Studies on Solitons and Pattern Formation.

Tal Carmon
Department of Physics, Technion-Israel ins. of Thechnology, Haifa 32000.
tal@caltech.edu
http://www.its.caltech.edu/~tal/

A. Introduction – Optical Spatial Solitons

Optical spatial solitons, or self-trapped optical beams, are very narrow optical beams that do not broaden, in spite of the broadening tendency of diffraction effects in homogeneous media. Spatial solitons exist by virtue of the balance between diffraction and nonlinearity. They propagate and interact with one another while displaying properties that are normally associated with real particles [1, 2]. Solitons, in general, manifest themselves in a large variety of wave/particle systems in nature: practically in any system that possesses both dispersion (in time or space) and nonlinearity. Solitons have been identified in fluids [3], plasma waves [4], sound waves in liquid 3He [5], condensed matter, particle physics, and even in astrophysics and in DNA chains [6]. In optics, solitons manifest themselves in numerous forms: temporal solitons in fibers [7, 8], spatial solitons [1,2], spatio-temporal solitons [9,10], as well as more sophisticated forms such as incoherent solitons [11,12], discrete solitons [13,14], Gap (or Bragg) solitons [15,16] and cavity solitons [17,18]. Over the past decade, the forefront of soliton research has shifted to optics, in particular to the various forms of spatial and spatio-temporal solitons.

B. Brief description of my research

b.1 Composite solitons

Prior to my research, optical spatial solitons which consist of more then one field (vector solitons) were demonstrated only in two dimensions. One dimension for propagation and the other in which the beam is self trapped. The third dimension was degenerate (a broad beam or a slab waveguide). In the first year of my doctoral studies I was the first to move from a 2D configuration to a 3D realization and demonstrate experimentally self-trapped **Dipole Vector Solitons in a 3D bulk medium** [19, 20]. These particle-like wave-packets exhibit propagation in one dimension and self trapped in two transverse dimensions (figure 1 and figure 2 second row).

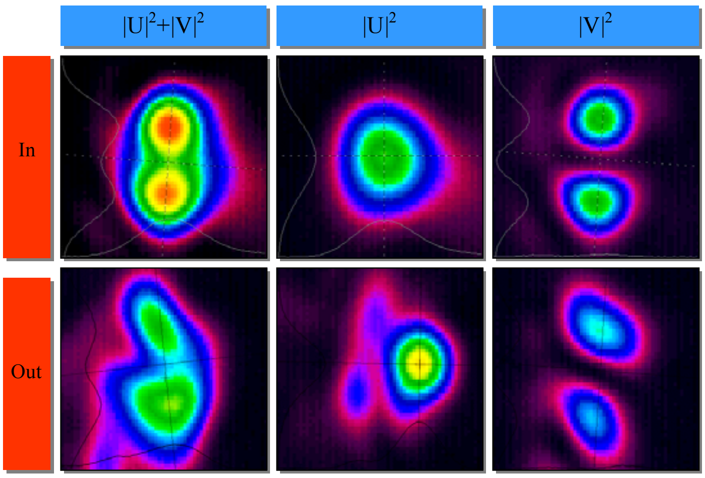

Figure 1: The intensity distribution of a 2+1 dimension vector soliton as was measured (by the applicant for the first time) at the input face of the crystal, and at the output face of the crystal (the crystal is 10 mm long). The components of this vector soliton are Gaussian like (U) and TEM_{01} like (V) fields. The distance between the peaks of V^2 is 15 μm .

This discovery opened the door to new directions. The movement from slab waveguide to 3D medium enabled me to demonstrate phenomena which cannot be demonstrated in 2D, such as a new type of vector solitons for which the energy structure rotates while propagating. These rotating **"propeller solitons"** [21-24] consist of a dipole that rotates along propagation and make a double helix structure in space (figure 2 last row). We have studied these propeller solitons experimentally, theoretically, and numerically. I am happy to note that this work on composite solitons which rotate during propagation has appeared in the special December 2001 issue of Optics & Photonics News [22]. This special issue summarizes the most important discoveries in optics in 2001.

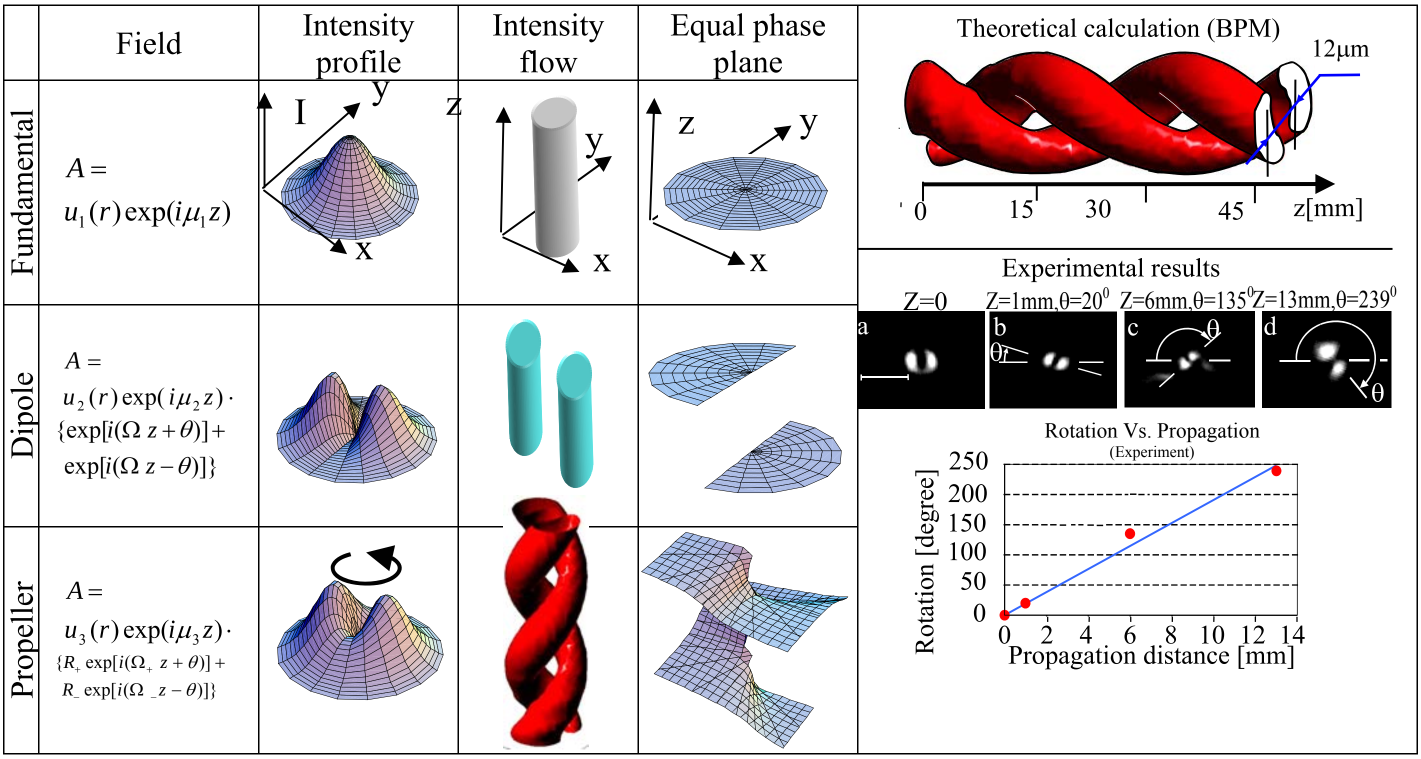

Figure 2: Field equation (slowly varying field), intensity distribution, intensity flow and equal phase plane (in space) for various kind of (2+1)D composite soliton components. On the right: theoretical calculation for the propeller intensity flow and experimental pictures of the propeller intensity distribution at various propagation distances.

The combination of rotation and propagation in 3D enabled us to go forward and investigate new phenomena such as collisions in space between rotating vector solitons [25, 26].

b.2 Pattern formation in incoherent cavities

Spontaneous formation of intricate patterns in optical cavities has been the subject of continuing interest since lasers were discovered [27]. Until very recently the light circulating in those cavities was coherent. In our recent series of papers we have revolutionized this area by demonstrating **Pattern formation in incoherent cavities** [28-30]. We have demonstrated experimentally and theoretically that the bandwidth of the spatial frequency spectrum of the pattern narrows as the feedback increases. This is a direct indication of a threshold and of the presence of phase transition phenomena in this weakly correlated, many body, nonlinear feedback system.

These ideas have many implications behind optics as they bridge the gap between phase independent ("classical") phase transition phenomena and phase-dependent ("quantum") phase transition phenomena. Prior to my work, all studies on pattern formation in optical cavities were in the coherent (phase-dependent) systems. Now we can study the evolution of and transition from the phase dependent case to the phase-independent case by investigating cavities of varying degrees of correlation

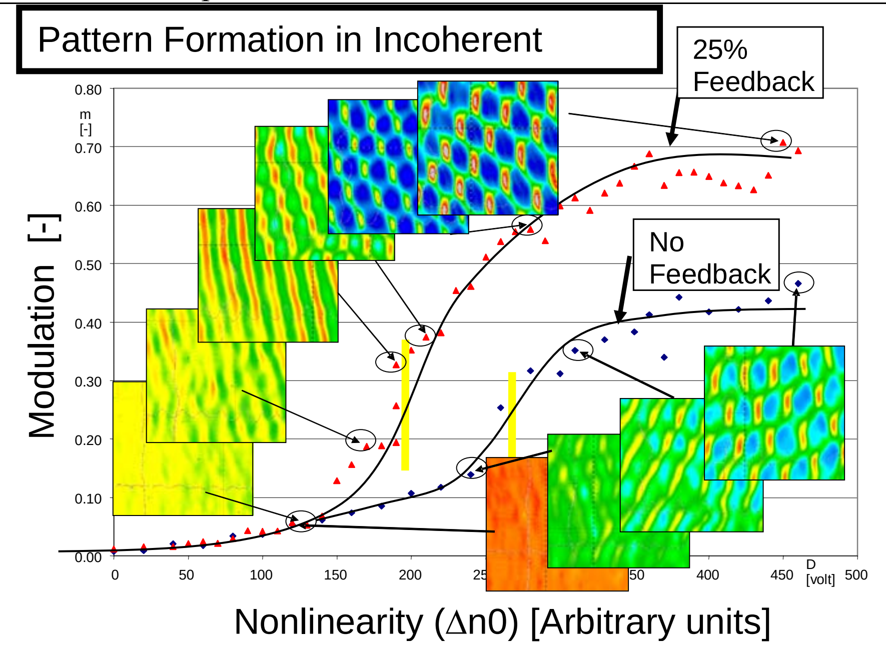

Figure 3: Pattern formation in an incoherent cavity. Plotted is the pattern modulation v. nonlinearity with and without feedback, along with pictures of the light intensity at the output of the crystal. Note that the threshold moves when feedback increases.

These days we are working on pattern formation with white light – the same light that get out of a light bulb (or coming from the sun). This will be the first time that pattern formation is demonstrated with natural light (like that which is coming from the sun). I.e., light which is spatially and temporally incoherent and also multi-spectral in its wavelength. We expect colorful pattern formation to appear, thanks to the different diffraction character for different wavelengths.

b.3 Solitons in fast semiconductors media, pattern formation with white light shook waves and elliptical solitons

As the senior graduate student in Prof. Segev's group, I instructed new students from the first step in the lab when I teach them the basic soliton experiments, until the stage of building new experimental systems and supervising their work. During my doctoral studies I instructed graduate students in the following projects: solitons in fast (ns) new material (CdZnTe) [33, 34], modulation instability of white incoherent light [43] shock waves in photorefractive medium [44] elliptical solitons [45] and vortex solitons [46].

b.4 Cascaded Collisions, discrete solitons, counter-propagating solitons and holographic solitons

During my doctoral studies I was collaborating in the following projects: Information Transfer through Cascaded Collisions of Vector Soliton [31, 32], holographic solitons [35], staggered discrete solitons in optically-induced photonic lattices [36-40] and Vector solitons consisting of counter-propagating fields [41,42].

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