A01 New Quantum Fluid Phases Realized by Correlation Control

ア. New quantum phases in 2D Helium (^{3}He, ^{4}He)

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イ. New quantum phenomena near quantum critical points

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Yukitoshi Motome (*Riken*)

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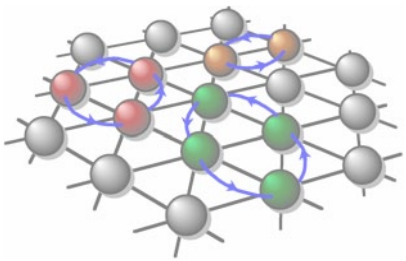
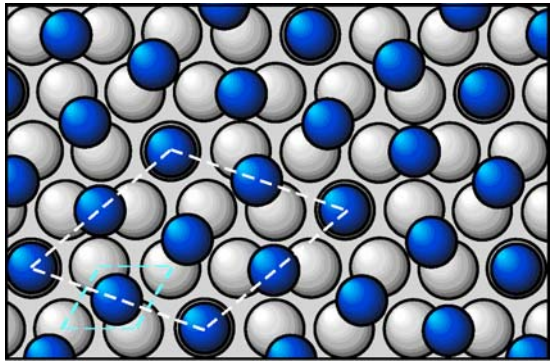
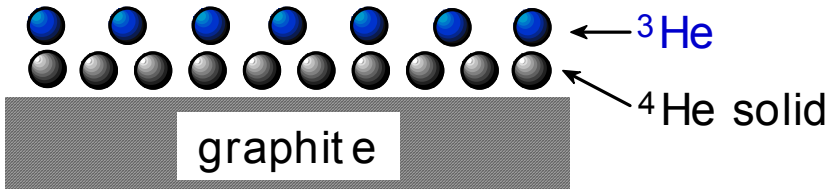


2D ^{3}He : Highly correlated Fermion system

Our system : 2nd-layer ^{3}He on graphite



1st layer 2nd layer



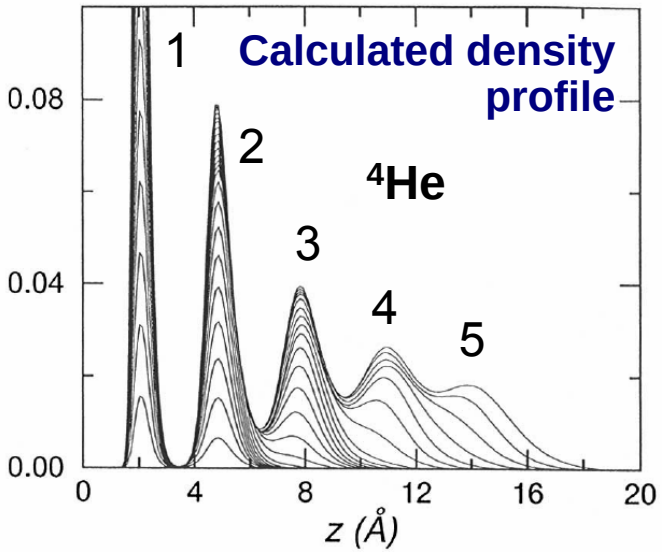
4/7 phase (commensurate phase)

- **Mott localized phase** A. Casey et al.,PRL **90**, 115301 (2003)
- **Ideal 2D Fermion system** with short-range repulsions

densities of 1st layer ^{4}He
= 12.04 nm^{-2} for HC samples
= 11.78 nm^{-2} for NMR samples

1st - 2nd layer : almost complete isolation
2nd - 3rd layer : frequent exchanges

M. Roger et al., JLTP **112**, 45 (1998)

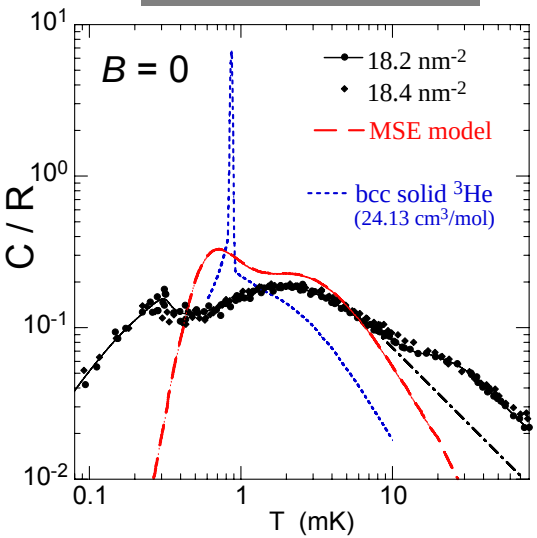


Frustrated magnetism in the 4/7 phase

- Absence of finite-T phase transitions ⋯ 2D
- Double peak in $C(T)$ ⋯ high frustration
- Gapless excitation

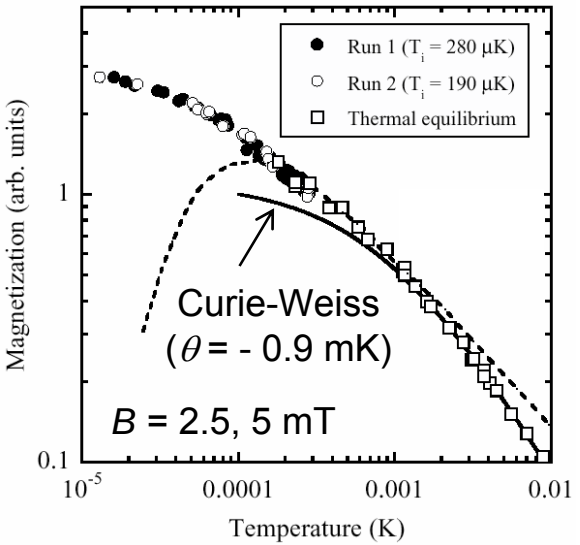
  absence of exponential T-dependencies of $C(T)$ and $M(T)$ at very low-T

Heat capacity

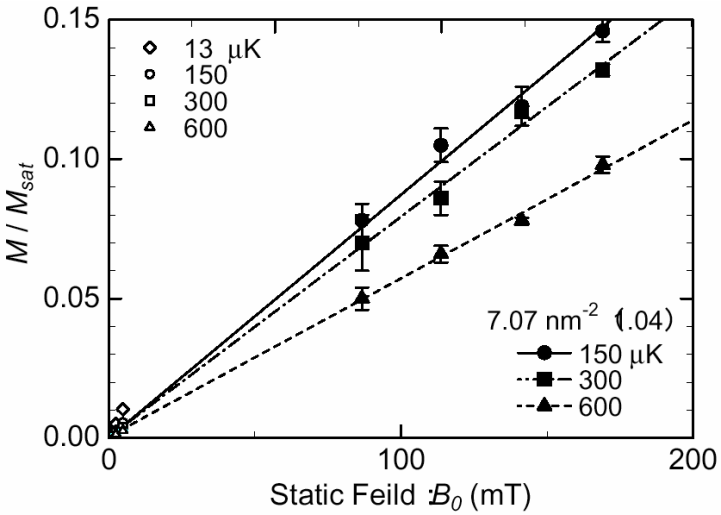


K. Ishida, Morishita, H. Fukuyama et al., PRL **79**, 3451 (1997)

magnetization



R. Masutomi, Ishimoto et al., PRL **92**, 025301 (2004)



S. Murakawa et al., to be published

magnetic ground state : Gapless quantum spin-liquid (QSL)

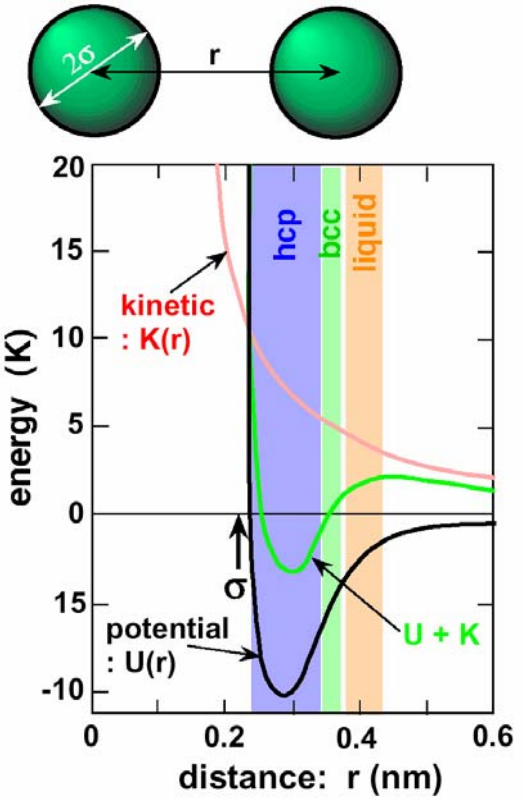
Physics of gapless quantum spin liquid

Mechanism

Frustration ⋯ **hardcore** system on **triangular** lattice

higher **correlations** at higher densities

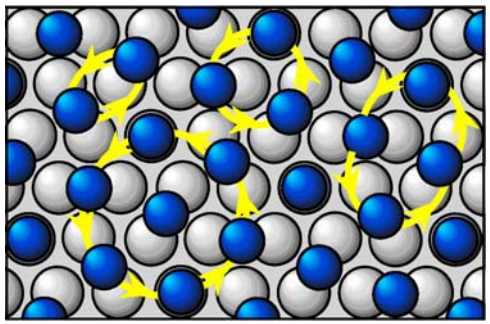
multiple spin exchange (**MSE**)



U (Coulomb) $\propto r^{-1}$

K (kinetic) $\propto r^{-2}$

U (hard core) $\propto r^{-12}$



Elementary excitation?

spinon (e.g., magnon in systems with LRO)

Effective Hamiltonian?

Ring exchange

$$H_{\text{eff}} = \sum_{P} (-1)^{P} J_{\text{P}} P$$

Momoi, Kubo

Hubbard

$$H = -t \sum_{\langle i,j \rangle,\sigma} c_{i\sigma}^{\dagger} c_{j\sigma} + U \sum_{i} n_{i\uparrow} n_{i\downarrow}$$

Imada, Watanabe

t-J

$$H = -t \sum_{\langle i,j \rangle,\sigma} P\left(c_{i\sigma}^{\dagger} c_{j\sigma} + h.c.\right)P + J \sum_{\langle i,j \rangle} S_i \bullet S_j$$

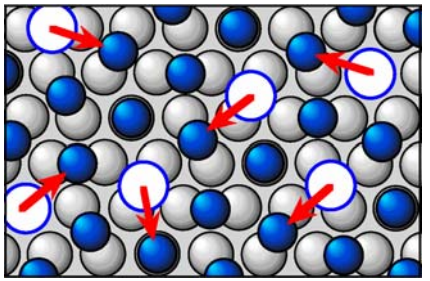
Ogata, Koretsune

Strongly correlated 2D fermion systems

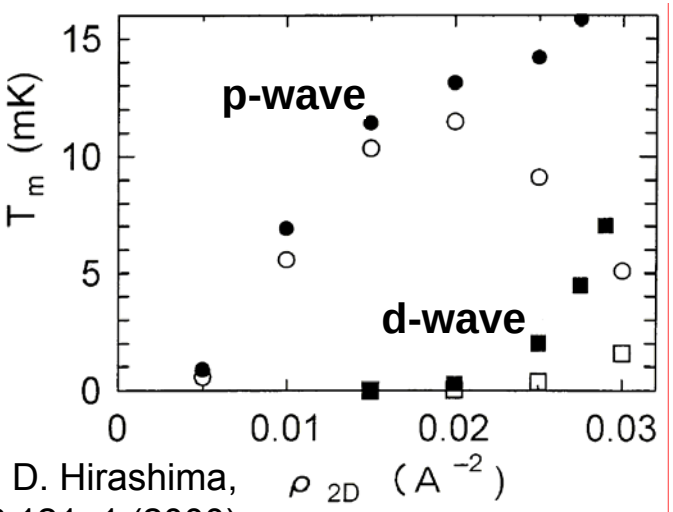
Can we dope holes or particles into the gapless QSL?

Possible new quantum phases

- vacancy doped phase?
- density modulated phases?
  domain walls (DW), DW fluid, …
- exotic magnetic phases?
- 2D superfluid phase?
  - s-wave spin-singlet … dilute limit
  - p-wave spin-triplet
    Takahashi-Hirashima (2000) … R- and K-matrix
  - d-wave spin-singlet … strongly correlated region
    Onishi-Miyake (1999) … paramagnon



vacancy doped phase

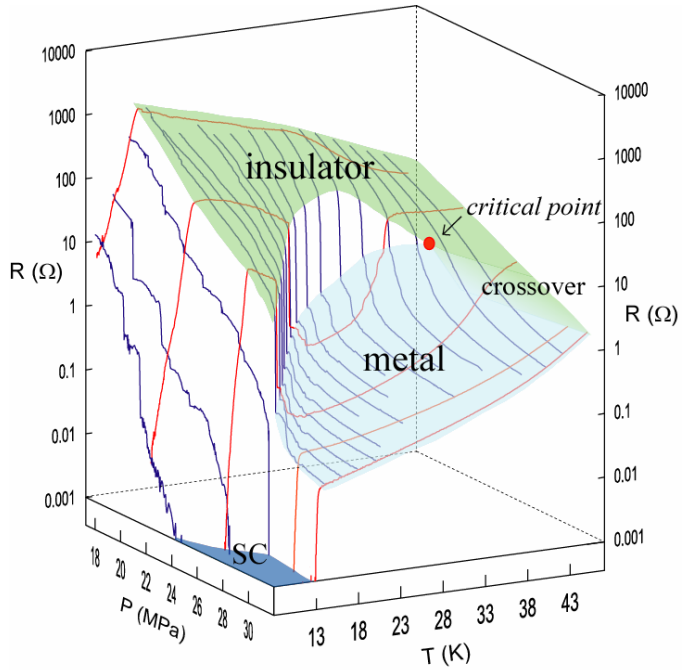


H. Takahashi and D. Hirashima,
JLTP 121, 1 (2000)

Other strongly correlated 2D fermion systems

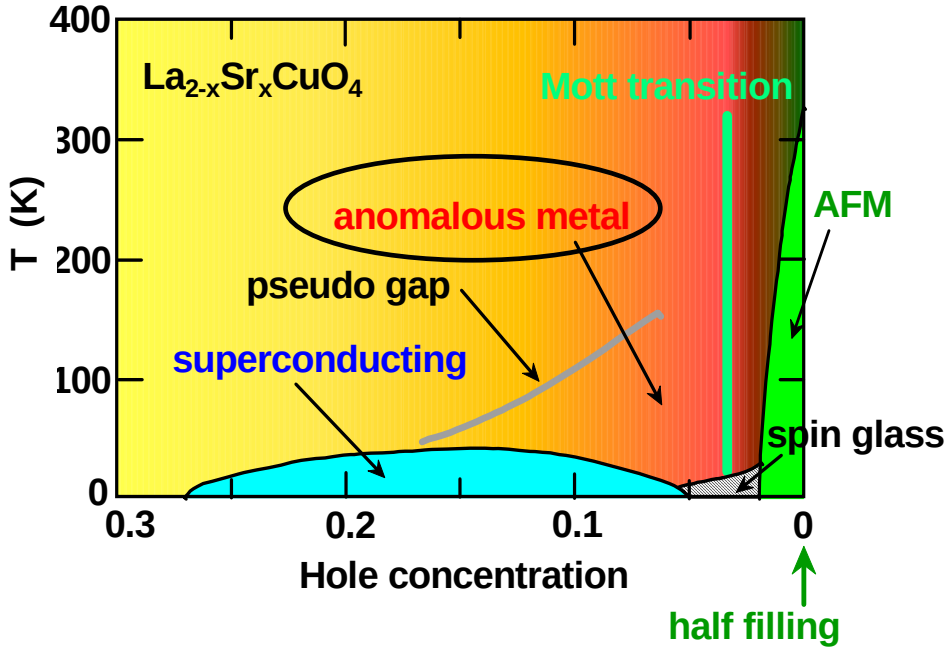
κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl

F. Kagawa, **K. Kanoda** et al., PRL. **91**, 107001 (2003)



- band width control (high pressure)
- triangular lattice
- gapless QSL

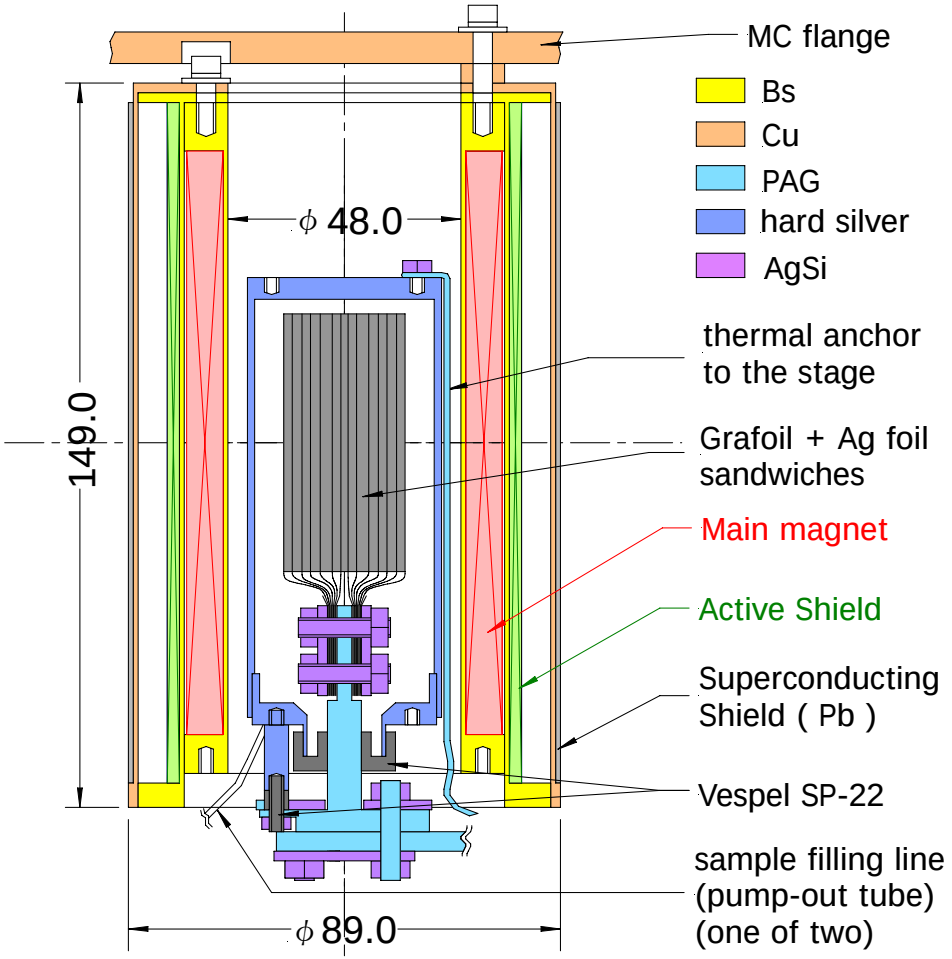
High T_c cuprates



- filling control
  (atom substitution)
- square lattice
- d-wave BCS state

Heat capacity sample cell

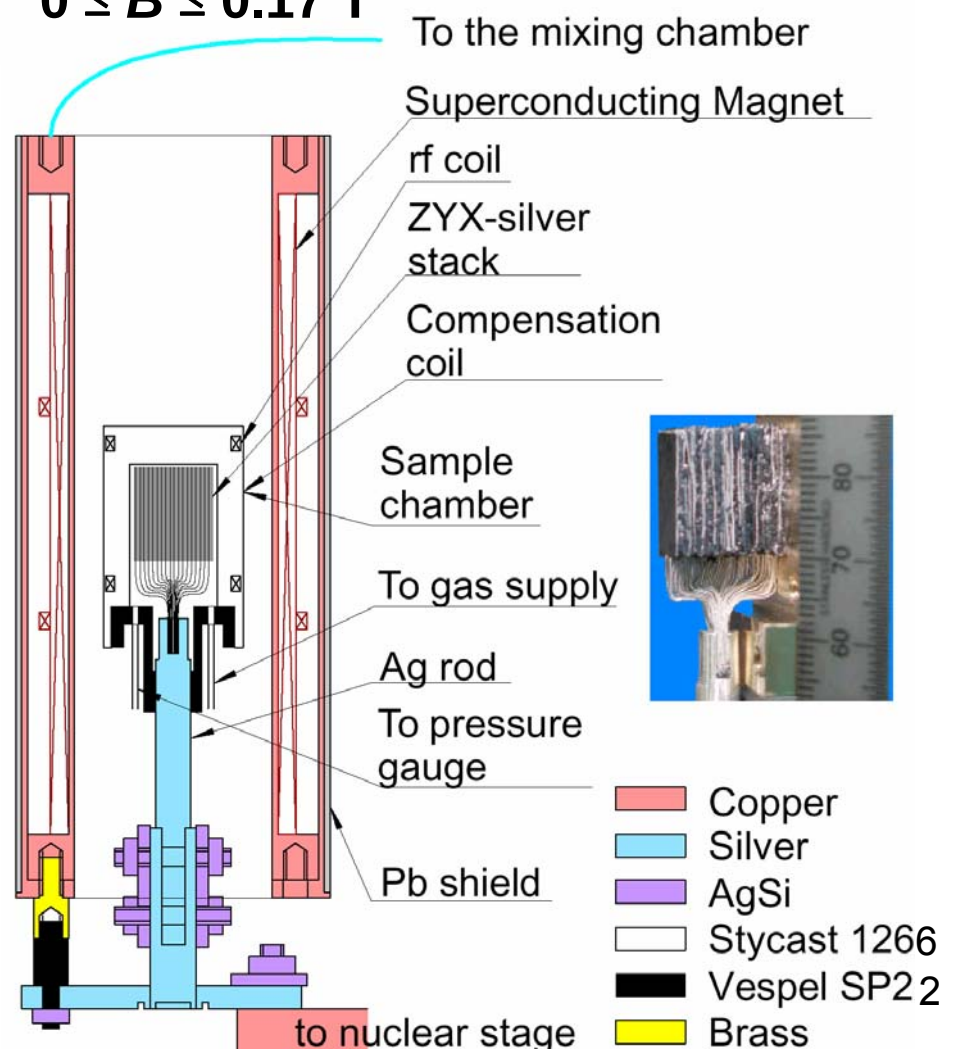
100 μK ≤ *T* ≤ 80 mK
0 ≤ *B* ≤ 1.2 T



Y. Matsumoto et al., Physica B **329-333**, 146 (2003)

NMR sample cell

60 μK ≤ *T* ≤ 500 mK
0 ≤ *B* ≤ 0.17 T

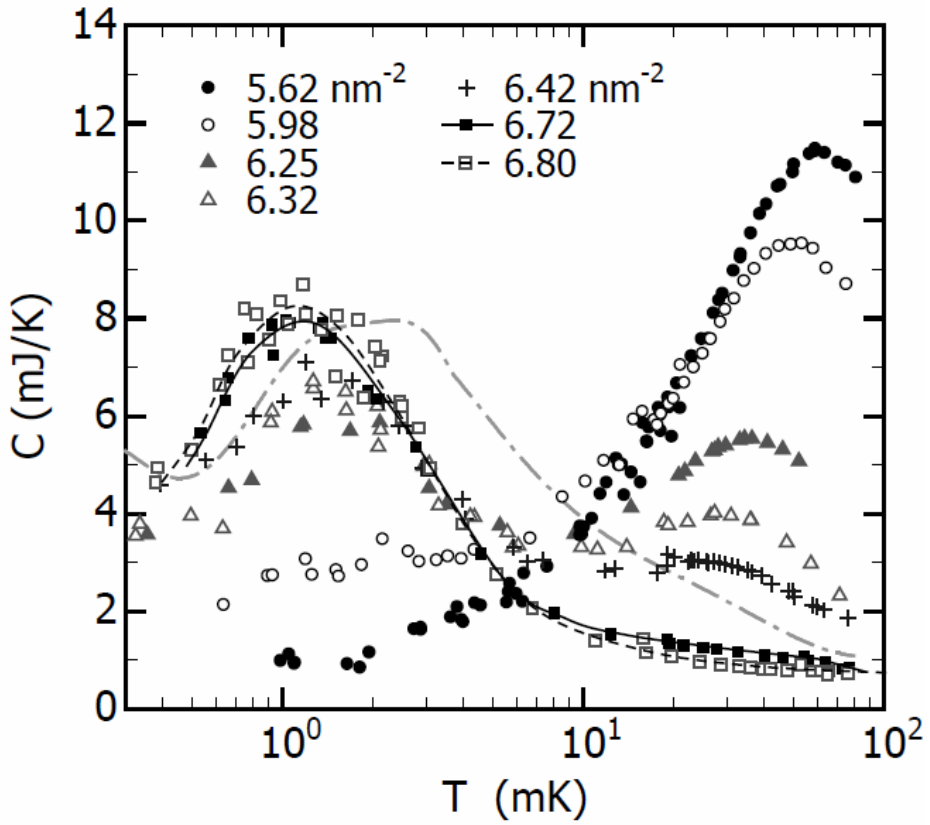


S. Murakawa et al., Physica B **329-333**, 144 (2003)

Heat capacities of 2D ^{3}He

low densities ($\rho \leq \rho_{4/7}$)

B = 0 T A = 556 m^2



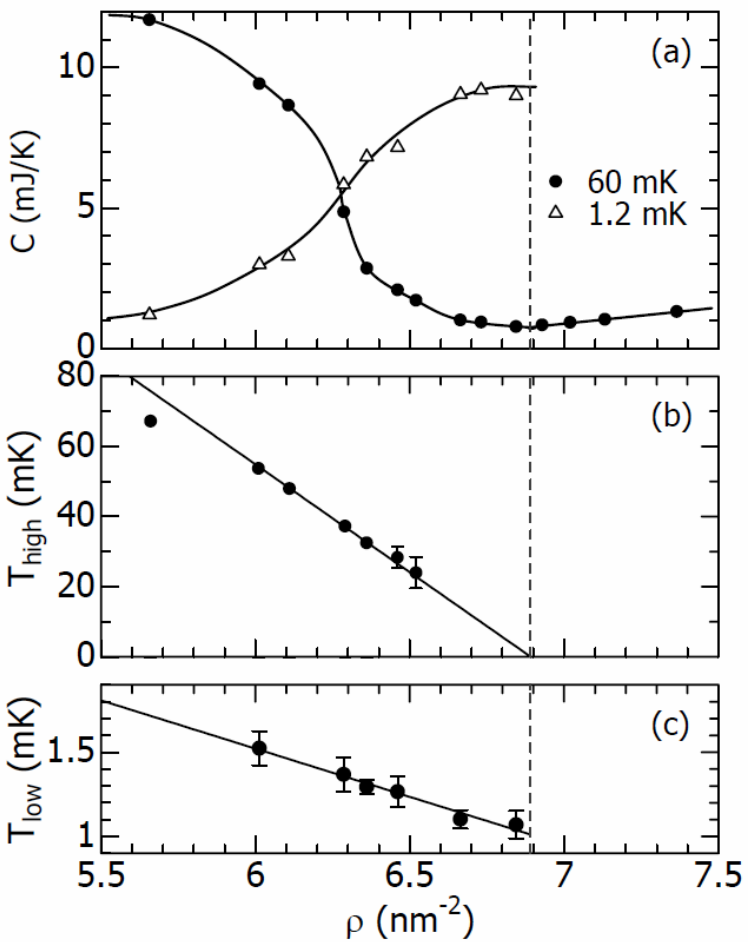
Y. Matsumoto et al., JLTP **138**, 271 (2005)

For more recent and unpublished heat capacity data including those at higher densities than $\rho_{4/7}$, please contact Hiroshi Fukuyama <hiroshi@phys.s.u-tokyo.ac.jp>

Heat capacity isotherms of 2D ^{3}He

low densities ($\rho \leq \rho_{4/7}$)

B = 0 T A = 556 m^2



Y. Matsumoto et al., Physica B (2006) to be published

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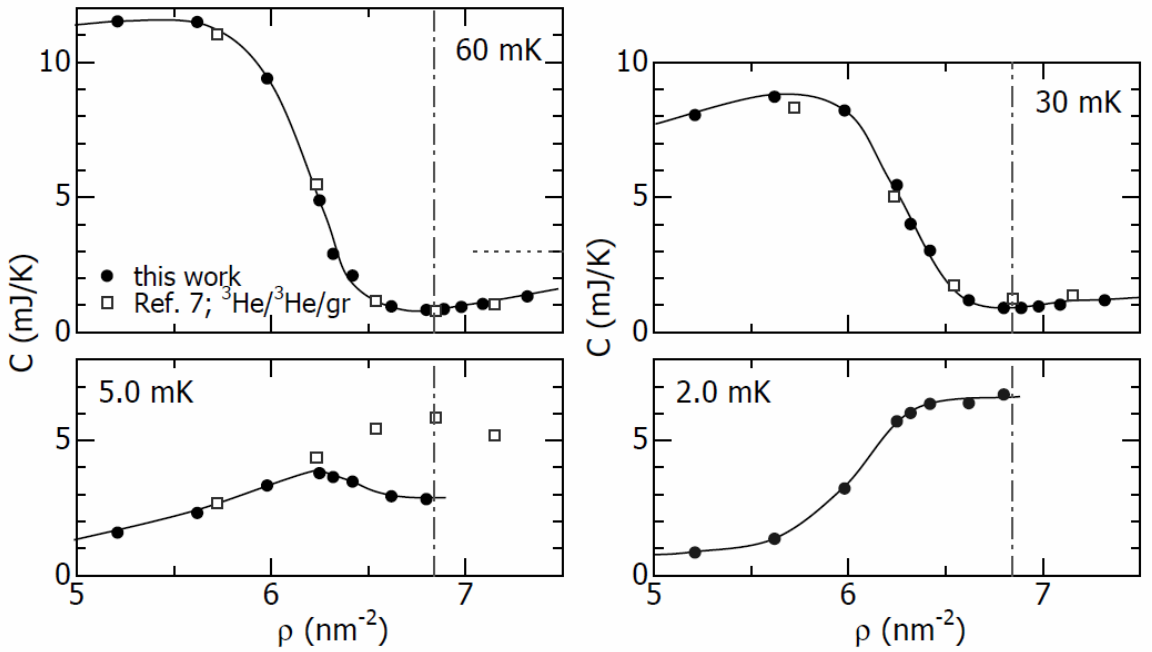


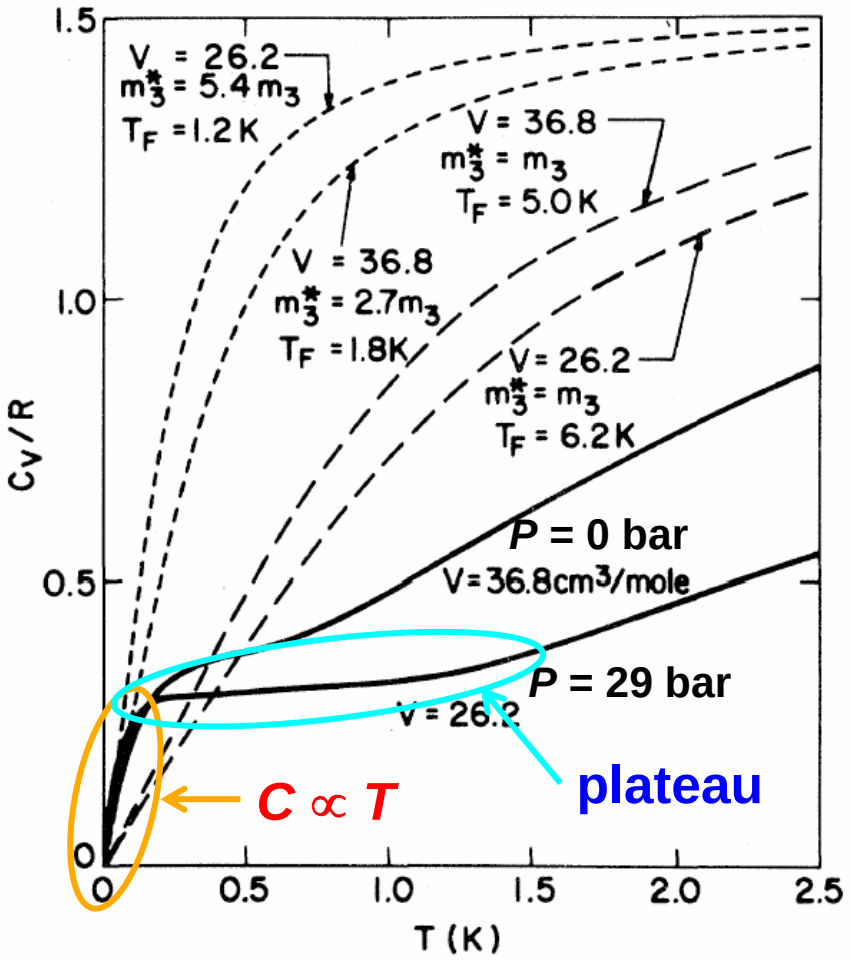
Y. Matsumoto et al., JLTP **138**, 271 (2005)

Strong correlation in bulk (3D) liquid ^{3}He

specific heat

D.S. Greywall, PRB **27**, 2747 (1983)

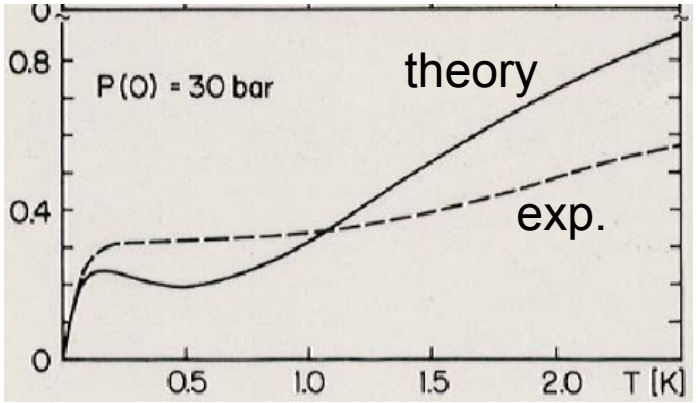
FL theory is applicable only to a very low T-region ($T \leq 50$ mK).

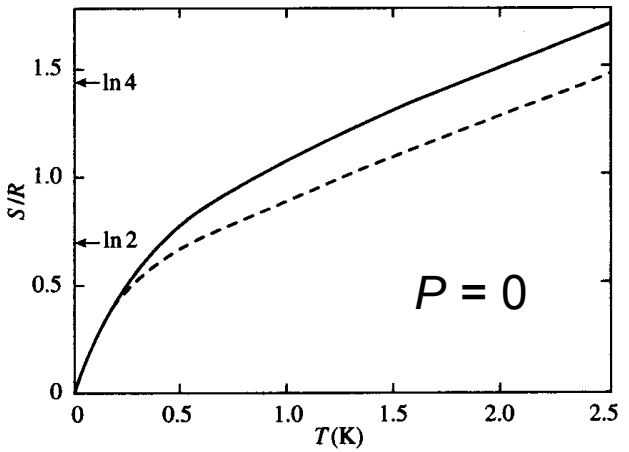


Almost localized model

K.Seiler at al., JLTP **64**, 195 (1986)

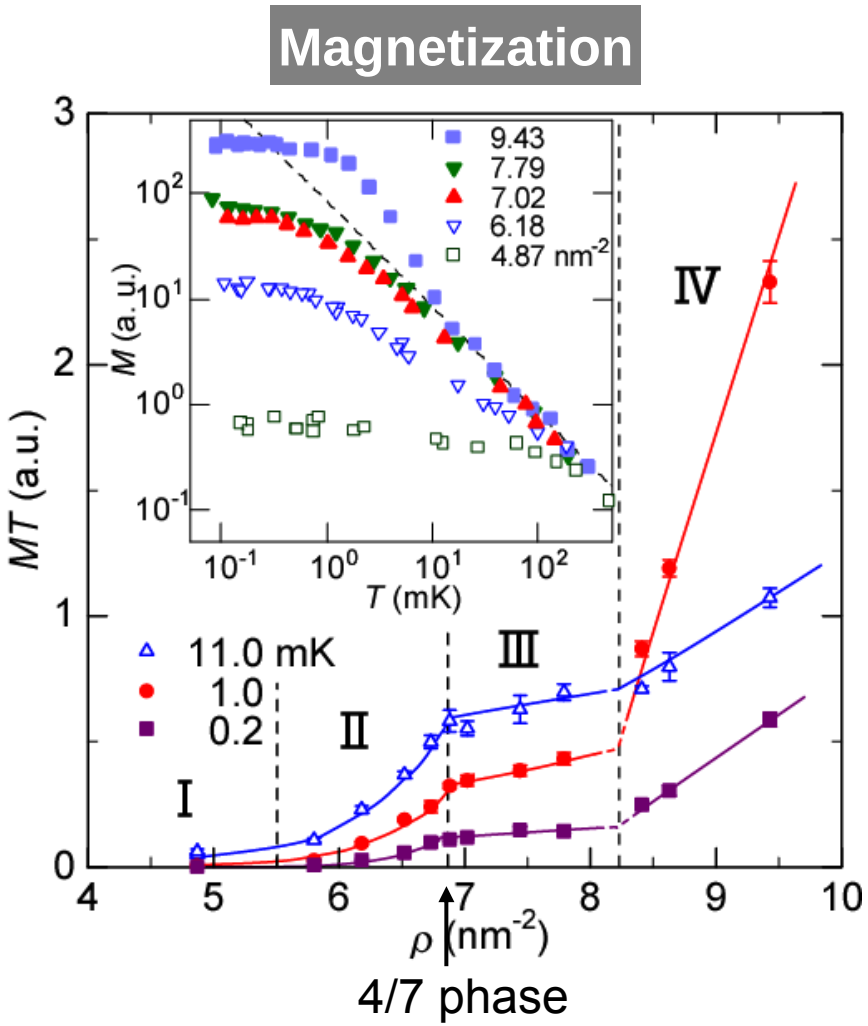
- spin fluctuations at low-T
- density fluctuations at high-T





Rich quantum phase diagram of 2D ^{3}He on graphite

Four different quantum phases



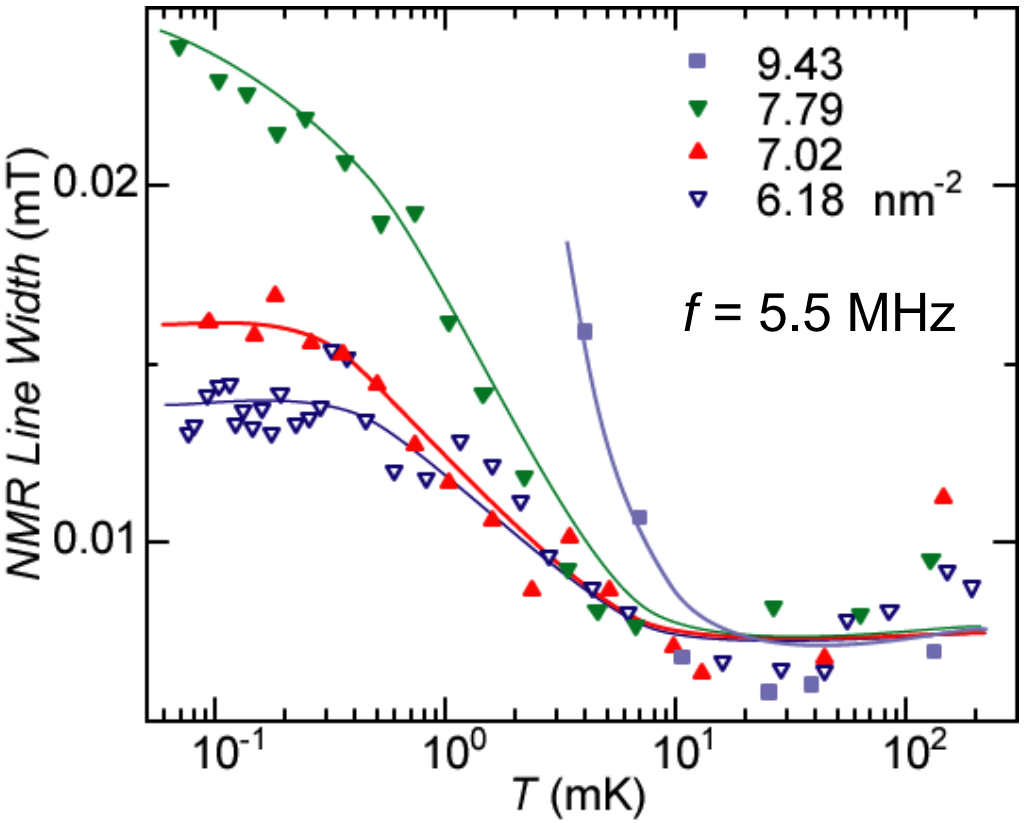
S. Murakawa et al., Physica B (2006)
to be published

For more recent and unpublished magnetization data, please contact Hiroshi Fukuyama <hiroshi@phys.s.u-tokyo.ac.jp>

NMR line width in Regions II-IV

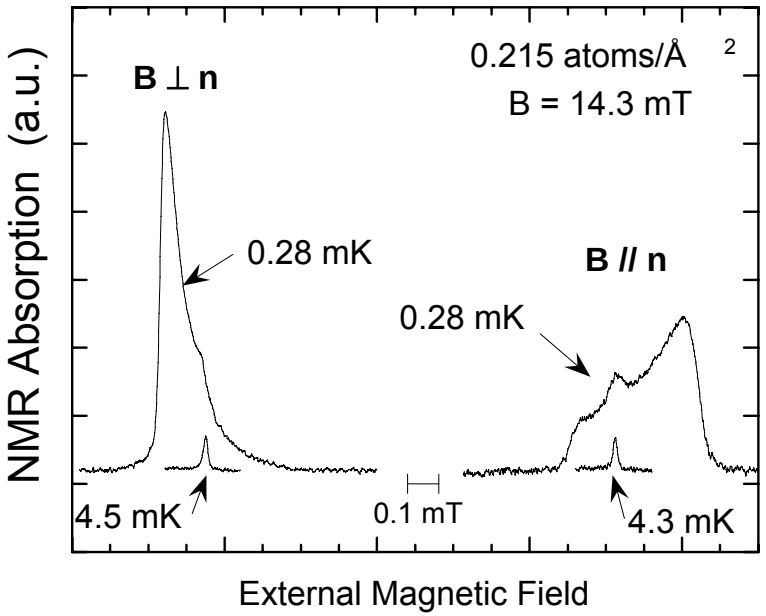
Region-II: **NMR spectrum** broadens on approaching localization (4/7 phase).

Region-IV: It broadens more rapidly because of large magnetization and mosaic spread of graphite platelets

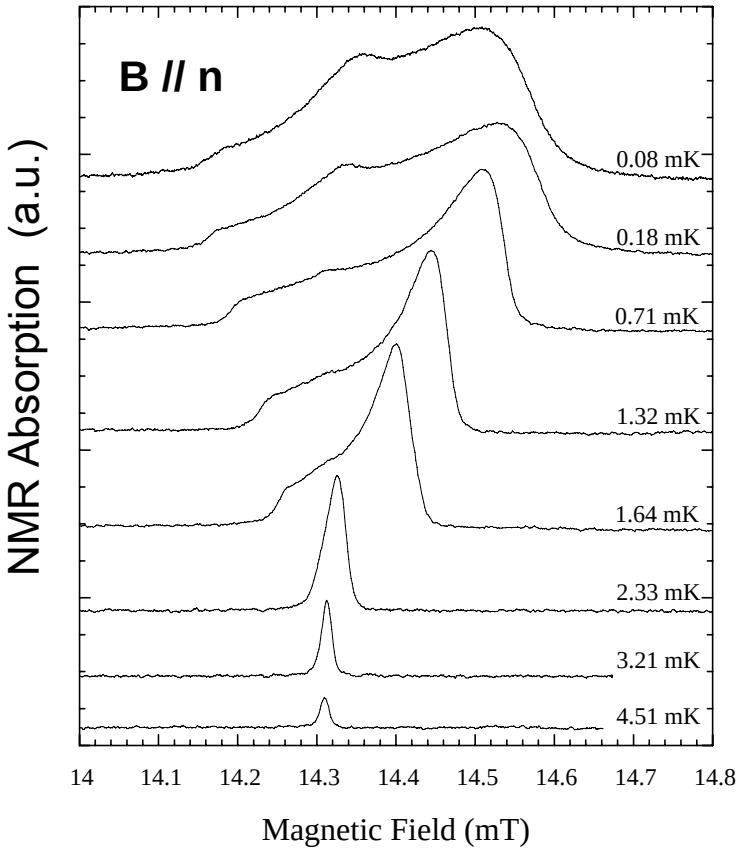


For more recent and unpublished NMR line width data, please contact Hiroshi Fukuyama <hiroshi@phys.s.u-tokyo.ac.jp>

NMR spectra (FM region)

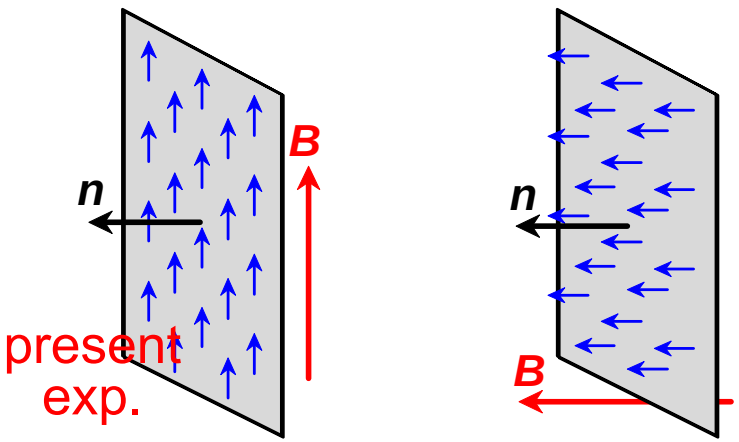


^{3}He/^{3}He/gr system



Demagnetizing effect in polarized 2D sheet:

$$\Delta B = -\gamma\hbar|M|\left\{1-3\left(\frac{B\bullet n}{|B|}\right)^2\right\}$$



Line broadening due to orientation distribution of platelets

P. Schiffer, H. Fukuayma *et al*., PRL **71**, 1403 (1993); JLTP **94**, 489 (1994)

In the next four years,

Detailed understandings of the new quantum phases

1) Construction of a new nuclear refrigerator specialized for NMR

2) Better substrates ⋯. ZYX (L ≈ 200 - 400 nm)
present: Grafoil (L ≈ 10 - 40 nm)

3) New techniques ⋯ torsional oscillator, quartz micro-balance,
pulsed NMR, SQUID NMR

Search for other quantum phases in different 2D systems

^{3}He on ^{4}He bilayer, hydrogen bilayer, Kr monolayer, ⋯..