

# Helmholtz dark spatial solitons in waveguides with defocusing saturable materials

M. J. Lundie<sup>1</sup>, J. M. Christian<sup>1</sup>, G. S. McDonald<sup>1</sup>, and P. Chamorro-Posada<sup>2</sup>

<sup>1</sup> *Materials & Physics Research Centre, University of Salford,  
Greater Manchester M5 4WT, U.K.*

<sup>2</sup> *ETSI Telecomunicación, Universidad de Valladolid,  
Campus Miguel Delibes Paseo Belén 15, E-47011 Valladolid, Spain*

Angular configurations play a fundamental role in essentially all nonlinear photonic architectures: from beam multiplexing applications, to scattering at a single interface, to evolution inside patterned optical structures. Equations of the nonlinear Helmholtz type are ideally suited to describing scalar oblique-propagation contexts. Knowledge of their exact solitons facilitates novel device designs, and the pursuit of these classes of solution is a key research objective of our collaboration.

Saturation under high-intensity illumination is a property of many photonic materials. Phenomenological descriptions of a saturable refractive index must go beyond polynomial-type expansions in the (local) light intensity [e.g., the cubic-quintic approximation (Pushkarov *et al.*, *Quantum Electron.* **11**, 471 (1979)), which eventually break down. However, such approaches almost always result in a governing equation that does not possess exact soliton solutions. A notable exception is the model proposed by Wood *et al.* [*Opt. Commun.* **69**, 156 (1988)].

We will present, for the first time, exact dark spatial solitons for a Helmholtz equation with a self-defocusing saturable nonlinearity. These novel solutions have been obtained by deploying a unified combination of analytical techniques (symmetry reduction, coordinate transformations, and direct integration). Multi-parameter asymptotic analysis recovers the predictions of conventional (paraxial) theory [Krolikowski and Luther-Davies, *Opt. Lett.* **18**, 188 (1993)], while convergence to its Kerr counterpart [Chamorro-Posada and McDonald, *Opt. Lett.* **28**, 825 (2003)] has been found in the limit of low light intensities. Computations involving perturbed initial-value problems have demonstrated that Helmholtz saturable dark solitons are highly robust nonlinear waves surrounded by wide basins of attraction.