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Electrostatic solitary waves in superthermal plasmas

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Electrostatic solitary waves in superthermal plasmas:

an overview of recent results

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Layout

- 1. Motivation: Superthermal electrons – occurrence, observations
- 2. Fundamental framework: κ distribution function, relation to electrostatic (ES) plasma modes
- 3. Question 1: Effect on ES solitary waves
  a) ion-acoustic waves (IAWs)
  b) electron-acoustic waves (EAWs)
- 4. Question 2: Nonlinear self-modulation of ES wavepackets
  - Modulational instability & envelope solitons
- 5. Conclusions

1. Motivation: Ubiquitous superthermal plasma behavior

- Superthermal electrons are ubiquitously observed in Space: Montgomery *et al*, PRL (1965), Vasyliunas, JGR (1968), Fitzenreiter *et al,* GRL (1998)

- Space plasmas: Saturn's Magnetosphere (Schippers *et al.* JGR 2008), Solar wind (Gaelzer & Yoon ApJ 2008)

- Plasma laboratory experiments: Kharchenko *et al,* Nucl. Fusion (1961), Kardfidov *et al,* Sov. Phys. JETP (1990), S. Magni *et al,* PRE (2005), G Sarri, M Borghesi *et al* (submitted to PRL, 2009)

- Numerical simulations: Petkaki JGR (2003), Yoon *et al*, PRL (2005), Kawahara *et al* JPSJ (2006)

- Beam-plasma interactions, e-acceleration in a turbulent medium Yoon et al, PRL (2005)

\+ Intense laser-matter interactions, non-Gaussian beam profile dynamics: M. Nakatsutsumi *et al*, NJP (2008)

2. κ (kappa) distribution - basics

$$f_\kappa(v) = \frac{n_0}{(\pi\kappa\theta^2)^{3/2}} \frac{\Gamma(\kappa+1)}{\Gamma(\kappa-1/2)} \left(1 + \frac{v^2}{\kappa\theta^2}\right)^{-\kappa-1}$$

[Ref. Vasyliunas JGR (1968),

Baluku & Hellberg, PoP (2008)]

Effective thermal speed:

$$\theta^2 = \frac{\kappa-3/2}{\kappa}\left(\frac{2k_B T}{m}\right)$$

T : kinetic temperature

κ : spectral index

[Fig. from:

Summers & Thorne, PF (1991)]

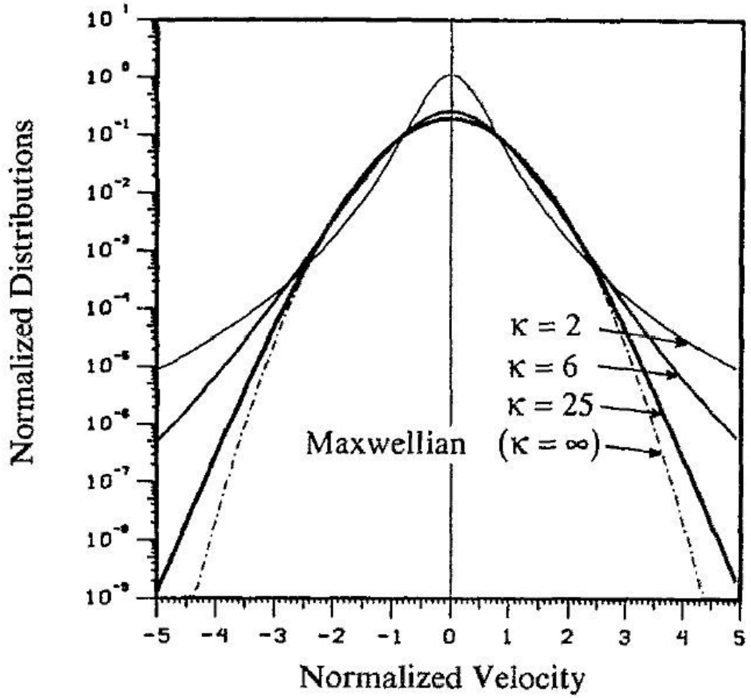

FIG. 1. Comparison of generalized Lorentzian distributions for the spectral index $\kappa = 2$, 6, and 25, with the corresponding Maxwellian distribution ($\kappa = \infty$).

Kappa (k) parameter measures deviation from thermal equilibrium

Smaller κ value → longer superthermal df tail, harder spectrum

Infinite κ value → Maxwellian *df, no* superthermal particles

Kappa distribution function (continued)

- First introduced to fit early Space observations [Vasyliunas, PF 1968], suggesting superthermal electrons + power-law dependence in *v* [Montgomery *et al*, PRL 1965]

- Kappa distribution studied in linear regime: Z_κ dispersion function [Summers & Thorne, PF (1991), Mace & Hellberg PoP (1995, 2009)]

- Anomalous Landau damping of ES plasma modes [Podesta PoP (2005); Lee PoP (2007)]

- Satellite observations; Foreshock, Magnetotail, Plasma sheet; Solar Exosphere, Solar wind, … (see next slides)

- Solar Corona anomalous temperature variation explained via kappa theory [Scudder ApJ (1992), Maksimovic *et al*, A&A (1997)]

- Cassini data, Saturn: s/thermal c/h-*e* obs. [Schippers *et al* JGR (2008)]

Kappa df *vs* Tsallis theory

- Apparent relation between kappa *df* and q-Gaussian *df* emerging as a stationary configuration within the nonextensive Tsallis thermodynamics [Tsallis J Stat Phys 1988];
- Kappa distributions turn out to be a consequence of the entropy generalization through the generalized Boltzmann *H* theorem;
- Recent study claims proof of exact equivalence [Livadiotis & McComas, JGR, 2009, in press, private comm.; earlier precursors promising]
- Future ?

Nonlinear Processes in Geophysics (2000) 7: 211–221

Nonlinear Processes in Geophysics

Functional background of the Tsallis entropy: "coarse-grained" systems and "kappa" distribution functions

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Received: 17 November 1999 – Revised: 28 February 2000 – Accepted: 22 March 2000

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, A07208, doi:10.1029/2008JA013098, 2008

Multi-instrument analysis of electron populations in Saturn's magnetosphere

P. Schippers,[1] M. Blanc,[1] N. André,[2] I. Dandouras,[1] G. R. Lewis,[3] L. K. Gilbert,[3] A. M. Persoon,[4] N. Krupp,[5] D. A. Gurnett,[4] A. J. Coates,[3] S. M. Krimigis,[6] D. T. Young,[7] and M. K. Dougherty[8]

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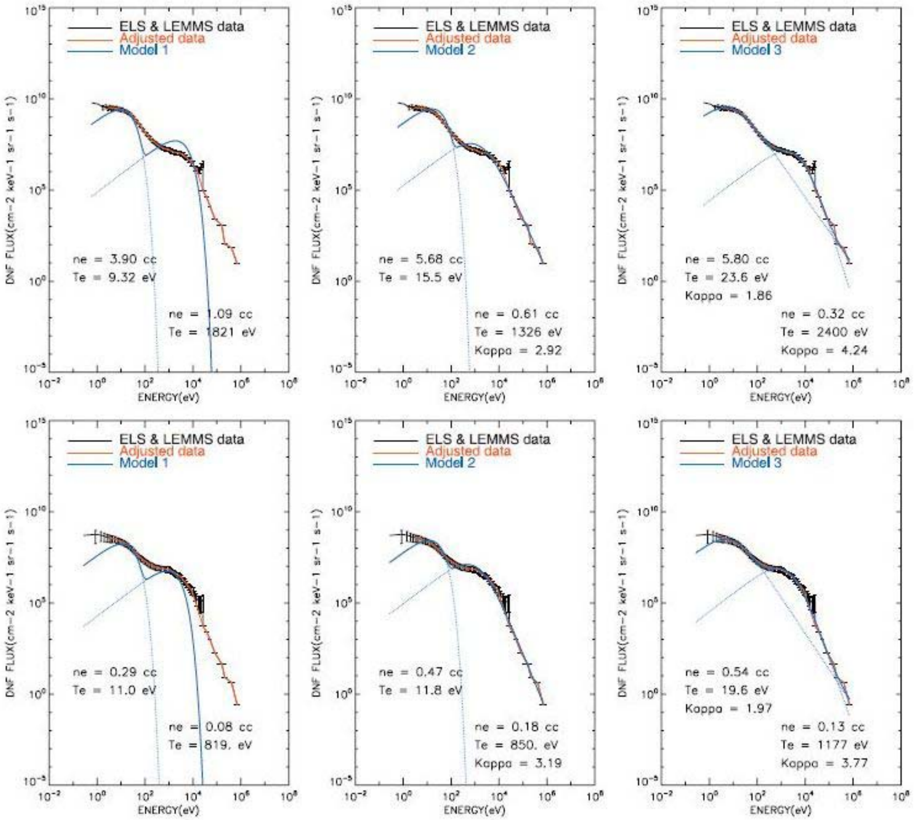

Figure 2. Composite CAPS/ELS and MIMI/LEMMS (energy channels C0-C7) spectral plots of electron intensities versus energy, observed at (top) 2200 UT ($R = 9\ R_s$, local time 18.32 h, latitude 0.23 degrees) and at (bottom) 0727 UT ($R = 12.8\ R_s$, local time 19.82 h, latitude 0.35 degrees) on days of year 142 and 143 of 2006 during Rev. 24, respectively. Original data are represented in black, our interpolated data are represented in red, and the results of our various models are represented in blue. (left) Model with 2 Maxwellian distributions. (middle) Model with one Maxwellian and one kappa distribution. (right) Model with two kappa distributions.

Cassini data from Saturn;

from:

Schippers *et al* JGR (2008)

Excellent 2-kappa df fit

over regions

$5.4\ R_S < R < 18\ R_S$

PRL **95,** 215003 (2005) PHYSICAL REVIEW LETTERS week ending 18 NOVEMBER 2005

Self-Consistent Generation of Superthermal Electrons by Beam-Plasma Interaction

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(Received 11 July 2005; published 16 November 2005)

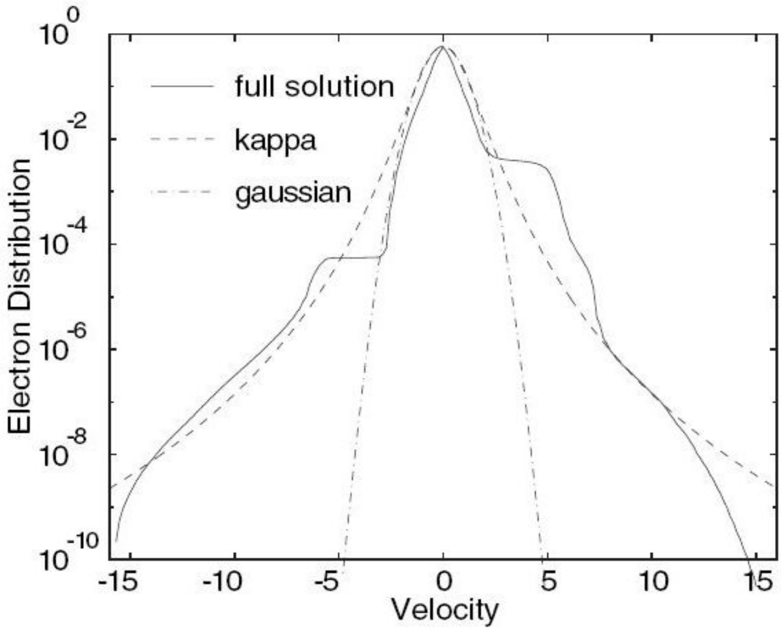

FIG. 4. Comparison of $F(u)$ at $\omega_{pe}t = 2 \times 10^4$ computed for $g = 5 \times 10^{-3}$ with κ distribution with index $\kappa = 3.5$ and the Gaussian.

Beam-plasma interactions;
from:
Yoon *et al* PRL (2005)

PRL 99, 145002 (2007) PHYSICAL REVIEW LETTERS week ending 5 OCTOBER 2007

Theory of Weak Bipolar Fields and Electron Holes with Applications to Space Plasmas

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(Received 4 May 2007; published 5 October 2007)

A theoretical model of weak electron phase-space holes is used to interpret bipolar field structures observed in space. In the limit $e\phi_{max}/T_e \ll 1$ the potential of the structure has the unique form, $\phi(x) = \phi_{max}\mathrm{sech}^4(x/\alpha)$, where ϕ_{max} depends on the derivative of the trapped distribution at the separatrix, while α depends only on a screening integral over the untrapped distribution. Idealized trapped and passing electron distributions are *inferred* from the speed, amplitude, and shape of satellite waveform measurements of weak bipolar field structures.

DOI: 10.1103/PhysRevLett.99.145002 PACS numbers: 52.35.Sb, 52.35.Mw, 94.05.Fg

EW LETTERS week ending 5 OCTOBER 2007

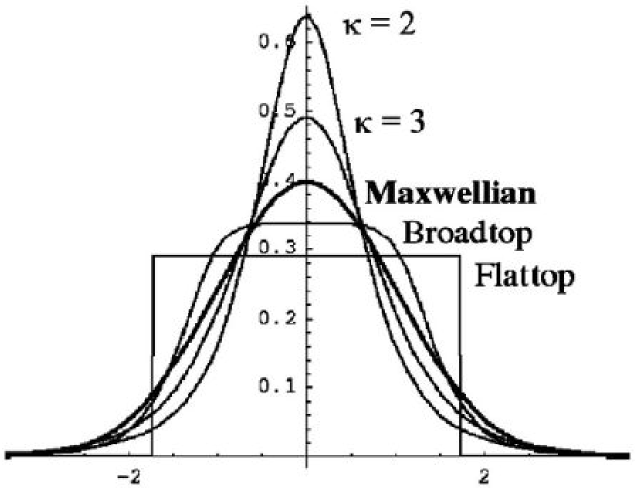

FIG. 1. Untrapped electron distributions used in Table I.

E-hole experiment:
excellent fit for kappa < 4 ;

Ref. recent experiments by
M Borghesi and G Sarri (2009)

PRL **100**, 055003 (2008) PHYSICAL REVIEW LETTERS week ending 8 FEBRUARY 2008

Superdiffusion and Non-Gaussian Statistics in a Driven-Dissipative 2D Dusty Plasma

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(Received 1 June 2007; published 6 February 2008)

Anomalous diffusion and non-Gaussian statistics are detected experimentally in a two-dimensional driven-dissipative system. A single-layer dusty plasma suspension with a Yukawa interaction and frictional dissipation is heated with laser radiation pressure to yield a structure with liquid ordering. Analyzing the time series for mean-square displacement, superdiffusion is detected at a low but statistically significant level over a wide range of temperatures. The probability distribution function fits a Tsallis distribution, yielding q, a measure of nonextensivity for non-Gaussian statistics.

DOI: 10.1103/PhysRevLett.100.055003 PACS numbers: 52.27.Lw, 52.27.Gr, 82.70.Dd

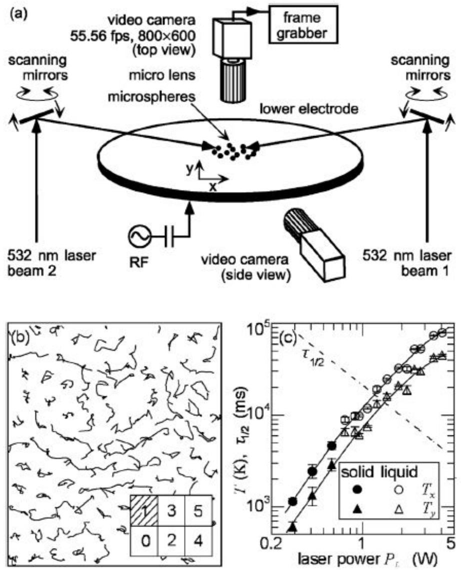


FIG. 1. (a) Apparatus. An argon plasma is formed in a vacuum chamber, not shown here. Microspheres suspended in a single layer above a lower electrode are kicked by a pair of rastered laser beams. (b) Particle trajectories for $P_L = 2.5$ W in cell 1. We divide the camera's full field-of-view (FOV) into 6 cells, as shown in the inset. Motion is mostly ballistic in the 0.5 s time interval shown here. (c) Heating. Kinetic temperatures, averaged over the full FOV, increase with P_L. Structures with $G_\theta < 0.1$ were identified as liquid and lacked large crystalline domains; structures identified as solid were not defect-free. At higher temperatures, threads have a shorter half-life $\tau_{1/2}$. The anisotropy $T_x > T_y$ is due to laser heating.

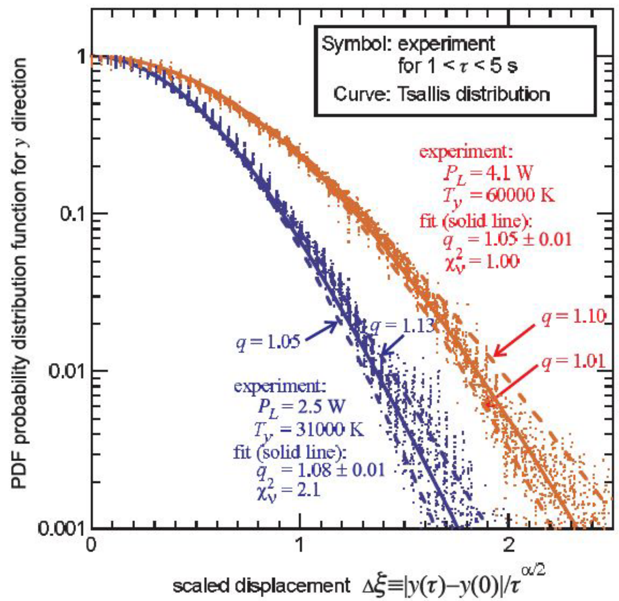


FIG. 3 (color online). PDF for the y direction, and the same conditions as in Fig. 2. Self-similarity is revealed by the collapse of PDFs at successive delays τ, with the scaled displacement $\Delta\xi \equiv |y(\tau) - y(0)|/\tau^{\alpha/2}$. Fitting to Eq. (1) yields the smooth solid curves and the measure of nonextensivity q. Other curves shown bracket the smooth curve for the fit.

Dusty Plasmas;

Liu and Goree PRL (2008)

3. (Dust-) ion-acoustic excitations (fluid description) (+ kappa-distributed e^- background) *

Continuity:

$$\frac{\partial n}{\partial t} + \frac{\partial (n u)}{\partial x} = 0$$

Momentum:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} = - \frac{\partial \phi}{\partial x}$$

Poisson Eq.:

$$\frac{\partial^2 \phi}{\partial x^2} = -n + n_e \mp Z_d n_d$$

dust - defects (stationary)

S/thermal *e* density: $n_e = n_{e,0} \left(1 - \frac{\phi}{\kappa - 3/2}\right)^{-\kappa + 1/2}$

Scaling: $n = \frac{n_i}{n_{i0}}, \quad u = \frac{u_i}{c_s}, \quad x = \frac{x}{\lambda_D}, \quad \phi = \frac{e\phi}{k_B T_e}, \quad t = \omega_{pi} t$

$c_s = \left(\frac{k_B T_e}{m_i}\right)^{1/2} \qquad \omega_{pi} = \left(4 \pi n_{i0} e^2 / m\right)^{1/2} \qquad \lambda_D = \left(k_B T_e / 4 \pi n_{i0} e^2\right)^{1/2}$

[* in collaboration with: NS Saini, S Sultana, T Baluku, M Hellberg]

Pseudopotential formalism for localized excitations

[Vedenov & Sagdeev 1961, Sagdeev 1966]

• stationary frame, single travelling coordinate $\xi = x - Mt$

* reduction of the fluid model PDEs in *{x, t}* to an ODE in ξ

* pseudo-energy-balance equation:

$$\frac{1}{2}\left(\frac{d\phi}{d\xi}\right)^2 + V(\phi) = 0$$

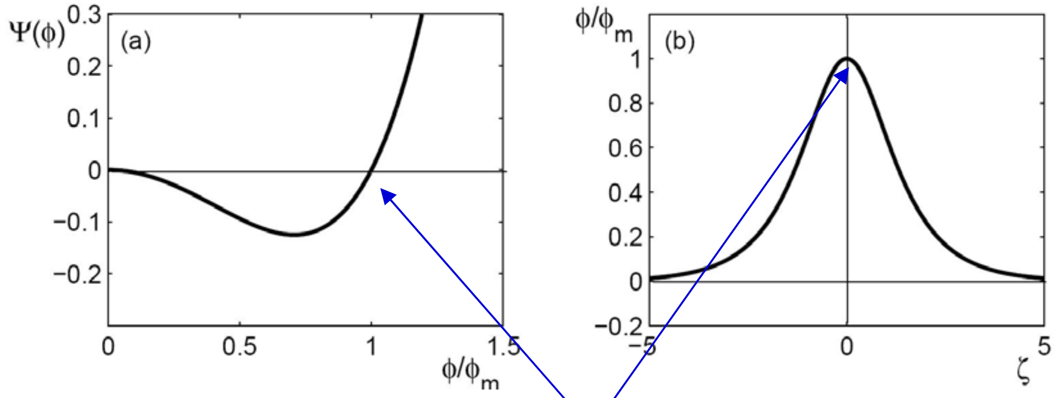
$$V(\phi) = M^2\left(1 - \sqrt{1 - \frac{2\phi}{M^2}}\right) + 1 - \left(1 - \frac{\phi}{\kappa - 3/2}\right)^{-\kappa+3/2}$$

* solution obtained (numerically) for the electric potential ϕ

* density and fluid velocity given by

$$n = \frac{1}{\sqrt{1 - 2\phi/V^2}} \qquad v = V - \sqrt{V^2 - 2\phi}$$

The generic solitary wave (pulse) solution bears the form:



potential pulse amplitude = root of V

Slower “supersonic” solitons

for smaller kappa values:

M_2: infinite compression point (choked flow)

M_1: κ-dependent “sound speed”

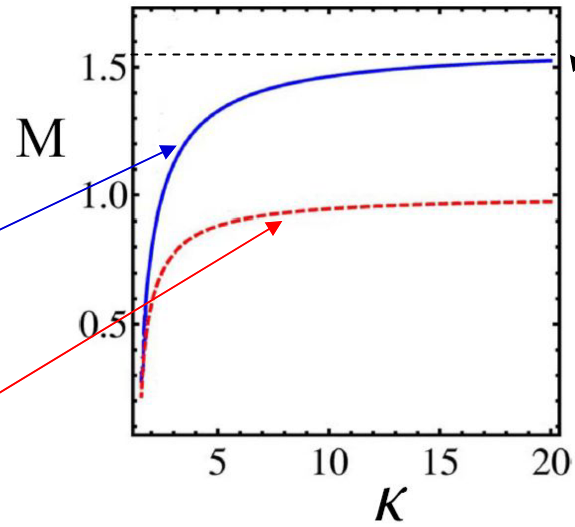


FIG. 1. (Color online) IA soliton existence domain in the parameter space of κ and Mach number, M. Solitons may be supported in the region between the two curves. The lower, dashed curve represents the minimum (soliton) condition, M_1, and the upper, solid curve the infinite compression limit, M_2.

Known limit 1.58 for infinite κ

Increased soliton amplitude for higher speed M (for given κ):

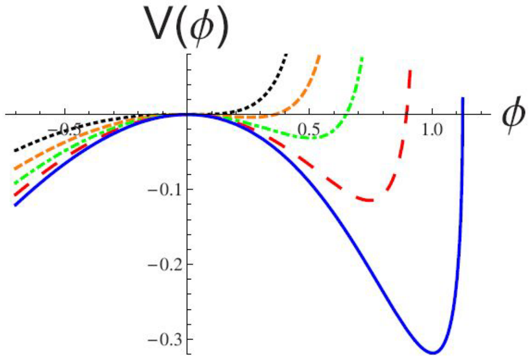


FIG. 2. (Color online) Variation of $V(\phi)$ for $\kappa=16$ and different values of Mach number, M. From top to bottom: Dotted curve: $M=0.97$; dashed curve: $M=1.10$; dotted-dashed curve: $M=1.23$; long-dashed curve: $M=1.36$; and solid curve: $M=1.50$.

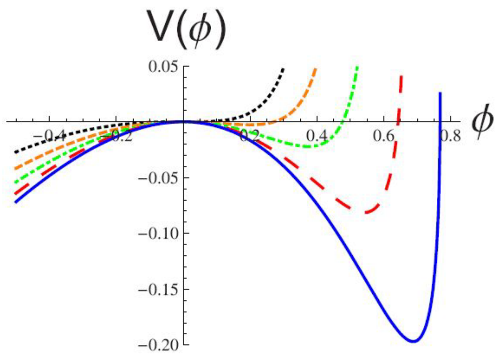


FIG. 3. (Color online) Variation of $V(\phi)$ for $\kappa=4$ and different values of Mach number, M. From top to bottom: Dotted curve: $M=0.85$; dashed curve: $M=0.95$; dotted-dashed curve: $M=1.05$; long-dashed curve: $M=1.15$; and solid curve: $M=1.24$.

and…

increased soliton amplitude for smaller kappa values (for fixed M) by a factor ~ 1.1 – 5: see bottom left

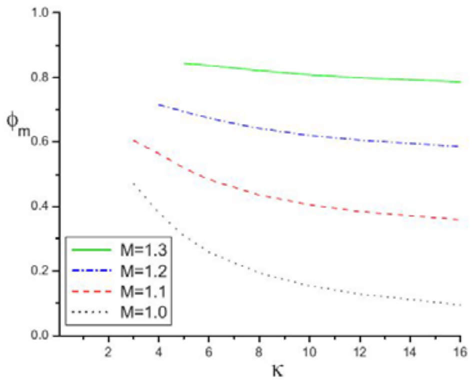


FIG. 8. (Color online) Variation of ϕ_m with κ for different values of the Mach number, M. The dotted curve corresponds to $M=1.0$; the dashed curve to $M=1.1$; the dotted-dashed curve to $M=1.2$; and the solid curve to $M=1.3$.

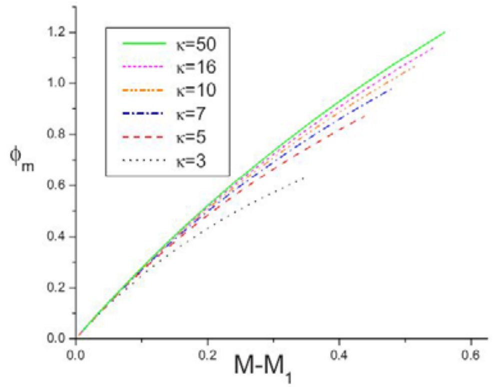
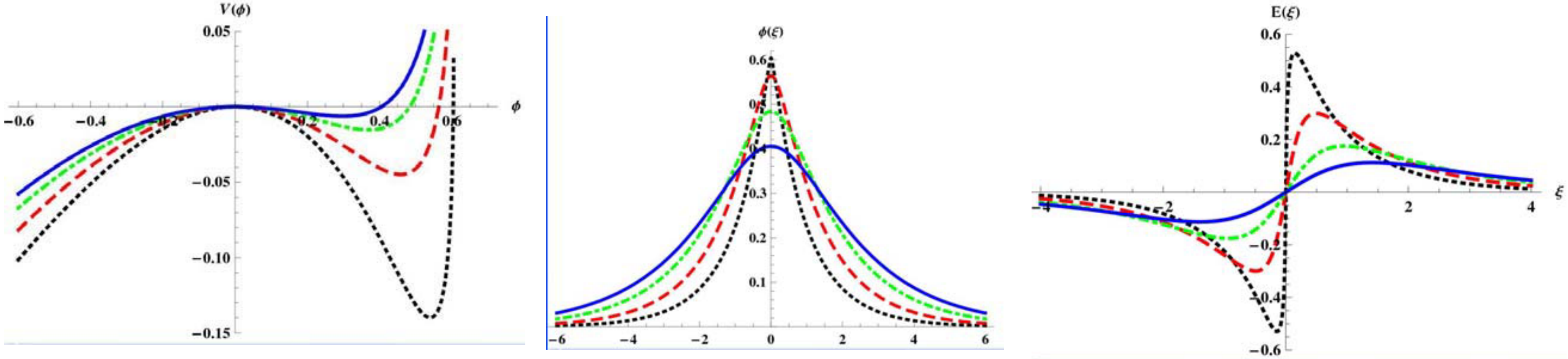


FIG. 4. (Color online) Variation of ϕ_m with $M-M_1$ for different values of κ. The dotted curve corresponds to $\kappa=3$, the dashed curve to $\kappa=5$, the dotted-dashed curve to $\kappa=7$, the dotted-dotted dashed curve to $\kappa=10$, the short-dashed curve to $\kappa=16$, and the solid curve to $\kappa=50$.

From: N S Saini, I Kourakis and MA Hellberg, Phys. Plasmas **16** 062903 (2009)

Increased soliton amplitude for lower κ!

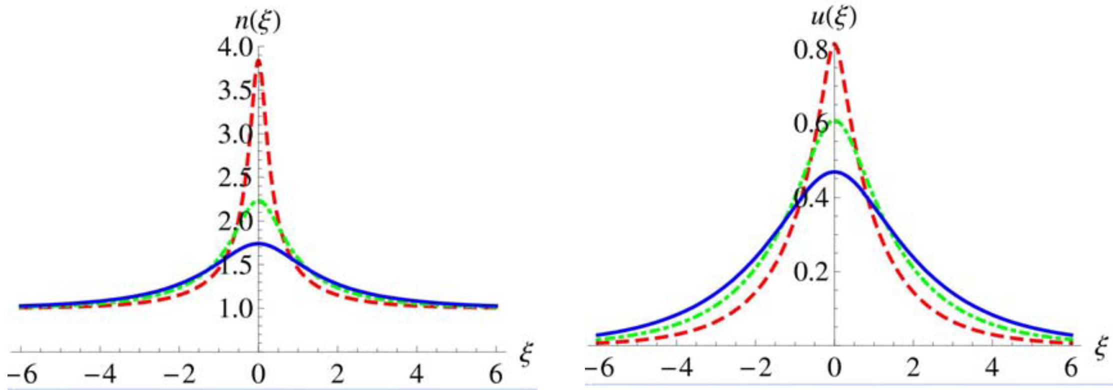


κ = 3 (black)

4 (red)

6 (green)

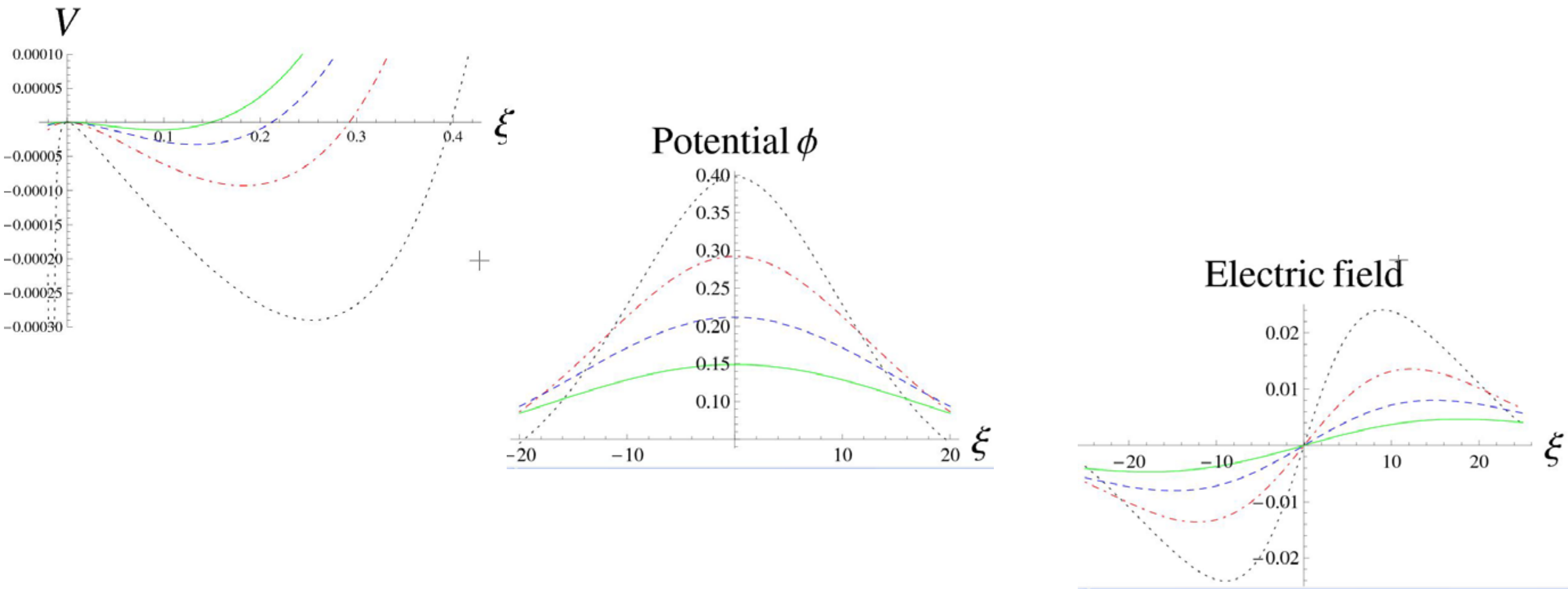
10 (blue)



- *Strong dependence on κ in the range (3, 6);*
- Quasi-Maxwellian behavior beyond κ = *10.*

From: N S Saini, I Kourakis and MA Hellberg, Phys. Plasmas **16** 062903 (2009)

Preliminary results on obliquely propagating IA solitons in magnetized plasmas: increased soliton amplitude for lower κ



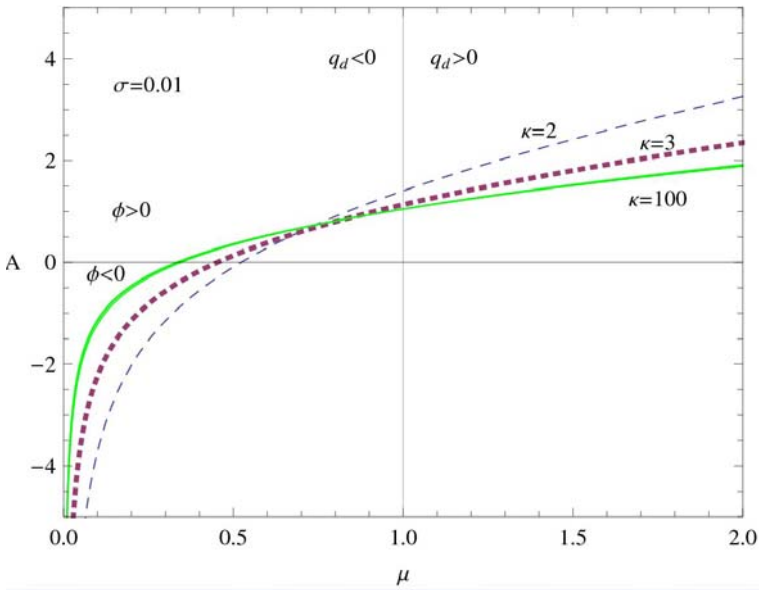
kappa = 3.5 (black); 5 (red); 7 (blue) ; 10 (green)

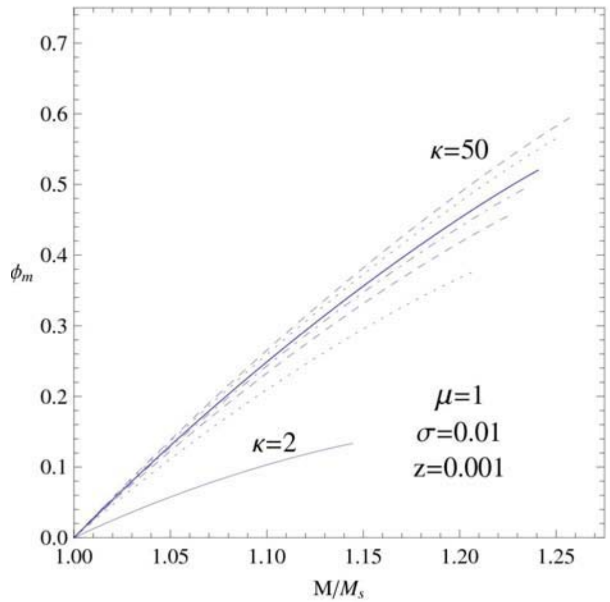
(and M=0.8, $\cos\theta$ *=0.8,* $\Omega^2/\omega_p^2 = 0.02$)

Preliminary results; from: S Sultana, I Kourakis, NS Saini and MA Hellberg, in preparation (2009)

*Preliminary results on **dust-IA solitons** :*

- *Positive-negative soliton shift for low μ (negative dust)*
- *Strong dependence of the soliton amplitude on κ*
- *Negative (weak) and positive (large) pulse co-existence in the presence of negative dust*
- *(The latter feature missed by KdV theory)*

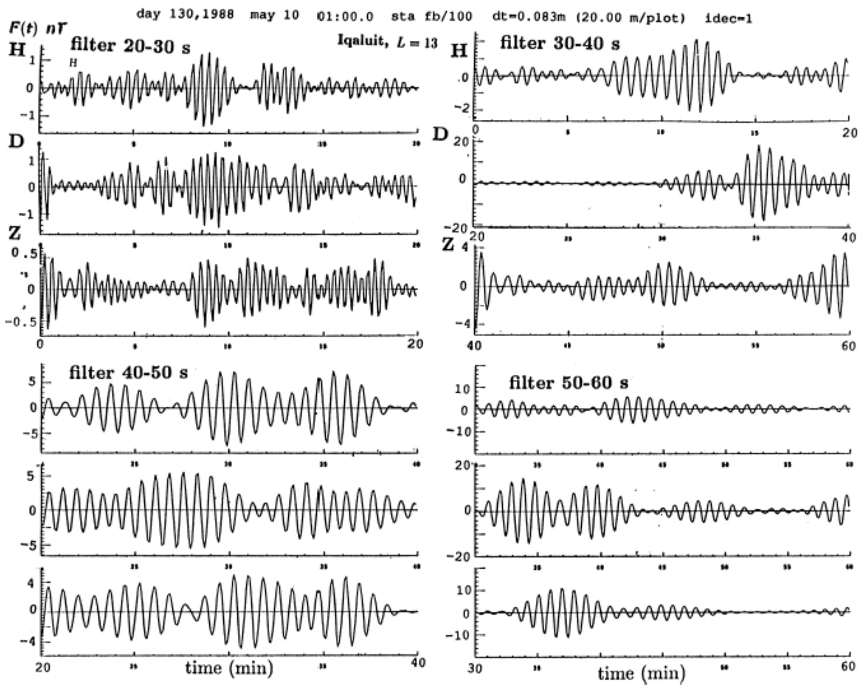




Preliminary results; from: T Baluku, MA Hellberg et al, in preparation (2009); ***see poster by T Baluku***

4. Nonlinear self-modulation of ES wavepackets *

- ***Amplitude modulation*** of ES plasma wavepackets due to carrier self-interaction: generic nonlinear mechanism, involving *harmonic generation, modulational instability, envelope soliton* generation, …



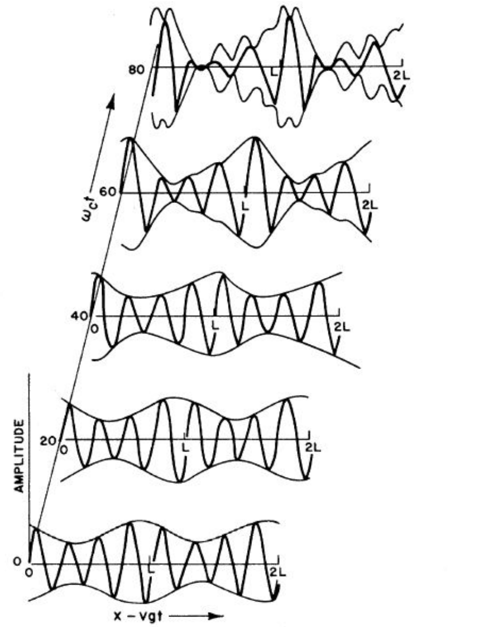


FIG. 1. Variation of wave amplitude A_y and energy $|A|$ with time and space; results of computer experiment.

[sources: Ya. Alpert, Phys. Reports **339**, 323 (2001)]); A Hasegawa PRL **24**, 1165 (1970)]

[* in collaboration with: NS Saini]

Background - literature

- On modulated ES waves: a Maxwellian background was considered for:
  - *Ion-acoustic waves (IAWs)*
    [Kakutani & Sugimoto, PF (1974), Durrani et al., PF (1979)]
  - Multi-ion plasma [Chabra & Sharma, PF (1986)]
  - Electron acoustic waves (EAWs) [Kourakis & Shukla, PRE (2004)]
  - Dusty plasmas: dust-ion-acoustic (DIA) & dust-acoustic (DA) modes
    [Kourakis & Shukla, PoP (2003); JPA (2003); Phys. Scr. (2004); NPG (2005)]

- Recent studies of ES soliton modes in *kappa*-distributed plasmas:
  - DA mode in dusty plasmas [Saini & Kourakis, PoP (2008)]
  - IAWs [Saini *et al*, PoP (2009); Sultana *et al* (in preparation)]
  - DIAWs [T Baluku *et al*, in preparation (2009)]
  - EAWs [Sultana *et al* (in preparation); Danehkar *et al* (in preparation)]

κ–dependent charge balance: expansion near equilibrium

Normalized electron density:

$$\left(1-\frac{\phi}{\kappa-3/2}\right)^{-\kappa+1/2} \cong 1+c_1\,\phi+c_2\,\phi^2+c_3\,\phi^3+\ldots$$

Superthermality traced via the κ–dependent coefficients:

$$c_1=\mu\,\frac{2\kappa-1}{2\kappa-3},\quad c_2=\mu\,\frac{4\kappa^2-1}{2(2\kappa-3)^2},\quad c_3=\mu\,\frac{(4\kappa^2-1)(2\kappa+3)}{6(2\kappa-3)^3}$$

Maxwellian *e-i* plasma limit (infinite κ): $c_n=1/n!\quad (n=1,2,3\ldots)$

The parameter μ measures the dust concentration:

$$\mu=1+s\,\frac{Z_d\,n_d}{Z_i\,n_{i,0}},\quad s=\pm 1$$ (for +/- dust charge sign)

Multiple scales perturbation technique

State variables $S = (n, u, \phi)$ expanded near $S^{(0)} = (1,0,0)$

$$S = S^{(0)} + \sum_{m=1}^{\infty} \varepsilon^m S^{(m)}; \quad m = 1, 2, 3.......$$

Harmonic expansion

$$S^{(m)} = \sum_{l=-m}^{m} S_l^{(m)}(X_m, T_m)\ \exp\left[il(kx - \omega t)\right]$$

Space/time stretching: $X_m = \varepsilon^m x, \qquad T_m = \varepsilon^m t$

Solution obtained to 2nd order (0th, 1st, 2nd harmonics):

$$S \cong \varepsilon\, S_1^{(1)} e^{i(kx-\omega t)} + \varepsilon^2 \left[S_2^{(0)} + S_2^{(2)}\ e^{2i(kx-\omega t)}\right] + O(\varepsilon^3)$$

Linear regime (*l*=*m*=*1*): Dispersion relation

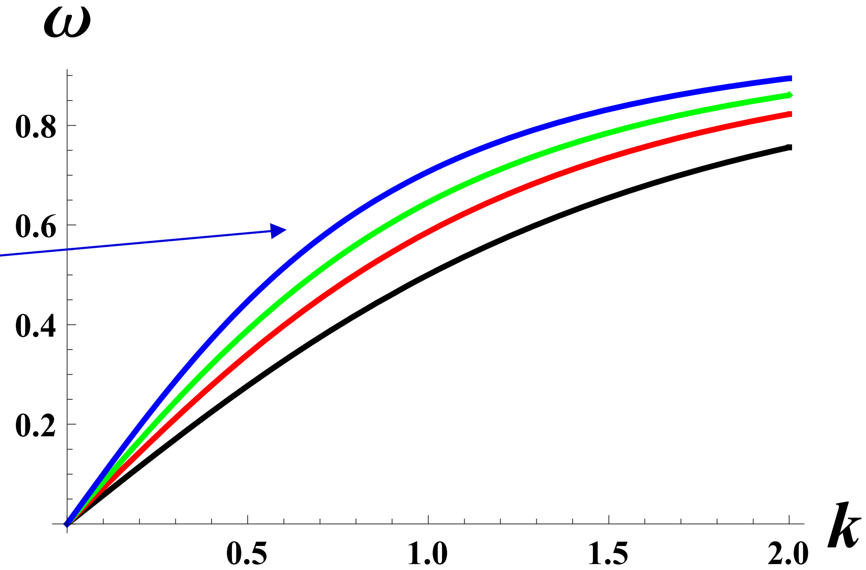
$$n_1^{(1)} = \left(k^2 + c_1\right)\phi_1^{(1)} \qquad u_1^{(1)} = \tfrac{k}{\omega}\,\phi_1^{(1)}$$

$$\omega^2 = \frac{k^2}{k^2 + c_1} \qquad c_1 = \frac{2\kappa - 1}{2\kappa - 3}$$

κ–modified Debye screening

!!! (*) $c_1 = k_D^2 = \lambda_{D,(\kappa)}^{-2} = \omega_{p,i}^2 / c_{s,(\kappa)}^2$

Blue: κ=∞ (Maxwellian)
Green: κ=4
Red: κ=2.6
Black: κ=2



(*) [Perfect agreement with Bryant JPP (1996), Mace & Hellberg (PoP 1995)]

Non-linear Schrödinger Equation (NLSE)

Solution obtained to ~ε^3 :

$$\phi \cong \varepsilon\, \psi\, e^{i(kx-\omega t)} + \varepsilon^2 \left[\phi_2^{(0)} + \phi_2^{(2)} e^{2i(kx-\omega t)}\right] + O(\varepsilon^3), \qquad \psi = \phi_1^1$$

The potential amplitude $\phi_1^{(1)} \equiv \psi(\zeta,\tau)$ satisfies:

$$\boxed{i\frac{\partial \psi}{\partial \tau} + P\frac{\partial^2 \psi}{\partial \zeta^2} + Q\left|\psi\right|^2 \psi = 0}$$

Slow envelope variables: $\zeta = \varepsilon\,(x - v_g t) \qquad \tau = \varepsilon^2 t$

Dispersion coefficient P: $P = -\frac{3c_1}{2}\frac{\omega^5}{k^4} = \frac{\omega''(k)}{2}$

Nonlinearity coefficient Q: $Q = \ldots = Q(k;\kappa;\ldots)$

Modulational (in)stability (MI) analysis

Perturbing around a harmonic amplitude solution, we obtain the *nonlinear (amplitude) dispersion relation*:

$$\hat{\omega}^2 = P\hat{k}^2\left(P\hat{k}^2 - 2Q\left|\hat{\psi}_{1,0}\right|^2\right)$$

P/Q < 0, a plane wave is modulationally stable

P/Q > 0, wavepacket unstable; MI threshold:

$$\hat{k} < k_{cr} \equiv \sqrt{\tfrac{2Q}{P}}\left|\hat{\psi}_{1,0}\right|$$

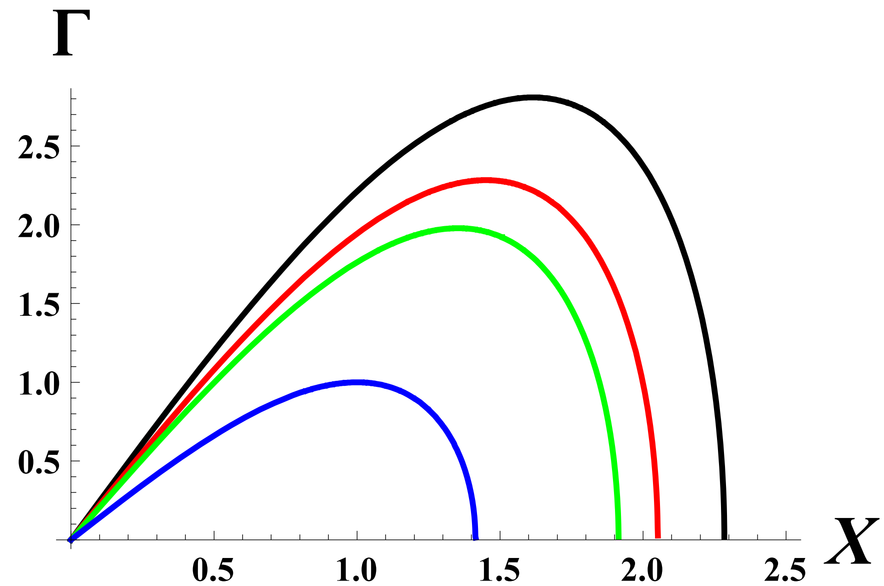
Maximum instability growth rate (κ dependent):

$$\Gamma_{\max} = Q\left|\hat{\psi}_{1,0}\right|^2$$

see next slide

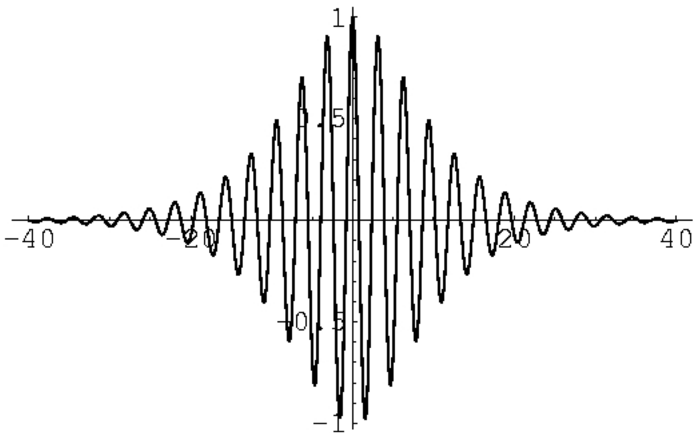
MI growth rate Γ vs perturbation wavenumber X
(normalized)

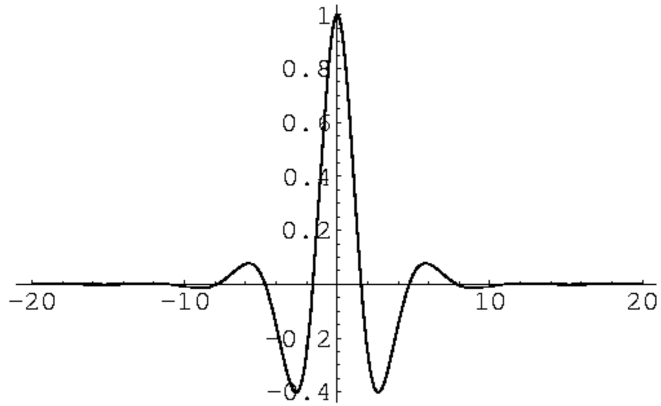
Black: κ=2.5
Red: κ=3
Green: κ=3.5
Blue: κ=∞ (Maxwellian)



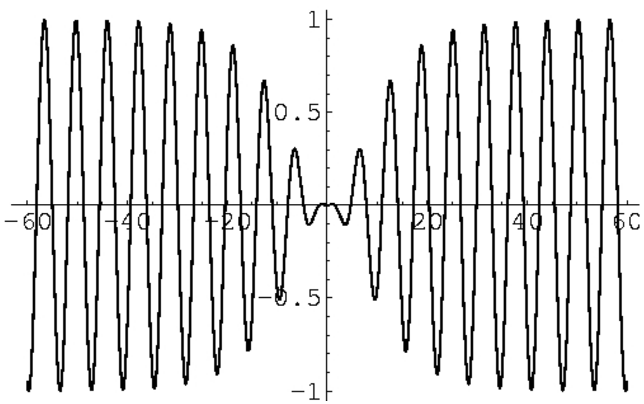
Enhanced instability growth rate due to superthermality !

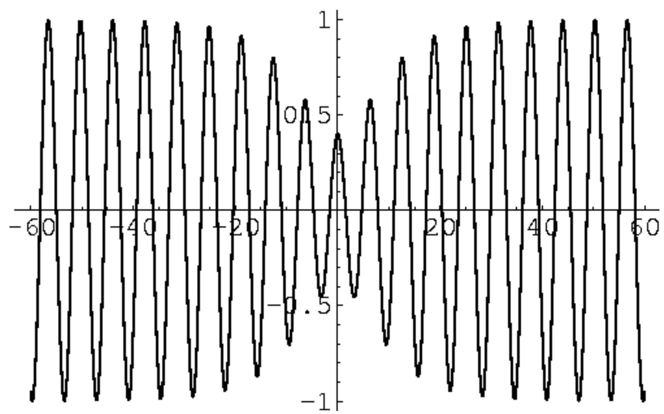
Envelope solitons





Bright-type envelope solitons (for P/Q>0)



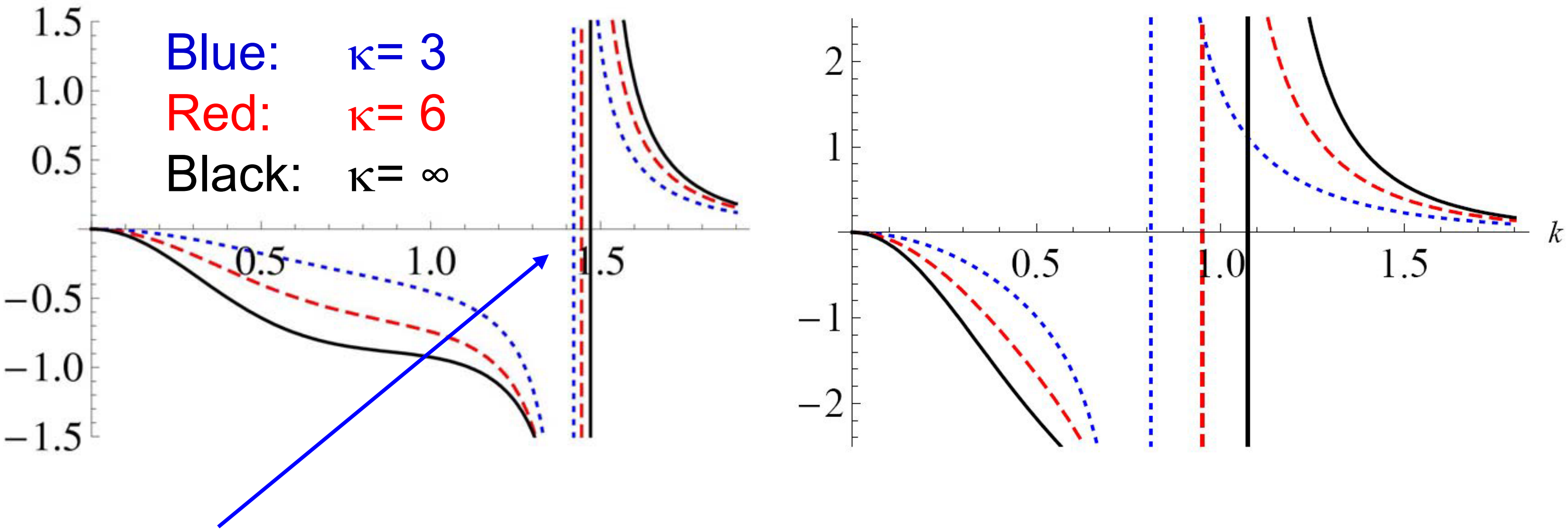


Dark (black/grey) type envelope solitons (for P/Q<0)

Parametric investigation of soliton characteristics 1

$$L\psi_0 = (P/Q)^{1/2}$$

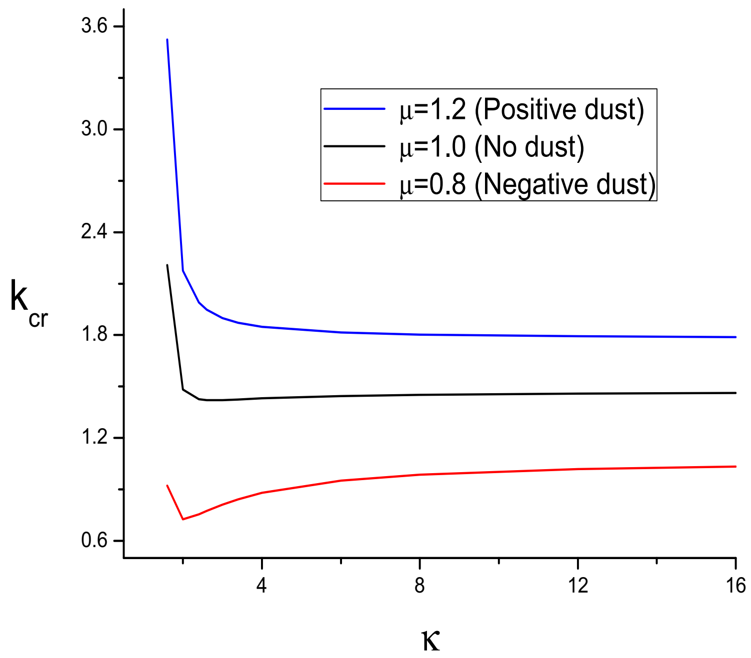
- Superthermality leads to a decrease in envelope width *L* (for given amplitude ψ): *enhanced envelope localization!*
- Lower instability threshold k_{cr} with smaller kappa
- Both effects increased with negative dust (right frame: $\mu = 0.8$)



- *Agreement (k_{cr}= 1.47) with Kakutani & Sugimoto PF,1974 (Maxwellian e-i plasma)*

Parametric investigation of soliton characteristics 2

- Modified instability threshold k_{cr} with kappa *and* with dust
- Modulational instability (MI) occurs at *longer wavelengths, in the presence of negative dust*
- MI less relevant with *positive dust*: stable wavepackets
- Remark: Landau damping omitted (yet less relevant for +d)



5. Electron-acoustic excitations *

EAWs: High frequency electron oscillations ("cool" e fluid)
against a "hot" electron background (+ immobile ions)

[Derfler & Simonen PF 1969; Henry JPP 1972; Thomsen *et al* JGR 1983, Feldman et al JGR 1983]

$$\frac{\partial n}{\partial t} + \frac{\partial (nu)}{\partial x} = 0,$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} = \frac{\partial \phi}{\partial x},$$

$$\frac{\partial^2 \phi}{\partial x^2} = n - (1+\beta) + \beta \left(1 - \frac{\phi}{\kappa_h - \frac{3}{2}}\right)^{-\kappa_h + 1/2}$$

S/thermal *e* density: (density ratio $\beta \equiv \dfrac{n_{h,0}}{n_{c,0}}$)

Scaling: $\dfrac{n_c}{n_{c,0}} \to n, \quad \dfrac{\phi}{k_B T_h/e} \to \phi, \quad \dfrac{u_c}{c_{h,s}} \to u, \quad t\omega_{pc} \to t, \quad \dfrac{x}{\lambda_{D,e}} \to x$

$$\omega_{pc} = (n_{c,0} e^2/\varepsilon_0 m_e)^{1/2} \qquad \lambda_D = (\varepsilon_0 k_B T_h / n_{c,0} e^2)^{1/2} \qquad c_{h,s} = (k_B T_h/m_e)^{1/2}$$

[* in collaboration with: A Danehkar, NS Saini, S Sultana, M Hellberg]

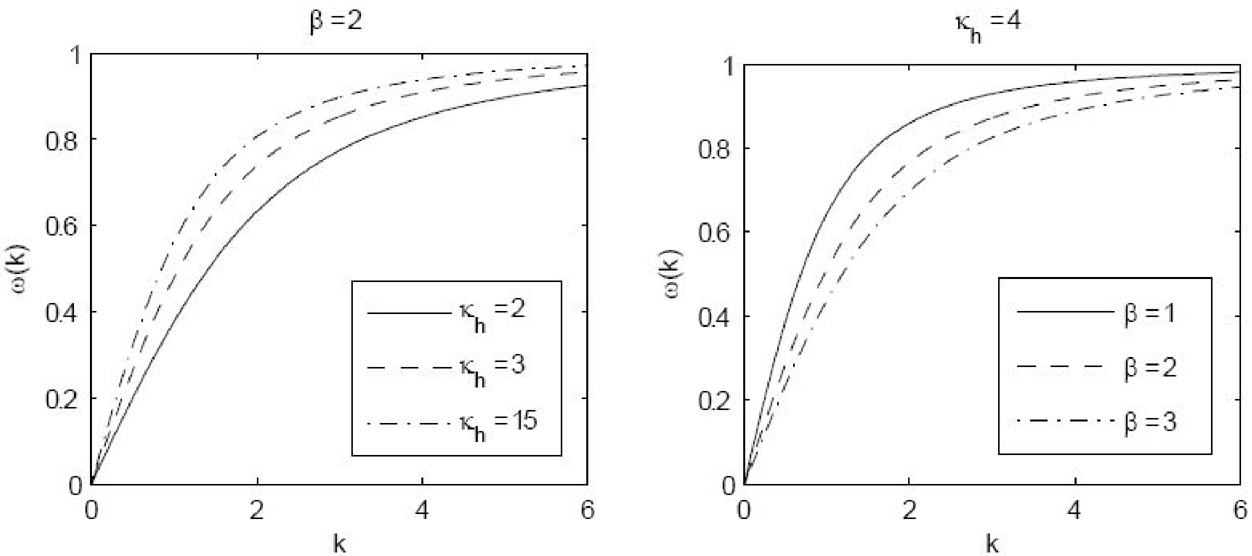
Linear dispersion relation

$$\omega^2 = \frac{k^2}{k^2 + k_D^2} \qquad k_D \equiv \frac{1}{\lambda_D} \equiv \left(\frac{\beta(\kappa_h - \frac{1}{2})}{\kappa_h - \frac{3}{2}} \right)^{1/2}$$

$$\omega^2 = \omega_{pc}^2 \frac{k^2 \lambda_{Dh}^2}{k^2 \lambda_{Dh}^2 + \left(\frac{\kappa_h - \frac{1}{2}}{\kappa_h - \frac{3}{2}} \right)}$$

Rem.: EAWs occur if $0.25 < \beta < 4$ and *T_c/T_h < 0.1*, for $0.2 < k\lambda_{D,c} < 0.8$

[Gary & Tokar PF 1995, Tokar & Gary GRL 1984]



[Agreement with previous works for infinite kappa (Maxwellian *e_h*)]

Small κ effect: larger - yet slightly slower – NL excitations:

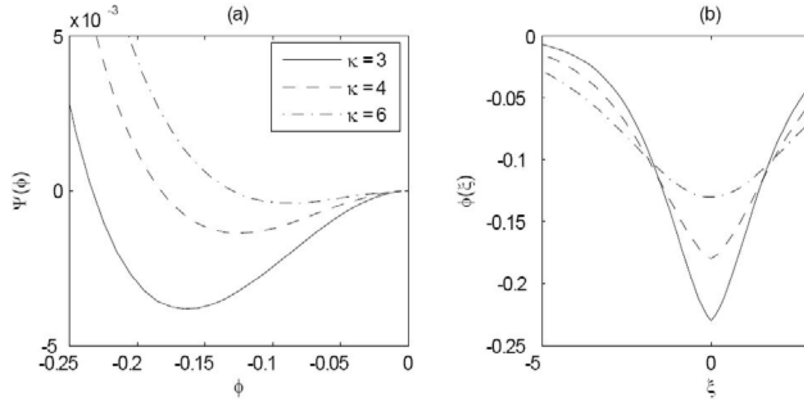


Figure 4: (a) Variation of pseudopotential $\Psi(\phi)$ with ϕ for different κ. (b) Variation of potential ϕ with X for different κ. Curves from bottom to top: $\kappa = 3$ (solid), 4 (dashed), 6 (dot-dashed curve). Here, $\sigma = 0.02$, $\beta = 1.1$, and $M = 1$.

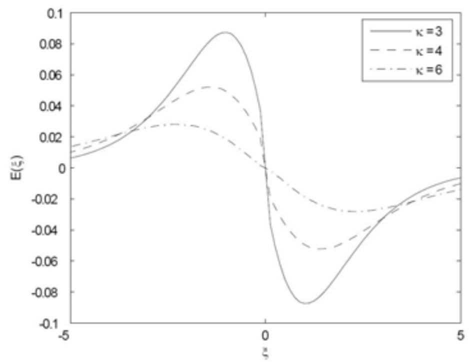


Figure 6: Variation of electric field of the EAWs $E(X)$ with X for different κ. Curves from top to bottom: $\kappa = 3$ (solid), 4 (dashed), 6 (dot-dashed curve). Here, $\sigma = 0.02$, $\beta = 1.1$, and $M = 1$.

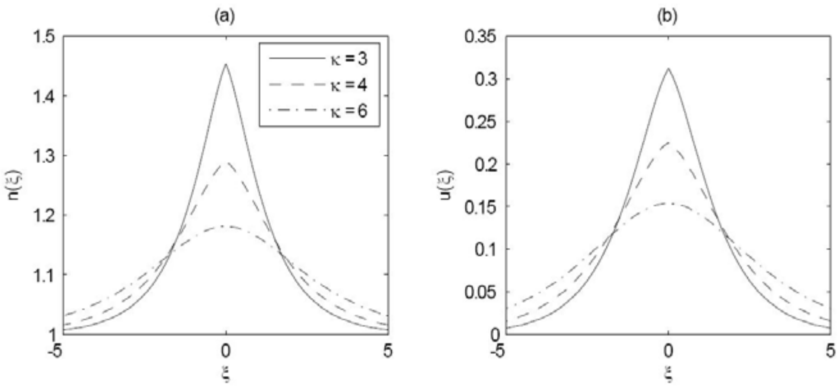


Figure 5: (a) Variation of denisity n with X for different κ. (b) Variation of velocity u with X for different κ. Curves from top to bottom: $\kappa = 3$ (solid), 4 (dashed), 6 (dot-dashed curve). Here, $\sigma = 0.02$, $\beta = 1.1$, and $M = 1$.

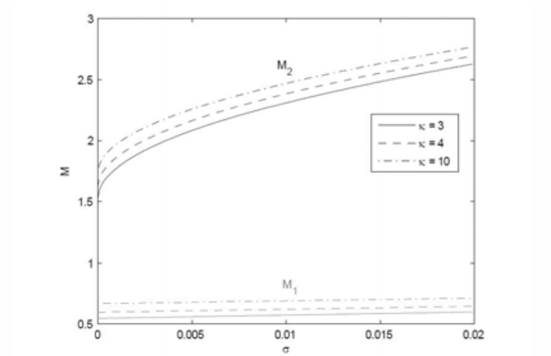


Figure 14: Negative potential soliton existence domain in the parameter space of σ and Mach number M. Solitons may be supported in the region between $M_1(\sigma)$ (gray curve) and $M_2(\sigma)$ (black curve). It shows variation of $M_1(\sigma)$ and $M_2(\sigma)$ with σ. Curves from bottom to top: $\kappa = 3$ (solid), 4 (dashed), 10 (dot-dashed curve). Here, $\beta = 2$.

Ongoing work on κ distributed plasmas:

- Oblique solitons in magnetized superthermal plasmas [S Sultana *et al*]

- Modulated dust-acoustic modes [NS Saini, I Kourakis] and EA modes [S Sultana]
  (see poster)

- Ion-beam – plasma modelling [NS Saini, IK]

- Dust-ion acoustic solitons: Sagdeev *vs* KdV / mKdV theory
  [T Baluku, M Hellberg *et al*] *(see poster)*

- Fundamental aspects of kappa *df* theory
  [M Hellberg, R Mace, T Baluku, NSS, IK]

- Non-Gaussian beam-profile dynamics [A Sharma, IK]

- EA soliton dynamics [A Danehkar, NSS, IK, M Hellberg]

- Interpretation of experimental observations via proton imaging diagnostics
  [G Sarri, M Borghesi, *et al*] *(talk by M Borghesi)*

Conclusions

- Accelerated electrons are present in most plasmas
- Superthermal plasmas are efficiently modelled by a kappa *df*
- Increased superthermality (smaller κ) leads to:
  - A strong modification in the characteristics of ES solitary waves
  - Enhanced modulational instability of wavepackets
  - Stronger localization of energy stored in envelope solitons
- For infinite kappa, the Maxwellian limit is recovered.
- Results to be confirmed by Space observations or/and in experiments (+ M Borghesi, laser-plasma interactions).
- Minus: *Landau damping* neglected (fluid description): to be included.

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Sharmin Sultana, Ashkbiz Danehkar

In collaboration with: Manfred Hellberg & Thomas Baluku (UKZN, Durban, S Africa)

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N S Saini, I Kourakis and MA Hellberg, *Phys. Plasmas* **16** 062903 (2009)
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A Danehkar, NS Saini, I Kourakis and MA Hellberg, in preparation (2009)
A Sharma and I Kourakis, in preparation (2009)

Slides at `www.kourakis.eu`