Bubbles in a ferromagnetic superfluid

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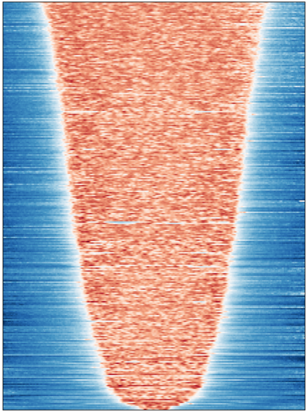
Overview

This presentation will cover:

- **Introduction**
- **Theoretical background**: Ferromagnetism in coherently coupled two-component spin-mixtures
- **Data analysis**: Characterization of false vacuum decay bubbles
- **Conclusions**



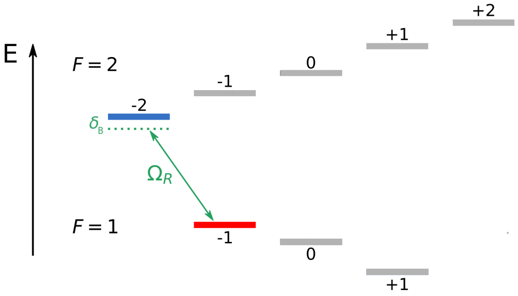
Introduction

Why **bubbles** in a ferromagnetic superfluid?

- First **experimental observation** of false vacuum decay (FVD) in the Pitaevskii BEC Center laboratories of the University of Trento.
- FVD provides information on **metastability** and is studied from quantum systems to cosmology
- Framework: **quantum gas** of Sodium atoms optically trapped and cooled below the condensation temperature

Experimental platform

- ^{23}Na atoms in the hyperfine states $|F, m_F\rangle = |2, -2\rangle = |\uparrow\rangle$ and $|F, m_F\rangle = |1, -1\rangle = |\downarrow\rangle$
- Contact interaction constants $g_{\uparrow\uparrow}$, $g_{\downarrow\downarrow}$, $g_{\uparrow\downarrow}$
- Rabi coupling strength Ω_R and detuning δ_B
- Harmonic trapping potential with $\omega_\perp/2\pi = 2$ kHz and $\omega_x/2\pi = 20$ kHz



Coherently coupled two-component spin mixtures

The GPEs contain the inter-species interaction constant and the coupling between the states:

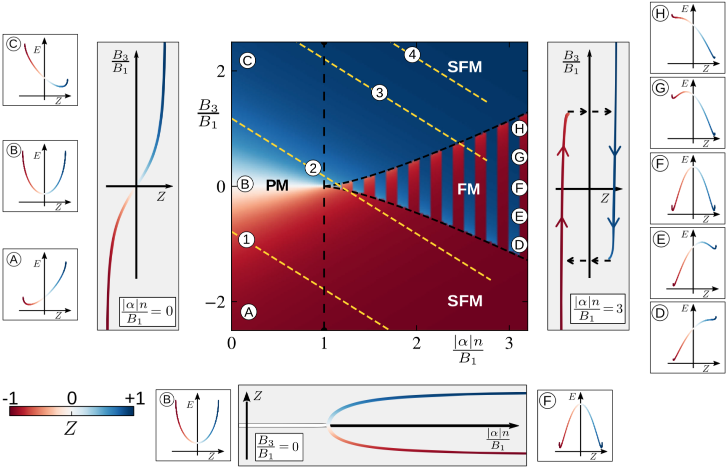
$$\left[-\frac{\hbar^2}{2m}\nabla^2 + V(x) - \frac{\delta_B}{2} + g_{\uparrow\uparrow}|\psi_\uparrow(x)|^2 + g_{\uparrow\downarrow}|\psi_\downarrow(x)|^2\right]\psi_\uparrow(x) - \frac{\hbar\Omega_R}{2}\psi_\downarrow(x) = \mu_\uparrow\psi_\uparrow(x)$$

$$\left[-\frac{\hbar^2}{2m}\nabla^2 + V(x) + \frac{\delta_B}{2} + g_{\uparrow\downarrow}|\psi_\uparrow(x)|^2 + g_{\downarrow\downarrow}|\psi_\downarrow(x)|^2\right]\psi_\downarrow(x) - \frac{\hbar\Omega_R}{2}\psi_\uparrow(x) = \mu_\downarrow\psi_\downarrow(x)$$

Magnetization $Z = (n_\uparrow - n_\downarrow)/(n_\uparrow + n_\downarrow)$ produces an energy landscape:

$$E_{\mathrm{MF}}(Z) = -\hbar\left(|\delta g|nZ^2 + 2\Omega_R\sqrt{1 - Z^2} + 2\delta_{\mathrm{eff}}Z\right)$$

Magnetic model



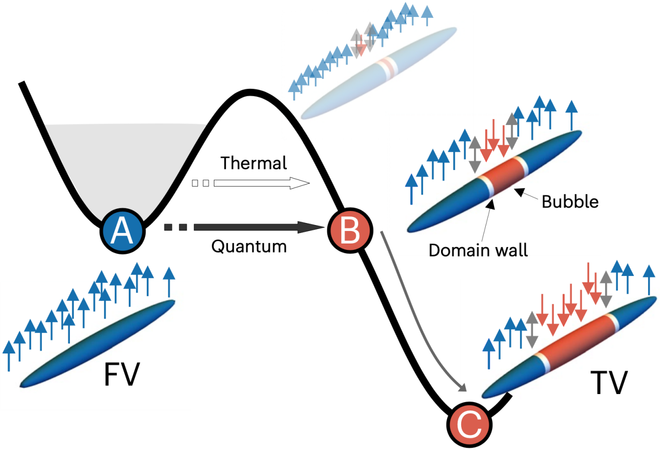
$\alpha \to \delta g$

$B_3 \to \delta_{\text{eff}}$

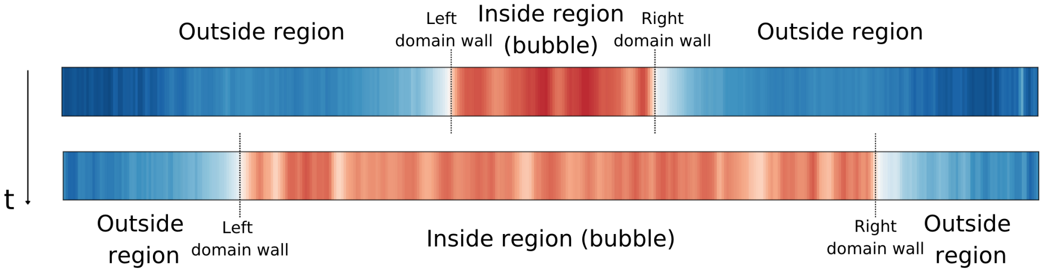
$B_1 \to \Omega_R$

False vacuum decay bubbles

- Quantum tunnelling from A to B (stochastic)
- Decay from B to C (what we want to study)
- Problem: when to take the shot?



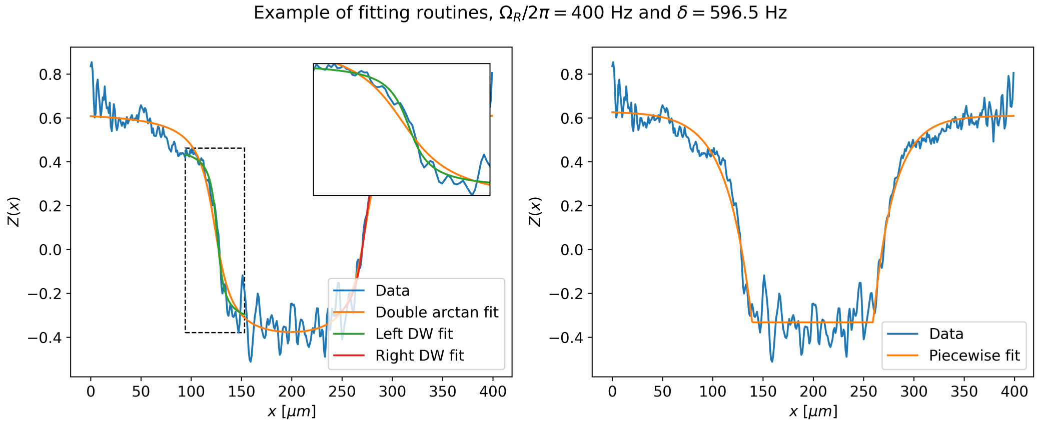
Example of bubble shots



Our aim is to study:

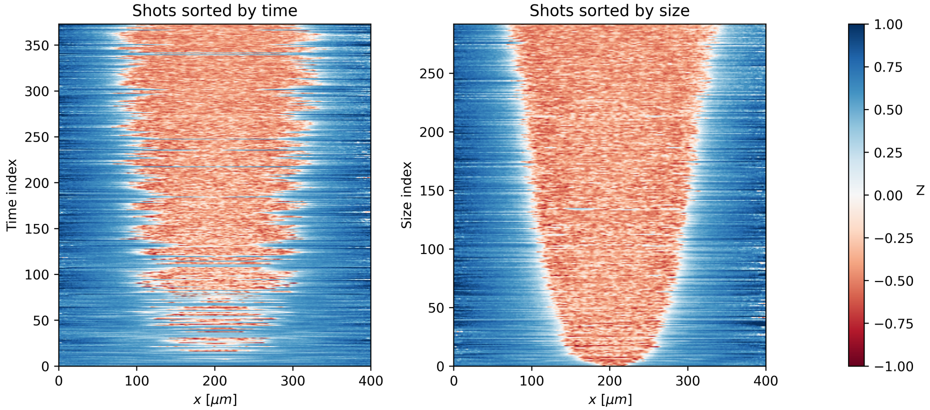
- Size σ_B and domain wall width w_D
- Spectrum inside/outside

Bubble fitting routines

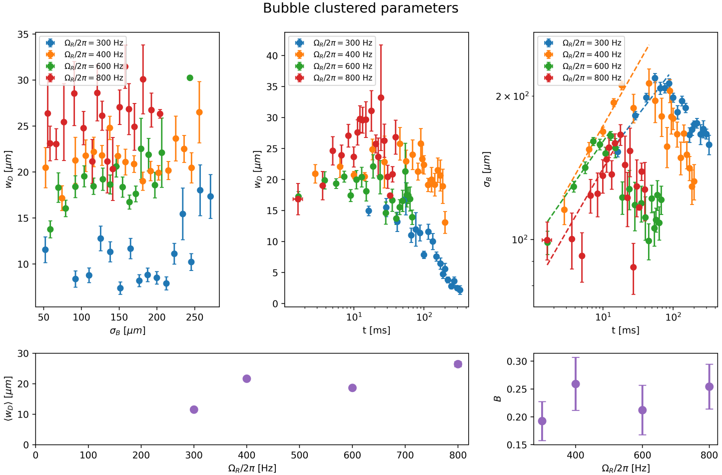


Shot sorting

Bubble shots with $\Omega_R/2\pi = 400$ Hz and $\delta = 596.5$ Hz



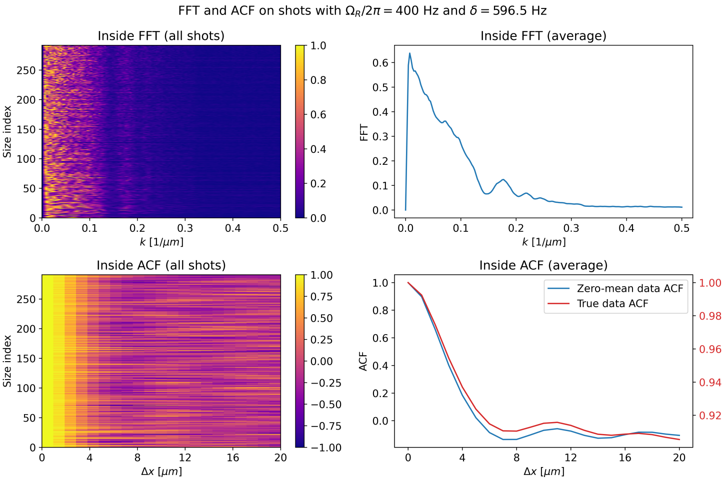
Analysis of size and domain wall width



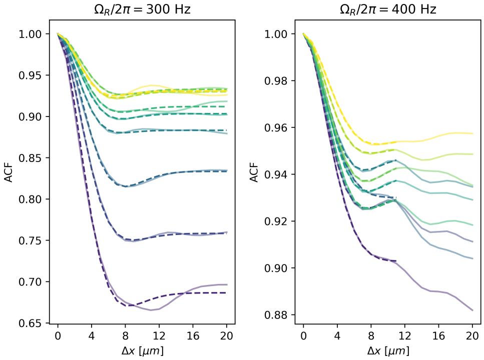
Fit function:

$$\sigma_B(t) = A\left(\frac{t}{1\ \text{ms}}\right)^B$$

Spectral analysis in the inside region



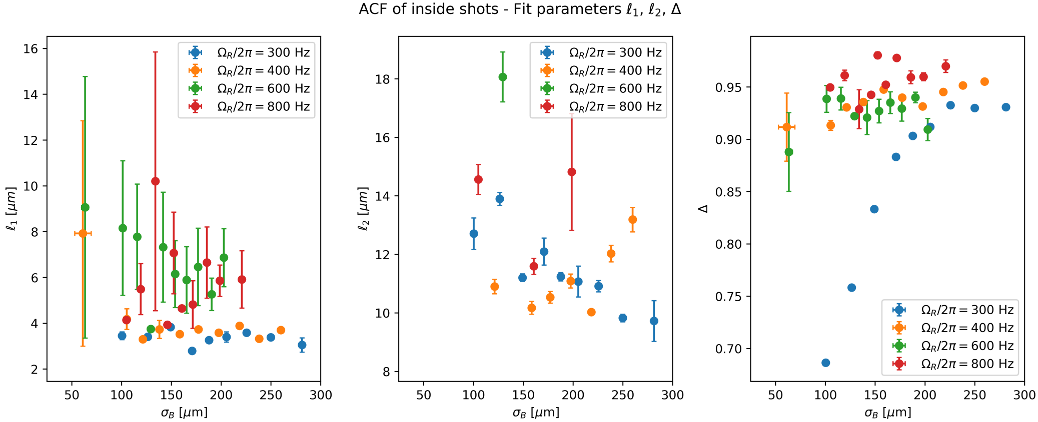
ACF analysis in the inside region (fits)



Fit function:

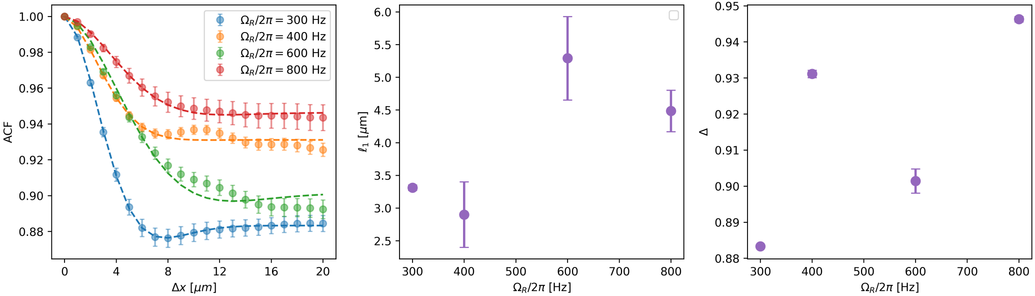
$$\mathcal{A}_{\mathrm{fit}}(x) = (1-\Delta)\cos\left(\frac{\pi x}{\ell_2}\right)\exp\left[-\frac{1}{2}\left(\frac{x}{\ell_1}\right)^{\alpha}\right]+\Delta$$

ACF analysis in the inside region (parameters)

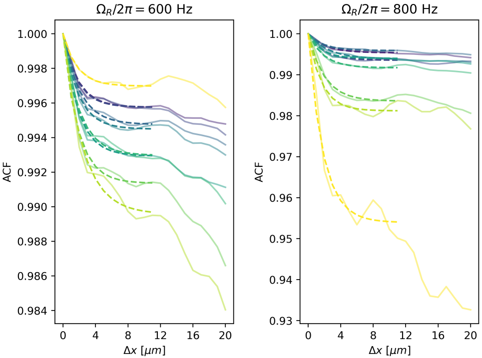


ACF analysis in the inside region (parameters)

ACF of inside shots - Fits and parameters ℓ_1, Δ



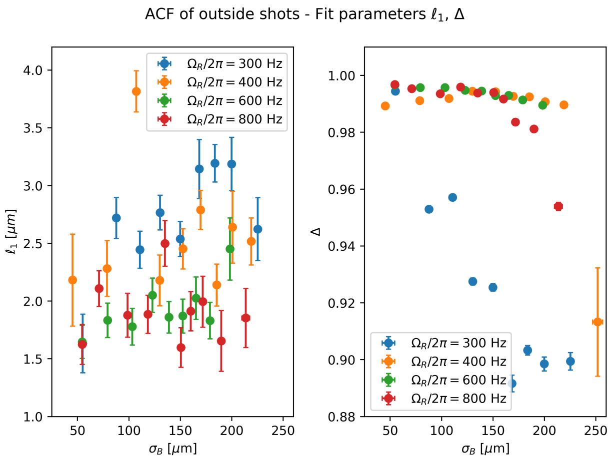
ACF analysis in the outside region (fits)



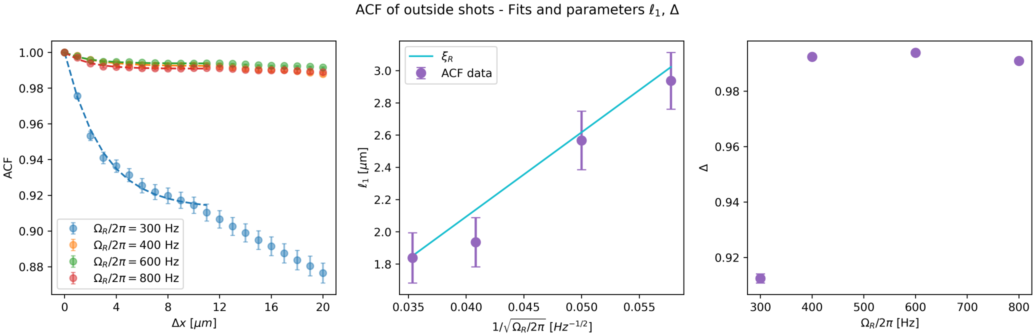
Fit function:

$$\mathcal{A}_{\text{fit}}(x) = (1-\Delta)\exp\left[-\frac{x}{2\ell_1}\right] + \Delta$$

ACF analysis in the outside region (parameters)



ACF analysis in the outside region (parameters)



Conclusions

What did we learn?

- The system shows **different properties** between inside and outside of the bubble
- Domain wall width **depends on the coupling** strength Ω_R
- Growth factor of the bubble size in time is **independent** of Ω_R
- In the bubble, periodic structures **disappear** with size increasing. They **appear**, instead, outside of the bubble.
- Length scale of information outside is related to the Rabi **healing length**

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Future research:

- Analysis of the **density** channel
- Comparison with numerical GPE **simulations**
- Behavior at different **temperatures**

Thank you for your attention!