Visualization of Bose-Einstein Condensates

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27 February 2001

Introduction

- Research team.
- BEC background.
- Motivation.
- Data.

Research Team

- Peter Ketcham (ITL, NIST)
- David Feder (PL, NIST)
- Charles Clark (PL, NIST)
- William Reinhardt (University of Washington)
- Steven Satterfield (ITL, NIST)
- Terence Griffin (ITL, NIST)
- William George (ITL, NIST)

BEC Background

- State of matter.
- Exists at extremely low temperatures.
- Behaves as a single quantum entity.

Motivation

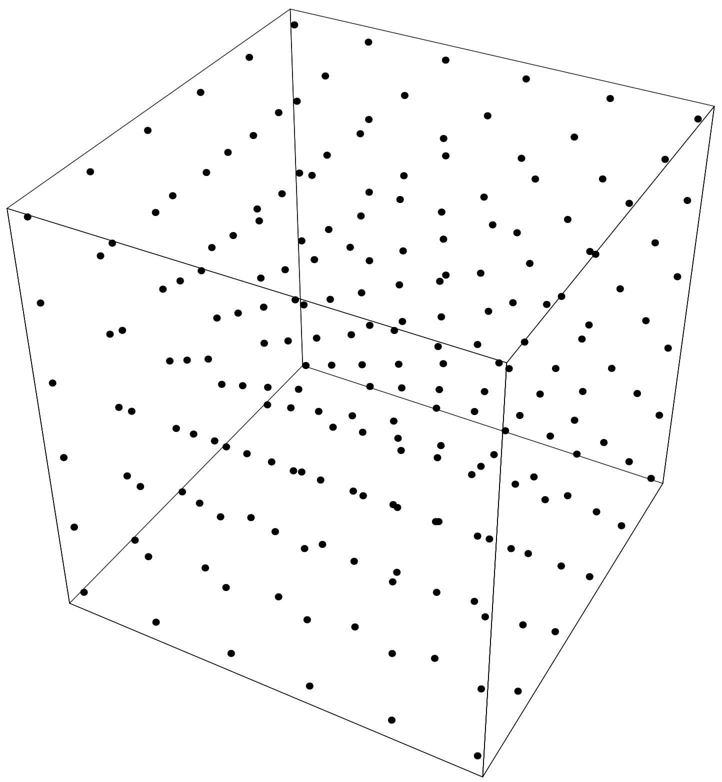
- Explore superfluidity.

- Study the evolution of the BEC wave function when subjected to rotation.

- Investigate existence of vortices.

Data

- Produced by computer simulation.
- 3D rectangular array of complex numbers at an instant in time.
- Grid of 200 points in each dimension.



Visualization Process

- Data presentation.

- Color and opacity assignment.

- Rendering.

- Summary animation.

Data Presentation

- Polar representation of complex-valued data (physics convention).

- Radial component referred to as “density”.

- Angular component referred to as “phase”.

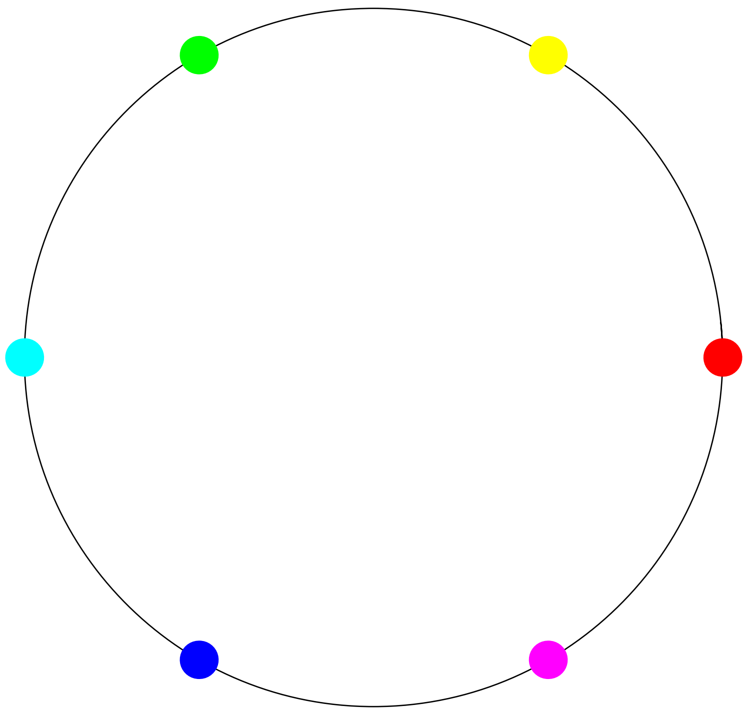
Color and Opacity Assignment

- Goal: Assign color and opacity to each data point in order to exhibit features of interest.

Qualitative Description

- Associate density with brightness to exhibit vortex structures.

- Associate phase with a color circle to convey periodicity.

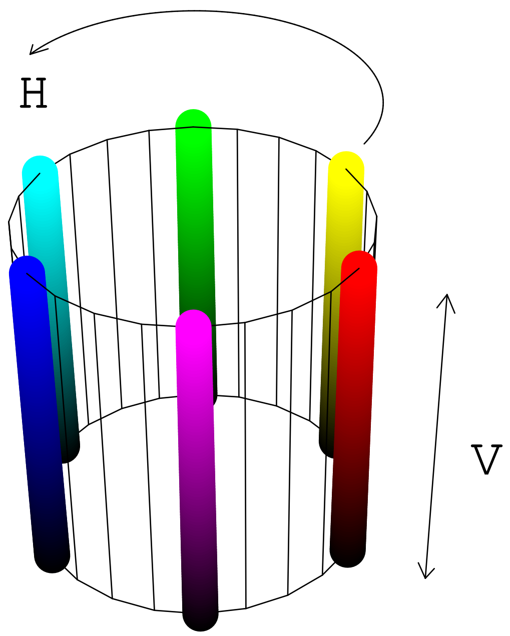


HSV Color Model

- Ideal for depicting density and phase components.

- Density mapped to Value (V).

- Phase mapped to Hue (H).

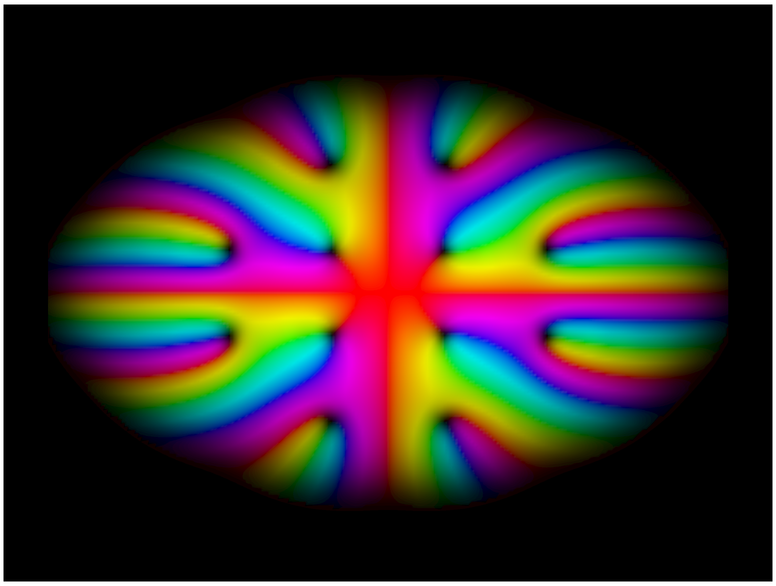


Rendering

- Initially with 2D data, then with 3D data.
- "Dense emitter" rendering model for 3D data with all points completely transparent.
- Application software is OpenDX.

2D Data

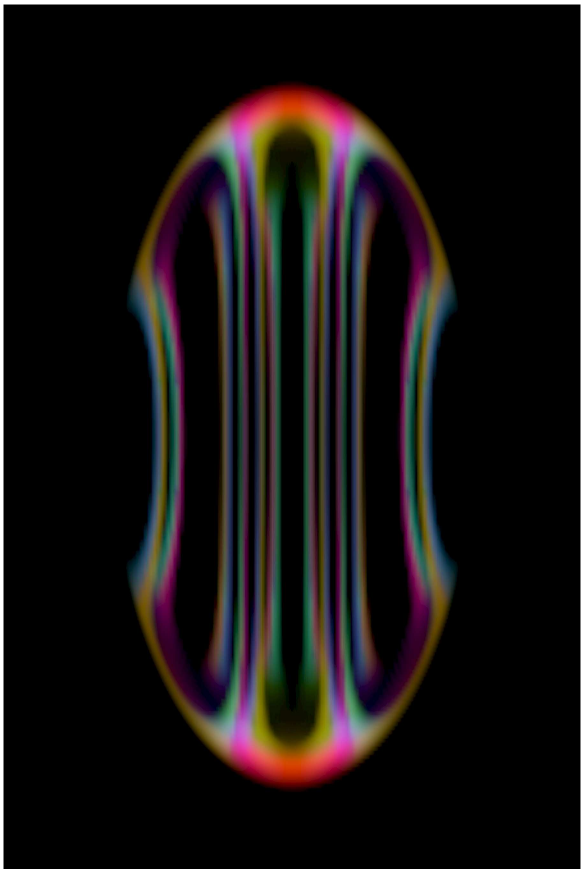
- For 2D data, low density regions are dark and high density regions are bright.



3D Data

- For 3D data, low density regions are bright and high density regions are dark.

- Rationale: The uninteresting, low-density, outer regions must not obscure the inner vortex structures.



Summary Animation

- Behind-the-scenes look at the visualization process for 3D data.

Impact

- Results.
- Feedback loop.
- Publications.
- Research stimulation.

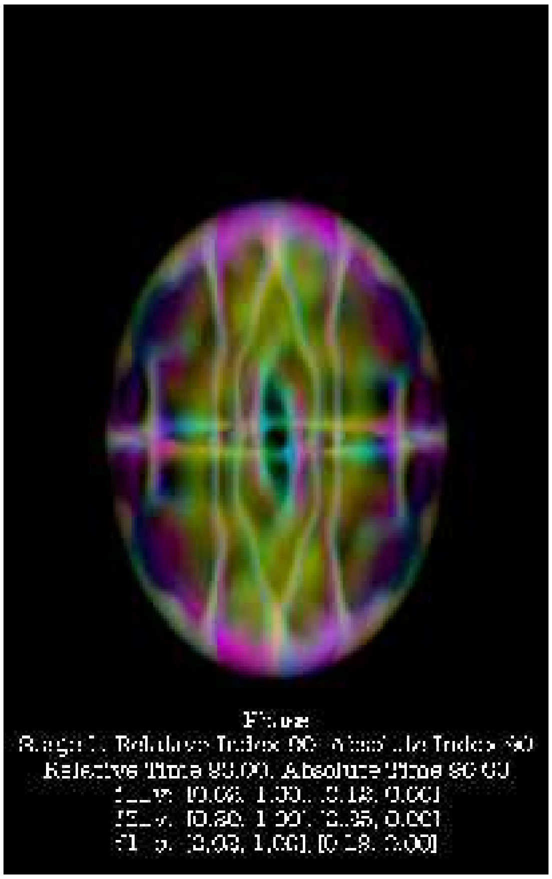
Results

- Theoretically demonstrated the existence of quantized vortex array structures.

- Theoretically demonstrated the spontaneous decay of a soliton into concentric quantized vortex rings (a "snake instability").

Feedback Loop

- Created a feedback loop from the visualization process to the simulation research.



Publications

- *Physics Today*, December 1999.
- *Parity*, August 2000.
- *Science*, 11 August 2000.
- *Scientific American*, December 2000.
- *Optics & Photonics News*, December 2000.

Physics Today Cover

Parity Cover

Science Cover

“One Hundred Years of Quantum Physics”

Scientific American Cover

“The Coolest Gas in the Universe”

Optics & Photonics News
Cover

“Solitons in a Bose-Einstein Condensate”

“Nonlinear Aharonov-Bohm Effect On Optical Vortices”

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In the first two sentences of this article, the authors write:

> Optical vortices, phase dislocations, or phase defects of electromagnetic waves are fundamental in singular optics. They are a unique class of objects that introduce new concepts into the physics of light linking it to superfluids and Bose-Einstein condensates. —*Kivshar, et al.*

Research Stimulation

In a recent communication to Judith Devaney:

> You might be interested to know that we followed up our original observation of this snake instability by a great deal of further simulations and calculations, and wrote up the results in a recent article [Phys. Rev. A 62, 053606 (2000)] that features some nice still images also rendered in the same way. Experimentalists at JILA, namely postdoc Brian Anderson and supervisor Eric Cornell, read the article and decided to attempt to generate these vortex rings in condensates in exactly this way. They have confirmed all the predictions, and we are in the process of writing up a joint theory-experimental paper on the subject. —*David Feder*