NON-LINEAR PHYSICS AT CFP

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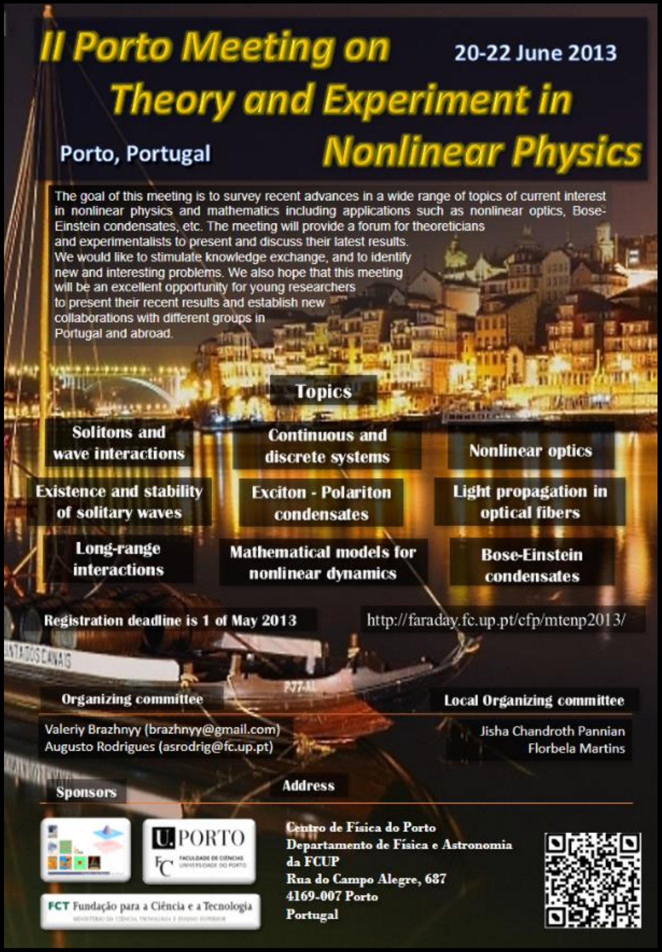
ORGANIZATION OF CONFERENCES

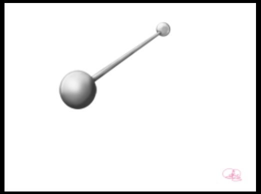
2010 Edition

2013 Edition



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

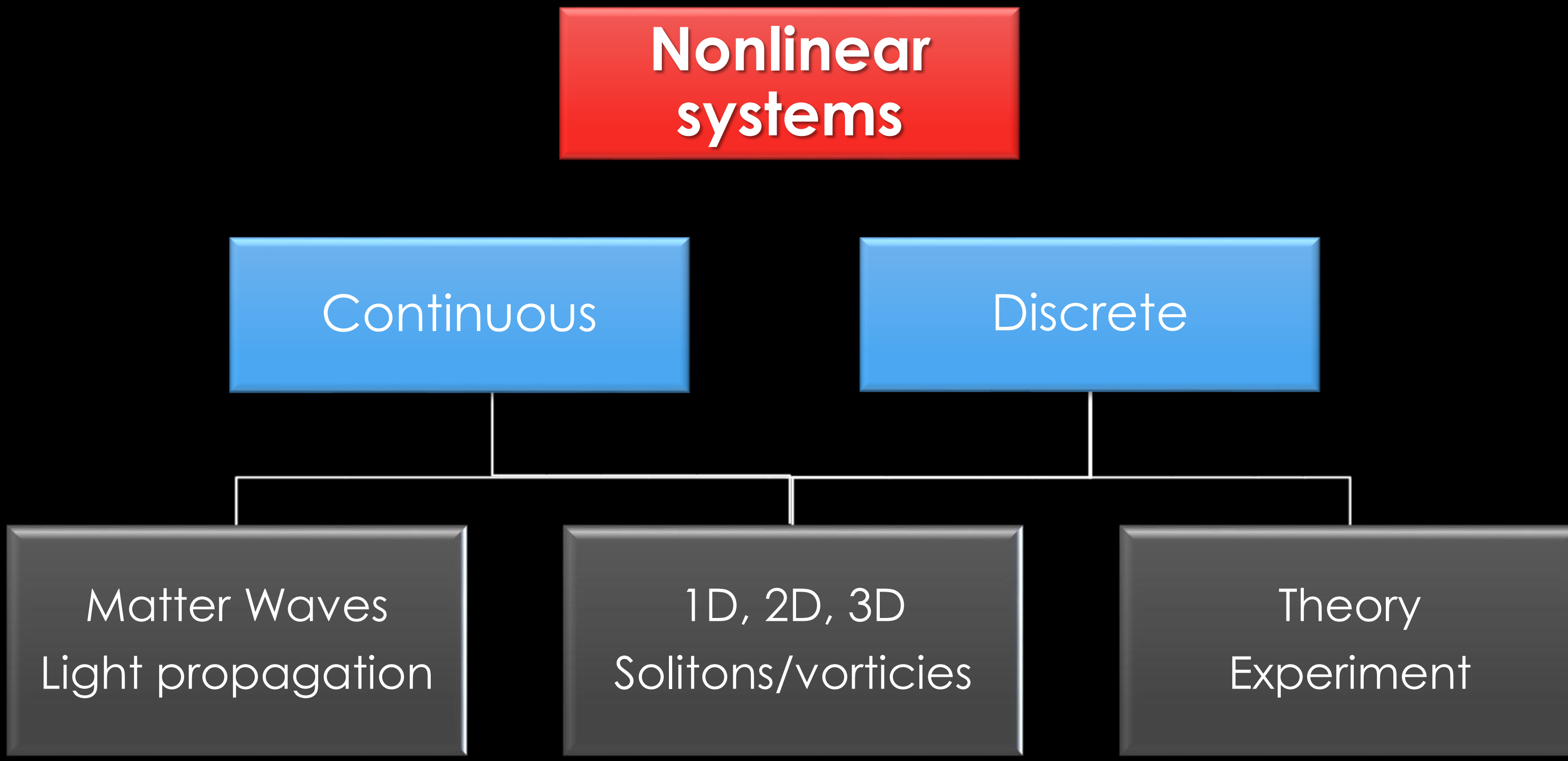
1) **Condensed atomic gases** (the theory of Bose-Einstein condensates)

   - 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



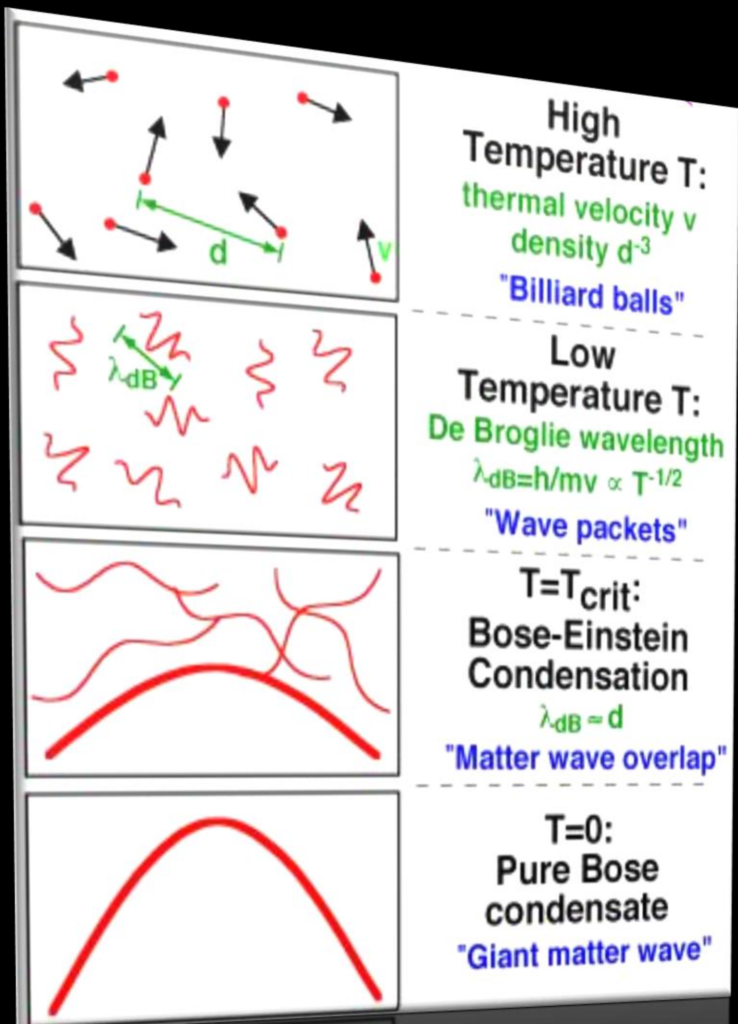
ONE EXAMPLE

BEC

Bose – Einstein condensate

Bose-Einstein condensate

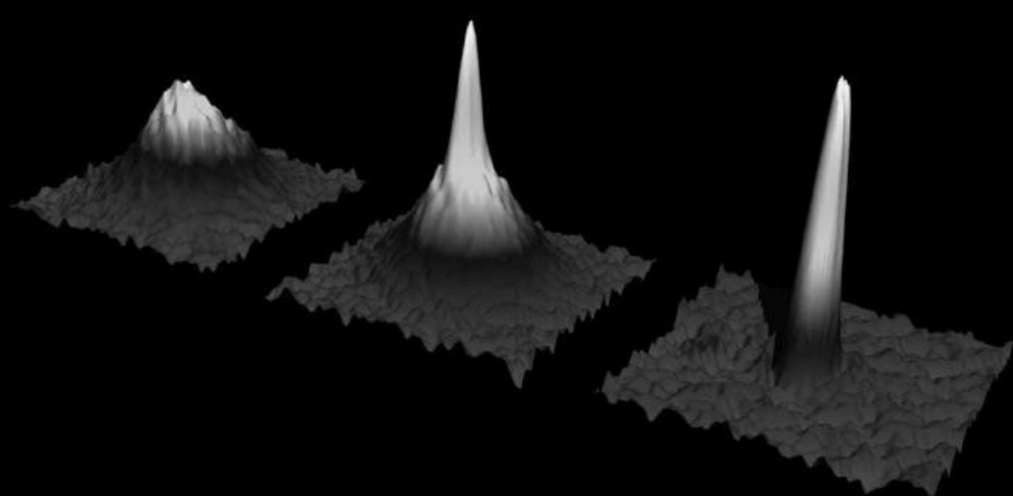
APPLICATIONS



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-PITAEVSKII 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)

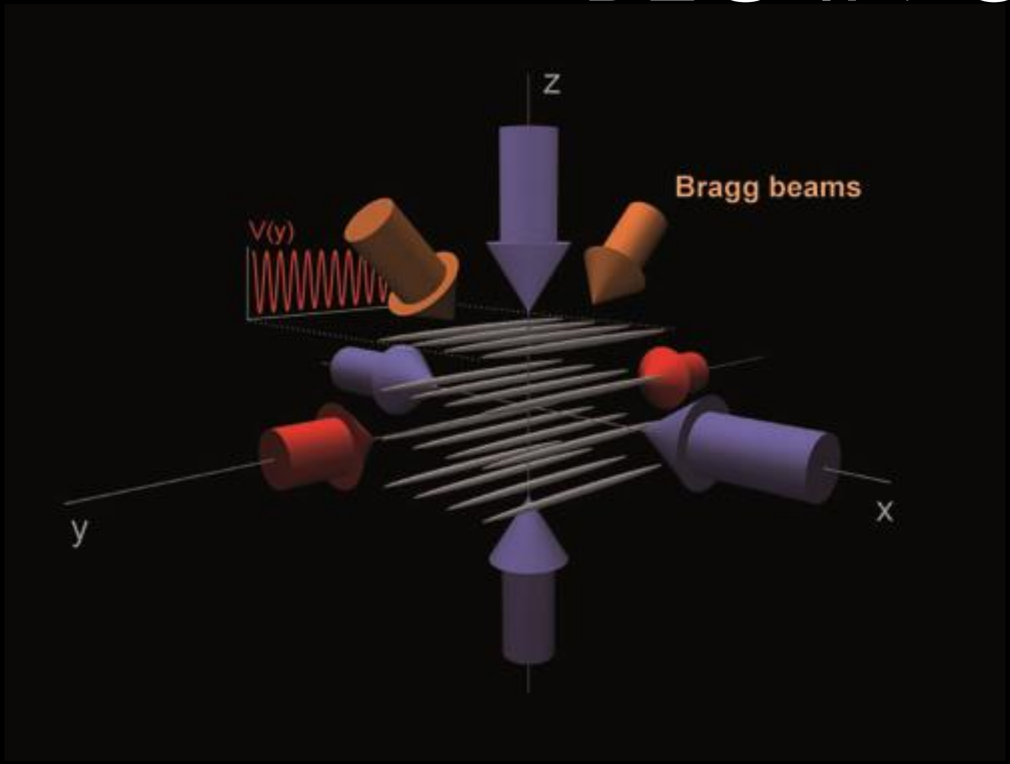
$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},t) = \left[-\frac{\hbar^2}{2m}\nabla^2 + V_{\text{ext}}(\mathbf{r}) + g|\Psi(\mathbf{r},t)|^2\right]\Psi(\mathbf{r},t)$$

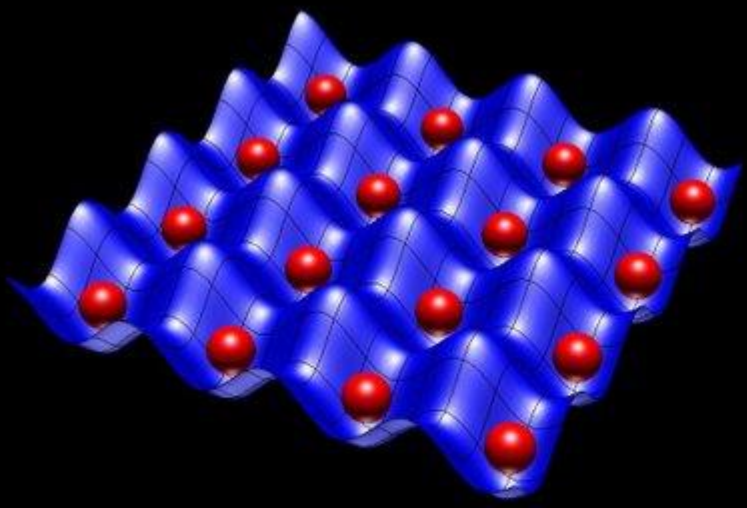
GP model possesses two integrals of motion

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

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

BEC IN OPTICAL LATTICE





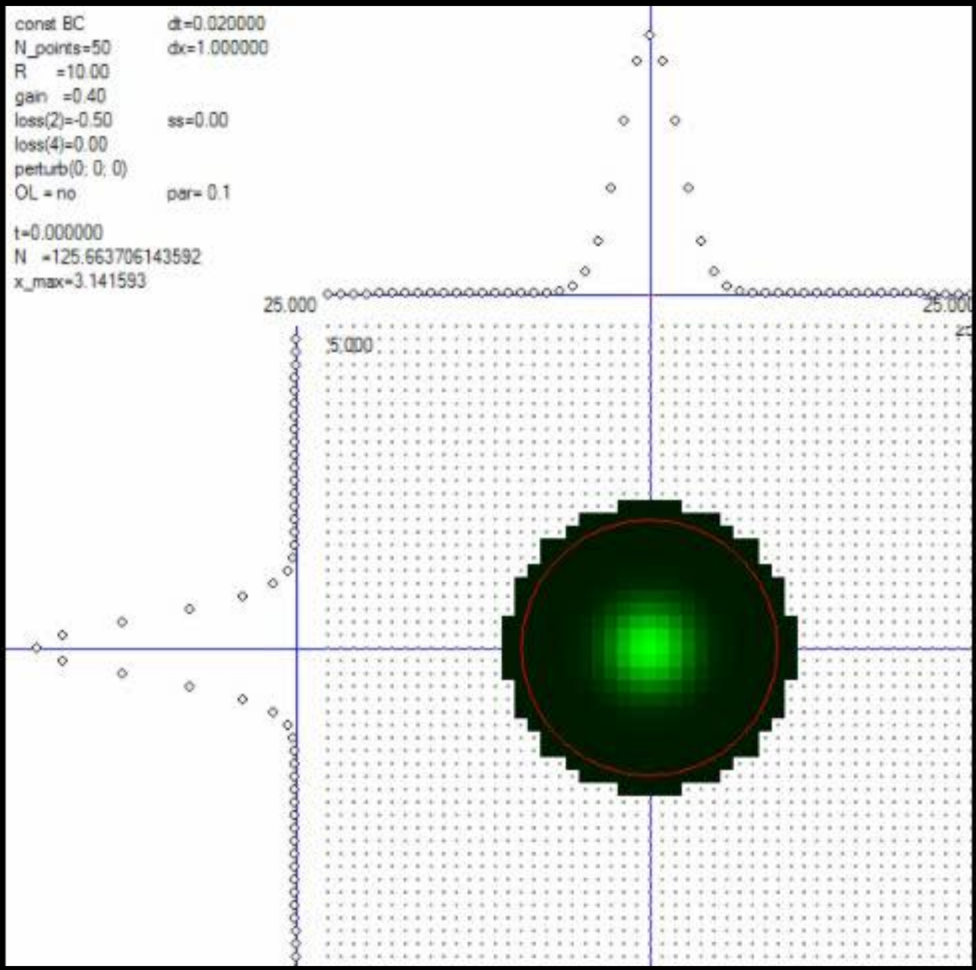
Advantages:
- Control over parameters
- Small noise
- Coherence

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**

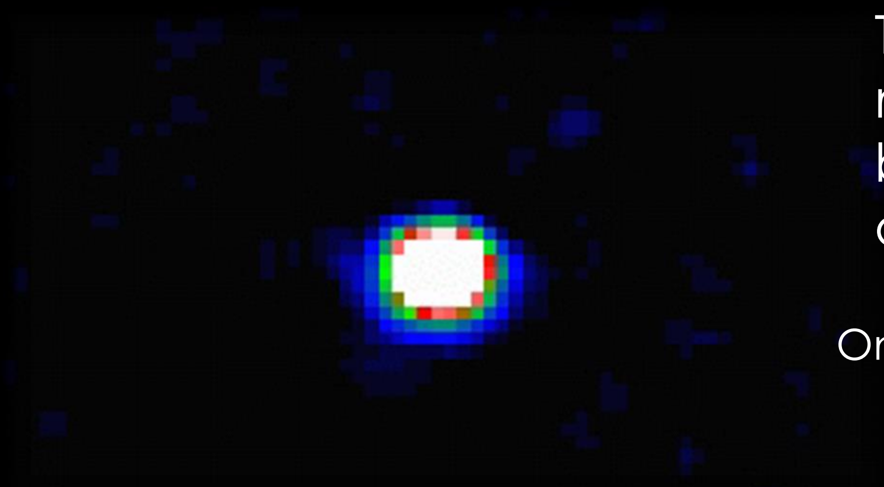
LETTERS

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

S. O. Demokritov[1], V. E. Demidov[1], O. Dzyapko[1], G. A. Melkov[2], A. A. Serga[3], B. Hillebrands[3] & A. N. Slavin[4]

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**

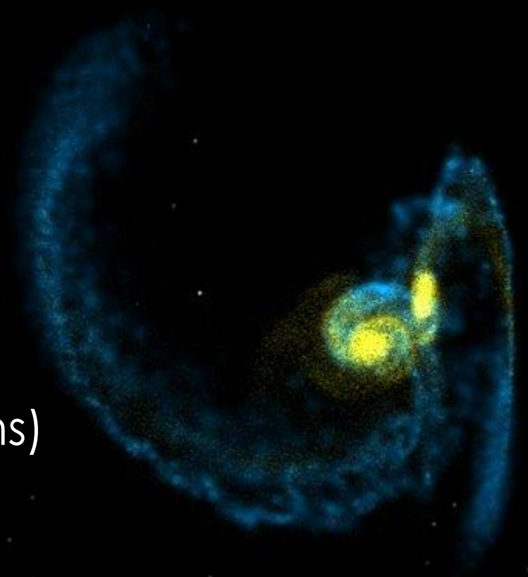
Other applications:

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

NONLINEAR PROBLEMS IN ASTROPHYSICS AND COSMOLOGY

All this 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…