© 2001 OSA/NLGW 2001

Cascading Collisions Between Vector Solitons

Charalambos Anastassiou,[1,2] Jason Fleisher, [2] Tal Carmon, [2] Mordechai Segev[1,2] and Ken Steiglitz[3]

(1) Electrical Engineering Department, Princeton University, Princeton, NJ 08544
Phone 609-258 0430, anastass@ee.princeton.edu

(2) Physics Department and Solid State Institute, Technion, Haifa 32000, Israel.

(3) Computer Science Department, Princeton University, Princeton, NJ 08544

Abstract: We present the first experimental observation of cascading two collisions between vector (Manakov-like) solitons. This experiment shows that it is possible to use collisions between vector solitons as a means of transferring information.

OCIS codes:, 190.3270, 190.5530

It is well known that when two scalar solitons (of a fully integrable system) collide, they experience only a phase shift while conserving their energies, linear momenta, and shapes [1]. Vector (Manakov-type) solitons, on the other hand, consisting of two [2] or more components, display a spectrum of interactions that is much richer than that of scalar solitons [3,4,5]. Each vector soliton as a whole preserves its shape and total intensity upon collisions with other vector (or scalar) solitons, yet the components that make up the vector soliton are free to exchange energy. (In the terminology used in the seventies, this is referred to as "polarization flipping".) For example, if a signal is represented by a particular field-component of a vector soliton, then subsequent collisions can be used to manipulate and split the signal in a very controlled and predictable fashion, depending on soliton parameters, e.g., collision angle, intensity, and width.

Here we investigate collisions of the form shown in Fig. 1, where a scalar soliton A_2 collides first with a vector soliton, (A_1, B_1), and then with a second scalar soliton, A_3. The A and the B fields can be thought of as orthogonally polarized just as in an ideal Manakov system [2].

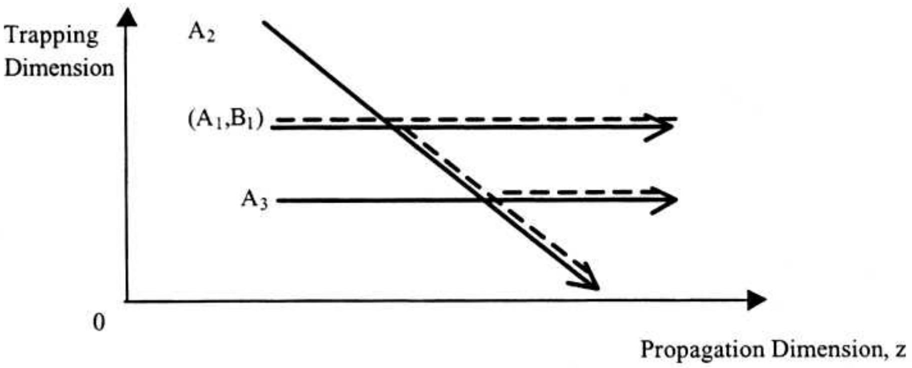

Fig1. The dotted line represents the B-field. Initially, at z=0, B only exists as B_1 which forms soliton 1 together with A_1. After the first collision B_1 splits and gives part of its energy to soliton 2 in the form of a new field component B_2 (A_2 and B_2 emerge as soliton 2 after the collision). At the second collision, B_2 splits to give energy to B_3.

To understand how the cascaded collisions work, let us first concentrate on the first collision between A_2 and vector soliton, (A_1, B_1). This collision is identical to the one studied in [5], for which exact analytical results exist for the Manakov system. Intuitively A_1 and A_2, which belong to the same field, write a grating inside the nonlinear medium. B_1, which travels in the A_1 direction, gets partially diffracted

© 2001 OSA/NLGW 2001

towards the A_2 direction. Following the first collision, A_2 and B_2 emerge as soliton 2, which has now two field components. Subsequently, this soliton 2 collides with another (initially scalar) soliton A_3. In the second collision, through a mechanism that is the same as the first collision, B_2 transfers some of its energy to B_3, and A_3 and B_3 emerge as soliton 3 (which at the end is a vector soliton as well). In this way, some of the energy contained in the B component of soliton 1 was transferred, in a sequential fashion, to both solitons 2 and 3 (shown schematically in Fig. 1). It is important to say that, to maintain the symmetry, wherever energy was transferred from the B field of soliton "i" to the B field of soliton "j", the exact amount of energy was transferred back between the A fields (from A_j to A_i).

We performed our experiment in a photorefractive SBN crystal using 1 dimensional solitons. The two fields are coupled through a saturable nonlinearity of the form $1/(|A|^2 + |B|^2)$ which differs from the one in the Manakov system, $(|A|^2 + |B|^2)$. Soliton interactions, however, are almost identical in both systems for collision angles greater than the (complementary) critical angle (for total internal reflection in the waveguide induced by each soliton; in our experiments, this angle is roughly 0.2 degrees) [5]. As for ideal Manakov solitons, our system dictates that the interference between A and B does not contribute to the nonlinearity, yet the self- and cross-phase modulation are identical, and there are no additional nonlinear (four wave mixing) terms. This is accomplished experimentally through the mutual incoherence method [6]: the beams have the same polarization and wavelength but B is reflected from a fast vibrating mirror (driven by a piezoelectric transducer). This causes the interference pattern of A and B to move much faster than the response time ($\tau_d \approx 3$ sec) of the photorefractive crystal. The input and output faces of the crystal are imaged on a CCD camera. The slow response of the crystal enables us to view each beam individually by blocking the remaining ones (with a mechanical shutter) and sampling the other within a time interval (~10 msec) shorter than τ_d.

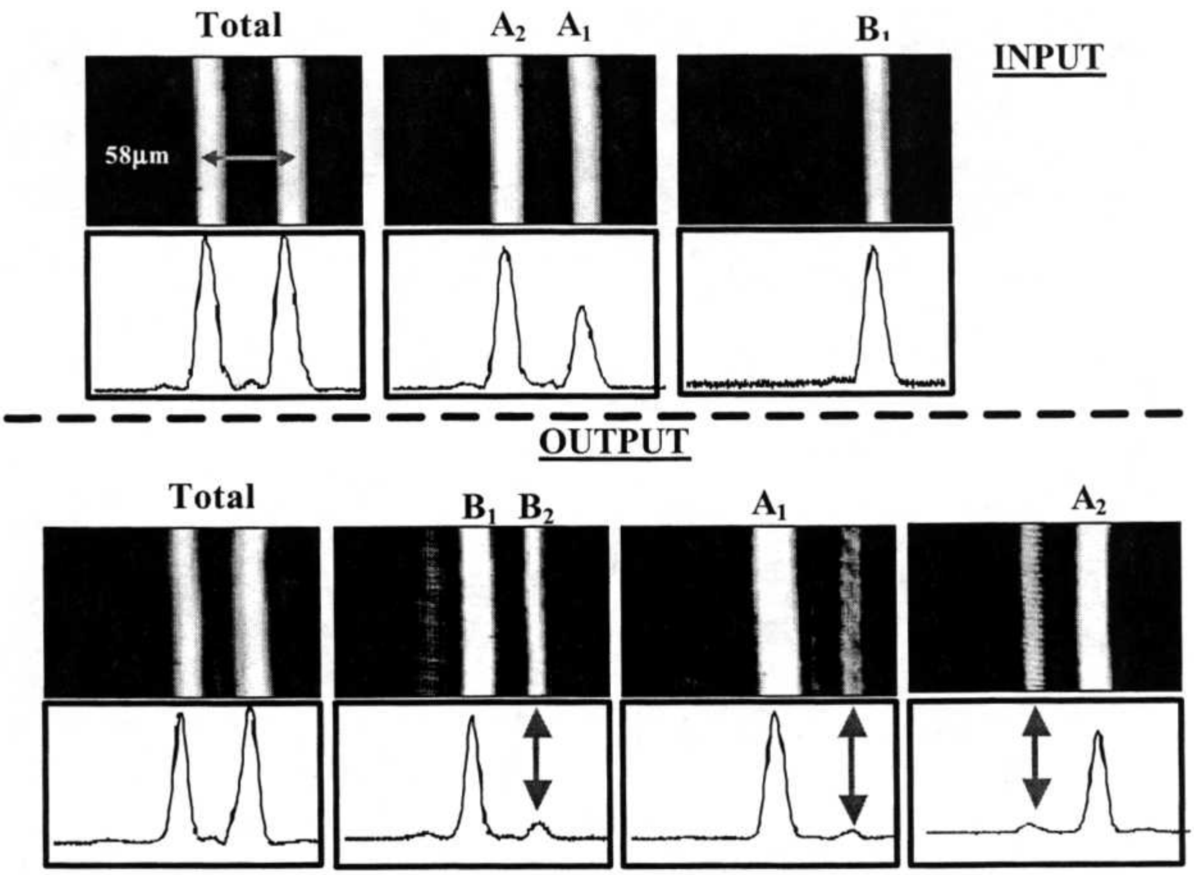

Fig2. Experiment for the first collision. The upper row shows the input conditions and the bottom row the output. The arrows point out the energy exchange.

© 2001 OSA/NLGW 2001

In Fig. 2 we show the results of the first collision, where we turn A_3 off. The solitons are 14 μm wide (FWHM) and they are 58 μm apart at the input and 48 μm at the output after 13 mm of propagation. The angle of collision is 0.46° and the maximum nonlinearity (change in the index of refraction) is 1.3×10^{-4}. Notice that the total intensity of each soliton is constant; the field components exchange energy in a symmetric (and opposite) way as to ensure that.

In the second experiment, shown in Fig.3, all the experimental conditions are the same as before but we now turn on (A_3) and launch it parallel to (A_1, B_1) as shown schematically in Fig. 1. As clearly shown in Fig. 3, the B field is part of both solitons 2 and 3 emerging from the collision.

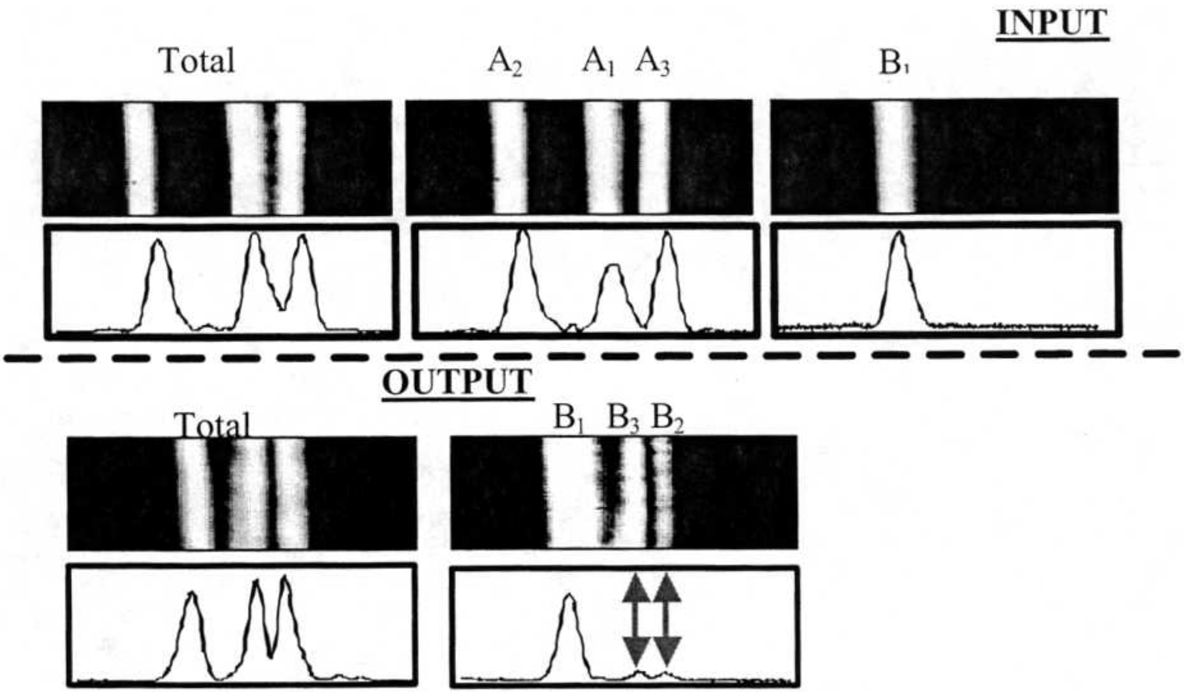

Fig3. Cascaded collisions. The emerging B components of solitons 2 and 3 are indicated by the red arrow.

In summary, we have demonstrated the cascaded collision between vector (Manakov-like) solitons. This experiment shows that information can be transferred from a soliton (an "input state") to a second soliton ("intermediate state") and eventually relayed to a third soliton ("final state"). The importance to the new concept of soliton computation is obvious: soliton collisions can serve as a means to transfer complex state information. Yet this experiment has importance even in modest integrated optics applications: if B_1 is thought of as a signal beam, this setup can be used for a very directional and tunable all optical beam splitter.

This work is part of the MURI project on Optical Spatial Solitons, funded through the ARO.

References

[1] V. E. Zakharov, A. B. Shabat, Sov. Phys. JETP 34, 62 (1972)

[2] S. V. Manakov, Sov. Phys. JETP 38, 248 (1974).

[3] R. Radhakrishnan, M. Lakshmanan and J. Hietarinta, Phys. Rev. E 56, 2213 (1997)

[4] M. H. Jakubowski, K. Steiglitz and R. Squier, Phys. Rev. E 58, 6752 (1998).

[5] C. Anastassiou, et al. Phys. Rev. Lett., 83, 2332 (1999).

[6] D.N. Christodoulides, S. R. Singh, M. I. Carvalho and M. Segev, Appl. Phys. Lett. 68, 1763 (1996).