Localized structures supported by a complex spatiotemporal pattern

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Pattern formation, and its complexity has been greatly studied in different systems out of equilibrium, such as nonlinear optics, chemistry, ecology and biology. In liquid crystal media, the formation of patterns with turbulent like behavior has already been observed and characterized [1], as well as the formation of localized pattern states with chaotic dynamics [2]. Both solutions have been well described by theoretical models of the LCLV, and phenomenological models. We show the experimental observations and characterizations of a new solution, that consists in localized structures of a homogeneous states that are supported by a spatiotemporal complex pattern. A theoretical model that exhibits similar behaviors is also presented.

Experimental setup

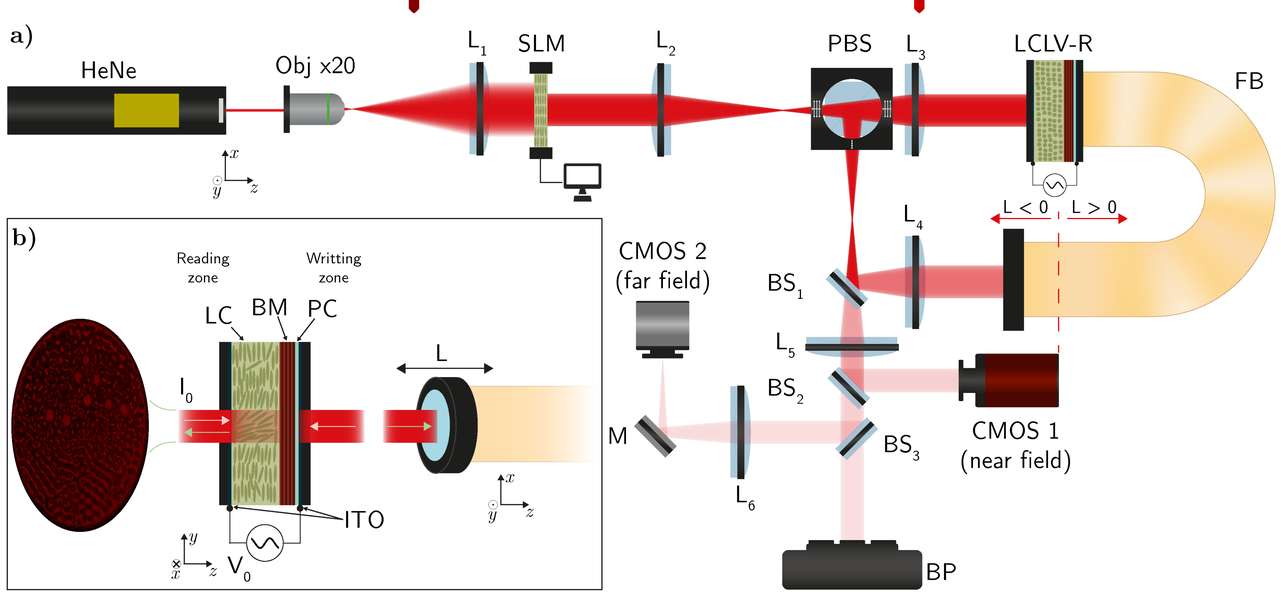

Figure 1: Localized structures supported by a spatiotemporal complex pattern. (a) Schematic representation of the experimental setup. (b) Schematic representation of the LCLV, and the induced solution.

Bifurcation diagram

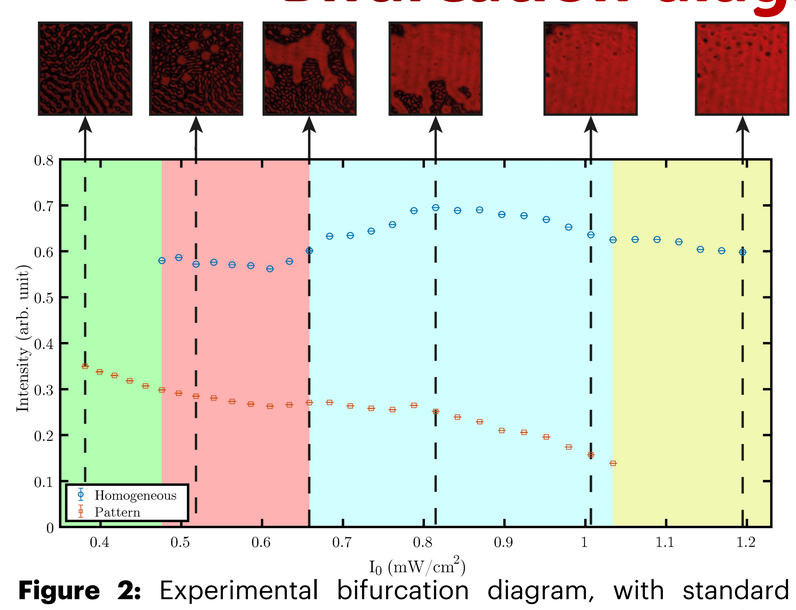

Figure 2: Experimental bifurcation diagram, with standard error error bars. The green – red – blue – yellow regions accounts for the pattern – localized structures – Homogeneous/pattern – Homogeneous solution respectively.

The LCLV with optical feedback experiment is a system that presents multistability. While changing the incoming light intensity, coexistence between a homogeneous state and a pattern state can be found.

Experimental results

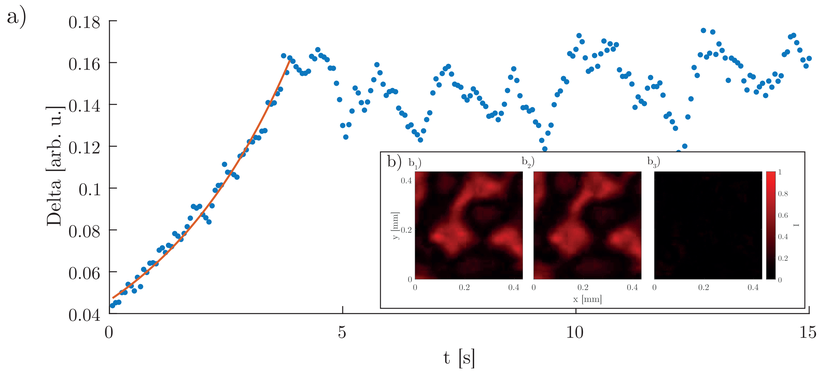

Figure 3: Largest Lyapunov Exponent analysis, with $\lambda = 0.0908\, s^{-1}$. (a) Delta in time. (b) Initial similar conditions (b_1) First initial condition, (b_2) second initial condition (b_3) difference.

To understand the pattern dynamics, we are computing the Largest Lyapunov Exponent (LLE) from the experimental data. The computed LLE confirms that the pattern has chaotic dynamics.

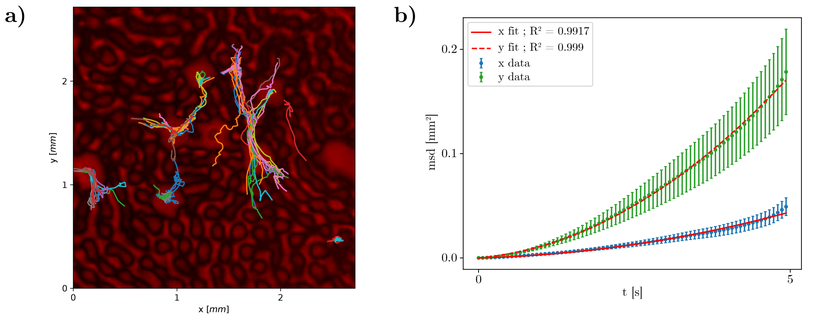

Figure 4: Tracked trajectories (longer tan 5 seconds) a) Trajectories tracks. b) Averaged MSD for every trajectory, with fitted quadratic.

To gain insight into the movement of the localized structures, we calculated the mean squared displacement (MSD) of the trajectories. The quadratic fit suggests that the localized structures exhibit a Brownian-like motion with drift.

Theoretical model

$$\partial_t u = -\eta + \mu u - u^3 + \nu \partial_{xx} u - \partial_{xxxx} u + b u \partial_{xx} u + c(\partial_x u)^2 \quad (1)$$

$$\partial_t u = u(u-1)(\alpha - u) + \partial_{xx} u + u\cos(kx)(\beta + \gamma \partial_x \Psi)$$
$$\partial_t \Psi = (\partial_x \Psi)^2 - \partial_{xx} \Psi - \partial_{xxxx} \Psi \quad (2)$$

The first-principles model of the LCLV is well known, but can be simplified to a prototype model with the minimal ingredients needed to observe these solutions (eq. 1) [3]. Phenomenological models can also be constructed (eq. 2) [2].

Conclusions

The underlying pattern solution exhibit chaotic dynamics and complex spatial organization.

The localized structures exhibit a Brownian-like motion with drift. The localized structures also have marked tracks.

Localized structures emerge probably due to LCLV imperfections, and their movement is governed by the pattern dynamics.

[1] P.J. Aguilera-Rojas, M.G. Clerc, S. Echeverría-Alar, Y. Soupart, M. Tlidi (2024). Fingerprint pattern bi-turbulence in a driven dissipative optical system. Chaos, Solitons & Fractals.
[2] Verschueren, N., Bortolozzo, U., Clerc, M. G., & Residori, S. (2013). Spatiotemporal chaotic localized state in liquid crystal light valve experiments with optical feedback. Physical review letters.
[3] Residori, S. (2005). Patterns, fronts and structures in a Liquid Crystal Light Valve with optical feedback. Physics Reports.

Supplementary material