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Ferromagnetic superfluids' spin waves in false vacuum decay via bubble formation

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To all my friends

Acknowledgments

I would like to thank all of my friends.

Abstract

This thesis analyses a BEC experiment and some data analysis

Contents

Introduction

Chapter 1

Theoretical picture

The experimental platform is composed of a bosonic gas of ^{23}Na atoms, optically trapped and cooled below the condensation temperature. The initial spin state in which the system is prepared is $|F, m_F\rangle = |2, -2\rangle = |\uparrow\rangle$, with F being the total angular momentum of the atom ($\mathbf{F} = \mathbf{I} + \mathbf{J}$, takes into account the nuclear spin and the total angular momentum of the electrons) and m_F its projection on the quantization axis. The $|\uparrow\rangle$ state is then coupled to $|1, -1\rangle = |\downarrow\rangle$ through microwave radiation with amplitude Ω_R.

The trapping potential is harmonic in all three directions, but strongly asymmetric concerning the radial (ρ) and axial (x) directions. In fact, the trapping frequencies are respectively $\nu_\rho = 2$ kHz and $\nu_x = 20$ Hz, yielding an elongated system (cigar-shaped) with inhomogeneous density. The spatial size of the system is given by the Thomas-Fermi radii $R_\rho = 2$ µm and $R_x = 200$ µm. This particular setup is helpful for suppressing the radial spin dynamics of the condensate and thus being able to study its longitudinal properties.

In order to extract the density distribution, the two spin states are treated independently one from another, and two imaging sequences are obtained at the end of each experimental realization. Then, an integration along the transverse direction is performed, obtaining two 1D density profiles $n_\uparrow(x)$ and $n_\downarrow(x)$, from which one can extract the relative magnetization

$$M(x) = \frac{n_\uparrow(x) - n_\downarrow(x)}{n_\uparrow(x) + n_\downarrow(x)}\,.$$

It is possible to study the two-component system by separating the treatment on the density ($n = n_\uparrow + n_\downarrow$) and the spin ($nM = n_\uparrow - n_\downarrow$) degrees of of freedom. While the density is described by a continuity equation, the spin behaviour is ruled by a magnetic mean-field Hamiltionian, that presents a first-order phase transition in the central region of the system when $\Omega_R < |k|n$, where $k \propto \Delta a$. At fixed values of Ω_R, the experiment can be tuned by the parameter δ, expressing the *detuning*. In general, the mean-field energy landscape $E(M)$ is described by an asymmetric double-well, that becomes symmetric for $\delta = 0$. In the case of $\delta > 0$, the energy is minimized by positive values of M, and the absolute minimum will correspond to

Chapter 2

Data analysis

2.1 Raw data processing

Raw data is organized in a hierarchical system. At a fixed instant, the condensate's measured data are called a *shot*. Each shot is part of a series of them that can be analyzed as the time evolution of a single system; this series is called a *sequence*. Eventually, during a *day* of measurements, many sequences may be collected, and a selection of them will be studied in the following analysis.

Thus, a shot contains all the information of the system at a certain instant, including the magnetization data, and that is what concerns this work.

2.1.1 Bubble parameters

The most interesting parameters to retrieve from a shot are the bubble center and width. In order to find those parameters, the magnetization data is fitted with a double-arctangent function

$$M(x) = -A\left[\frac{2}{\pi}\arctan\left(\frac{x-x_1}{w_1}\right) - \frac{2}{\pi}\arctan\left(\frac{x-x_2}{w_2}\right)\right] + \delta\,,$$

where x_1 and x_2 are the centers of the arctangent "shoulders", and w_1 and w_2 are the arctangent widths. In some cases, especially when the magnetization does not reach the minimum value $M_{\text{min}} = -1$ in the bubble center, it is better to use a gaussian profile, such as

$$M(x) = -A\exp\left\{-\frac{(x-x_0)^2}{2w^2}\right\} + \delta\,,$$

with x_0 being the bubble center and w its width.

Conclusions

Appendix A

Albero

Appendix B

Barca

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