# Ferrofluidity in dipolar Bose-Einstein condensates

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# Magnetic liquid

**Colloidal mixture of**

**~10 nm ferromagnetic particles**

**in a carrier fluid**


**Normal-field or Rosensweig instability**

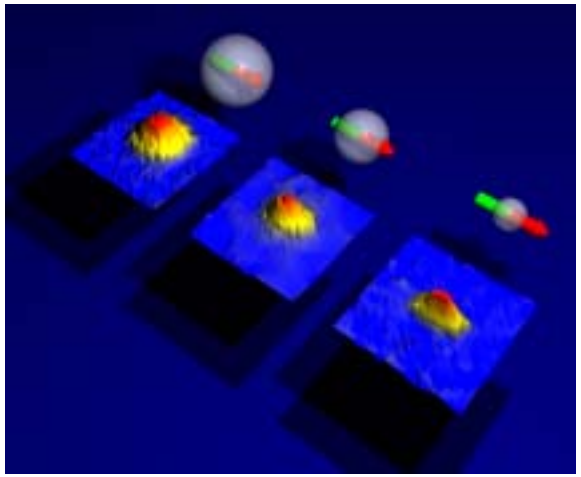

**Cowley & Rosensweig, J. Fluid Mech. 30, 671 (1967)**

# Purpose of this study

**Similar phenomena in a dipolar BEC?**

**New physics?**

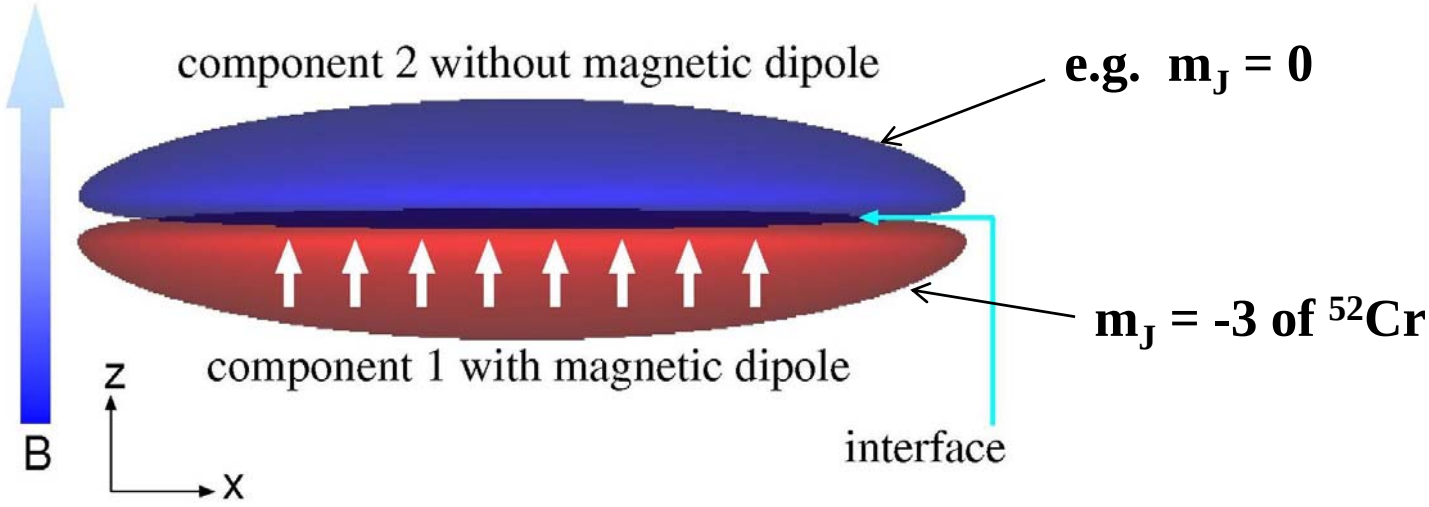
**BEC of $^{52}$Cr with** $\mu = 6\mu_B$



**Stuttgart**

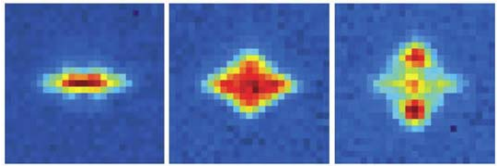
**Griesmaier *et al.*, PRL 94, 160401 (2005)**

# Two-component system




**Why two components?**

**dipolar collapse**



**Lahaye et al., PRL 101, 080401 (2008)**

**Texture formation is easier than density pattern formation.**

# Method of calculation

**Nonlocal Gross-Pitaevskii equation (mean-field approximation)**

$$i\hbar\frac{\partial\psi_1}{\partial t}=\left[-\frac{\hbar^2}{2m}\nabla^2+V_{\text{trap}}(\mathbf{r})+\mu B'z\right]\psi_1+g_{11}|\psi_1|^2\psi_1+g_{12}|\psi_2|^2\psi_1+\int U_{\text{dd}}(\mathbf{r}-\mathbf{r}')|\psi_1(\mathbf{r}')|^2\psi_1(\mathbf{r})$$

$$i\hbar\frac{\partial\psi_2}{\partial t}=\left[-\frac{\hbar^2}{2m}\nabla^2+V_{\text{trap}}(\mathbf{r})\right]\psi_2+g_{22}|\psi_2|^2\psi_2+g_{12}|\psi_1|^2\psi_2$$

$$i\to -1$$

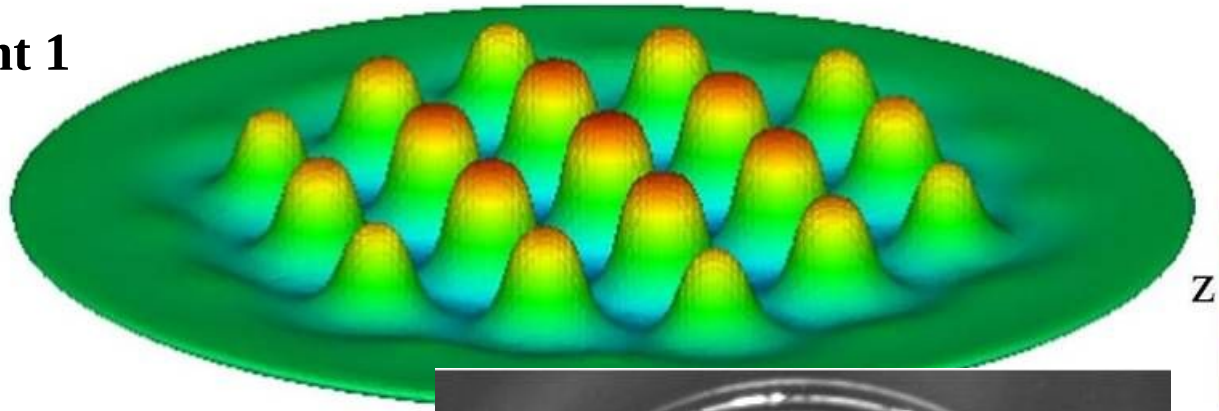
**Imaginary-time propagation gives stationary states.**

$$U_{\text{dd}}(\mathbf{r})=\frac{\mu_0\mu^2}{4\pi}\frac{1-3\cos^2\theta}{r^3}$$

$$V_{\text{trap}}=\frac{m}{2}\left[\omega_\perp^2(x^2+y^2)+\omega_z^2z^2\right]$$

# Rosensweig instability and pattern formation

**component 1**



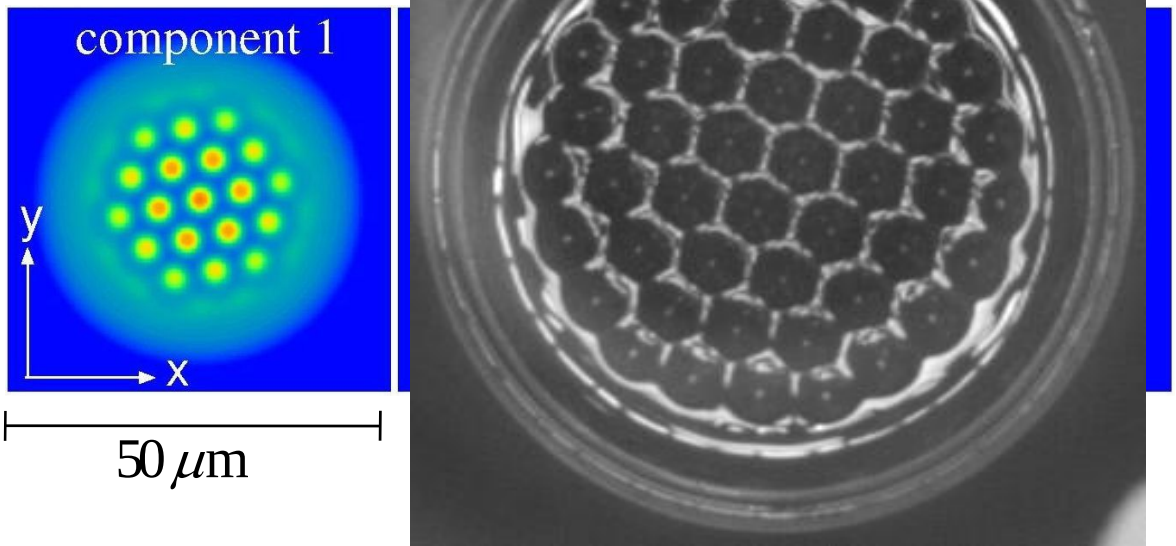

$\nu_\perp = 100\,\mathrm{Hz}$

$\nu_z = 800\,\mathrm{Hz}$

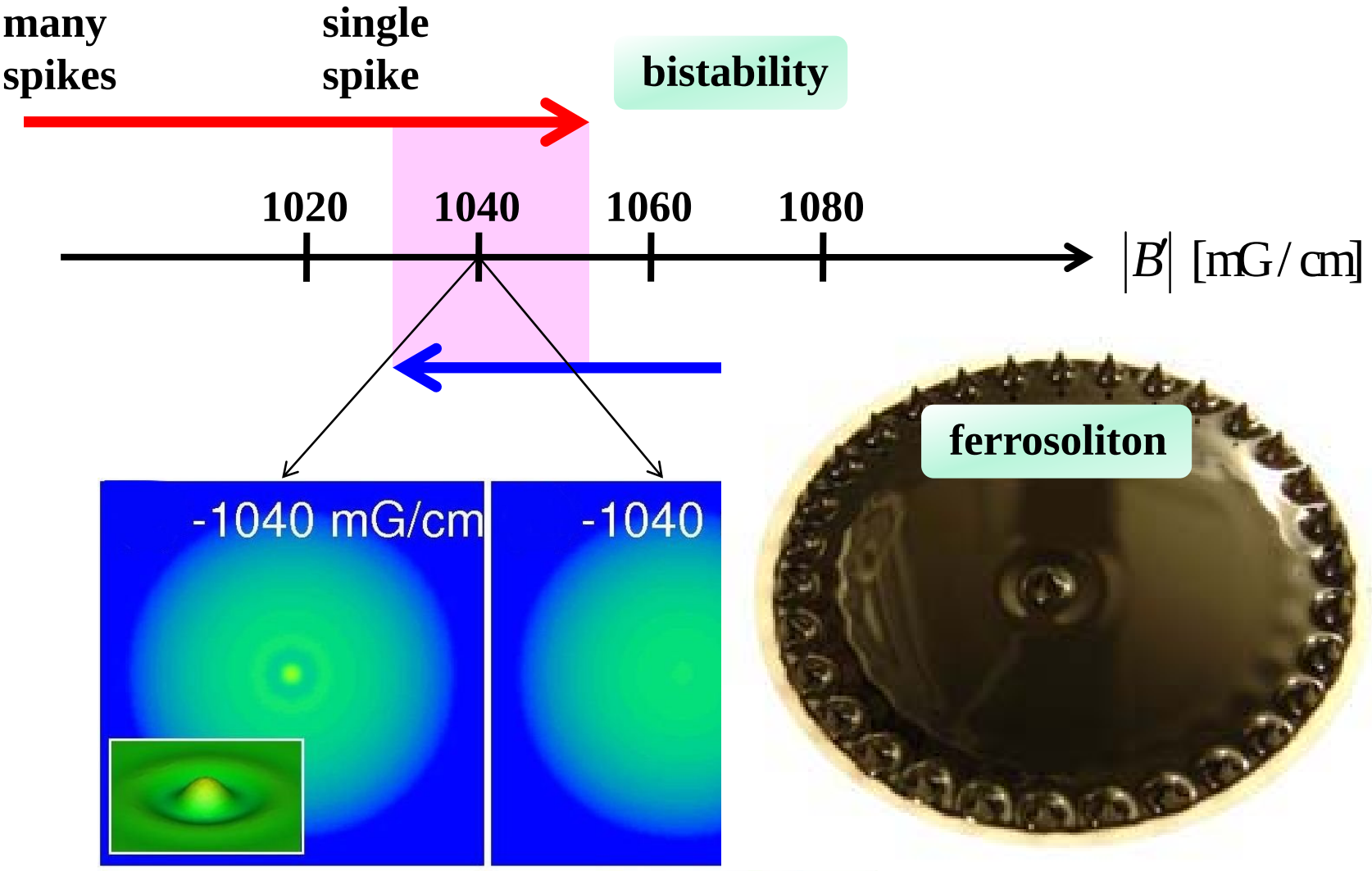
$N = 4\times10^6$

$B' = -0.6\,\mathrm{G/cm}$

$a_{11} = a_{22} = a_{12} = 100 a_B$



# Hysteresis



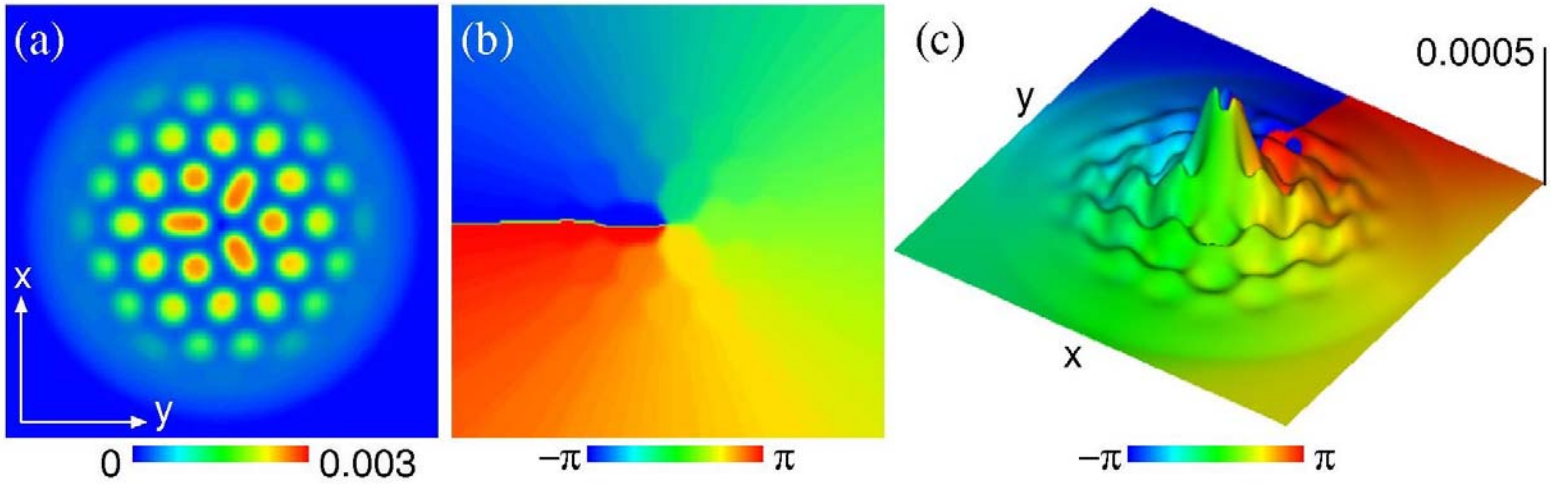

Richter et al., PRL 94, 184503 (2005)

# Supersolidity

**density of component 1**

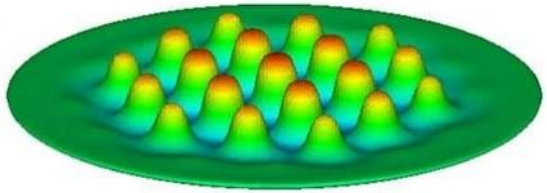
**phase of component 1**

**flux of component 1**

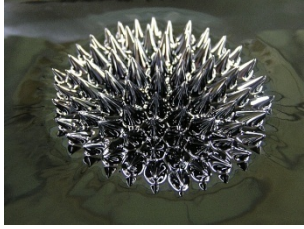



**superflow + diagonal order** ⟶ **supersolidity**

**vortex pinning by pattern** ⟶ **persistent current**



# Summary



**Similarities between dipolar BECs and magnetic liquids**

**Rosensweig patterns, hysteresis, ferrosoliton, labyrinthine pattern …**

**Novel phoenmena**

**Supersolidity, persistent current …**

**HS, YK, & MU, arXiv:0812.0278**