Field-Angle Resolved Zero Energy Density of States for UPt_3

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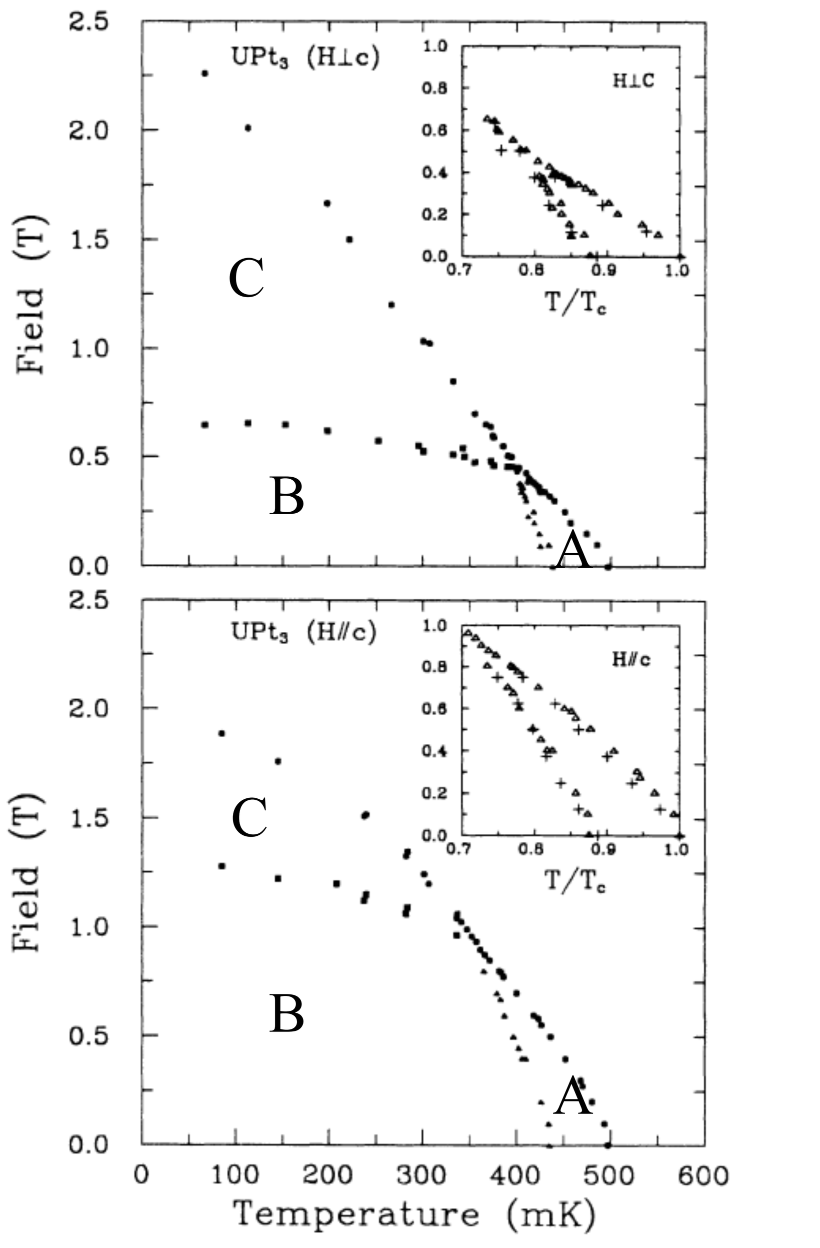
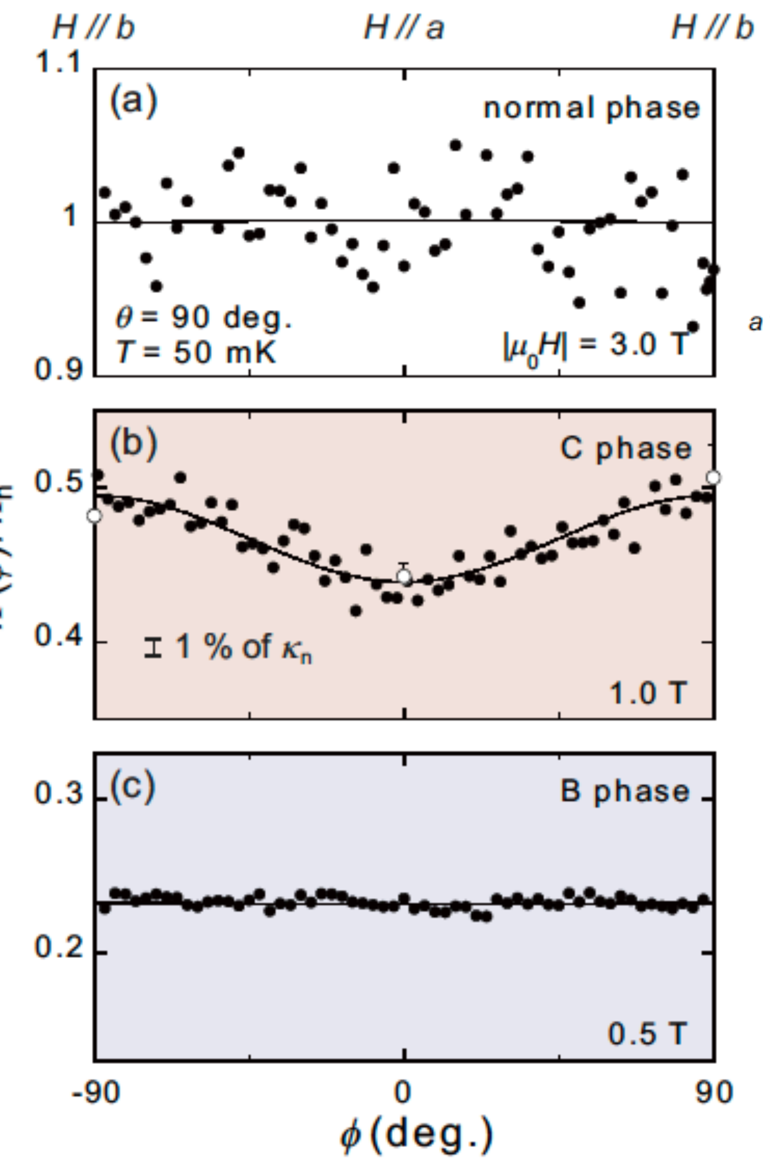
Introduction

Phase diagram



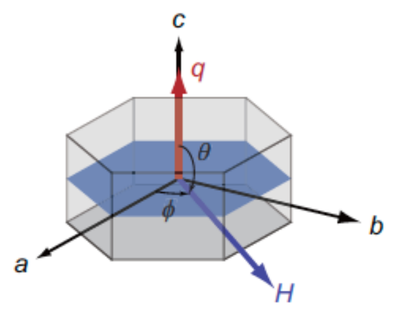
S. Adenwalla *et al.*, PRL **65**, 2298 (1990).

Thermal conductivity



Y. Machida *et al.*, arXiv:1107.3082v1.

twofold oscillation in C phase

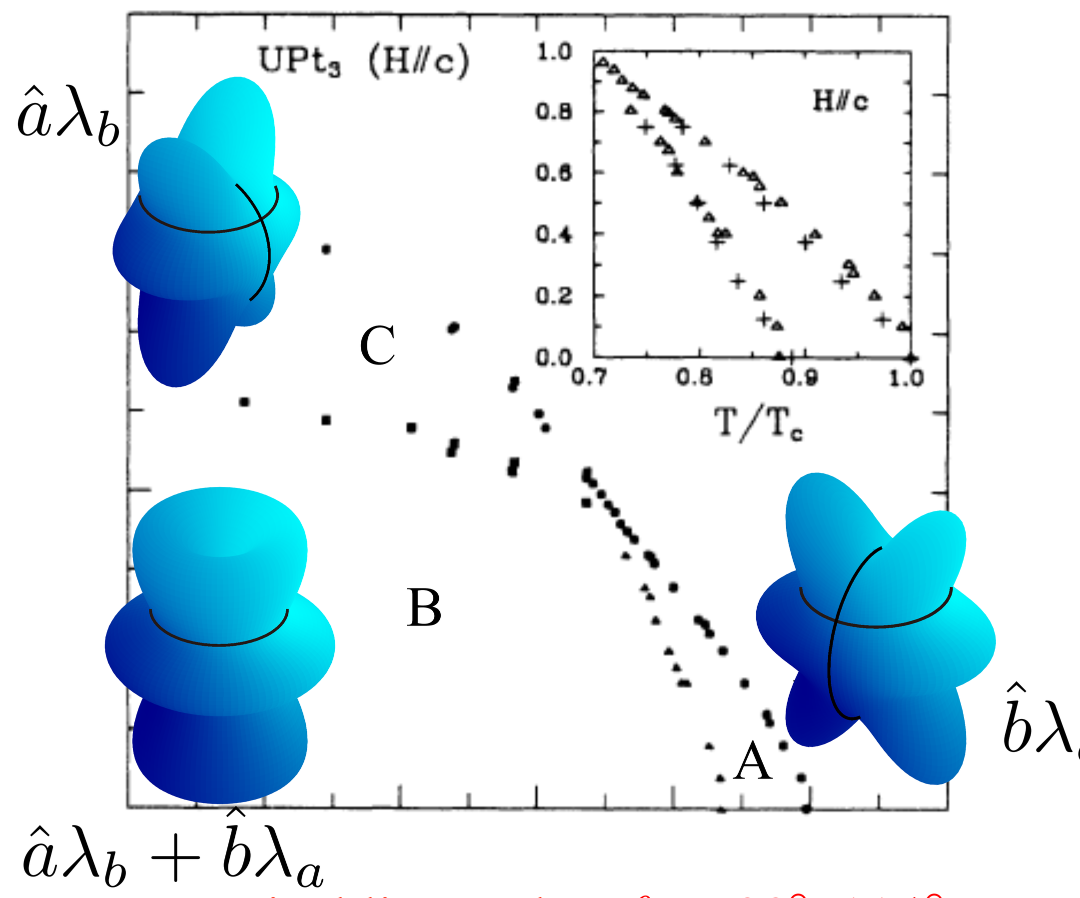


Determination of gap functions which satisfy the following conditions

- line node
- spin-triplet
- twofold symmetry in C phase

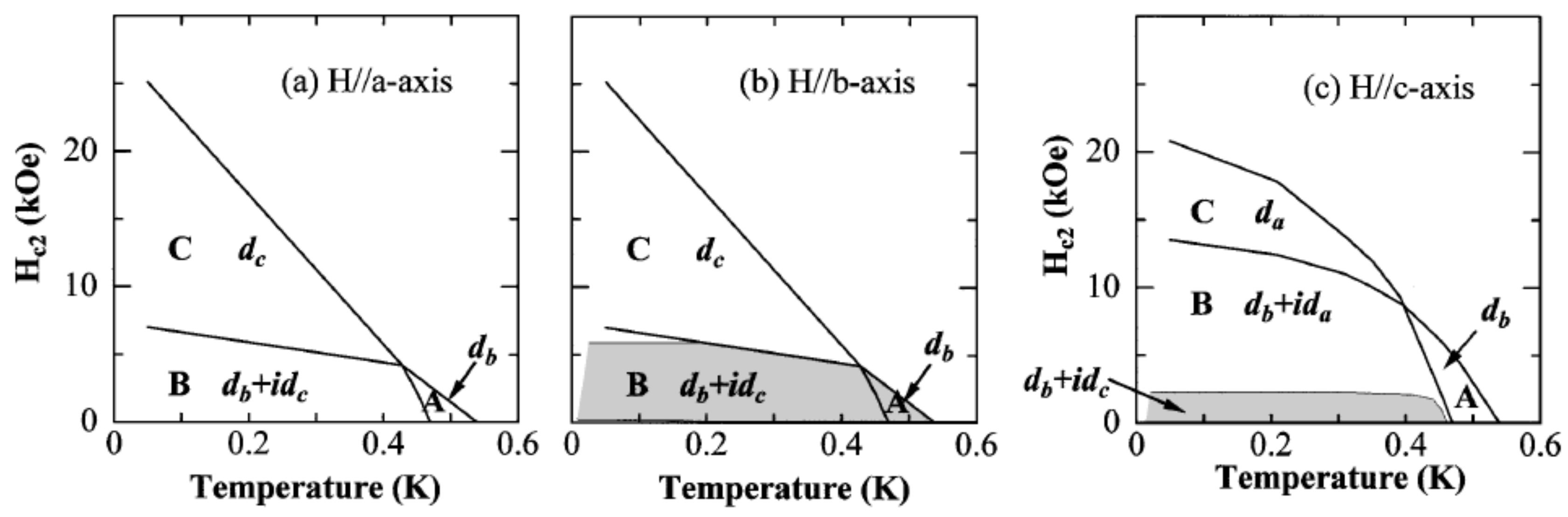
E_{1u} representation

$$\lambda_a = k_a(5k_c^2-1),\ \lambda_b = k_b(5k_c^2-1)$$



tropical line nodes: $\theta \approx 66^\circ, 114^\circ$

NMR Knight shift



H. Tou *et al.*, PRL **80**, 3129 (1998).

We have compared thermal conductivity and field-angle resolved zero energy density of states for this E_{1u} model and the other E_{1g} and E_{2u} models.

Quasi-Classical Theory

Eilenberger equation

$$-i\hbar \boldsymbol{v}_F\cdot\boldsymbol{\nabla}\hat{g}(\boldsymbol{k}_F,\boldsymbol{r},\omega_n) = \left[\begin{pmatrix} (i\omega_n - \boldsymbol{v}_F\cdot\boldsymbol{A})\hat{1} & -\hat{\Delta}(\boldsymbol{k}_F,\boldsymbol{r}) \\ \hat{\Delta}^\dagger(\boldsymbol{k}_F,\boldsymbol{r}) & -(i\omega_n - \boldsymbol{v}_F\cdot\boldsymbol{A})\hat{1}\end{pmatrix}, \hat{g}(\boldsymbol{k}_F,\boldsymbol{r},\omega_n)\right]$$

$$\hat{g} = -i\pi\begin{pmatrix}\hat{g} & i\hat{f} \\ -i\hat{\underline{f}} & -\hat{\underline{g}}\end{pmatrix} \qquad \hat{\Delta}, \boldsymbol{A}$$

Self-consistent condition

$$\hat{\Delta}(\boldsymbol{k}_F,\boldsymbol{r}) = N_0\pi k_B T \sum_{-\omega_c\le\omega_n\le\omega_c}\left\langle V(\boldsymbol{k}_F,\boldsymbol{k}'_F)\hat{f}(\boldsymbol{k}'_F,\boldsymbol{r},\omega_n)\right\rangle_{\boldsymbol{k}'_F}$$

$$\boldsymbol{A} = \boldsymbol{B}\times\boldsymbol{r}/2+\boldsymbol{a} \qquad \boldsymbol{j}_s = -\frac{2T}{\kappa^2}\sum_{0\le\omega_n\le\omega_c}\langle \boldsymbol{v}_F \mathrm{Im}\{g_0\}\rangle_{\boldsymbol{k}_F}$$

$$\boldsymbol{\nabla}\times\boldsymbol{\nabla}\times\boldsymbol{a} = \boldsymbol{j}_s$$

Density of states (DOS)

$$\hat{g} = \begin{pmatrix} g_0+g_z & g_x-ig_y \\ g_x+ig_y & g_0-g_z\end{pmatrix}$$

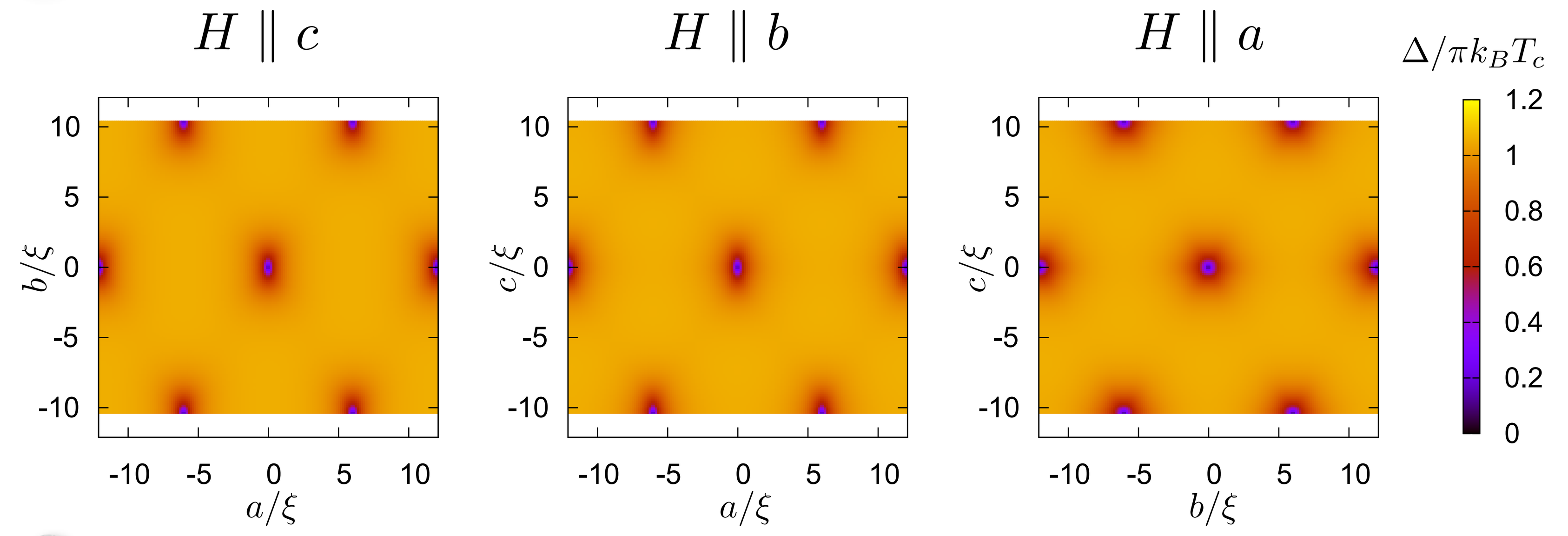
$$N(E) = \frac{1}{S}\int dSN(\boldsymbol{r},E) = \frac{1}{S}\int dSN_0\left\langle \mathrm{Re}[g_0(\boldsymbol{k}_F,\boldsymbol{r},\omega_n)|_{i\omega_n\to E+i\eta}]\right\rangle_{\boldsymbol{k}_F}$$

Numerical calculation

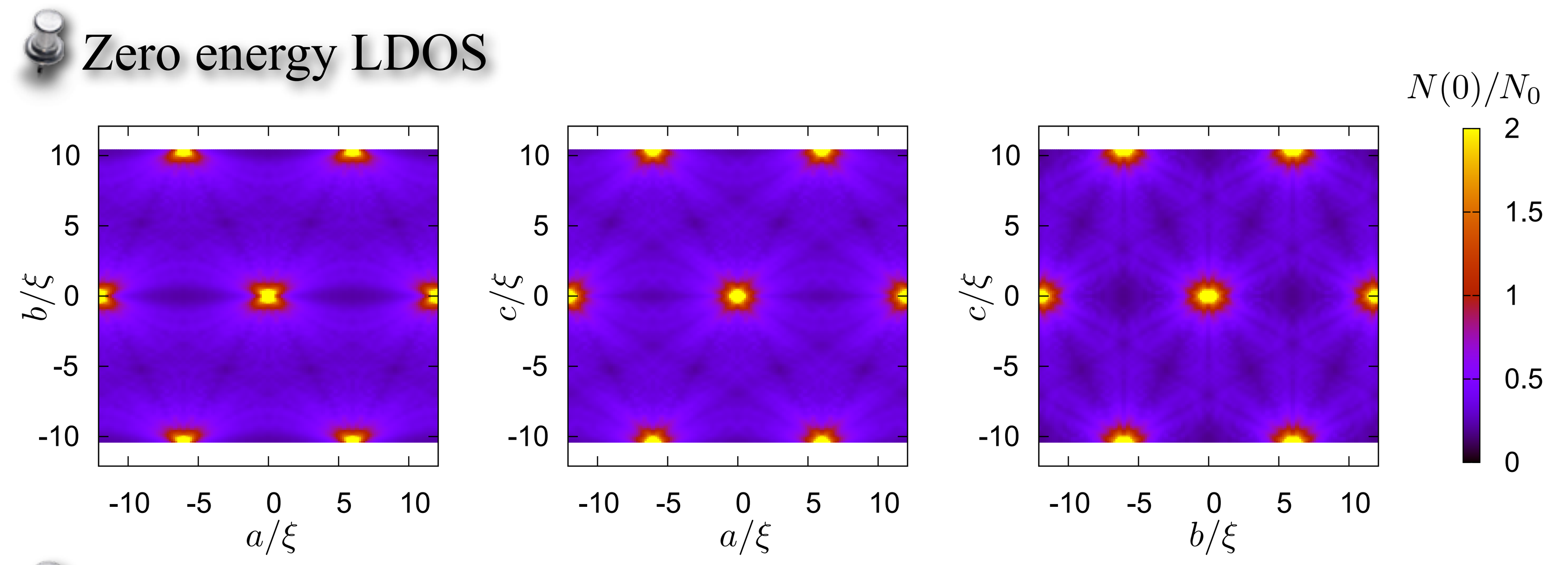
- C phase: $V(\boldsymbol{k}_F,\boldsymbol{k}'_F)\propto\lambda_b(\boldsymbol{k}_F)\lambda_b(\boldsymbol{k}'_F)$, fixed spin state
- Fermi sphere
- triangular lattice
- GL parameter: $\kappa = 60$
- $T = 0.2T_c,\ B = 0.05\ (B_{c2}\sim 1)$
- $\eta = 0.01\pi k_B T_c$

Result

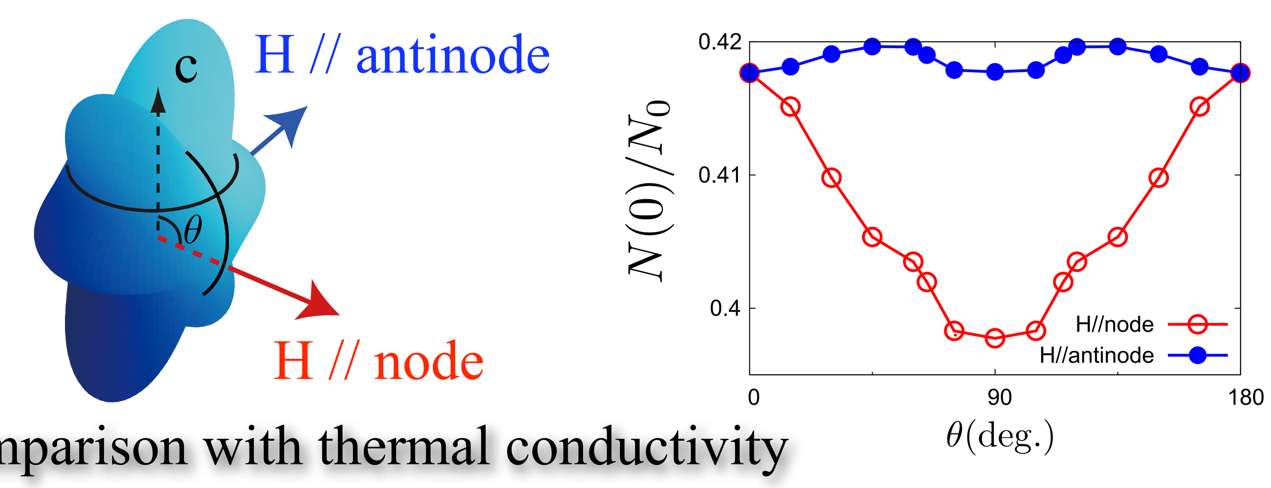
Order parameter



Zero energy LDOS

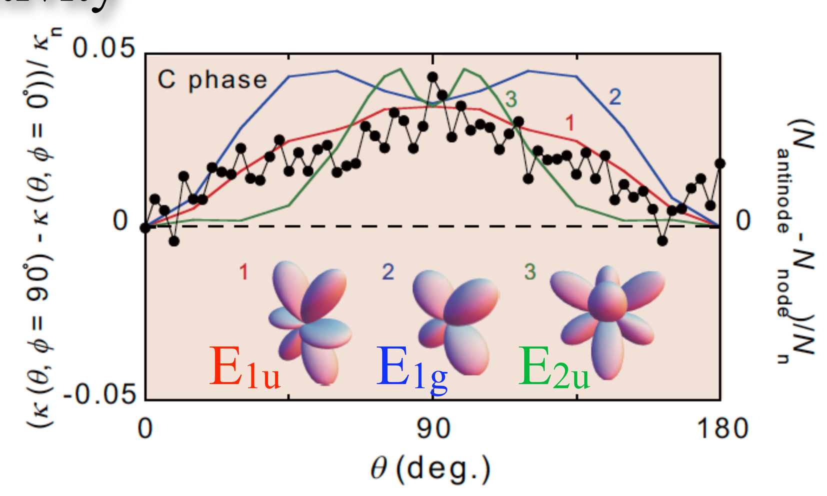


Field-angle resolved zero energy DOS



Comparison with thermal conductivity

We have subtracted ZEDOS along nodal direction from that along antinodal direction to remove influence of heat current.
The only E_{1u} model has a maximum at $\theta = 90^\circ$ by tropical line nodes.
This behavior is consistent with thermal conductivity.



Y. Machida *et al.*, arXiv:1107.3082v1.

Summary

- New E_{1u} model is consistent with the recent experiment of thermal conductivity and previous experiments.
- Direct evidence of E_{1u} model is expected in vortex state.
  - Vortex lattice structure in C phase by twofold symmetry
  - Unconventional vortex in B phase by multicomponent