

Μαθηματική Μοντελοποίηση Μη-Γραμμικών Κυματικών Φαινομένων σε Φυσικά Συστήματα

Εφαρμογές στη Φυσική Πλάσματος, στην Επιστήμη Υλικών,
στην Αστροφυσική κ.α.

Σύντομη παρουσίαση ερευνητικής δραστηριότητας

Ιωάννης Κουράκης

Ruhr Universität Bochum, Theoretische Physik IV
Facultät für Physik und Astronomie
D-44780 Bochum, Γερμανία

Email: ioannis@tp4.rub.de

www.tp4.rub.de/~ioannis/200704-EAP-oral.pdf

Ελληνικό Ανοικτό Πανεπιστήμιο, Πάτρα, 28 Απρ. 2007

1. Εισαγωγή

● 1α. Γενικά

- * **Εμπειρία:** Γαλλία (U. Bourgogne), Βέλγιο (ULB, UGent), Γερμανία (RUB, MPIeP), Ελλάδα (Παν. Κρήτης, Παν. Θεσσαλίας).
- * **Χρηματοδότηση:** Ε.Ε., Max Planck Institut, DFG (Γερμανία), Ομοσπονδία Euratom-Ελληνική Δημοκρατία, ARC (Αυστραλία).
- * **Δημοσιεύσεις:** 52 +3 (+5) άρθρα σε περιοδικά με κριτές (*PRE, PRL, Phys. Plasmas, Phys. Lett. A, Astron. & Astrophys., ...*), 31 συμμετοχές σε συλλογικούς τόμους & πρακτ. Συνεδρίων.
- * **Ερευνητική συνεργασία** με ~18 ερευνητές από 9 χώρες, ~14 co-authors.
- * **Επίβλεψη** ερευνητικής εργασίας μεταπτυχιακών φοιτητών (3), συμμετοχή σε επιτροπές διδακτορικών (2).

1. Εισαγωγή

● 1β. Πεδία ενασχόλησης – σύνοψη

- * **Μη-Γραμμική (ΜΓ) Φυσική & Θεωρία Σολιτονίων.**
ΜΓ PDEs: NLS, KdV, KP, ZK, ΜΓ αστάθειες, dromions, ...
- * **Φυσική Πλάσματος:** ΜΥΔ (MHD) πλάσματος, Ηλεκτροστατικά (ΗΣ)/Ηλεκτρομαγνητικά (ΗΜ) κύματα, κινητική θεωρία πλάσματος (Landau, FPE), **κρυσταλλικά φαινόμενα σε Πλάσμα με Σκόνη** (*Dusty Plasmas, Complex Plasmas*).
- * **Στατιστική Φυσική Εκτός-Ισορροπίας:** Κινητική Θεωρία, φαινόμενα μεταφοράς & διάχυσης, διάδοση κοσμικής ακτινοβολίας στην Αστροφυσική, ...
- * **Θεωρία Υλικών, Μη-Γραμμική Οπτική:** Αριστερόστροφα Υλικά (LHM), NL metamaterials, BECs.

2. Θεματική επιλογή

Θέμα 1^ο: Μη-γραμμικές ΗΣ/ΗΜ διεγέρσεις στο Πλάσμα.

- *Μοντελοποίηση*: Ρευστοδυναμική περιγραφή πλάσματος, πληθώρα φυσικών μηχανισμών:

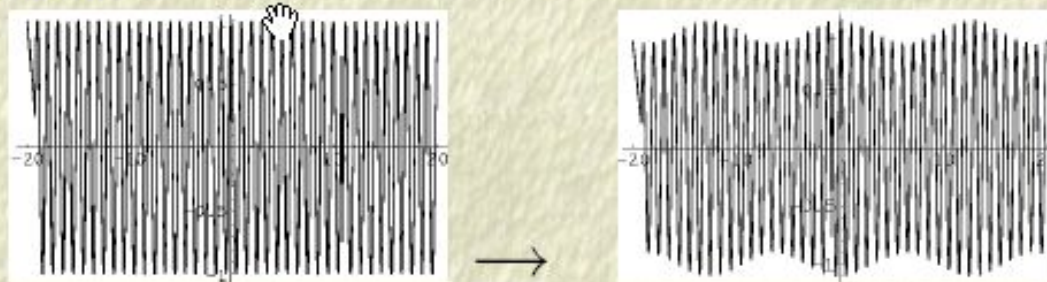
μη-γραμμικότητα + διασπορά → Ευσταθείς σολιτονικές λύσεις !

+ thermal effects, viscosity, απόσβεση, δυναμική φόρτιση, ...

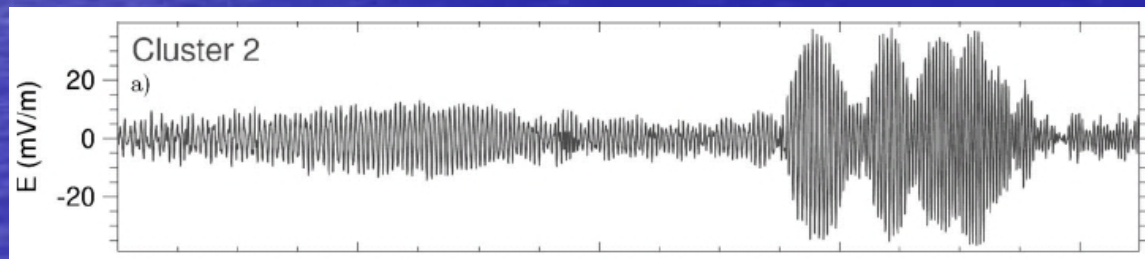
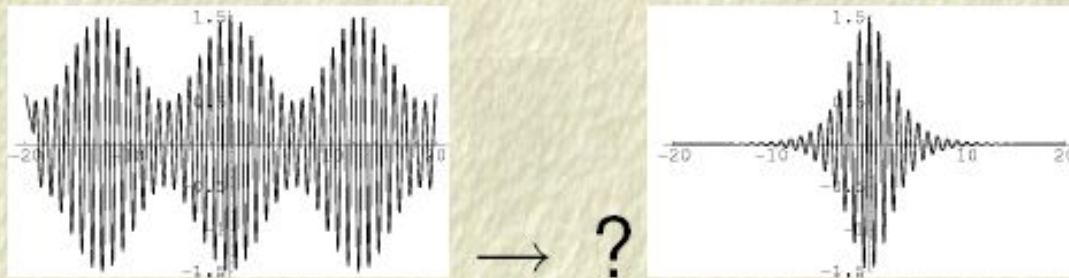
- *Θεωρητικό ενδιαφέρον 1*: Διάδοση εντοπισμένων κυματοπακέτων (envelope solitons), ενεργειακός εντοπισμός (localization), αστάθεια διαμόρφωσης (modulational instability), ...
- *Θεωρητικό ενδιαφέρον 2*: Σύνδεση με το οπλοστάσιο της Μη-γραμμικής Φυσικής - Εξισ. KdV vs. NLS, pseudo-Hamiltonian περιγραφή.
- *Εφαρμογή*: σύγκριση με δορυφορικές παρατηρήσεις (ESA Cluster), πειραματικές παρατηρήσεις.

Διαμόρφωση πλάτους (*amplitude modulation*): Ένας "πανταχού παρών" μη-γραμμικός μηχανισμός

The *amplitude* of a harmonic wave may vary in space and time:



This *modulation* (due to nonlinearity) may be *strong* enough to lead to wave *collapse (modulational instability)* or to the formation of *envelope solitons*:



Ref.
I. Kourakis *et al.*,
Nonlin. Proc. Geophysics
(2005).

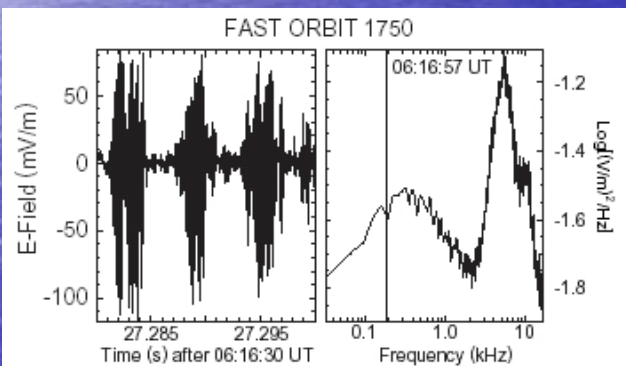
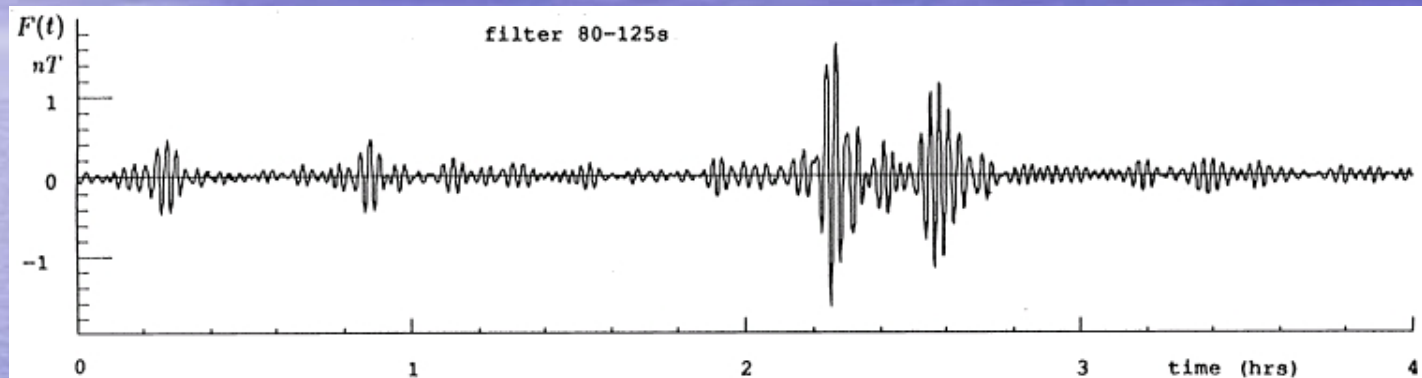
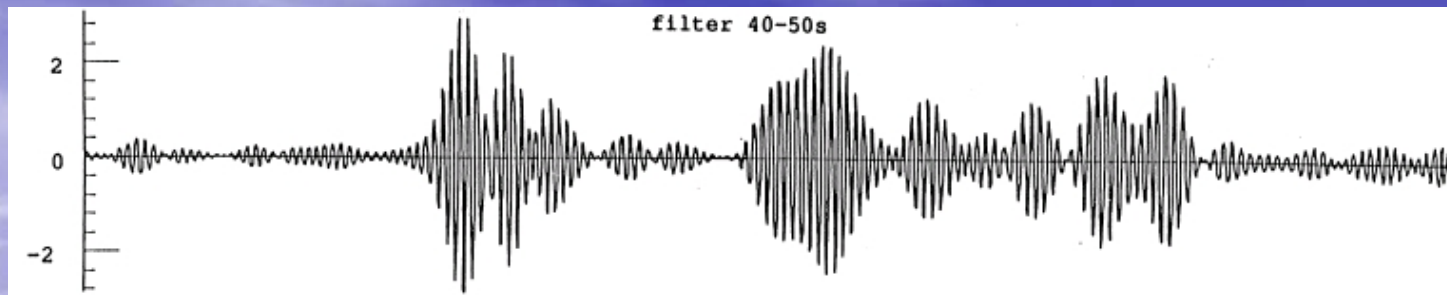


Figure 2. *Left:* Wave form of broadband noise at base of AKR source. The signal consists of highly coherent (nearly monochromatic frequency of trapped wave) wave packets. *Right:* Frequency spectrum of broadband noise showing the electron acoustic wave (at ~ 5 kHz) and total plasma frequency (at ~ 5 kHz) peaks. The broad LF maximum near 300 Hz belongs to the ion acoustic wave spectrum participating in the 3 ms modulation of the electron acoustic waves.

FAST data from:

O. Santoliket *et al*,
J. Geophys. Res. **108**, 1278 (2003);

R. Pottelette *et al*,
Geophys. Res. Lett. **26**, 2629 (1999).

Βήμα 1^ο: Ρευστοδυναμικό μοντέλο πλάσματος

Density n_α (*continuity*) equation:

$$\frac{\partial n_\alpha}{\partial t} + \nabla \cdot (n_\alpha \mathbf{u}_\alpha) = 0$$

Mean velocity \mathbf{u}_α equation:

$$\frac{\partial \mathbf{u}_\alpha}{\partial t} + \mathbf{u}_\alpha \cdot \nabla \mathbf{u}_\alpha = -\frac{q_\alpha}{m_\alpha} \nabla \Phi - \frac{1}{m_\alpha n_\alpha} \nabla p_\alpha$$

Pressure p_α equation:

$$\frac{\partial p_\alpha}{\partial t} + \mathbf{u}_\alpha \cdot \nabla p_\alpha = -\gamma p_\alpha \nabla \cdot \mathbf{u}_\alpha$$

The potential Φ obeys *Poisson's eq.:*

$$\nabla^2 \Phi = -4\pi \sum_{\alpha''=\alpha, \{\alpha'\}} q_{\alpha''} n_{\alpha''} = 4\pi e (n_e - Z_i n_i + \dots)$$

Ref. I. Kourakis *et al.*, *PRE* (2004); *Nonlin. Proc. Geophysics* (2005).

I. Κουράκης, ΕΑΠ, 28.04.2007

www.kourakis.eu

Βήμα 2^ο: Αναγωγική Θεωρία Διαταραχών + ανάπτυγμα κοντά στη Θ.Ι.

– 1st step. Define *multiple scales* (*fast* and *slow*) i.e. (in 2d)

$$X_0 = x, \quad X_1 = \epsilon x, \quad X_2 = \epsilon^2 x, \quad \dots$$

$$Y_0 = y, \quad Y_1 = \epsilon y, \quad Y_2 = \epsilon^2 y, \quad \dots$$

$$T_0 = t, \quad T_1 = \epsilon t, \quad T_2 = \epsilon^2 t, \quad \dots$$



– 2nd step. Expand near equilibrium:

$$n_\alpha \approx n_{\alpha,0} + \epsilon n_{\alpha,1} + \epsilon^2 n_{\alpha,2} + \dots$$

$$\mathbf{u}_\alpha \approx \mathbf{0} + \epsilon \mathbf{u}_{\alpha,1} + \epsilon^2 \mathbf{u}_{\alpha,2} + \dots$$

$$p_\alpha \approx p_{\alpha,0} + \epsilon p_{\alpha,1} + \epsilon^2 p_{\alpha,2} + \dots$$

$$\phi \approx 0 + \epsilon \phi_1 + \epsilon^2 \phi_2 + \dots$$

($p_{\alpha,0} = n_{\alpha,0} k_B T_\alpha$; $\epsilon \ll 1$ is a *smallness parameter*).

Ref. I. Kourakis *et al.*, *Phys. Rev. E* (2004); *Nonlin. Proc. Geophysics* (2005).

I. Κουράκης, ΕΑΠ, 28.04.2007

www.kourakis.eu

Βήμα 3^ο: Προβολή στο χώρο Fourier – γένεση αρμονικών

– 3rd step. Project on Fourier space, i.e. consider $\forall m = 1, 2, \dots$

$$S_m = \sum_{l=-m}^m \hat{S}_l^{(m)} e^{il(\mathbf{k} \cdot \mathbf{r} - \omega t)} = \hat{S}_0^{(m)} + 2 \sum_{l=1}^m \hat{S}_l^{(m)} \cos l(\mathbf{k} \cdot \mathbf{r} - \omega t)$$

for $S_m = (n_m, \{u_{x,m}, u_{y,m}\}, p_m, \phi_m)$, i.e. essentially:

$$n_1 = n_0^{(1)} + \tilde{n}_1^{(1)} \cos \theta, \quad n_2 = n_0^{(2)} + \tilde{n}_1^{(2)} \cos \theta + \tilde{n}_2^{(2)} \cos 2\theta, \text{ etc.}$$

– 4th step. (for multi-dimensional propagation) *Modulation obliqueness*: the slow amplitudes $\hat{\phi}_l^{(m)}$, etc. vary only along the x -axis:

$$\hat{S}_l^{(m)} = \hat{S}_l^{(m)}(X_j, T_j), \quad j = 1, 2, \dots$$

while the fast carrier phase $\theta = \mathbf{k} \cdot \mathbf{r} - \omega t$ is now:

$$k_x x + k_y y - \omega t = k r \cos \alpha - \omega t .$$

Ref. I. Kourakis *et al.*, *Phys. Rev. E* (2004); *Nonlin. Proc. Geophysics* (2005).

--> Αναγωγή στη *Μη-Γραμμική Εξίσωση Schrödinger*

- Compatibility equation (from $m = 3, l = 1$), in the form of:

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

i.e. a *Nonlinear Schrödinger-type Equation (NLSE)* .

- Variables: $\zeta = \epsilon(x - v_g t)$ and $\tau = \epsilon^2 t$;

- *Dispersion coefficient P*:

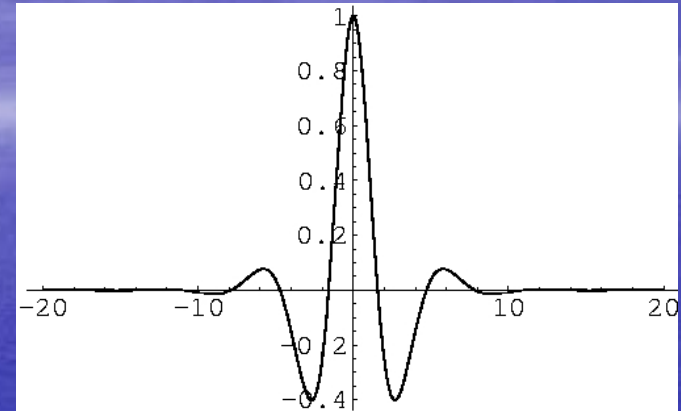
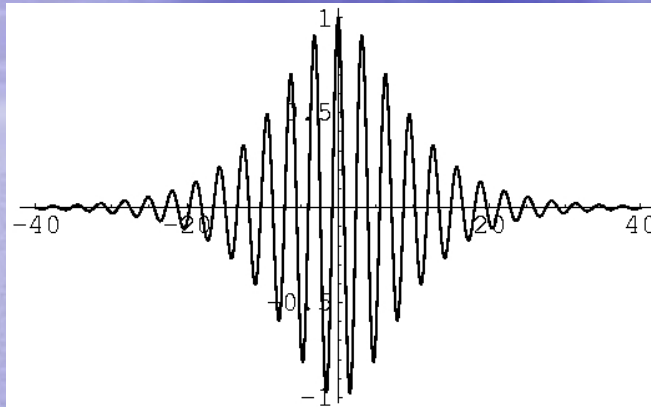
$$P = \frac{1}{2} \frac{\partial^2 \omega}{\partial k_x^2} = \frac{1}{2} \left[\omega''(k) \cos^2 \alpha + \omega'(k) \frac{\sin^2 \alpha}{k} \right];$$

- *Nonlinearity coefficient Q*: ...

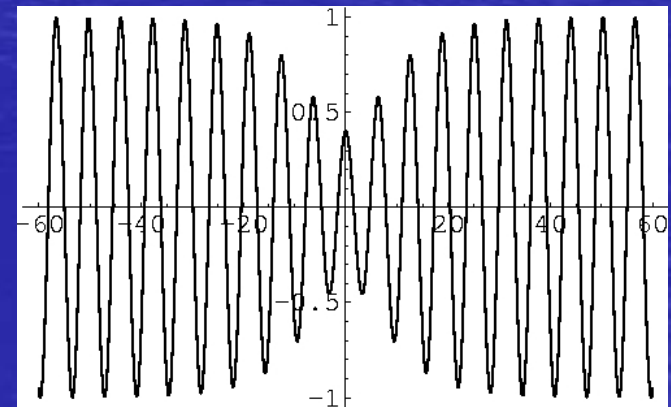
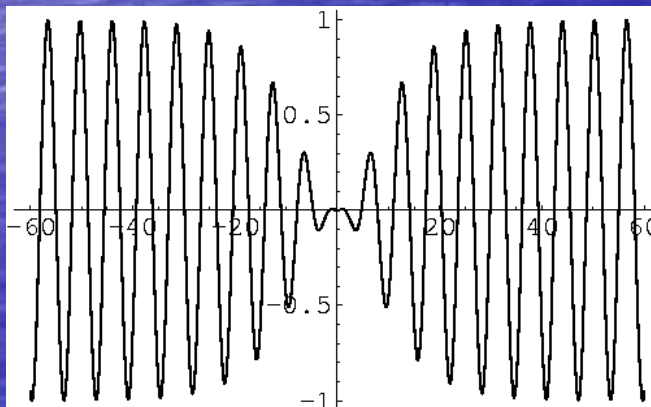
A (*lengthy!*) function of k , **angle α** and $T_e, T_i, \dots \rightarrow$ (*omitted*).

Ref. I. Kourakis *et al.*, *Phys. Rev. E* (2004); *Nonlin. Proc. Geophysics* (2005).

--> For $PQ > 0$: *Modulational Instability*,
may lead to **Bright** Envelope Solitons



--> For $PQ < 0$: *Stable wave packets*,
may propagate as **Dark/Grey** Envelope Solitons



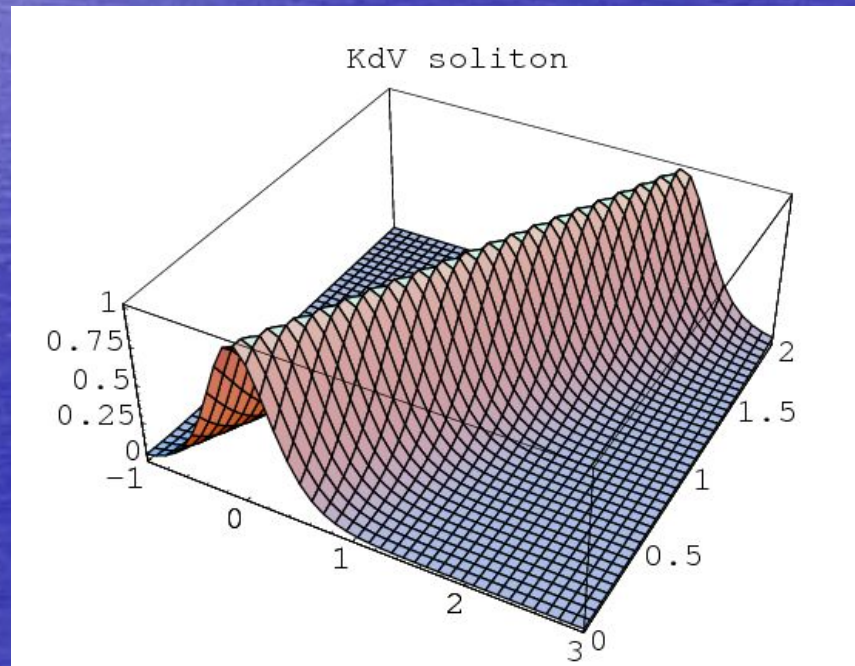
Εναλλακτικό μη-γραμμικό “σενάριο” ρευστού πλάσματος 1:

* Αναγωγική Θεωρία Διαταραχών, μέσω διαφορετικού scaling

>>> *Εξίσωση Korteweg – de Vries (KdV)*

(για διεγέρσεις μικρού πλάτους)

$$\phi_{\tau} + a\phi\phi_{\zeta} + b\phi_{\zeta\zeta\zeta} = 0$$



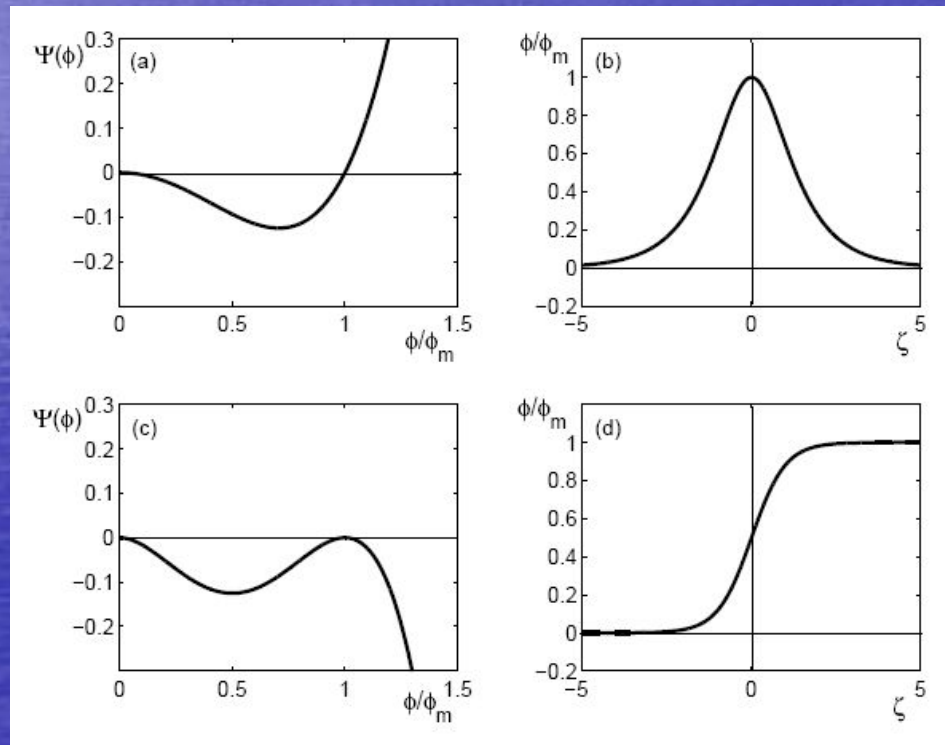
Εναλλακτικό μη-γραμμικό “σενάριο” ρευστού πλάσματος 2:

* *Ansatz* οδεύοντος κύματος:

$$\zeta = x - Mt$$

>>> **Ψευδο-δυναμικό Sagdeev**
(διεγέρσεις μεγάλου πλάτους)

$$\frac{1}{2} \left(\frac{\partial \phi}{\partial \zeta} \right)^2 + V(\phi; M; \{\dots\}) = 0$$



Ref. W. Moslem, I. Kourakis and P. K. Shukla, *Phys. Plasmas* (2007).

I. Κουράκης, ΕΑΠ, 28.04.2007

www.kourakis.eu

Θέμα 2^ο: Μη-γραμμικές διεγέρσεις σε κρυστάλλους Debye.

* *Μοντελοποίηση:*

* 1d, 2d (hexagonal) πλέγματα (πειραματικές παρατηρήσεις).

* Ηλεκτροστατικές αλληλεπιδράσεις + Δυναμικό υποστρώματος

$$H = \sum_n \frac{1}{2} M \left(\frac{d\mathbf{r}_n}{dt} \right)^2 + \sum_{m \neq n} U_{int}(r_{nm}) + \Phi_{ext}(\mathbf{r}_n)$$

● *Θεωρητικό ενδιαφέρον:*
πρότερη γνώση για διεγέρσεις
πλέγματος (*lattice solitons*),

● + extra dusty plasma effects ...

● *Εφαρμογή:*
πειραματικές παρατηρήσεις,
τήξη (melting), σολιτόνια ...

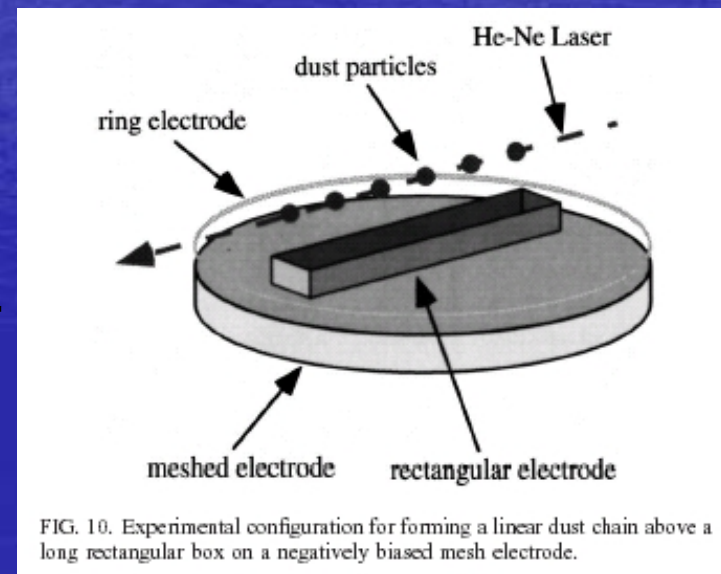


FIG. 10. Experimental configuration for forming a linear dust chain above a long rectangular box on a negatively biased mesh electrode.

From Takamura *et al.*, Phys. Plasmas (2001)

Αναρμονικό δυναμικό υποστρώματος:

(i) *Sheath environment (anharmonic vertical potential):*

$$\Phi(z) \approx \Phi(z_0) + \frac{1}{2}M\omega_g^2(\delta z_n)^2 + \frac{1}{3}M\alpha(\delta z_n)^3 + \frac{1}{4}M\beta(\delta z_n)^4 + \dots$$

cf. experiments [Ivlev *et al.*, PRL **85**, 4060 (2000); Zafiu *et al.*, PRE **63** 066403 (2001)];

$\delta z_n = z_n - z(0)$; α, β, ω_g are defined experimentally

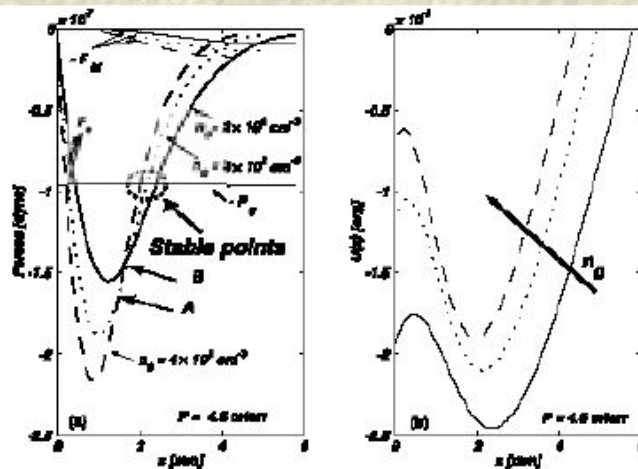


Figure 3: (a) Forces and (b) trapping potential profiles $U(z)$ as function of distance from the electrode for: $n_0 = 2 \times 10^8 \text{ cm}^{-3}$ (solid line), $n_0 = 3 \times 10^8 \text{ cm}^{-3}$ (dashed line), $n_0 = 4 \times 10^8 \text{ cm}^{-3}$ (dotted line). The parameters are: $P = 4.6 \text{ mtorr}$, $T_e = 1 \text{ eV}$, $T_i = T_n = 0.05 \text{ eV}$, $R = 2.5 \mu\text{m}$, $\rho_d = 1.5 \text{ g cm}^{-3}$, $\phi_w = 6 \text{ V}$.

Source: Sorasio *et al.* (2002).

Μη-γραμμικό δυναμικό αλληλεπίδρασης:

(ii) *Interactions* between grains: Electrostatic character (e.g. repulsive, Debye), long-range (yet charge screened: $r_0/\lambda_D \approx 1$), *anharmonic*; typically: $U_{Debye}(r) = \frac{q^2}{r} \exp(-r/\lambda_D)$.

Expanding $U_{int}(r_{nm}) = U_{int}(\sqrt{(\Delta x_{nm})^2 + (\Delta z_{nm})^2})$ near equilibrium:

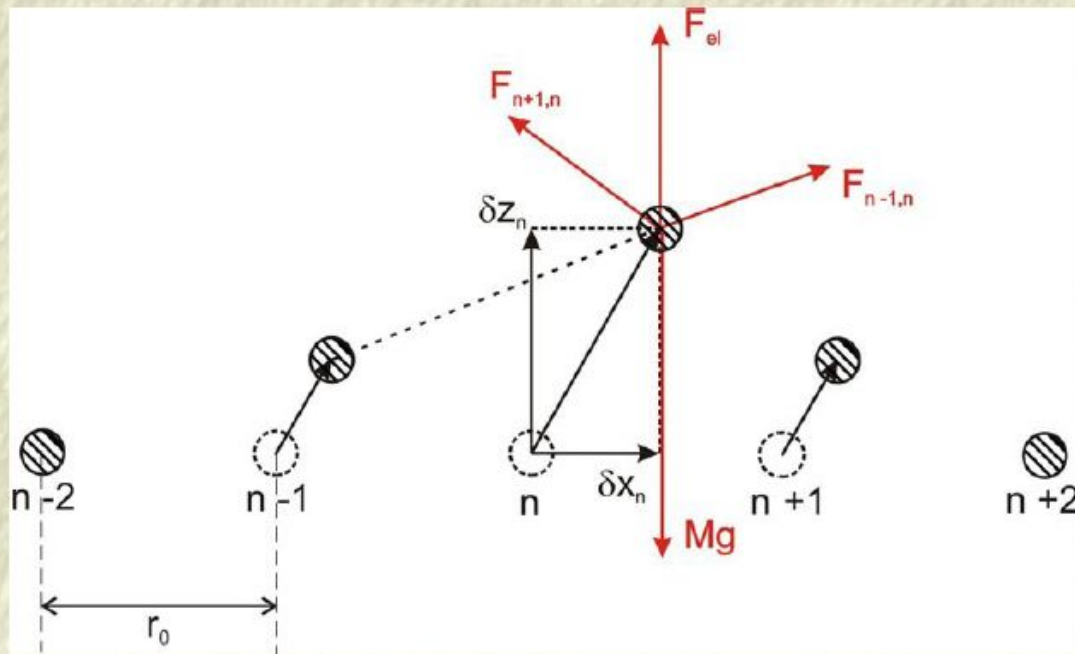
$$\Delta x_{nm} = x_n - x_{n-m} \approx mr_0, \quad \Delta z_{nm} = z_n - z_{n-m} \approx 0,$$

one obtains:

$$\begin{aligned} U_{nm}(r) \approx & \frac{1}{2}M\omega_{L,0}^2(\Delta x_{nm})^2 + \frac{1}{2}M\omega_{T,0}^2(\Delta z_{nm})^2 \\ & + \frac{1}{3}u_{30}(\Delta x_{nm})^3 + \frac{1}{4}u_{40}(\Delta x_{nm})^4 + \dots + \frac{1}{4}u_{04}(\Delta z_{nm})^4 + \\ & + \frac{1}{2}u_{12}(\Delta x_{nm})(\Delta z_{nm})^2 + \frac{1}{4}u_{22}(\Delta x_{nm})^2(\Delta z_{nm})^2 + \dots \end{aligned}$$

Σύζευξη μεταξύ διαφορετικών βαθμών ελευθερίας:

(iii) *Mode coupling* also induces non linearity:
anisotropic motion, *not* confined along one of the main axes
($\sim \hat{x}, \hat{z}$).



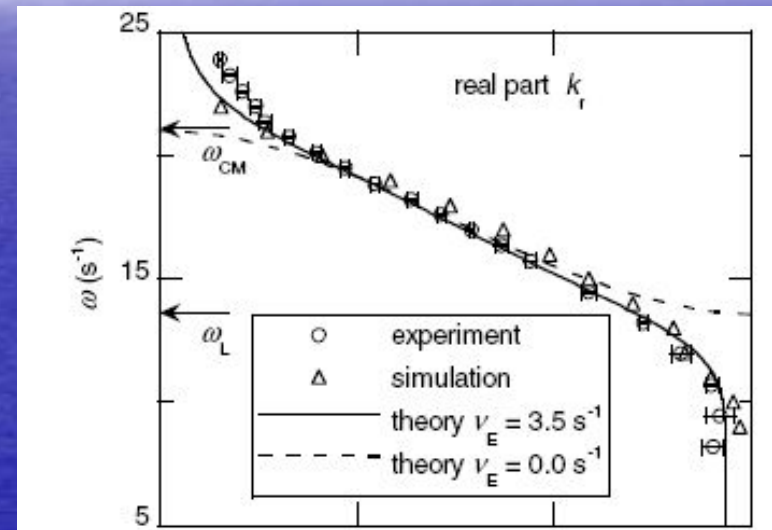
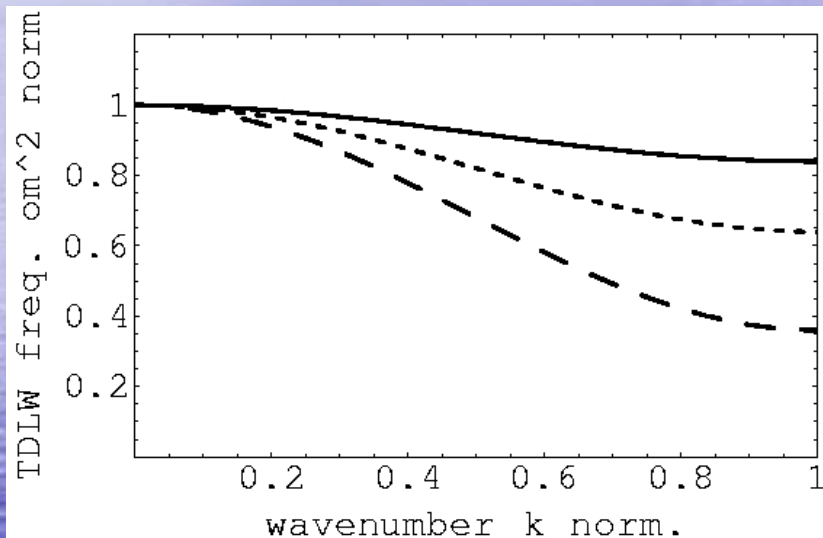
[cf. A. Ivlev *et al.*, PRE **68**, 066402 (2003); I. Kourakis & P. K. Shukla, Phys. Scr. (2004)]

Συζευγμένες εξισώσεις κίνησης:

$$\begin{aligned}
 \frac{d^2(\delta x_n)}{dt^2} + \nu \frac{d(\delta x_n)}{dt} &= \omega_{0,L}^2 (\delta x_{n+1} + \delta x_{n-1} - 2\delta x_n) \\
 &\quad - a_{20} \left[(\delta x_{n+1} - \delta x_n)^2 - (\delta x_n - \delta x_{n-1})^2 \right] \\
 + a_{30} \left[(\delta x_{n+1} - \delta x_n)^3 - (\delta x_n - \delta x_{n-1})^3 \right] &+ a_{02} \left[(\delta z_{n+1} - \delta z_n)^2 - (\delta z_n - \delta z_{n-1})^2 \right] \\
 - a_{12} \left[(\delta x_{n+1} - \delta x_n)(\delta z_{n+1} - \delta z_n)^2 - (\delta x_n - \delta x_{n-1})(\delta z_n - \delta z_{n-1})^2 \right], & \\
 \frac{d^2(\delta z_n)}{dt^2} + \nu \frac{d(\delta z_n)}{dt} &= \omega_{0,T}^2 (2\delta z_n - \delta z_{n+1} - \delta z_{n-1}) - \omega_g^2 \delta z_n \\
 &\quad - K_1 (\delta z_n)^2 - K_2 (\delta z_n)^3 + \frac{a_{02}}{r_0} \left[(\delta z_{n+1} - \delta z_n)^3 - (\delta z_n - \delta z_{n-1})^3 \right] \\
 + 2 a_{02} \left[(\delta x_{n+1} - \delta x_n)(\delta z_{n+1} - \delta z_n) - (\delta x_n - \delta x_{n-1})(\delta z_n - \delta z_{n-1}) \right] & \\
 - a_{12} \left[(\delta x_{n+1} - \delta x_n)^2 (\delta z_{n+1} - \delta z_n) - (\delta x_n - \delta x_{n-1})^2 (\delta z_n - \delta z_{n-1}) \right]. &
 \end{aligned}$$

Transverse (linear) mode: Backward wave behavior

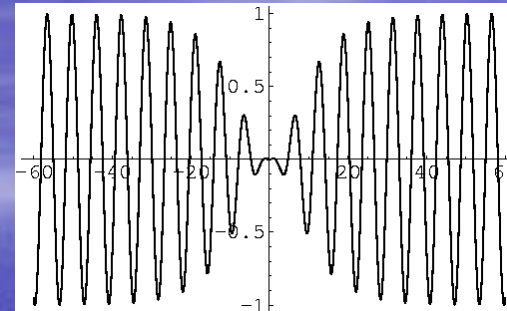
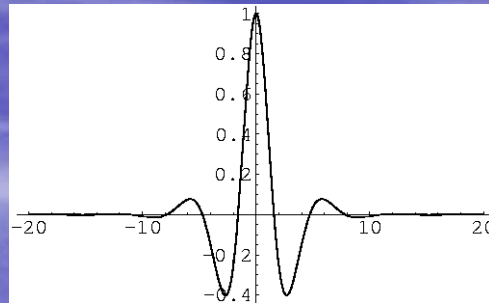
Cf. *Left-handed materials*, LHM (see video)



From: (left) Kourakis *et al*, PoP (2005); (right) Liu *et al*, PRL (2003).

Αποτελέσματα (Transverse/Longitudinal Dust-Lattice excitations):

TDL
envelope solitons:
(NLS theory)
+ DBs



LDL pulse solitons:
(KdV, Boussinesq
models)

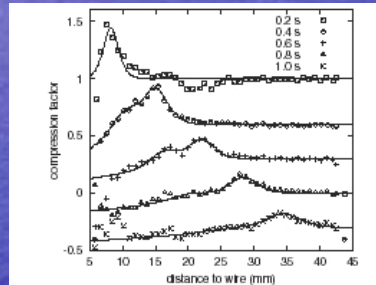


FIG. 3. Compression factor n/n_0 versus distance to the wire at different times. The solid lines show the theoretical fits to the experimental data. Two solitons are present. The fits and experimental points at later times are offset down (by 0.4, 0.7, 1.0, 1.3, respectively).

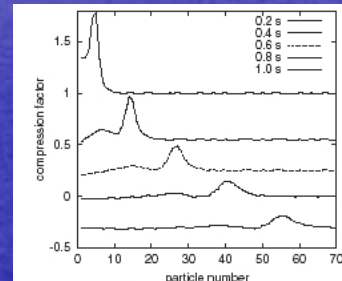
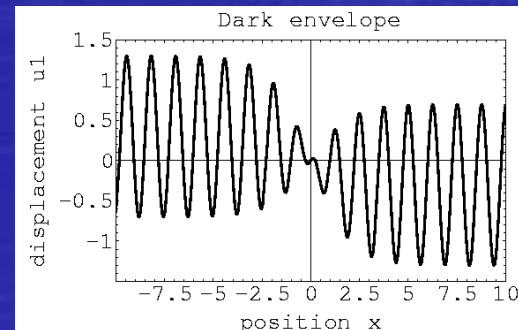
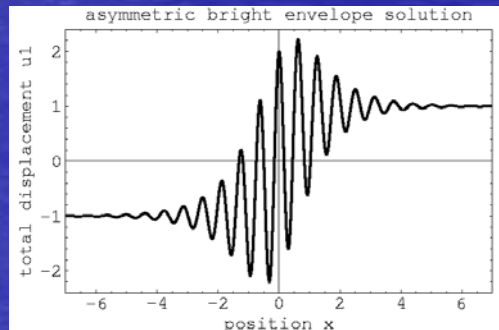


FIG. 5. Compression factor versus particle number for a simulated linear chain model. It describes the formation of two (or more) solitons by a single excitation pulse and qualitatively agrees with the experiment. The curves at later times are offset down (by 0.45, 0.75, 1.0, and 1.3, respectively).

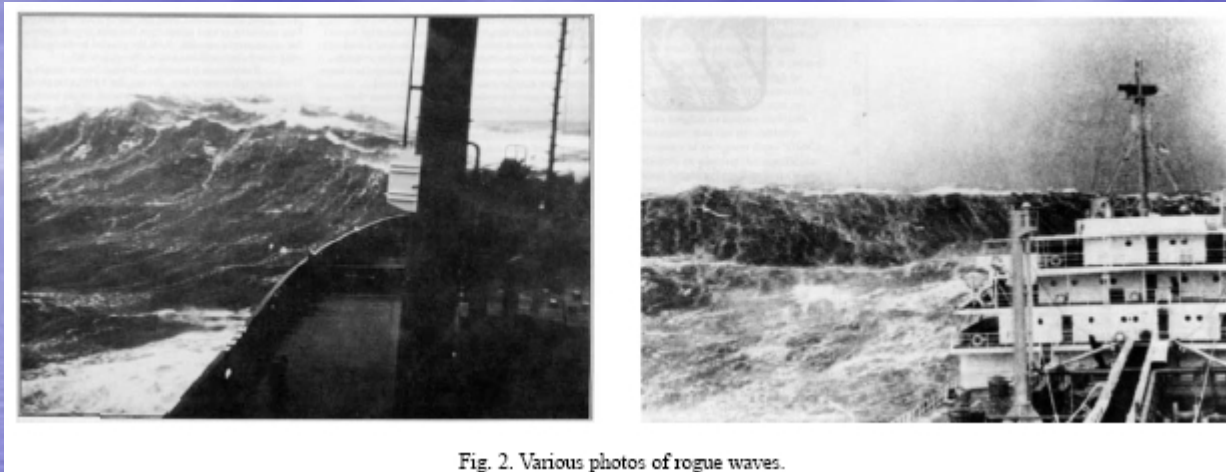
Kourakis & Shukla, PoP (2004);
ibid, EPJB (2004);
Koukouloyannis & Kourakis,
PRE (in press, 2007);

Samsonov *et al*, PRL 2002.

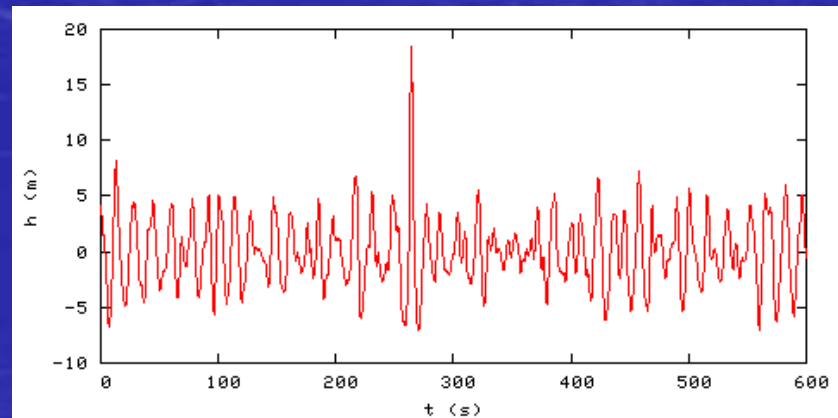
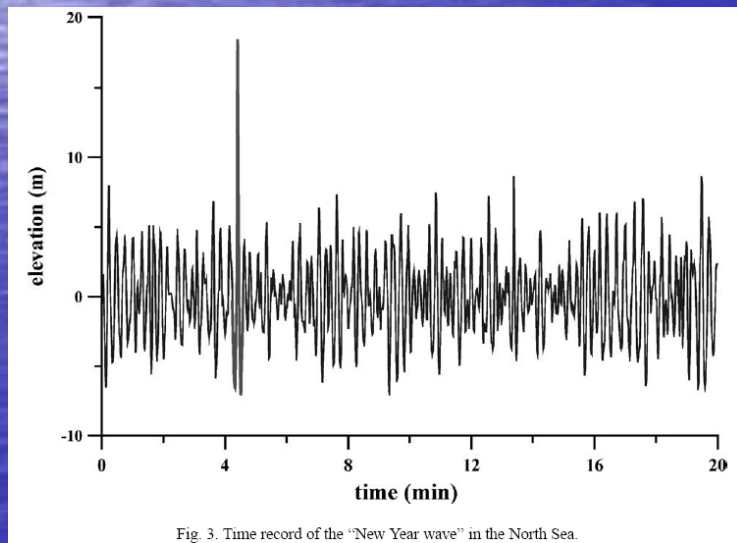
LDL asymmetric
envelope solitons:
(modified NLS)
+ DBs (?)



Θέμα 3^ο: *Rogue Waves* (Freak/Monster Waves).



From:
Kharif & Pelinovsky,
Eur. J. Mechanics B/Fluids (2003)



Instability and Evolution of Nonlinearly Interacting Water Waves

P. K. Shukla,^{1,2} I. Kourakis,² B. Eliasson,² M. Marklund,¹ and L. Stenflo¹

¹Centre for Nonlinear Physics, Department of Physics, Umeå University, SE-90187 Umeå, Sweden

²Institut für Theoretische Physik IV and Centre for Plasma Science and Astrophysics, Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, D-44780 Bochum, Germany

(Received 16 February 2006; published 30 August 2006)

$$i\left(\frac{\partial A}{\partial t} + C_x \frac{\partial A}{\partial x} + C_y \frac{\partial A}{\partial y}\right) + \alpha \frac{\partial^2 A}{\partial x^2} + \beta \frac{\partial^2 A}{\partial y^2} + \gamma \frac{\partial^2 A}{\partial x \partial y} - \xi |A|^2 A - 2\zeta |B|^2 A = 0, \quad (1a)$$

and

$$i\left(\frac{\partial B}{\partial t} + C_x \frac{\partial B}{\partial x} - C_y \frac{\partial B}{\partial y}\right) + \alpha \frac{\partial^2 B}{\partial x^2} + \beta \frac{\partial^2 B}{\partial y^2} - \gamma \frac{\partial^2 B}{\partial x \partial y} - \xi |B|^2 B - 2\zeta |A|^2 B = 0, \quad (1b)$$

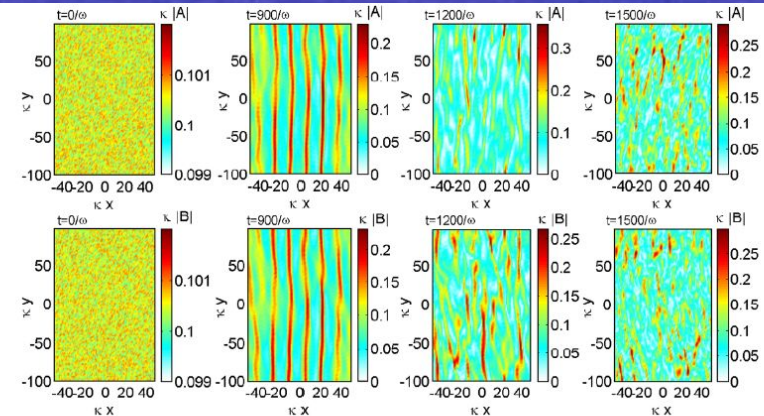


FIG. 4 (color online). The interaction between two waves, initially with equal amplitudes $|A| = |B| = 0.1\kappa^{-1}$ and a propagation angle of $\theta = \pi/8$ relative to the dichotome. Added to the initially homogeneous wave envelopes is a low-amplitude noise of order $10^{-3}/\kappa$ to give a seed to the modulational instability.

Cf. Onorato et al., PRL (2006)

New theory (and old equations) may explain causes ship-sinking freak waves



A freak wave approached this oil fr Languedoc, near Durban, South Af masts are about 82 feet above sea which broke over the deck, causesc Photo credit: Philippe Lijour.

Physical Review
Focus

Phys. Rev. Lett. 97, 084501
(issue of 1 September 2006)
Title and Authors

Waves of Destruction

The movie *Poseidon* features a giant wave that comes out of nowhere to flip a star-packed ocean liner. Such freakishly tall waves in the middle of the ocean are no longer considered fictional, thanks in part to recent satellite observations and computer simulations. In the 1 September PRL, a team describes a new simulation where two wave trains meet at an angle. They observed so-called rogue waves appearing more rapidly and looking more realistic than in other simulations. Researchers in the field hope that better understanding of the causes of such waves will

For further information, please contact:

Please register to view contact details



10 August 2006 Small waves can produce monster waves

Normal waves can unexpectedly turn into waves the size of a ten-story building. What's more, these monster waves arise many times more rapidly than was previously thought. This has been shown by researchers at Umeå University in Sweden.

It is generally known among seafarers that in normal waves you can suddenly stand eye to eye with 25- to 30-meter waves, so-called monster waves. Unlike a tsunami, which is formed by powerful earthquakes at the bottom of the sea, monster waves arise out to sea among regular waves caused by winds. These monster waves are believed to have caused many shipwrecks through the years, and it is well known that oil platforms, like those off the Norwegian coast, are occasionally shaken by these waves.

Now, under the direction of Padma Shukla, scientists Bengt Eliasson, Mattias Marklund, and Lennart Stenflo of Umeå University and Ioannis Kourakis of Ruhr-Universität Bochum, Germany, have shown that normal random small waves, from gusts of wind, for instance, can suddenly give rise to monster waves. If the conditions are right, these monster waves grow by 'borrowing' energy from surrounding waves, a so-called non-linear effect, and these scientists have now managed to use computer simulations and other methods to produce images of how these waves are created. The results achieved by the Umeå researchers also show that such waves grow to enormous proportions many times more quickly than was previously believed.

Наука и технологии

Гигантские океанские волны описываются уравнением Шредингера



Торговое судно в Бискайском заливе столкнулось с гигантской волной. Фото: National Oceanic and Atmospheric Administration

Антон Образцов

18.09.06

Исследователи обнаружили, что гигантские океанические волны подчиняются уравнению Шредингера – основному уравнению квантовой физики. Гигантские волны – нелинейные одиночные волны, иногда возникающие в океане и служащие причиной гибели судов. Высота таких волн может достигать 60 метров.

Этот неожиданный результат, свидетельствующий об удивительном единстве явлений природы на самых разных уровнях, получила группа ученых из Университета Умеа (Umea University) в Швеции и Рурского университета в Бохуме (Ruhr-Universität Bochum) в Германии. Гигантские океанические волны подчиняются уравнению Шредингера – основному уравнению квантовой физики, описывающему поведение электрона и других квантовомеханических объектов.

Теоретическое исследование шведских и немецких ученых показывает, что гигантские волны возникают в некоторых условиях при суперпозиции обычных волн, накладывающихся друг на друга под определенным небольшим углом. При этом происходит нелинейный рост амплитуды, подобно росту амплитуды колебаний при резонансе.

Wie entsteht eine "Monsterwelle"?

Berichte über haushohe, so genannte Monsterwellen oder "freak waves" sind kein "Seemannsgarn". Spätestens seit der Begegnung des Kreuzfahrtschiffs Queen Mary 2 im Jahre 1995 mit einer solchen Monsterwelle weiß man um deren Existenz. Wie sie entstehen, haben Physiker der Ruhr-Universität Bochum und der Universität Umeå in Schweden nun erstmals analysiert und simuliert.



Das Ergebnis ihrer Berechnungen: Treffen zwei Wellen in einem bestimmten, relativ kleinen Winkel aufeinander, können sie sich gegenseitig "aufschaukeln" und die normalen, stabilisierenden physikalischen Effekte des Wassers außer Kraft setzen. Im Falle dieses nicht-linearen Verhaltens von Wellen entsteht eine neue Instabilität. Begünstigt durch starke Strömung und - entgegen gesetzten - starken Wind kann sich daraus die gigantische Welle

kontinuierlich aufbauen. Darüber berichteten die Forscher vor kurzem in der Zeitschrift "Physical Review Letters".

Neues Zwei-Wellen-Modell

Grundlage der Berechnung sind die so genannten Schrödinger-Gleichungen aus der Quantenmechanik, die eigentlich dazu dienen, das wellenartige Verhalten von Elektronen in Atomen zu beschreiben. Die Bochumer Physiker Prof. Padma Kant Shukla, Dr. Ioannis Kourakis und Dr. Bengt Eliasson und ihre schwedischen Kollegen Prof. Mattias Marklund und Prof. Lennart Stenflo wendeten diese Gleichungen auf das Verhalten von Wasser an, dadurch konnten sie eine neue Theorie über ein "Zwei-Wellen-System" entwickeln. Prof. Shukla: "Zwei nicht-lineare, miteinander wechselwirkende Wellen verhalten sich demnach ganz anders als eine einzelne Welle, die normale Instabilitäten zeigt und sich in mehrere kleine Wellen auflöst, die dann linear zueinander verlaufen."

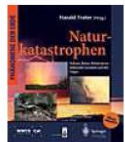
Aus zwei nicht-linearen Wellen resultiere indes ein "neues Verhalten" des Wassers, zum Beispiel die Entstehung regelrechter "Wellenpakete" mit dreimal höheren Amplituden als



Das Internetmagazin für

Geo- / Naturwissenschaften

Klicken Sie hier, wenn Sie mehr zu diesem und anderen spannenden Themen rund um unseren Planeten wissen wollen. ...Weiter!



Naturkatastrophen

Gefahrlos Katastrophen simulieren mit eindrucksvollem Lerneffekt! Von Vulkanausbrüchen

