Optical bullets in 2-dimensional fiber arrays

A, B. Aceves[1*], C. Castro-Castro[1], C. O. V. Shtyrina[2,3], A. M Rubenchik[4], M.P. Fedoruk[2,3] and S. K. Turitsyn[2,5]

[1]*Department of Mathematics, Southern Methodist University, Dallas, Texas 75275, USA*
[2]*Novosibirsk State University, Novosibirsk, Pirogova 2, 630090, Russia*
[3]*Institute of Computational Technologies, Novosibirsk, Lavrentjeva 6, 630090, Russia*
[4]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
[5]*Aston Institute of Photonic Technologies, Aston University, Birmingham, B4 7ET, UK*
**aaceves@smu.edu*

Abstract: We report on recent work on the properties of optical light bullets propagating in 2 dimensional fiber arrays under very general configurations, including arrays having parity-time (PT)-symmetric loss-gain profiles.

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1. Introduction

Technological advances in multi-core fiber arrays presents an opportunity to study spatio-temporal effects of confined light bullets (LB) [1], with numerous important applications including for example fiber laser arrays [2] and efficient communication strategies [3]. This paper presents results on the robustness of light bullet formation under general array configurations [4]. Our theoretical work which combines an asymptotic approach that approximates LB with stability analysis proves that above critical powers stable localized states independent of the details of the 2-d array geometrical configuration. These results are corroborated by numerical simulations. This most recent work [4] provides a platform to test other effects in the array. For example one can test the persistence of LB in the presence of disorder. Here instead we extend our work to the study of parity-time (PT)-symmetry breaking phenomena in multi-core fibers [5]. PT-symmetry in this case refers to an array configuration that introduces loss/gain in symmetric fashion. For small loss/gain, we anticipate the persistence of spatio-temporal localization dynamics observed in Hamiltonian systems modeled by discrete nonlinear Schrödinger-like equations (DNLSE). This behavior, we predict will break down when the loss/gain strength is above a critical value, leading to a phase transition, although it is yet to be well understood what type of outcome will result. As a start, research on this direction extend those in [5] by inclusion of nonlinear and temporal effects.

2. Model and Results

The model we consider is that of a 2-dimensional fiber array where the configuration can take different forms. Two scenarios are shown in figure 1 (right). The field envelope at the (n,m) core is described by $U_{nm}(z,t)$ and its evolution under dispersion, coupling and Kerr-nonlinearity is governed by the DNLSE

$$i\partial_z U_{nm} + (\underline{\underline{C}}\underline{U})_{nm} + \partial_{t^2}^2 U_{nm} + 2|U_{nm}|^2 U_{nm} = 0 \qquad (1)$$

The specific properties of the 2-d geometrical configuration define the coupling matrix $\underline{\underline{C}}$. For the examples shown in figure 1:

$$(\underline{\underline{C}}\underline{U})_{nm}^{square} = c(U_{n-1,m} + U_{n+1,m} + U_{n,m-1} + U_{n,m+1}) \qquad (2a)$$

$$(\underline{\underline{C}}\underline{U})_{nm}^{hexagon} = c(U_{n-1,m-1} + U_{n-1,m+1} + U_{n,m-2} + U_{n,m+2} + U_{n+1,m-1} + U_{n+1,m+1}) \qquad (2b)$$

Highly localized LB have most of the energy in the central fiber $U_{00} = \sqrt{\lambda}\,\mathrm{sec}\,h(\sqrt{\lambda}t)e^{i\lambda z}, \lambda >> 1$ with neighbors having small amplitudes which decay in inverse powers of λ as the separation distance to the central core increases. This is shown in figure 1 (right). We find by analytical means that these solutions are be stable in the high energy $(\lambda >> 1)$ regime for both geometries and we expect this to be true for other 2d configurations. Interesting extensions we have considered include non-uniform separation between cores, making the coupling coefficients in

(2) to depend on (n,m). Two particularly relevant scenarios are first the role of disorder in achieving localization [6] and the study of binary-arrays [7].

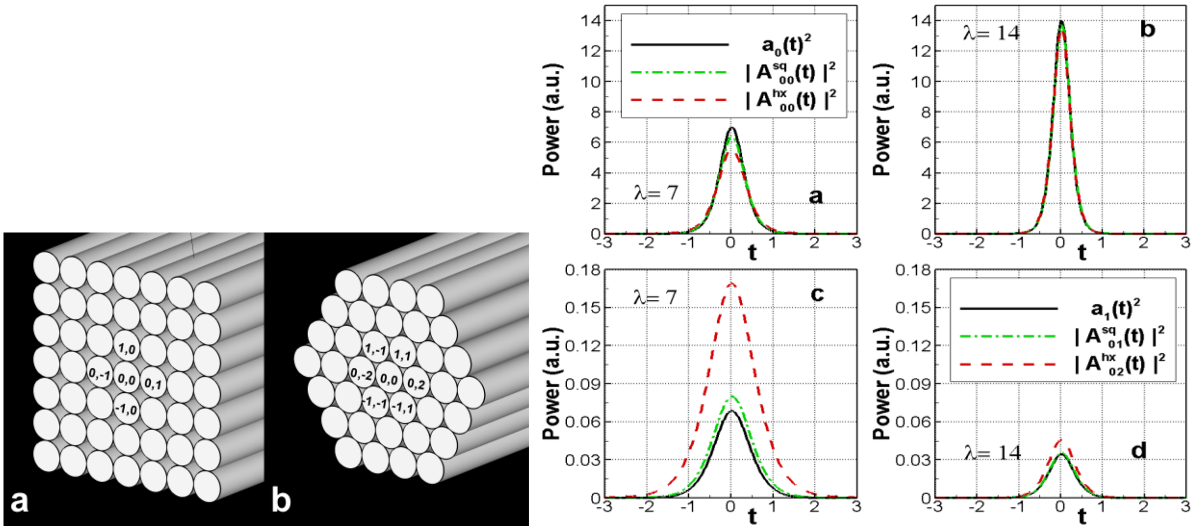

FIG. 1: (Left) Square and hexagonal waveguide structures. (Right) Comparison of numerical solutions (color) with their analytical approximations (black solid) for different λ in the central waveguide (top) and closer neighbor waveguide (bottom) for 33x33 square (green dashed dotted) and 33x65 hexagonal (red dashed) waveguides structures.

3. PT-fiber array system

Recent work [5] considers a circular multicore array whereby twisting the fiber along the z-axis introduces a Peierls phase in the coupling constant. Furthermore each core was assumed to have gain or loss and only coupled to its nearest neighbor, leading to the model

$$i\partial_z U_n + \kappa e^{i\phi} U_{n+1} + \kappa e^{-i\phi} U_{n-1} - i\gamma_n U_n = 0$$

Here the author explores transitions from unbroken to broken PT-symmetry, reflected o differences in for example the transmission properties. Here the twist produces an artificial gauge field. As it is already indicated in [5], it would be of interest adding nonlinear effects. We have begun extensions of this work in a more general two dimensional geometry and with the inclusion of nonlinear effects and temporal effects. Initial findings will be reported at the conference.

4. References

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