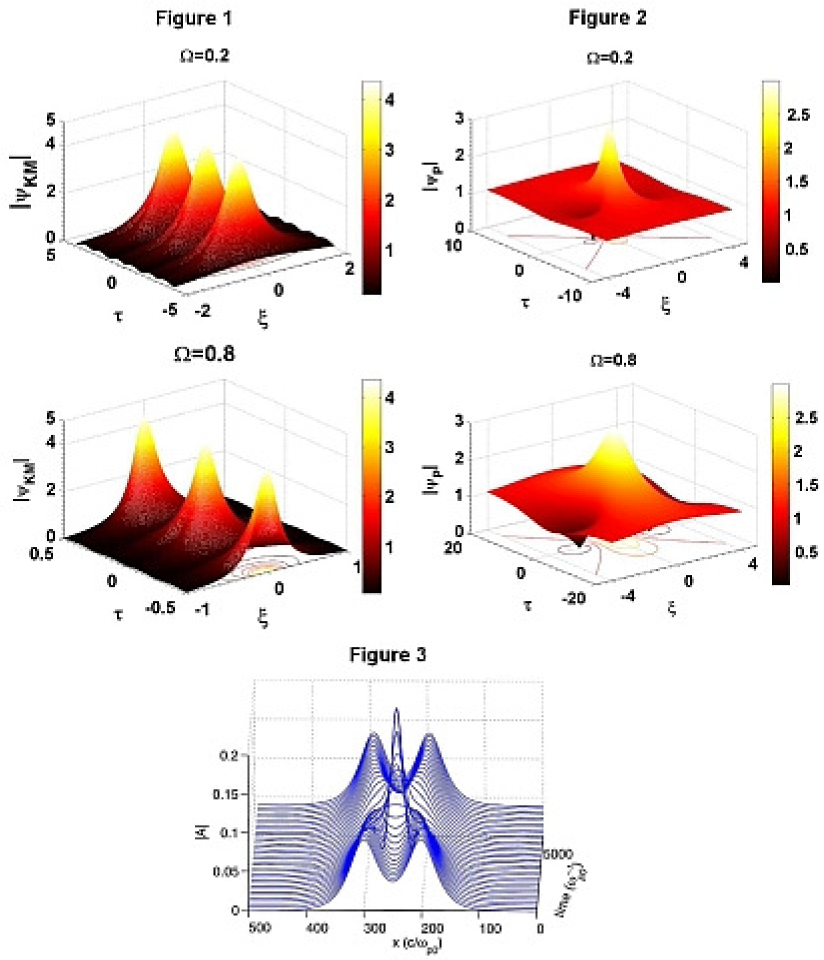
IOPscience

Monster waves in a laser beam: myth or reality?

How can ultra-strong electromagnetic excitations be formed during the interaction of a laser beam with a plasma?



(http://images.iop.org/objects/jio/labtalk/4/5/25/Image1.jpg)

Optical rogue wave structures. (http://images.iop.org/objects/jio/labtalk/4/5/25/Image1.jpg)

The unexpected occurrence of a huge water-wall (generally termed a rogue wave, or freak wave) has been a nightmare for seafarers (Onorato *et al* 2001 *Phys. Rev. Lett.* **86** 5831 (http://link.aps.org/doi/10.1103/PhysRevLett.86.5831) ; Shukla *et al* 2006 *Phys. Rev. Lett.* **97** 094501 (http://link.aps.org/doi/10.1103/PhysRevLett.97.094501)) and a fascinating subject of research for nonlinear physicists (Akhmediev *et al* 2009 *Phys. Rev.* A **80** 043818 (http://link.aps.org/doi/10.1103/PhysRevA.80.043818)). The amplitude of these giant waves is often reported to exceed twice or thrice the average height of surrounding waves (background turbulence), a fact suggesting a nonlinear description should be adopted as a model. This is a hot topic of current research, both in ocean physics and in other areas, including nonlinear optics, photonics and, more recently, in plasma physics. A better understanding of the formation of such destructive waves in the ocean would lead to the possibility of predicting, or even suppressing their occurrence. On the other hand, in nonlinear optics they can be used to generate high amplitude pulses when required. Significant research effort is being invested in elucidating the conditions for such excitations to occur, and in identifying their spatial and temporal characteristics.

In charged matter (plasma), by now recognized as the fourth state of matter and as the main constituent of the visible part of the universe, the topic of rogue wave formation is rather fresh. Plasmas can support waves of either electrostatic or electromagnetic (EM) nature. Localized structures in plasmas represent isolated lumps of EM energy which may propagate with constant profile. Elucidating the dynamical characteristics of these excitations is of importance in contexts like laboratory plasmas (where solitary waves and collisionless shocks occur during laser–matter interactions), in space plasmas (where localized structures are observed in measurements aboard satellite missions). Recently, EM pulses and shocks are recognized as effective energy carriers in inertial confinement fusion (ICF) scenarios for energy production. Harnessing this energy transport mechanism therefore is an important issue in future energy production schemes, and thus naturally a cutting edge area of frontier research in modern plasma science.

Researchers from the Centre for Plasma Physics (http://www.qub.ac.uk/research-centres/CentreforPlasmaPhysics/) at Queen's University Belfast (UK), collaborating with colleagues in Athens (Greece) and Ardabil (Iran), have investigated from first principles the dynamics of electromagnetic rogue waves in laser–plasma interactions, in the presence of an ambient magnetic field (published in 2013 *J. Opt.* 15 064003 (http://iopscience.iop.org/2040-8986/15/6/064003/article)). Focusing on circularly polarized wavepackets, the investigation relies on the nonlinear Schrödinger equation model which, despite being an approximate description, captures the essential features of strong (large-amplitude) electromagnetic wavepackets in plasmas, pretty much as in the case of ocean surface waves.

Multiscale analytical techniques have been utilized to reduce the fluid-plasma/Maxwell model to an effective nonlinear Schrödinger equation, involving dispersive and nonlinearity coefficients which are expressed in terms of an externally imposed magnetic field, in addition to intrinsic plasma parameters. A parametric investigation reveals that the strength of the field may act as a tuning parameter, by affecting the characteristics of rogue waves (space localization, time duration) and even suppressing their formation.

This investigation complements an earlier series of computational studies by the same team (Saxena *et al* 2013 *Phys. Lett.* A **377** 473 (http://dx.doi.org/10.1016/j.physleta.2012.12.010)), carried out as a joint effort with researchers from Max-Planck Institute for Complex Plasmas (Dresden, Germany) and Universidad Politecnica (Madrid, Spain), which suggested that mutual interactions among standing electromagnetic solitary waves can serve as a paradigm for electromagnetic rogue wave formation. Further research along this promising direction is planned, both analytically and numerically, in terms of modeling rogue waves as sudden events due to interacting pulses, or as intrinsic localized modes occurring during beam–plasma interactions. This is an ongoing joint project between the Belfast groups and collaborating teams overseas.

More details (http://iopscience.iop.org/2040-8986/15/6/064003/article) from the authors on this work are published in a special issue of *Journal of Optics* dedicated to optical rogue waves. Read more about the work of the Belfast group (http://www.tp4.rub.de/~ioannis/) .

About the author

Giorgos Veldes is carrying out his graduate research, supervised by Professor Dimitri J Frantzeskakis, at the National and Kapodistrian University of

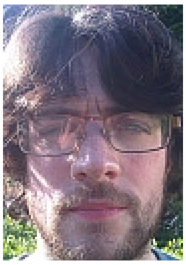
(http://images.iop.org/objects/jio/labtalk/4/5/25/Kourakis.jpg)

Athens (Greece). The activities of the research group focus on nonlinear waves with applications to various physical contexts, including Bose–Einstein condensates, nonlinear optics, metamaterials, and others. **Michael McKerr**, **Dr Vikrant Saxena** and **Dr Ioannis Kourakis** are nonlinear plasma physicists, working at Queen's University Belfast (UK). Since 2007, the research activity of the theoretical group, led by Dr Kourakis, has focused on several aspects of nonlinear plasma dynamics (solitary wave and shock dynamics, instabilities), with emphasis on beam–plasma interactions during laser-plasma experiments, but also in space. **Dr Jafar Borhanian** is an Assistant Professor and Researcher working at University of Mohaghegh Ardabili (Iran). His research activities include nonlinear electrostatic and electromagnetic structures in plasmas, and gas discharge physics.

I Kourakis (http://images.iop.org/objects/jio/labtalk/4/5/25/Kourakis.jpg)


(http://images.iop.org/objects/jio/labtalk/4/5/25/Frantzeskakis.jpg)
D J Frantzeskakis (http://images.iop.org/objects/jio/labtalk/4/5/25/Frantzeskakis.jpg)


(http://images.iop.org/objects/jio/labtalk/4/5/25/Saxena.jpg)
V Saxena (http://images.iop.org/objects/jio/labtalk/4/5/25/Saxena.jpg)


(http://images.iop.org/objects/jio/labtalk/4/5/25/McKerr.jpg)
M McKerr (http://images.iop.org/objects/jio/labtalk/4/5/25/McKerr.jpg)


(http://images.iop.org/objects/jio/labtalk/4/5/25/Borhanian.jpg)
J Borhanian (http://images.iop.org/objects/jio/labtalk/4/5/25/Borhanian.jpg)


(http://images.iop.org/objects/jio/labtalk/4/5/25/Veldes.jpg)
G P Veldes (http://images.iop.org/objects/jio/labtalk/4/5/25/Veldes.jpg)

IOP Publishing