact locally with a limited number of other oscillators that lie within a small interaction radius. Figure 1 presents a summary of our results, which are presented and analyzed in detail in [4].

We observed that in the edge of the phase transitions to the previously reported dynamical states, a certain degree of irregularity and intermittence appears. To our extent, these behaviors are yet not found in experimental realizations, and we believe that they could be of highly physical interest. First, in the transition from FS to SS, we present three different situations, showed in panels a), b) and c) of the Figure XX. Panel a) represent the time series of a small set of out-of-phase oscillators. This state is characterized by a synchronization loss caused by the existence of multiple synchronization waves across the system, which only phase locks the oscillators in the wavefront. Panel b) corresponds to a slightly higher coupling, right after the phase transition, and shows a double peak oscillation that only experiment a small sub-ensemble of the oscillators, while the rest remain super-synchronized with the solution and performing single large oscillations. Panel c) represents the averaged time series of all the oscillators in the system, showing a synchronized intermittence between the two dynamical states. There is a coexistence of large amplitude, low frequency oscillations that correspond to the SS state, followed by several low amplitude, high frequency oscillations characteristic from the FS state. This behavior was found to be persistent in time with no underlying patterns in the number of small oscillations that occur after a large oscillation or in the time-occurrence of the latter.

Secondly, in the transition from SS to OD, panel d) shows a similar behavior to the one in panel c), but with an abrupt cease of oscillating activity of all the ensemble right after the large amplitude synched oscillation. In the transition from FS to OD, and only in a situation of zero mixing, we found spatial clusters of oscillatory activity while the rest of oscillators underwent oscillation death. Panels e) and f) show the time series of oscillators with different amplitude and the spatial visualization of the oscillating cluster.

In summary, all the states briefly described above correspond to poor-mixing configurations that are likely to be experimentally observed, either with chemical or with other kind of biological oscillators. The extrapolation of these results to real examples might help to understand other collective behaviors in nature.

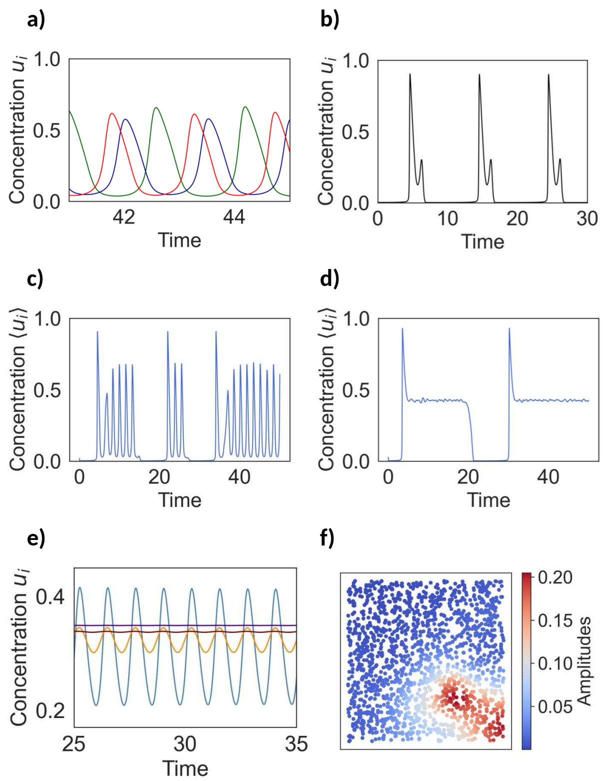

Fig. 1. Intermittence regimes found in the phase transitions from FS to SS (a-c), from SS to OD (d) and from FS to OD (e). Panel f) represents the spatial visualization of the amplitudes in panel e). More details in [4].

[1] G. Ghoshal, A. P. Muuzuri and J. Prez-Mercader, Sci Rep, 6, 19186 (2016)

[2] M. R. Tinsley, A. F. Taylor, Z. Huang and K. Showalter, PRL, 102, 15, 158301 (2009)

[3] S. Nkomo, M. R. Tinsley and K. Showalter, PRL, 110, 24, 244102 (2013)

[4] A. Carballosa and A.P. Muñuzuri, Submitted (2022)