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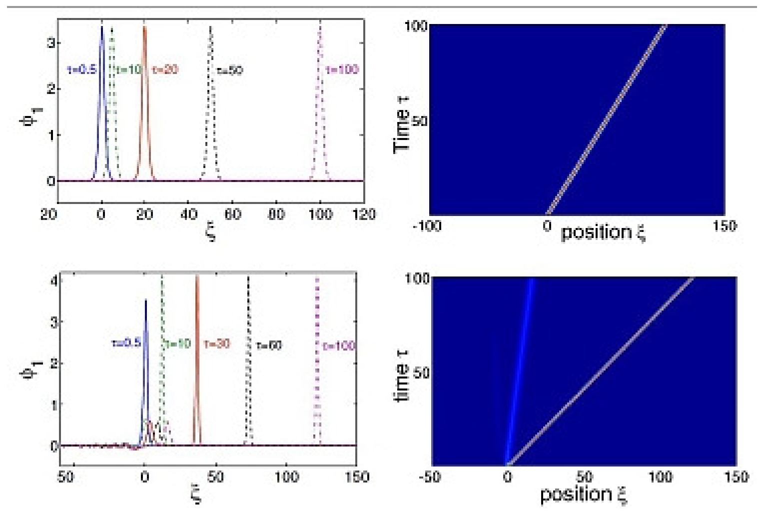
Plasmas beyond the Maxwellian border: how do energetic (suprathermal) particles affect the dynamics of shocks and solitary waves?

Abundant evidence from Space and laboratory observations suggests the ubiquitous existence of highly energetic particles, due to various acceleration mechanisms in plasmas. Adopting a generic paradigm from Space plasma distributions (the kappa-type distribution function), the dynamics of waves and nonlinear excitations in superthermal plasmas is elucidated.



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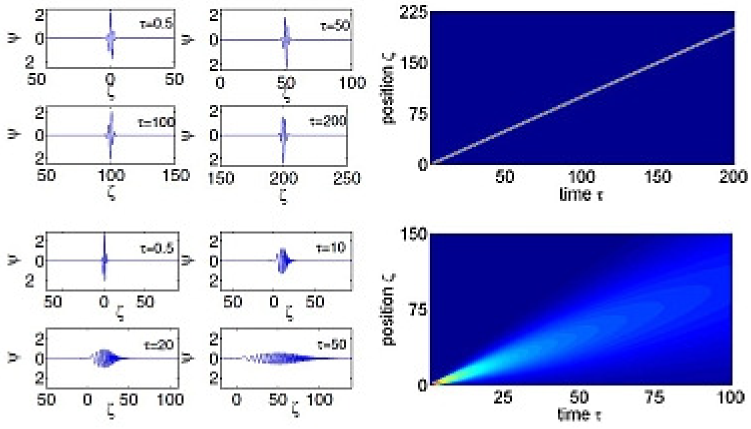
Electrostatic solitary waves change at interface (http://images.iop.org/objects/jio/labtalk/4/7/13/Figure1.jpg)

Space observations suggest the common occurrence of non-thermal (non-Maxwellian) plasmas, featuring superthermal wings in their electron or ion statistical distribution [1]. A similar behaviour is observed in the laboratory, for instance in laser-plasma interaction experiments, where energetic electron populations are generated during beam-target interactions, marking their impact on the characteristics of electrostatic structures propagating in the ambient plasma cloud [2]. Various scenarios have been proposed, to model this qualitative behaviour. The standard paradigm employed consists of the so-called “kappa”-type [1,3] distribution function, which was first introduced in the 1960s to model the power-law velocity dependence characterising these highly energetic particle populations, in fact a long standing problem in Space Physics [4]. The kappa distribution has been commonly used to fit particle data measured by satellite missions [5], as well as in laboratory devices [6]. It describes a distribution function that has a Maxwellian-like core and a high-energy component of power-law form, which reproduces smoothly the velocity dependence manifested in Space observations. Interestingly, it has recently [7] been argued that the kappa distribution may have a more solid theoretical foundation, linked to non-extensive (Tsallis) thermodynamics [8].

Researchers from the Centre for Plasma Physics (http://www.qub.ac.uk/research-centres/CentreforPlasmaPhysics/) at Queen's University Belfast (UK) joined forces with colleagues at the University of KwaZulu-Natal (http://physicsdbn.ukzn.ac.za/Academic_Staff_Profiles/Manfred_A_Hellberg.aspx) in Durban (South Africa), in a combined effort to elucidate from first principles the dynamics of electrostatic solitary waves in plasma environments characterized by ultra-energetic electron populations. Relying on a fluid plasma model, combined with a kappa distribution function to model excess superthermality of the electron



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Stability profile of bright-type envelope modes (http://images.iop.org/objects/jio/labtalk/4/7/13/Figure2.jpg)

distribution, it was shown that the dramatic modification of the Debye shielding properties in strongly nonthermal plasmas affects the generation and propagation mechanisms dominating collective excitations in the plasma. Different types of nonlinear excitations, in the form of solitary waves (pulses) [9], shocks [10], or envelope solitons (modulated wavepackets) [11], have been covered by this study. A detailed parametric analysis of the dynamical properties of nonlinear structures reveals a sensitive dependence of their propagation characteristics (velocity, geometry) and stability profile on the nonthermal background. Numerical simulations were employed to confirm theoretical predictions, namely in terms of the stability of electrostatic pulses, as well as the modulational stability profile of bright- and dark-type envelope solitons.

This investigation complements an earlier series of theoretical studies of superthermal plasmas [12-15] involving, apart from the main core of the Belfast (UK) and Durban (SA) groups, collaborating partners from Pwani University (Kenya), Macquarie University (Sydney, Australia), Guru-Nanak Dev University (Amritsar, India) and Jahangirnagar University (Dhaka, Bangladesh). Further research along this promising direction is planned, as an ongoing joint project between the Belfast group and collaborating teams overseas.

Read the complete article in *Plasma Physics and Controlled Fusion* (http://iopscience.iop.org/0741-3335/54/12/124001)

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Dr Ioannis Kourakis (http://www.tp4.rub.de/~ioannis/) and **Dr Sharmin Sultana** are nonlinear plasma physicists, working at Queen's University Belfast (http://www.qub.ac.uk/research-centres/CentreforPlasmaPhysics/) (UK), during the execution of the research

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project. (S Sultana has recently moved to Dhaka Bangladesh, where she occupies an Assistant Professorship at Jahangirnagar University.) 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 in laser-plasma experiments and in Space. Professor Manfred Hellberg (http://physicsdbn.ukzn.ac.za/Academic_Staff_Profiles/Manfred_A_Hellberg.aspx) is Emeritus Professor and Senior Research Associate at the University of KwaZulu-Natal in Durban, South Africa. His research encompasses theoretical studies of nonlinear solitary structures in multi-component space plasmas and linear waves in kappa distribution plasmas.