Dipolar fermions in a two-dimensional lattice at nonzero temperature

Anne-Louise Gadsbølle (1,2) and Georg M. Bruun (1)

1) Department of Physics and Astronomy, University of Aarhus, DK 8000 Aarhus C, Denmark
2) Theoretische Physik, ETH Zürich, Zürich CH-8093, Switzerland

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

INSTITUT FOR FYSIK OG ASTRONOMI
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Lundbeck Foundation Theoretical Center for Quantum System Research

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Basic formalism

$$\hat{H} = -t\sum_{\langle ij\rangle}\left(\hat{c}_i^\dagger\hat{c}_j + h.c.\right) + \sum_i\left(\frac{1}{2}m\omega^2r_i^2 - \mu\right)\hat{n}_i + \frac{1}{2}\sum_{i\neq j}V_D(\mathbf{r}_{ij})\hat{n}_i\hat{n}_j$$

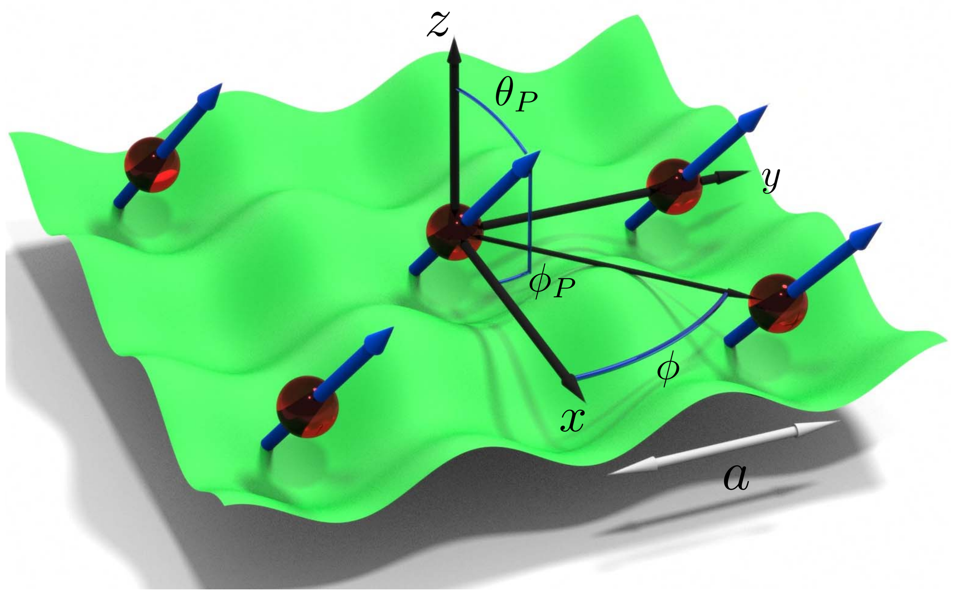
$$V_D(\mathbf{r}) = \frac{D^2}{r^3}\left[1 - 3\cos^2(\phi_P - \phi)\sin^2(\theta_P)\right]$$

The Bogoliubov-de Gennes equations

$$\sum_j\begin{pmatrix} L_{ij} & \Delta_{ij} \\ \Delta_{ji}^* & -L_{ij}\end{pmatrix}\begin{pmatrix} u_\eta^j \\ v_\eta^j\end{pmatrix} = E_\eta\begin{pmatrix} u_\eta^i \\ v_\eta^i\end{pmatrix},$$

with $\Delta_{ij} = V_D(\mathbf{r}_{ij})\langle\hat{c}_j\hat{c}_i\rangle$ and $L_{ij} = -t\delta_{\langle ij\rangle} + (\sum_k V_D(\mathbf{r}_{ik})\langle n_k\rangle + \frac{m}{2}\omega^2r_i^2 - \mu)\delta_{ij}$

$$g = D^2/a^3$$



The untrapped system at T=0:

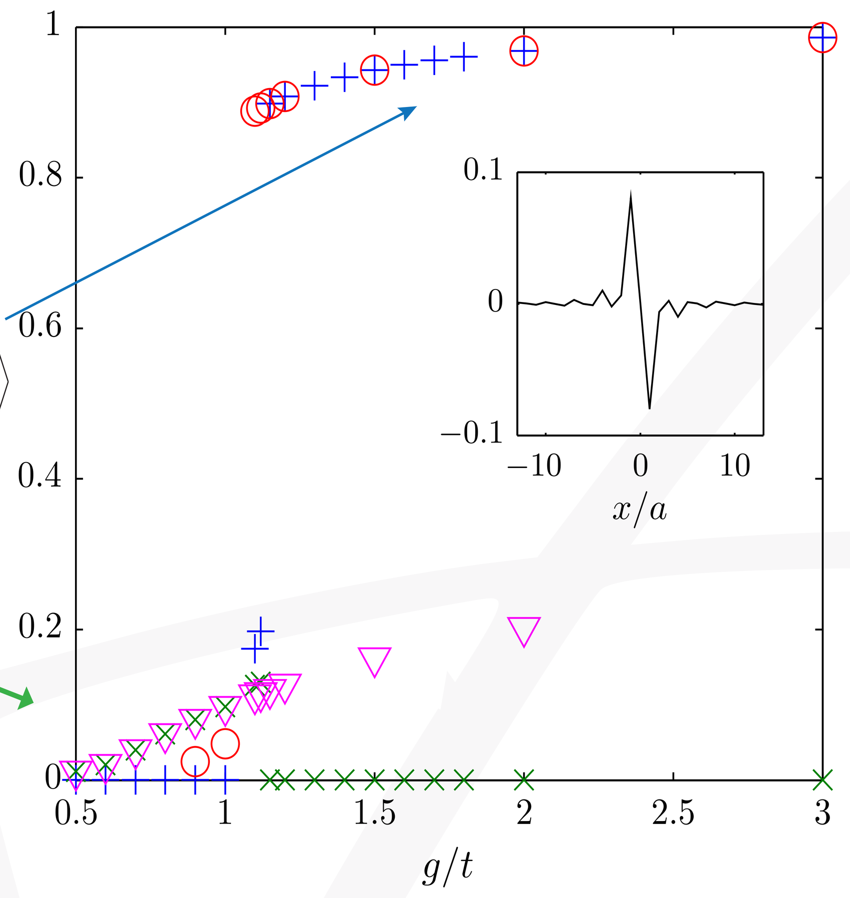
p-wave pairing and striped density order for f=1/3

$$(\theta_P,\varphi_P) = \left(\frac{\pi}{2},0\right)$$

+: density order $M = \left\langle\hat{n}_i - \hat{n}_{i+e_y}\right\rangle$

x: p-wave pairing $\left|\left\langle\hat{c}_i\hat{c}_{i+e_x}\right\rangle\right|$

$$\theta_P > \arcsin\left(\frac{1}{\sqrt{3}}\right)$$



Melting of density order:

Self-consistency for stripes: $1 = \frac{1}{N_L}\sum_{k_y>0}\frac{\tilde{V}_D(0,\pi/a)\left(f(E_{1\mathbf{k}}) - f(E_{2\mathbf{k}})\right)}{\sqrt{4t^2\cos^2 k_ya + \left(\frac{\tilde{V}_D(0,\pi/a)}{2}M\right)^2}}$

Critical temperature: $T_c = -\frac{1}{4}\begin{cases}\tilde{V}_D(0,\pi/a) & \textbf{Stripes} \\ \tilde{V}_D(\pi/a,\pi/a) & \textbf{Checkerboard}\end{cases}$

$T_c \propto g$

Superfluid melting:

Phase-twist on order parameter: $\Delta_{ij} \to \Delta_{ij}e^{i(x_i+x_j)\delta\theta/a}$ $v_s = \frac{\hbar\delta\Theta}{2m^*a}$

Energy cost: $F_\theta - F_0 \approx \frac{J_x^{XY}}{2}\sum_i\delta\Theta^2 = \frac{N}{2}\rho_{s,x}m^*v_s^2$

Equivalent to gauge transformation: $\hat{H}_\Theta = e^{-i\delta\theta\sum_l\hat{x}_l/a}\hat{H}e^{i\delta\theta\sum_l\hat{x}_l/a}$

$$T_{BKT} = \frac{\pi\bar{J}}{2} = \frac{\pi}{4}\frac{N}{N_L}\bar{\rho}_s t$$

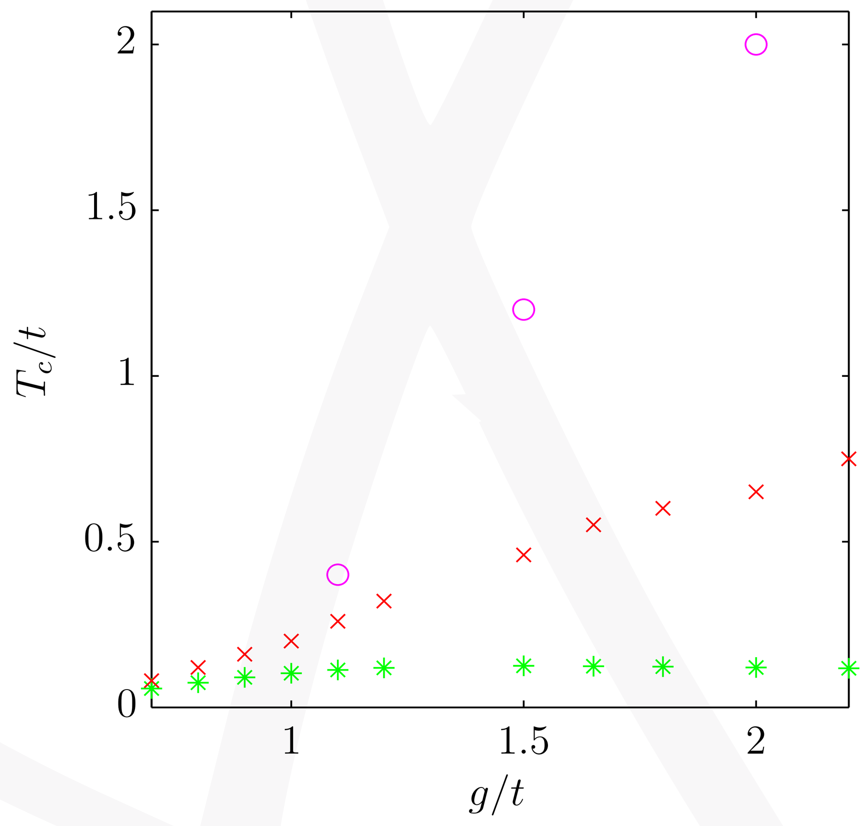
Critical temperature in the untrapped system:

o: T_c^{st}

x: T^*

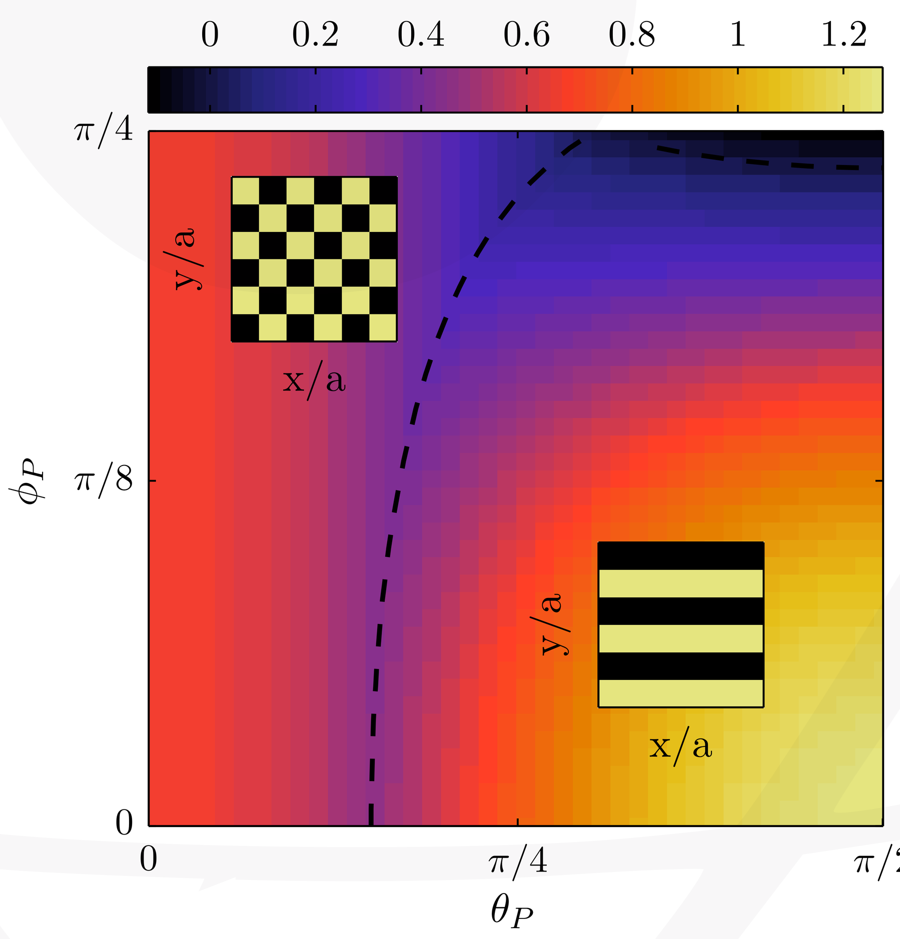
*: T_{BKT}

f=1/3



The critical temperature for the superfluid phase ($*$'s) and the striped phase ($\circ$'s) for $(\theta_P,\phi_P) = (\pi/2,0)$ as a function of coupling strength for one third filling obtained from a numerical calculation on a 27×27 lattice. The $\times$'s give the mean-field superfluid transition temperature T^*. For illustrative purposes, we plot the critical temperature of the superfluid phase even for $g/t > 1.15$, where stripe order suppresses superfluidity.

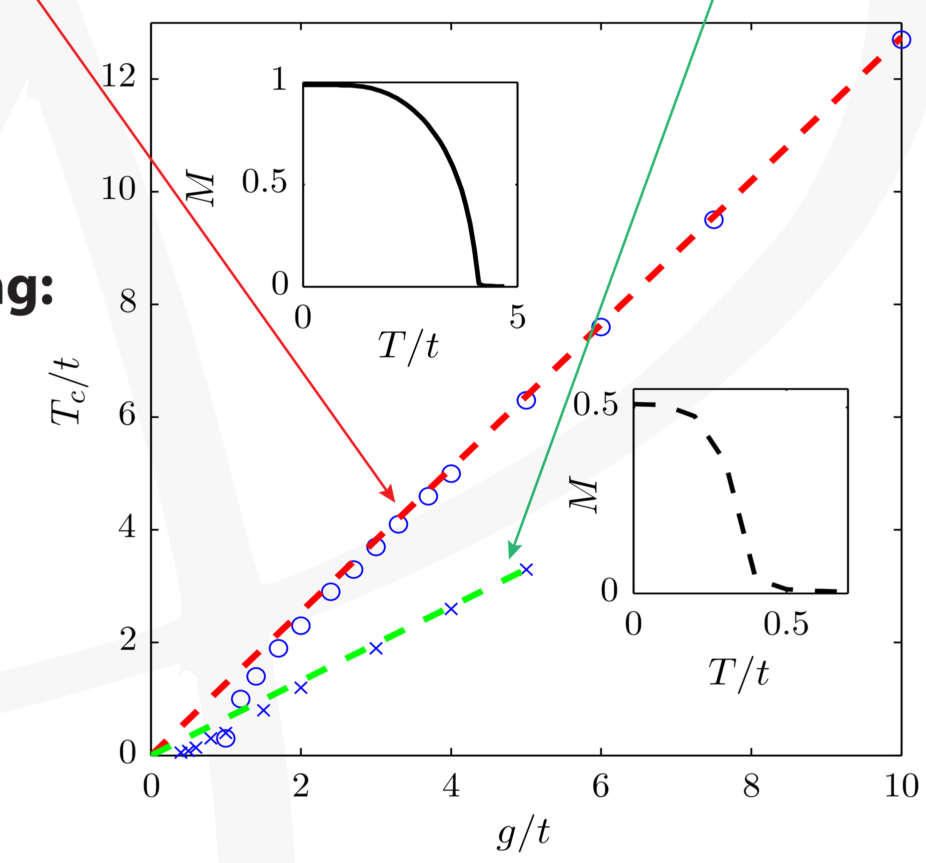
Critical temperature in the strong coupling regime:



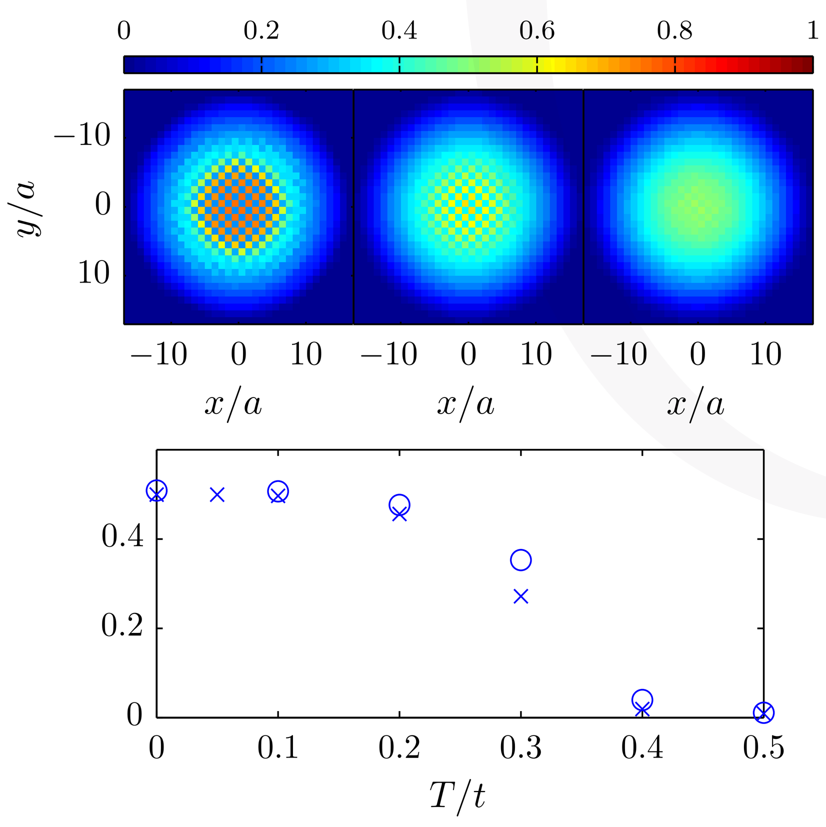
$T_c^{st} = -\frac{1}{4}\tilde{V}_D(0,\pi/a)$

$T_c^{CB} = -\frac{1}{4}\tilde{V}_D(\pi/a,\pi/a)$

Half-filling: f=1/2



Checkerboard melting: $\theta_P = 0$



$$M = \left\langle\hat{n}_i - \hat{n}_{i+e_y}\right\rangle$$

$$\frac{1}{2}\left(\left|\left\langle\hat{c}_{i+e_x}\hat{c}_i\right\rangle\right| + \left|\left\langle\hat{c}_i\hat{c}_{i+e_x}\right\rangle\right|\right)$$

Stripe and superfluid melting: $(\theta_P,\varphi_P) = \left(\frac{\pi}{2},0\right)$