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Nonparaxial refraction laws for spatial solitons at cubic-quintic material interfaces

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The behaviour of light at the interface between different materials essentially underpins the entire field of Optics. In nonlinear photonics, a building-block geometry comprises a spatial soliton incident on the planar boundary between two dissimilar Kerr-type media. Seminal analyses by Aceves and co-workers [Phys. Rev. A **39**, 1809 (1989)] were ground-breaking and highly instructive, but they were limited by the assumption of the paraxial approximation. Interface geometries are, in general, intrinsically nonparaxial: angles of incidence, reflection, and refraction (measured relative to the interface *in the laboratory frame*) may be of arbitrary magnitude.

Sánchez-Curto *et al.* have proposed a Snell law governing arbitrary-angle refraction of spatial solitons at the interface between different Kerr materials [Opt. Lett. **35**, 1347 (2010); **32**, 1127 (2007)]. Analyses were facilitated by solution of an underlying nonlinear Helmholtz equation, and they completely lifted the angular limitation that is inherent to paraxial theory.

In addition to angular (off-axis) nonparaxial effects, material considerations are also central to studies of refraction. Here, we extend our early Kerr-based analyses to non-Kerr regimes involving optical media with the classic cubic-quintic nonlinearity [Opt. Quantum Electron. **11**, 471 (1979)]. A key result is the derivation of a generalized Snell law, which was obtained through the deployment of exact analytical bistable Helmholtz solitons [Phys. Rev. A **76**, 033833 (2007)]. Excellent agreement has been uncovered, across wide parameter ranges, between theoretical predictions and direct numerical calculations. Simulations have also identified qualitatively new phenomena, strongly dependent on the beam incidence angle, that were not captured by analysis.