Graphene supports the propagation of subwavelength optical solitons

Maxim L. Nesterov[1,2,*], **Jorge Bravo-Abad**[1], **A. Yu. Nikitin**[2], **Francisco J. García-Vidal**[1], **Luis Martín-Moreno**[2]

[1] Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, España

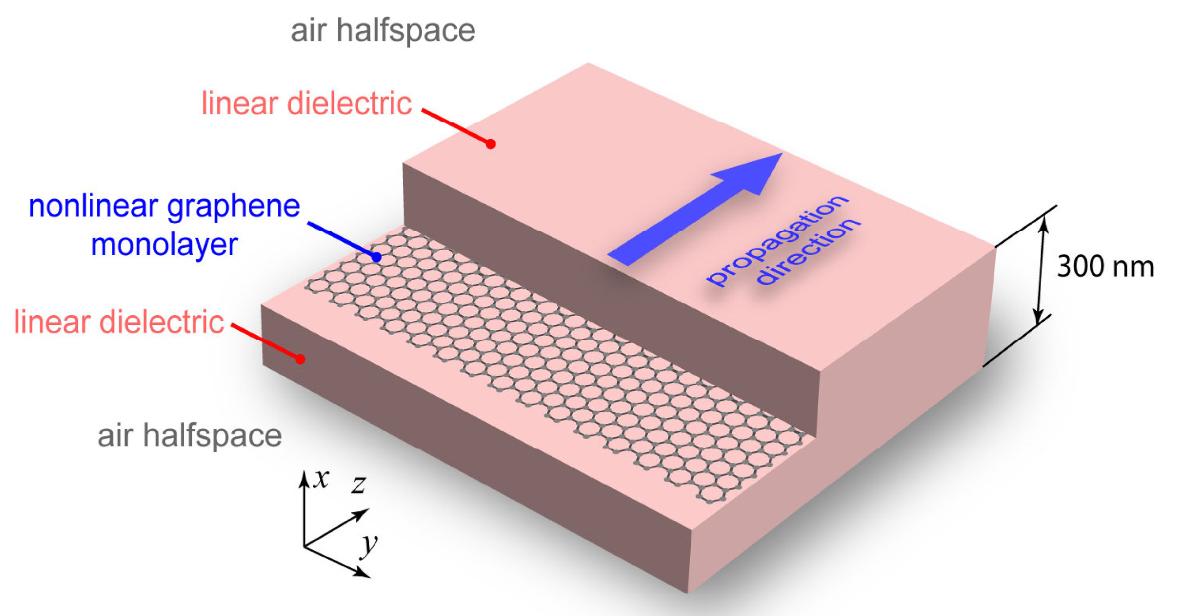
[2] Departamento de Fisica de la Materia Condensada-ICMA, Universidad de Zaragoza-CSIC, Zaragoza, Spain

* nesterovml@gmail.com

We study theoretically nonlinear propagation of light in a graphene monolayer. We show that the large intrinsic nonlinearity of graphene at optical frequencies enables the formation of quasione-dimensional self-guided beams (spatial solitons) featuring subwavelength widths at moderate electric-field peak intensities. We also demonstrate a novel class of nonlinear self-confined modes resulting from the hybridization of surface plasmon polaritons with graphene optical solitons.

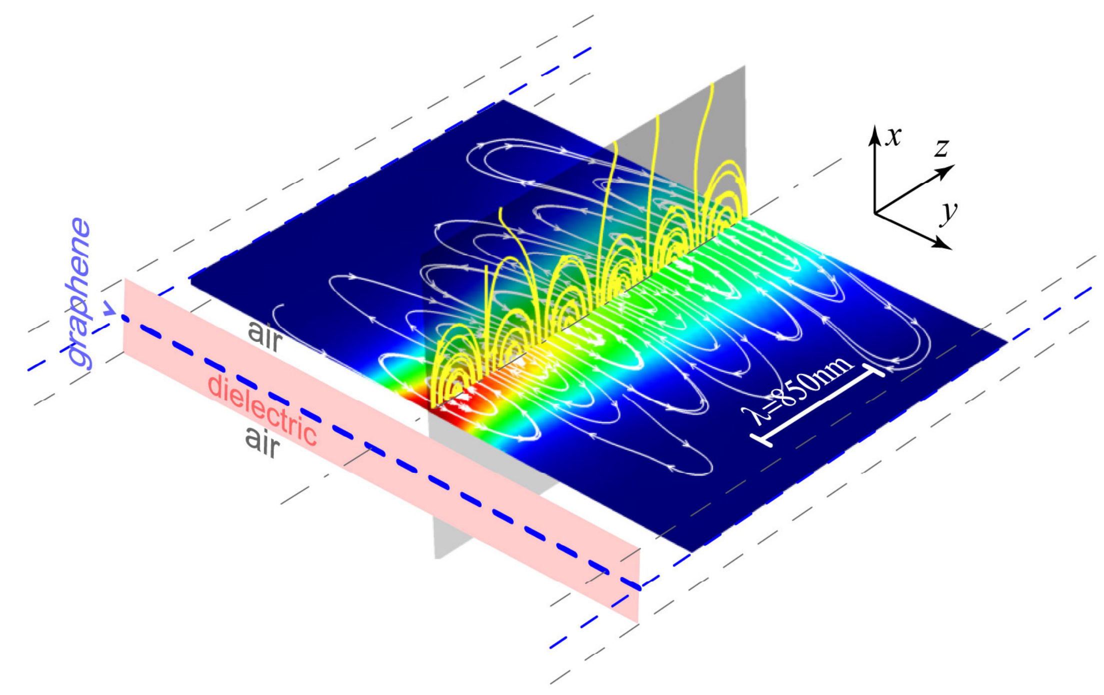
Geometry

Sketch of the studied system.



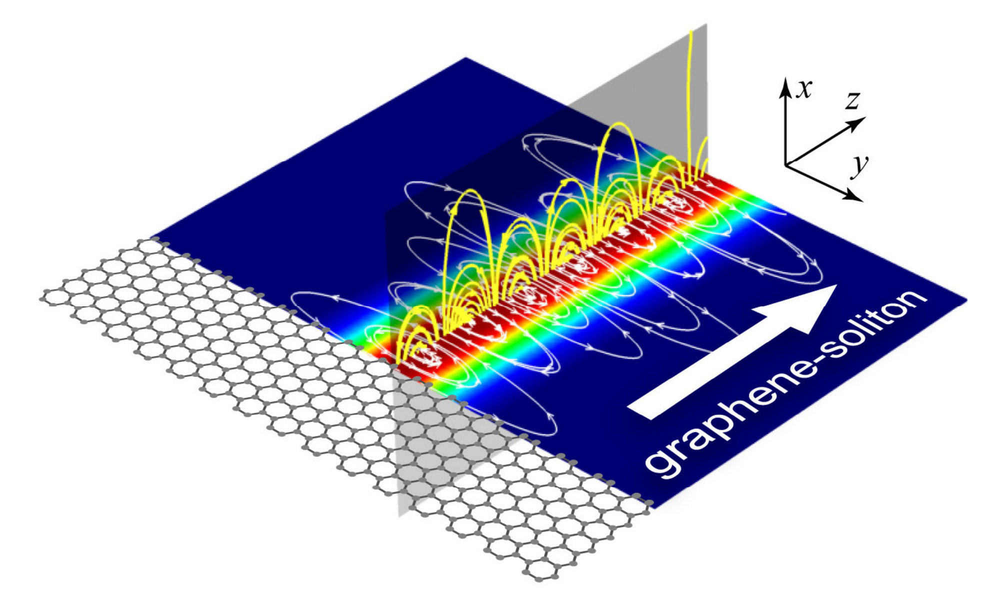
Diffraction

Linear propagation: decay of the input beam.



Spatial soliton

Propagation without change of the profile.



Quasi-analytical model:

We assume that solutions has this form

$$E = \frac{1}{2}[A(x)f(y,z)\exp(i\beta_0 z) + c.c.]$$

Nonlinear 2D current

$$\mathbf{j} = \partial\mathbf{P}/\partial t = \delta(x)\sigma_{\rm gr}(E)\mathbf{E}$$

Nonlinear 2D conductivity

$$\sigma_{\rm gr}(E) = \sigma_{\rm LIN} + \frac{3}{4}\sigma^{(3)}_{\rm gr}|E|^2$$

Inhomogeneous Helmholtz equation

$$c^2\nabla^2\mathbf{E} - \frac{\partial^2\mathbf{E}}{\partial t^2} = \frac{1}{\epsilon_0}\frac{\partial^2\mathbf{P}}{\partial t^2}$$

Nonlinear Schrodinger equation

$$2i\beta_0\frac{\partial f}{\partial z} + \frac{\partial^2 f}{\partial y^2} + g|f|^2 f = 0$$

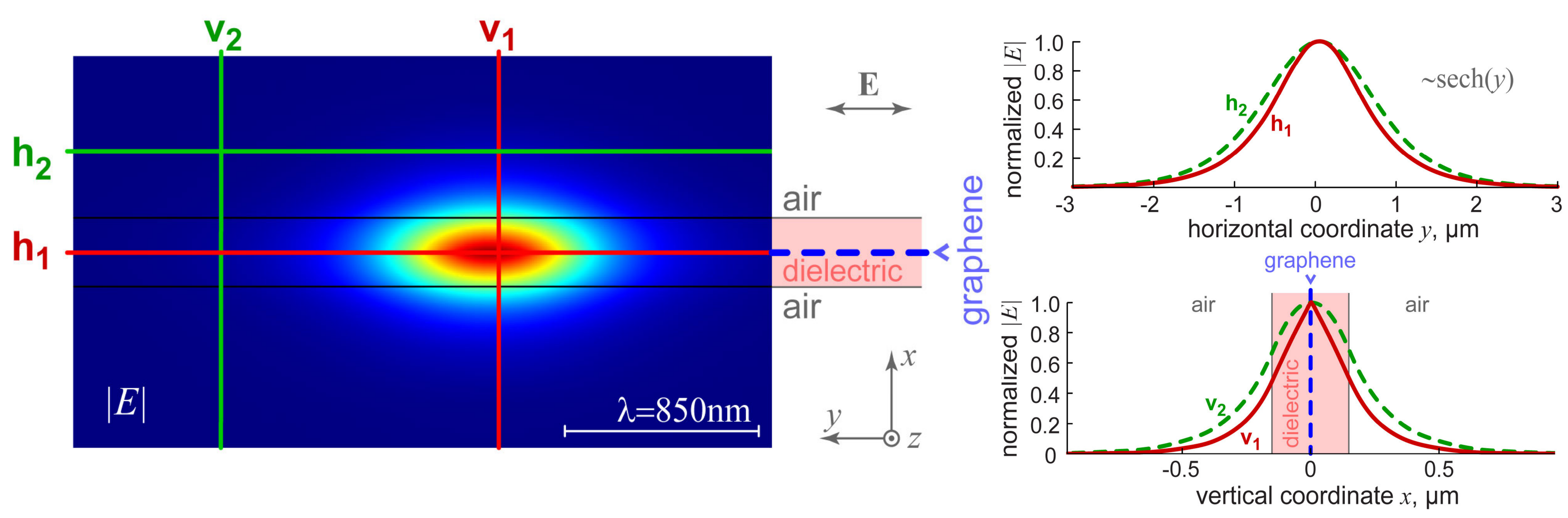
The parameters are

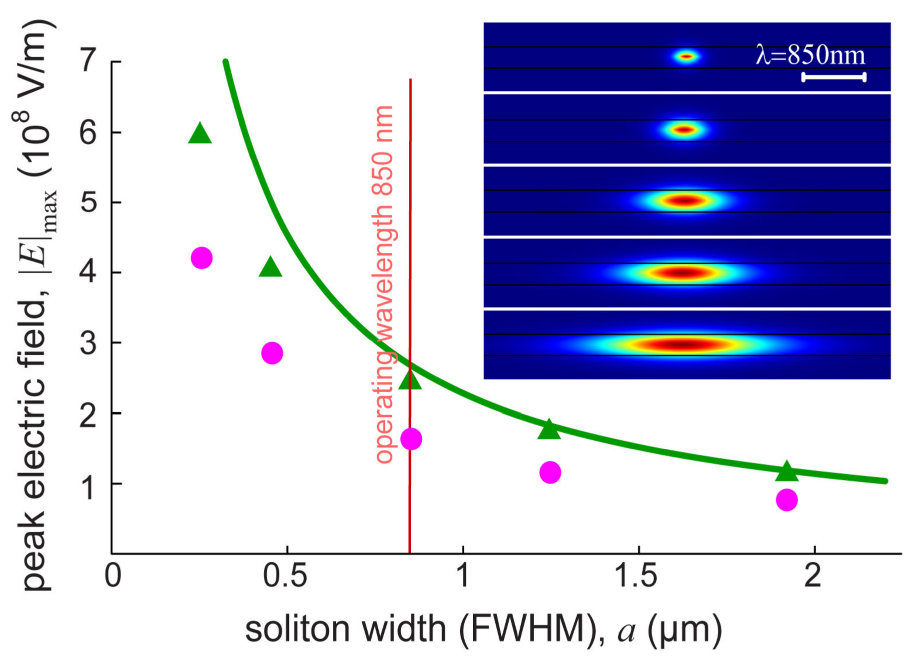
$$g = \frac{3}{4}i\sigma^{(3)}_{\rm gr}\omega/\varepsilon_0 c^2 I, \quad I = \textstyle\int_{-\infty}^{\infty}|A(x)|^2dx$$

Canonical first-order soliton solution

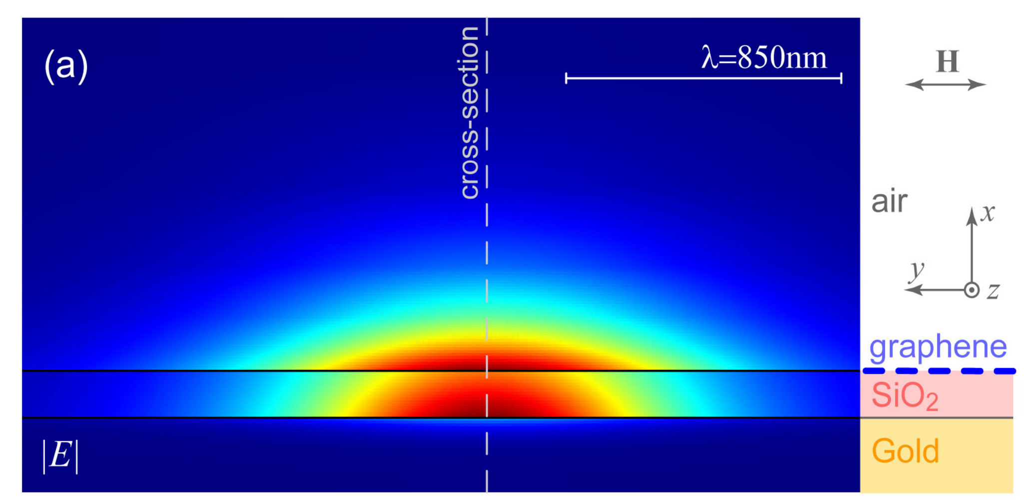
$$f(y,z) = \frac{1}{w}\sqrt{\frac{2}{g}}\,\mathrm{sech}(y/w)\exp(iz/2\beta_0 w^2)$$

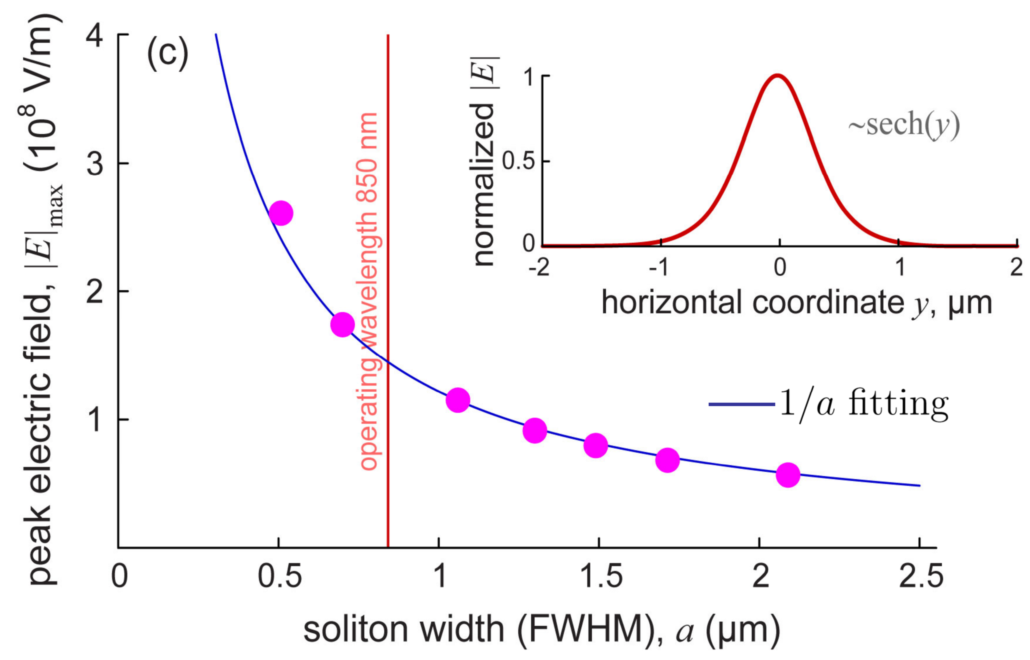
Graphene-solitons

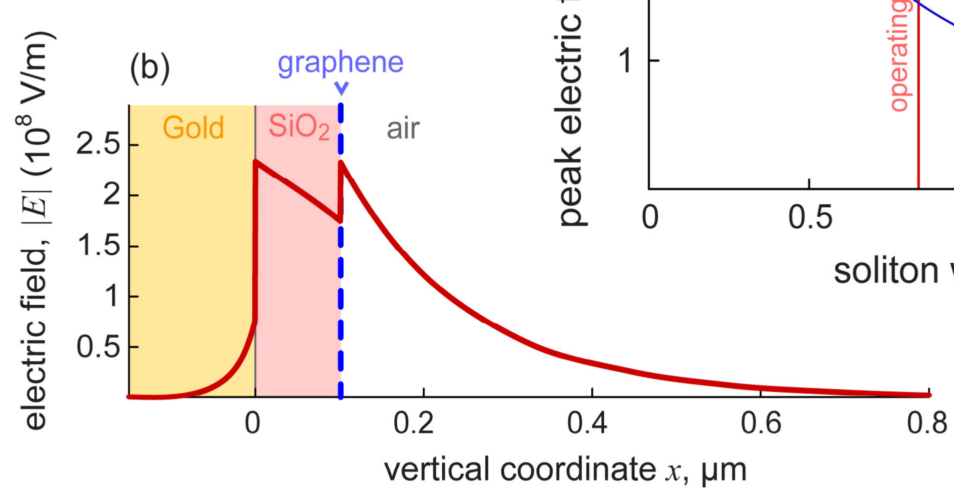




Hybrid graphene-SPP-solitons







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Summary:

- **Graphene monolayers can support both TE and TM spatial optical solitons** due to the extremely large magnitude of its nonlinear third-order susceptibility.
- **Graphene-solitons can have a subwavelength lateral width.**
- **Quasi-analytical model predicts the field intensities needed for soliton formation.**