北海道大学　大学院理学院
Graduate School of Science
Hokkaido University

物性物理学専攻
Department of Condensed Matter Physics

先端機能物性理論研究室
Condensed Matter Theory Group

北海道大学 - NIMS 連係大学院
Hokkaido University-NIMS
Joint Graduate Program

博士研究の実施場所：NIMS, つくば市千現
PhD project at NIMS, Sengen, Tsukuba

NIMS ジュニア研究員制度
NIMS Graduate Research Assistantship

https:www.nims.go.jp/nqt/yamase/

量子多体物性の理論的研究

電子間にはクーロン相互作用やスピン交換相互作用が働いています。固体中のような
アボガドロ数程の多数の電子がいる環境では、それらの相互作用は集団励起を引き起こし、
物質は低温で超伝導や磁性を始めとする様々な特性を示します。このような電子間の
多体相互作用という観点から物質の基礎的概念の創出を理論的に研究しています。
特に、解析的な理論手法と数値計算を駆使して、高温超伝導、超伝導と磁性の共存・競合、
臨界現象と量子相転移、電子ネマチック相等の新規量子状態の研究を進めています。

博士課程では、「理論」という道具を使って如何にして物性を理解していくか。この感覚を身に
付け物質科学の発展に貢献する力を養います。研究は物質・材料研究機構（茨城県つくば市）
で行い、NIMSジュニア研究員という肩書きも持ちます。

博士課程進学の前に、インターンとして最大90日間、物質・材料研究機構にある本研究室で
経験を積むこともできます。ただし、博士課程に進学する意思がある場合に限ります。

スケジュール

1. （インターンシップ: 毎年1月と5月に公募）
2. 北大院試
3. 修士課程入学
4. NIMSジュニア研究員への応募
   毎年5月、10月
   修士2年の時
5. 北大院試
6. 博士課程入学
   物質・材料研究機構にて博士論文の研究。
7. 学位取得（3年以内）

Theoretical study of quantum-many body states

Materials contain a huge number of electrons, typically in the order of Avogadro's number, which interact with each other via Coulomb forces and spin exchang. These interactions generate collective excitations, which in turn give rise to various properties such as superconductivity and magnetism at low temperatures. We are interested in such phenomena driven by many-body effects and are seeking to innovate fundamental concepts of material by utilizing analytical and computational methods. We are currently working on high-temperature superconductivity, interplay of superconductivity and magnetism, critical phenomena and quantum phase transitions,and novel quantum states such as an electronic nematic state.

The present PhD course emphasizes the development of ability to perceive and innovate fundamental concepts of materials through theoretical studies. PhD students carry out their porjects at National Institute for Materials Science in Tsukuba and will receive the NIMS Graduate Research Assistantship.

We offer the NIMS Internship Program for those who wish to work with us up to 90 days before their entering the PhD course.

Schedule

1. (Internship program: application in January)
2. Entrance exams of the master course in Hokkaido Univ.
3. Master project
4. Application for NIMS Graduate Research Assistantship
   May or October
   when students are in the second grade of the master course
5. Entrance exams of the doctor course in Hokkaido Univ.
6. PhD project
   at National Institute for Materials Science, Tsukuba
7. PhD degree within 3 years

PHYSICAL REVIEW B **91**, 195121 (2015)

Electronic nematic phase transition in the presence of anisotropy

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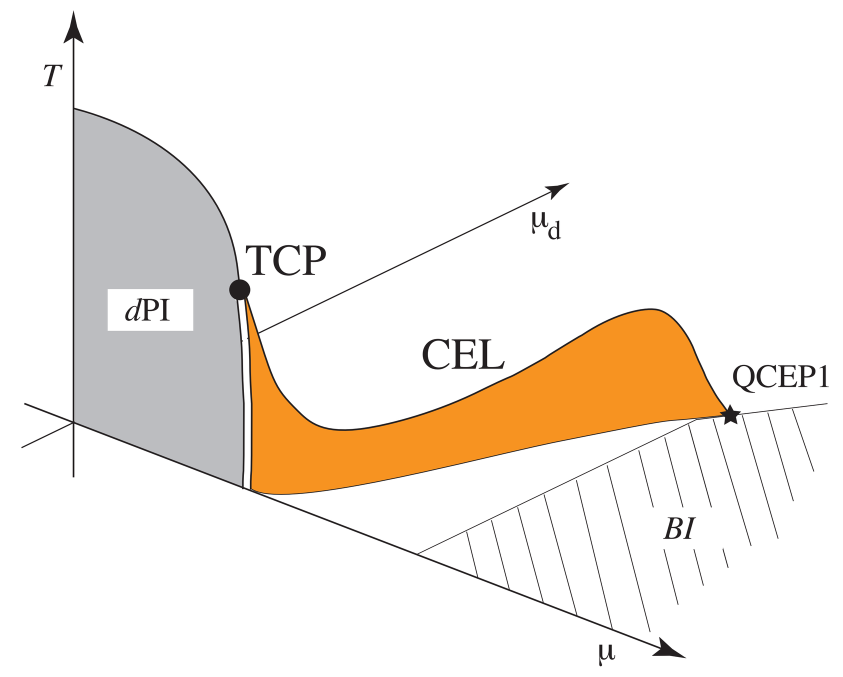
(Received 5 March 2014; revised manuscript received 29 April 2015; published 13 May 2015)

We study the phase diagram of electronic nematic instability in the presence of xy anisotropy. While a second-order transition cannot occur in this case, mean-field theory predicts that a first-order transition occurs near Van Hove filling and its phase boundary forms a wing structure, which we term a Griffiths wing, referring to his original work of He^3-He^4 mixtures. When crossing the wing, the anisotropy of the electronic system exhibits a discontinuous change, leading to a metanematic transition, i.e., the analog to a metamagnetic transition in a magnetic system. The upper edge of the wing corresponds to a critical end line. It shows a nonmonotonic temperature dependence as a function of the external anisotropy and vanishes at a quantum critical end point for a strong anisotropy. The mean-field phase diagram is found to be very sensitive to fluctuations of the nematic order parameter, yielding a topologically different phase diagram. The Griffiths wing is broken into two pieces. A tiny wing appears close to zero anisotropy and the other is realized for a strong anisotropy. Consequently three quantum critical end points are realized. We discuss that these results can be related to various materials including a cold atom system.

DOI: 10.1103/PhysRevB.91.195121　　PACS number(s): 05.30.Fk, 64.70.Tg, 71.10.Hf, 71.18.+y



Griffiths wing (orange) associated with electronic nematic phase transition

$$\partial_\Lambda \Gamma^\Lambda[\phi] = \frac{1}{2}\mathrm{tr}\frac{\partial_\Lambda R^\Lambda}{\Gamma_2^\Lambda[\phi] + R^\Lambda}$$

$$\Gamma^\Lambda[\phi] = \frac{1}{2}\sum_q{}' \left[\phi_q\left(A^\Lambda\frac{|\omega_n|}{|\mathbf{q}|} + Z^\Lambda \mathbf{q}^2\right)\phi_{-q}\right] + \mathcal{U}^\Lambda[\phi]$$

RAPID COMMUNICATIONS
PHYSICAL REVIEW B **88**, 180502(R) (2013)

Superconductivity from orbital nematic fluctuations

Hiroyuki Yamase[1,2] and Roland Zeyher[1]
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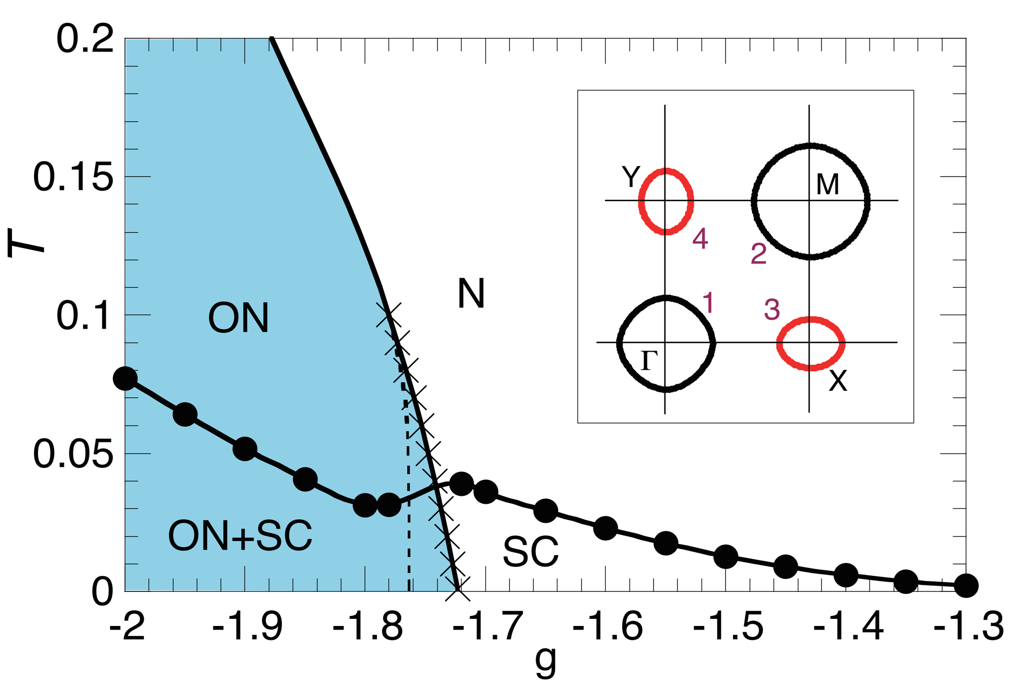
(Received 12 March 2013; revised manuscript received 18 October 2013; published 6 November 2013)

Recent experiments suggest that, besides antiferromagnetic fluctuations, nematic fluctuations may contribute to the occurrence of superconductivity in iron pnictides. Motivated by this observation, we study superconductivity from nematic fluctuations in a minimal two-band model. The employed band parameters are appropriate for iron pnictides and lead to four pockets for the Fermi line. It is shown that low-energy, long-wavelength nematic fluctuations within the pockets give rise to strong-coupling superconductivity whereas the large momenta density fluctuations between pockets are rather irrelevant. The obtained transition temperatures are similar to those typically found in the pnictides and are rather robust against repulsive Coulomb interactions. The superconducting and nematic states coexist in a large region of the phase diagram.

DOI: 10.1103/PhysRevB.88.180502　　PACS number(s): 74.20.Mn, 74.25.Dw, 74.70.Xa, 75.25.Dk



high-T_c superconducting mechanism from orbital nematic fluctuations

$$\Delta_i(i\omega_n)Z_i(i\omega_n) = -\pi T \sum_{j,n'} N_j \frac{\tilde{g}_{ij}(i\omega_n - i\omega_{n'})}{|\omega_{n'}|}\Delta_j(i\omega_{n'})$$

$$Z_i(i\omega_n) = 1 - \pi T \sum_{j,n'} N_j \frac{\omega_{n'}}{\omega_n}\frac{\tilde{g}_{ij}(i\omega_n - i\omega_{n'})}{|\omega_{n'}|}$$

PRL **108,** 186405 (2012)　　PHYSICAL REVIEW LETTERS　　week ending 4 MAY 2012

Fermi-Surface Truncation from Thermal Nematic Fluctuations

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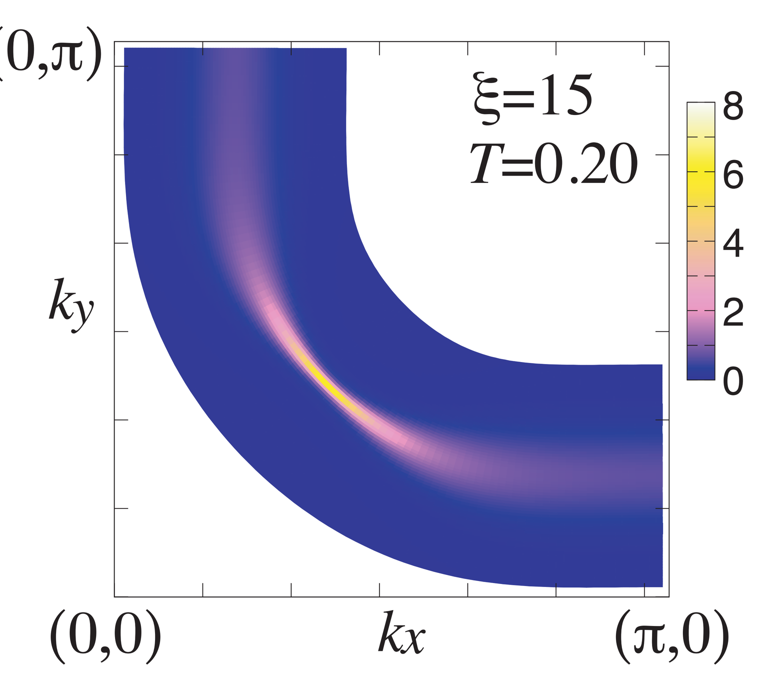
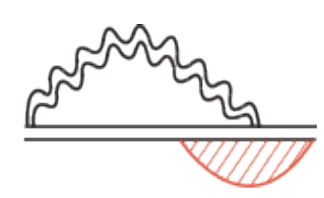
(Received 24 November 2011; published 4 May 2012)

We analyze how thermal fluctuations near a finite temperature nematic phase transition affect the spectral function $A(\mathbf{k}, \omega)$ for single-electron excitations in a two-dimensional metal. Perturbation theory yields a splitting of the quasiparticle peak with a *d*-wave form factor, reminiscent of a pseudogap. We present a resummation of contributions to all orders in the Gaussian fluctuation regime. Instead of a splitting, the resulting spectral function exhibits a pronounced broadening of the quasiparticle peak, which varies strongly around the Fermi surface and vanishes upon approaching the Brillouin-zone diagonal. The Fermi surface obtained from a Brillouin-zone plot of $A(\mathbf{k}, 0)$ seems truncated to Fermi arcs.

DOI: 10.1103/PhysRevLett.108.186405　　PACS numbers: 71.18.+y, 71.10.Hf, 71.27.+a



Fermi surface truncation from thermal nematic fluctutaoins

$\Sigma(\mathbf{k},\omega) =$ 

$$\hat{A}(x) = \frac{1}{2\pi v_{\mathbf{k}_F}} \exp\left[\int_0^x dx' \int_0^{x'} dx'' \, T \frac{\tilde{g} d_{\mathbf{k}_F}^2}{2\pi v_{\mathbf{k}_F}^2} K_0(x''/\xi)\right]$$