NEEDS 2009 Workshop
Nonlinear Evolution Equations and Dynamical Systems
Isola Rossa, May 16–23, 2009.

Experimental Evidence of Three–wave Zakharov–Manakov Solitons

F. Baronio[a], M. Conforti [a], C. De Angelis [a], S. Wabnitz [a],
A. Degasperis [b], M. Andreana [c], V. Couderc [c], A. Barthelemy [c]

February 27, 2009

a. Department of Electronics, University of Brescia, Brescia 25123 Italy.

b. Department of Physics, University La Sapienza, Rome 00146 Italy.

c. XLIM Research Institute, University of Limoges, Limoges 87060 France.

1 General remarks

Three–wave nonlinear resonant interaction (TWRI) is typically encountered in the description of any conservative nonlinear medium where the nonlinear dynamics can be considered as a perturbation of the linear wave solution, the lowest–order nonlinearity is quadratic in the field amplitudes, the three–wave resonance can be satisfied [1]. Indeed TWRI is the lowest–order nonlinear effect for a system approximately described by a linear superposition of discrete waves. TWRI has been extensively studied alongside with the development of plasma physics, since it applies to the saturation of parametric decay instabilities, nonlinear collisions of large–amplitude wave packets, radio frequency heating, and laser–plasma interactions [2, 3, 4]. In the domain of nonlinear optics, TWRI describes parametric amplification, frequency conversion, stimulated Raman and Brillouin scattering [5, 6, 7]. TWRIs have also been studied in the context of interactions of water waves [8, 9], interactions of bulk acoustic waves, surface acoustic waves [10] and wave–wave scattering in solid state physics.

The physical model describing TWRI is completely integrable [11]. Integrability gives us mathematical tools to investigate several problems such as the evolution of given initial physical data by exploiting spectral methods [12, 13], and the existence of particular analytic solutions (f.i. solitons) [14, 15]. Soliton solutions are of particular interest in various nonlinear environments: from sound waves and charge–density waves to matter waves and electromagnetic waves [16, 17]. In spite of the large diversity of the systems in which soliton exist, the basic properties of solitons always follow the same trends [18]. The most fascinating feautures of solitons are their particle–like interaction phenomena [19, 20], and the interactions between solitons can result in soliton fusion, fission and annihilation, spiralling, breakup and so on.

Here we present the TWRI dynamics of two input wave packets at frequency ω_1, ω_2 which mix to generate a field at the sum frequency ω_3. Depending on the input intensities, three different regimes exist. Linear regime: the wave packets

at frequency ω_1 and ω_2 don't interact. Frequency conversion: the wave packets at frequency ω_1 and ω_2 interact and generate a field at the sum frequency ω_3. Solitonic regime: the wave packets at frequency ω_1 and ω_2 interact and generate a field at the sum frequency ω_3; the generated field at ω_3 sustains a TWRI soliton which decays into solitons at frequencies ω_1, ω_2 [14]. Here we report the experimental evidence of the transition from steady frequency wave generation to solitonic decay in optics. To our knowledge, this is the first experimental observation of TWRI soliton dynamics.

References

[1] D.J. Kaup, A. Reiman and A. Bers, Rev. Mod. Phys. **51**, 275 (1979).

[2] A. Hasegawa, *Plasma Instabilities and Nonlinear Effects* (Springer-Verlag, Berlin, 2001).

[3] Y. Tsidulko, V. Malkin and N. Fisch, Phys. Rev. Lett. **88**, 235004 (2002).

[4] W. Cheng et al. Phys. Rev. Lett. **94**, 045003 (2005).

[5] B. Kim, J. Blake, H. Engan and H. Shaw, Opt. Lett. **11**, 389 (1986).

[6] P. Russel, D. Culverhouse and F. Farahi, IEEE J. Quantum Electron. **27**, 836 (1991).

[7] E. Ibragimov and A. Struthers, Opt. Lett. **21**, 1582 (1996).

[8] A. Craik, *Wave Interactions and Fluid Flows* (Cambridge Univ. Press, Cambridge, 1985)

[9] K. Lamb, Geophys. Res. Lett. **34**, L18607 (2007)

[10] L. Svaasand, Appl. Phys. Lett. **15**, 300 (1969)

[11] V.E. Zakharov, *What is integrability?* (Springer Verlag, Berlin, 1991).

[12] V.E. Zakharov and S.V. Manakov, Sov. Phys. JEPT Lett. **18**, 243 (1973).

[13] F. Calogero and A. Degasperis, *Spectral Transform and Solitons* Vol. 1 (North Holland Publishing, Amsterdam, 1982).

[14] V.E. Zakharov and S.V. Manakov, Jept. Lett. **18**, 243 (1976).

[15] A. Degasperis, M. Conforti, F. Baronio and S. Wabnitz Phys. Rev. Lett. **97**, 093901 (2006).

[16] J. Denschlag et al., Science **287**, 97 (2000).

[17] J. Fleischer, M. Segev, N. Efremidis and D. Christodoulides, Nature **422**, 147 (2003).

[18] G. Stegeman and M. Segev, Science **286**, 1518 (1999).

[19] C. Rotschild, B. Alfassi, O. Cohen and M. Segev, Nature Phys. **2**, 769 (2006).

[20] C. Becher et al. Nature Phys. **4**, 496 (2008).