



NON-LINEAR PHYSICS AT CFP

Valeriy Brazhnyy

NONLINEAR PART OF CONDENSED MATTER GROUP

Post-Doc

Student



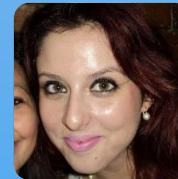
Augusto
Rodrigues



Valeriy
Brazhnyy



Jisha
Chandroth
Pannian



Bruna
Gabrielly
Moraes

AND COLLABORATORS:

Mario Salerno (Italy)
Panos Kevrekidis (USA)
Fatkhulla Abdullaev (Uzbekistan)
Boris Malomed (Israel)

Jesus Cuevas (Spain)
Victor Pérez García (Spain)
Majid Taki (France)
Egor Alfimov (Russia)



ORGANIZATION OF CONFERENCES

2010 Edition

2013 Edition

First Porto Meeting on Theory and Experiment in Nonlinear Physics

7-9 of July 2010, Porto, Portugal

The goal of this meeting is to survey recent advances on a wide range of topics of current interest in nonlinear physics and mathematics including wide range of applications such as nonlinear optics, Bose-Einstein condensates, Biology, etc. The meeting will provide a forum for theoreticians and experimentalists to present and discuss their latest results. We would like to stimulate knowledge exchange, and to identify new marginal problems. We also hope that this meeting will be an excellent opportunity for young researchers to present their recent results and establish new collaborations with different groups in Portugal and abroad.



- Physics of Bose-Einstein condensation
- Solitons and wave interactions in optics
- Nonlinear optics and optical diagnostics of nanostructures
- Nonlinear hydrodynamics and fluid dynamics
- Nonlinear phenomenon in biological and social systems
- Mathematical models for nonlinear dynamical systems
- Other related topics

Invited speakers:

Mario Salerno (University of Salerno, Italy)
Bose-Einstein condensates in deep optical lattices subjected to strong nonlinearity management

Majid Taki (University of Lille, France)
Observation of extreme temporal events in a photonic crystal fiber: Optical Rogue Waves

Victor M. Pérez García (IMACI, Spain)
Modelling cancer using differential equations: A physical and mathematical trip into medical problems

Leonor Cruzeiro (University of Algarve, Portugal)
The VES hypothesis and protein function

Fatkhulla Abdullaev (Physical-Technical Institute, Uzbekistan)
Dissipative periodic waves, solitons and breathers of the nonlinear Schrödinger equation with complex potentials



Local organizing committee:

Valeriy Brazhnyy (brazhnyy@gmail.com)
Augusto Rodrigues (asrodrig@fc.up.pt)

Registration deadline: 15 of May 2010

Sponsors



FCT Fundação para a Ciência e a Tecnologia
SECRETARIA DE CIÊNCIA, TECNOLOGIA E INOVAÇÃO

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Centro de Física do Porto
Departamento de Física e Astronomia da FCUP
Rua do Campo Alegre, 687
4169-007 Porto
Portugal

<http://faraday.fc.up.pt/cfp/mtenp2010/>

II Porto Meeting on Theory and Experiment in Nonlinear Physics

20-22 June 2013
Porto, Portugal

The goal of this meeting is to survey recent advances in a wide range of topics of current interest in nonlinear physics and mathematics including applications such as nonlinear optics, Bose-Einstein condensates, etc. The meeting will provide a forum for theoreticians and experimentalists to present and discuss their latest results. We would like to stimulate knowledge exchange, and to identify new and interesting problems. We also hope that this meeting will be an excellent opportunity for young researchers to present their recent results and establish new collaborations with different groups in Portugal and abroad.

Topics

Solitons and wave interactions	Continuous and discrete systems	Nonlinear optics
Existence and stability of solitary waves	Exciton - Polariton condensates	Light propagation in optical fibers
Long-range interactions	Mathematical models for nonlinear dynamics	Bose-Einstein condensates

Registration deadline is 1 of May 2013

<http://faraday.fc.up.pt/cfp/mtenp2013/>

Organizing committee

Valeriy Brazhnyy (brazhnyy@gmail.com)
Augusto Rodrigues (asrodrig@fc.up.pt)

Local Organizing committee

Jisha Chandroth Pannian
Florbelá Martins

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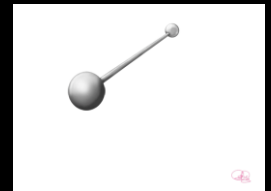
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WHAT IS NON-LINEAR PHYSICS?

- Almost all real systems are non-linear
- For a nonlinear system the **superposition principle** breaks down:
 - the response of the system is not proportional to the input it received (for example, *pendulum* problem)
 - the sum of two solution is not a solution any more



AREAS OF NON-LINEAR PHYSICS

- Nonlinear phenomena are important in many fields of physics:
 - dynamical systems,
 - fluid dynamics,
 - materials science,
 - statistical physics
 - particle physics,
 - astrophysics, etc

But also in chemistry, biology, economy, and social science

RESEARCH INTERESTS

Actual research areas include theoretical and computational investigation of nonlinear phenomena in

- 1) **Condensed atomic gases** (the theory of Bose-Einstein condensates)
 - dynamics of matter waves;
 - pattern formations in dissipative nonlinear systems;
 - effects of the inhomogeneity and nonlocality;
 - dynamics of discrete systems
- 2) **Nonlinear optics** (light propagation in nonlinear media)

Mathematical questions such as **existence of solutions**, their **stability**, and **dynamical evolution**.

THE PROBLEMS WE ARE DEALING WITH

**Nonlinear
systems**

Continuous

Discrete

Matter Waves
Light propagation

1D, 2D, 3D
Solitons/vortices

Theory
Experiment



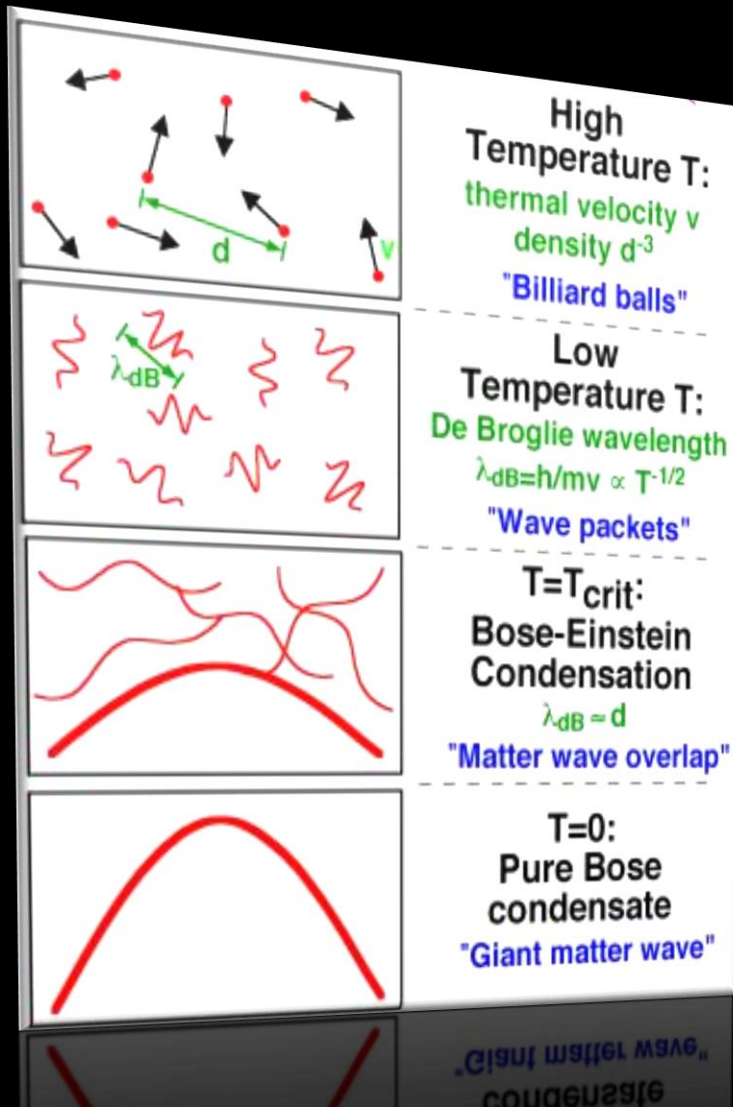
ONE EXAMPLE

BEC

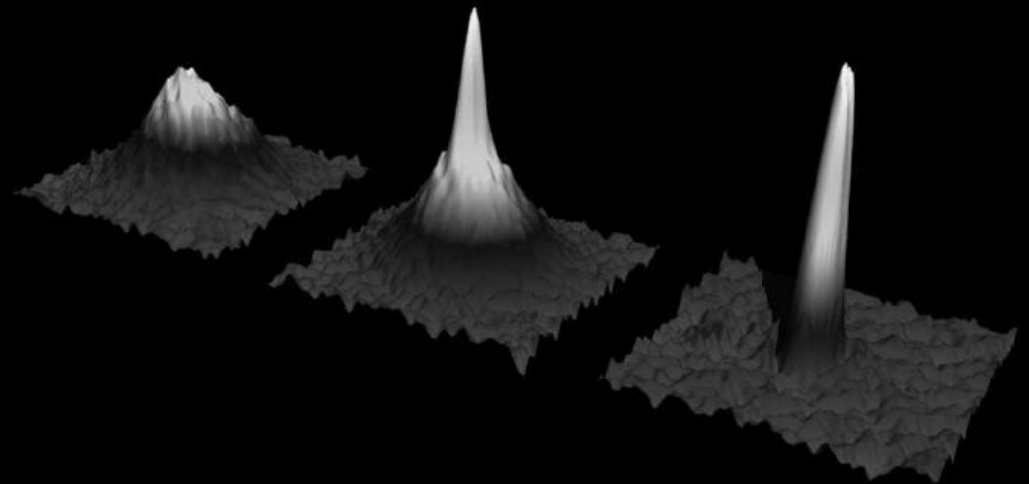
Bose – Einstein condensate

Bose-Einstein condensate

APPLICATIONS



- 1924** Theoretical Prediction
- 1995** Experimental realization
- 2001** Nobel prize



BEC THEORETICAL MODEL

The many-body Hamiltonian

$$\hat{H} = \int d\mathbf{r} \hat{\Psi}^\dagger(\mathbf{r}, t) \hat{H}_0 \hat{\Psi}(\mathbf{r}, t)$$

$$+ \frac{1}{2} \int d\mathbf{r} d\mathbf{r}' \hat{\Psi}^\dagger(\mathbf{r}, t) \hat{\Psi}^\dagger(\mathbf{r}', t) V(\mathbf{r} - \mathbf{r}') \hat{\Psi}(\mathbf{r}', t) \hat{\Psi}(\mathbf{r}, t)$$

$$\hat{\Psi}(\mathbf{r}, t)$$

field operator

$$\hat{H}_0 = -(\hbar^2 / 2m) \nabla^2 + V_{\text{ext}}(\mathbf{r})$$

the “single-particle” operator

$$V(\mathbf{r} - \mathbf{r}')$$

two-body
interatomic potential

GROSS-PITAEVSKI EQUATION (GP)

Bogoliubov approximation, 1947

$$\hat{\Psi}(\mathbf{r}, t) = \Psi(\mathbf{r}, t) + \hat{\Psi}'(\mathbf{r}, t)$$

macroscopic
wavefunction

non-condensate
part

$$V(\mathbf{r}' - \mathbf{r}) = g\delta(\mathbf{r}' - \mathbf{r})$$

effective local interaction potential
 $g > 0$ (repulsion), $g < 0$ (attraction)

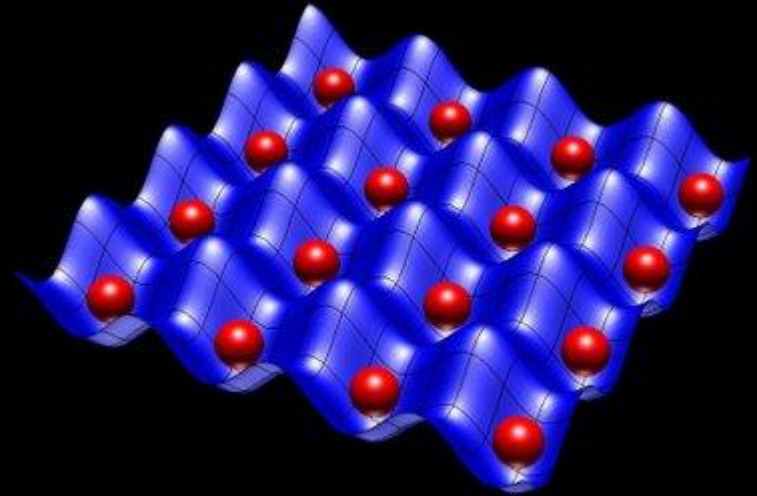
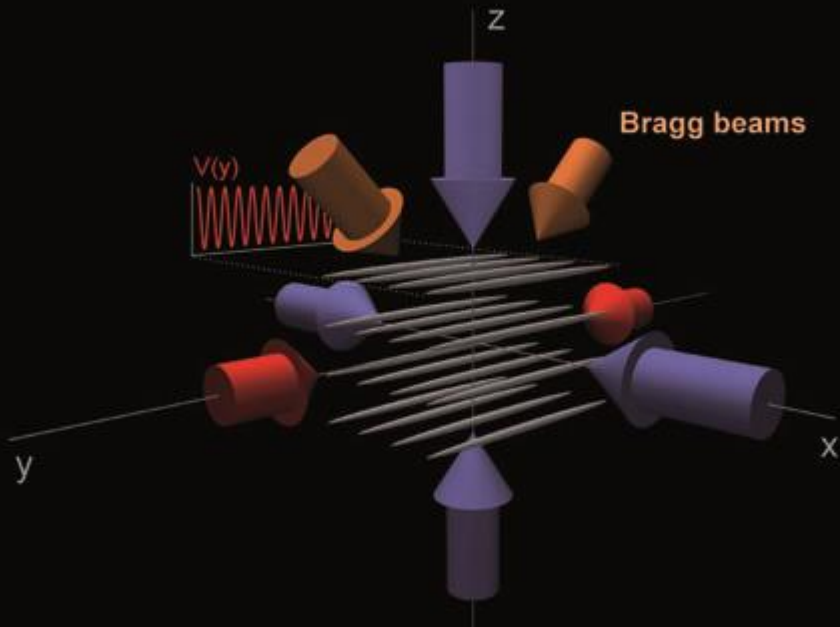
$$i\hbar \frac{\partial}{\partial t} \Psi(\mathbf{r}, t) = \left[-\frac{\hbar^2}{2m} \nabla^2 + V_{\text{ext}}(\mathbf{r}) + g|\Psi(\mathbf{r}, t)|^2 \right] \Psi(\mathbf{r}, t)$$

GP model possesses two integrals of motion

$$N = \int |\Psi(\mathbf{r}, t)|^2 d\mathbf{r},$$

$$E = \int d\mathbf{r} \left[\frac{\hbar^2}{2m} |\nabla \Psi|^2 + V_{\text{ext}} |\Psi|^2 + \frac{1}{2} g |\Psi|^4 \right]$$

BEC IN OPTICAL LATTICE



Advantages:

- Control over parameters
- Small noise
- Coherence

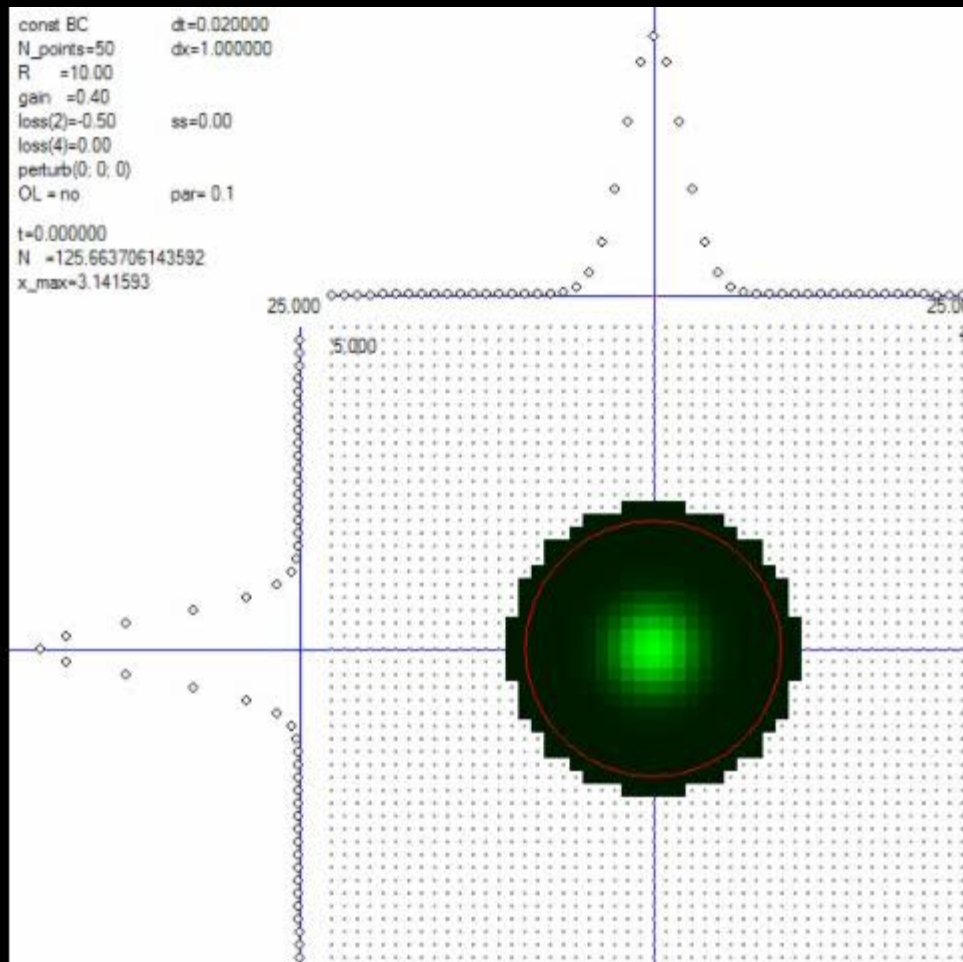
Some results:

- Landau-Zener tunneling
- Bloch oscillations,
- Gap solitons

SOME TOOLS FOR THE ANALYSIS

- **Direct methods**
 - Variational approximation
 - Momentum method
 - Scaling transformations (lens transformation, Lie group theory)
- **Methods from the linear and nonlinear limits**
 - Existence and stability
 - Perturbation theory for solitons
- **Direct numerical integration**

EXAMPLES OF RESULTS



Rotating vortex lattices in
an exciton-polariton
condensate

OTHER RECENT APPLICATIONS

25 NOVEMBER 2010 | VOL 468 | NATURE | 545

LETTER

doi:10.1038/nature09567

Bose–Einstein condensation of photons in an optical microcavity

Jan Klaers, Julian Schmitt, Frank Vewinger & Martin Weitz

Bose-Einstein-Condensation of Photons



Article: [Nature 468, 545 \(2010\)](#)

"All the photons marched in lockstep,"
Weitz says.

like atoms in atomic BEC "sing in unison"

OTHER RECENT APPLICATIONS

The observation of **Bose–Einstein condensation** in a gas of **magnons** at room temperature.

nature

Vol 443|28 September 2006|doi:10.1038/nature05117

LETTERS

Bose–Einstein condensation of quasi-equilibrium magnons at room temperature under pumping

S. O. Demokritov¹, V. E. Demidov¹, O. Dzyapko¹, G. A. Melkov², A. A. Serga³, B. Hillebrands³ & A. N. Slavin⁴

HOW CLOSE WE ARE TO ASTROPHYSICS?

2010

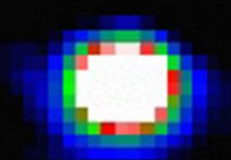
BEC experiment was used to induce a very small, supernova-like explosion changing the trapping magnetic field .

The bosenova behavior of a BEC may provide insights into the behavior of a **neutron star** or a **pulsar**

On the picture **bosenova** or **bose supernova**

Other applications:

- **Cosmic inflation** using BEC
- **Black hole** configurations in BECs



NONLINEAR PROBLEMS IN ASTROPHYSICS AND COSMOLOGY

All these achievements in condensed matter physics can be useful in solving nonlinear problems of astrophysics and cosmology.

Relaxation of the N-body gravitating systems + mean-field approach allows to study:

Celestial mechanics

(dynamics of solar and extrasolar planetary systems)

Dense Stellar systems

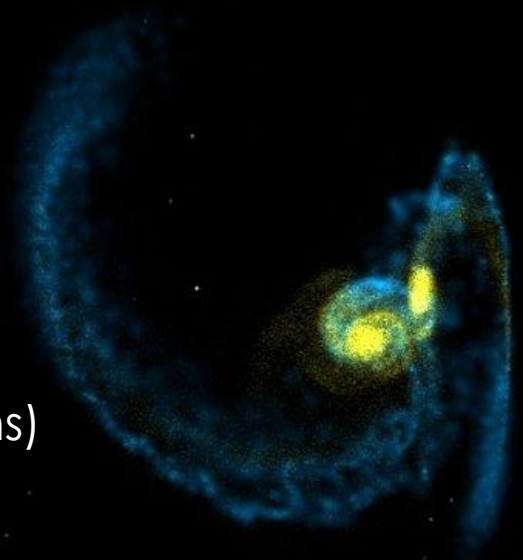
(such as open clusters and globular clusters)

Sphere of influence of a massive Black Hole

(gravity of the BH dominates over gravity of the host galaxy)

Galaxy dynamics and cosmology

(dynamics is described by the Collisional Boltzmann Equation, which can be approximately solved using Fokker-Plank methods)



OUTLOOK

Hope that you agree that
in order to be **successful** we need to
have **open mind** strategy

New applications ...

New problems ...

New collaborations...