Search for exotic magnetic phases with μSR

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Superconductors that break time-reversal symmetry (BTRS)

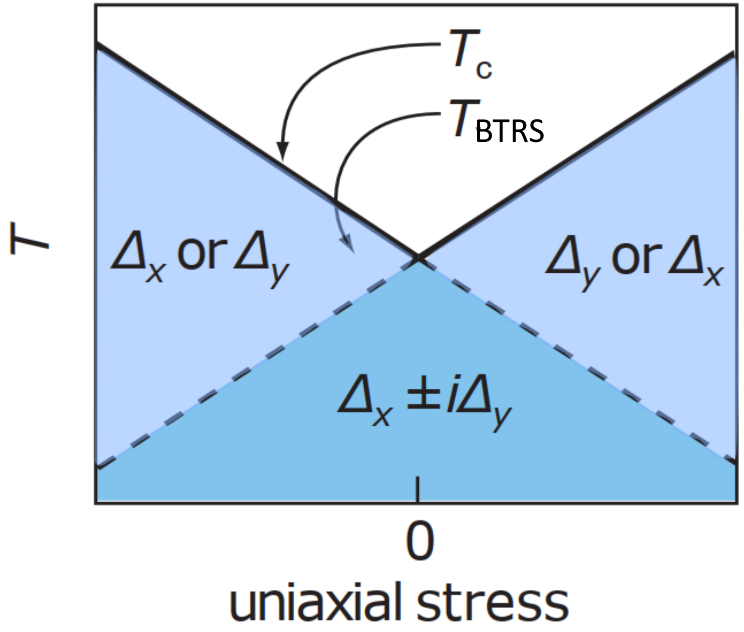
***Two-component* order parameter** $|\Delta_{1(2)}|e^{i\varphi 1(2)}$ **with double degenerate states:**

$$\{|\Delta_1|, |\Delta_2|, \varphi_1 - \varphi_2 = \theta_{12}\} \rightarrow \{|\Delta_1|, |\Delta_2|, \varphi_1 - \varphi_2 = -\theta_{12}\}$$

Degenerate order parameter

Intrinsically $|\Delta_1| = |\Delta_2|$, $\theta_{12} = \pm\pi/2$ ⟹ $T_c = T_{BTRS}$

Examples: $p_x \pm ip_y$, $d_{xz} \pm id_{yz}$, …



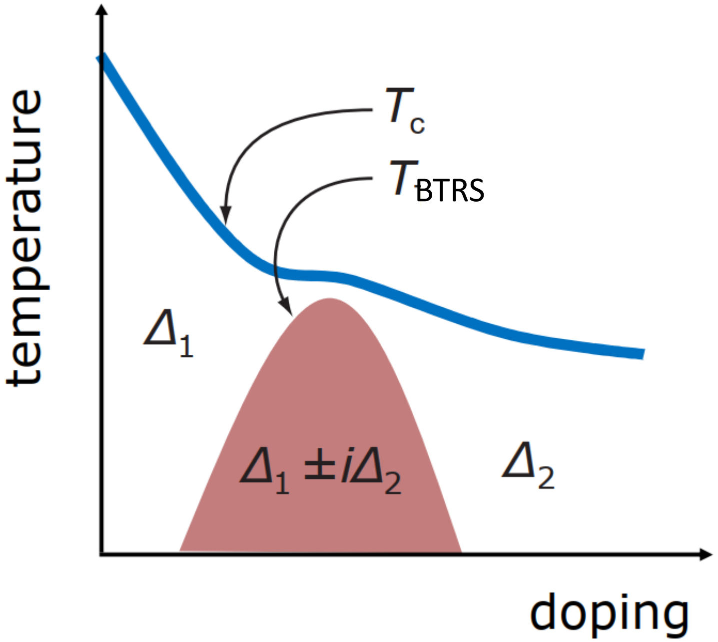
Symmetry-breaking perturbations of the crystal lattice lift the degeneracy.

V. Grinenko, S. Ghosh *et al.* *Nat. Phys.* **17,** 748–754 (2021).

Non-degenerate or accidentally degenerate order parameter

$|\Delta_1| \neq |\Delta_2|$, $\theta_{12} \neq 0,\pi$ ⟹ fine tuning for $T_c = T_{BTRS}$

Examples: $s \pm is'$, $s \pm id$, $d \pm ig$, …



The degeneracy is lifted by any perturbation.

V. Grinenko *et al.*, *Nat. Phys.* **17,** 1254–1259 (2021).

μSR investigations of Sr_2RuO_4

Tsung-Dao Lee Institute

μSR is local probe
and it is sensitive to all types of BTRS states!

- **Split superconducting and BTRS transition under uniaxial strain in Sr_2RuO_4;**
- **Strain induced spin density wave (SDW) with magnetic moment ~ $0.1\mu_B$;**

V. Grinenko, S. Ghosh et al., *Nat. Phys*. **17,** 748–754 (2021).
V. Grinenko et al., Phys. Rev. B **107**, 024508 (2023).

- **BTRS superconductivity under hydrostatic pressure.**

V. Grinenko et al., *Nat Commun* **12**, 3920 (2021).

The main collaborators :

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The Johns Hopkins University

Hubertus Luetkens

Rustem Khasanov

en

Manfred Sigrist
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SJTU, Shangahi

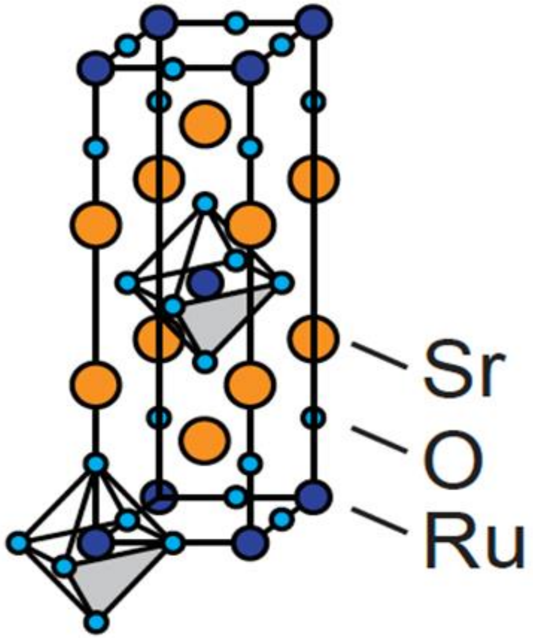
Zurab Guguchia
PSI Villegen

Yoshiteru Maeno
Kyoto University

Naoki Kikugawa
NIMS

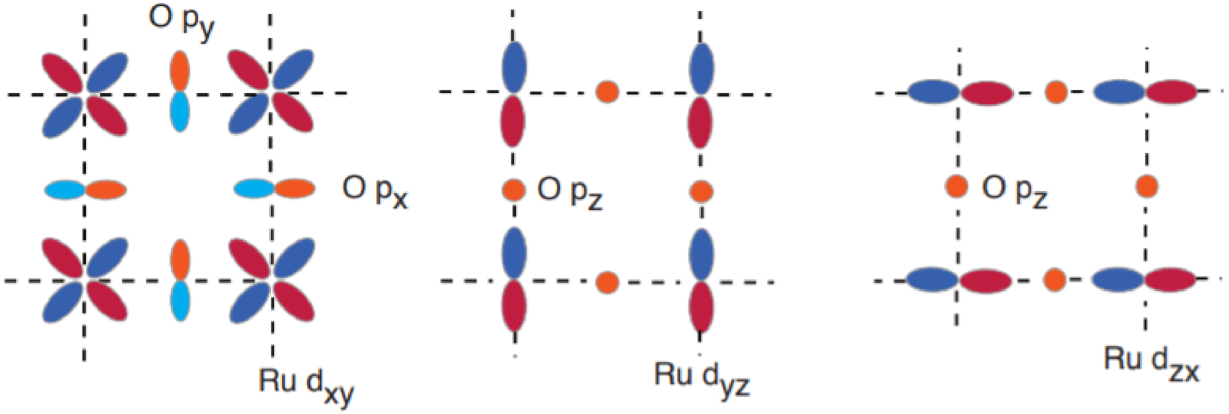
Sr_2RuO_4 is multiband superconductor

Crystal structure

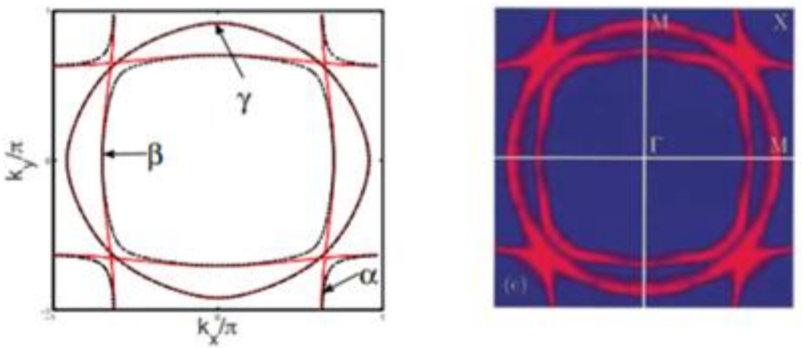


C. Hicks, MPI Dresden

Electronic orbitals relevant for conductivity



Fermi surface

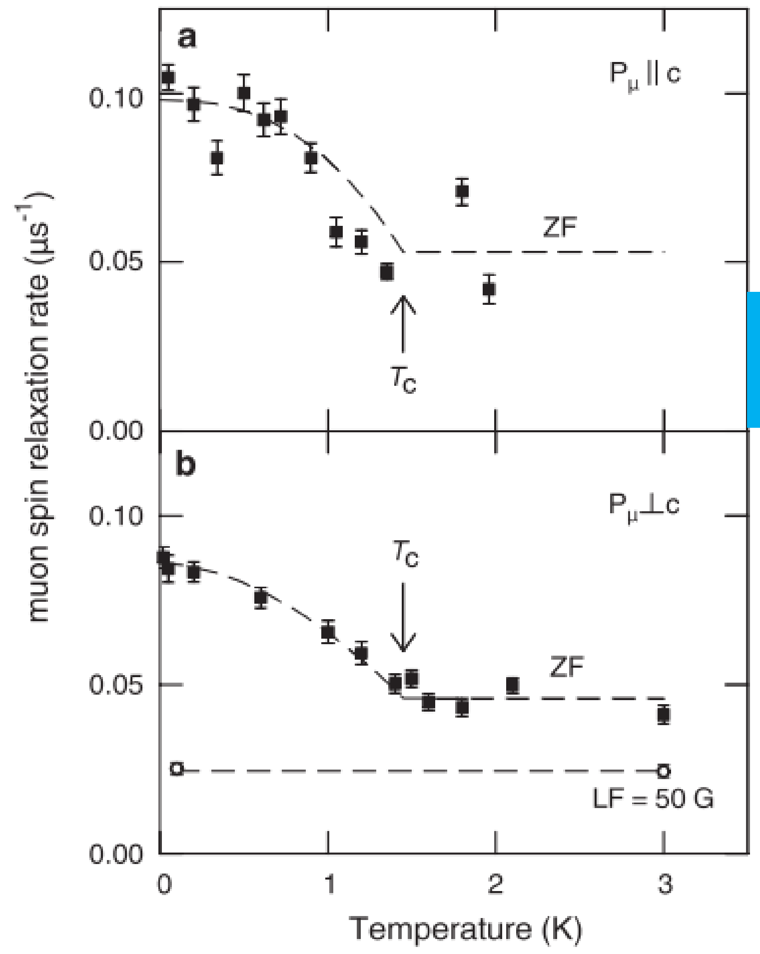


S. Raghu et al., Journal of Physics: Conference Series **449**, 012031 (2013).

Sr_2RuO_4 has a complex electronic structure, makes it similar to Fe-based superconductors.

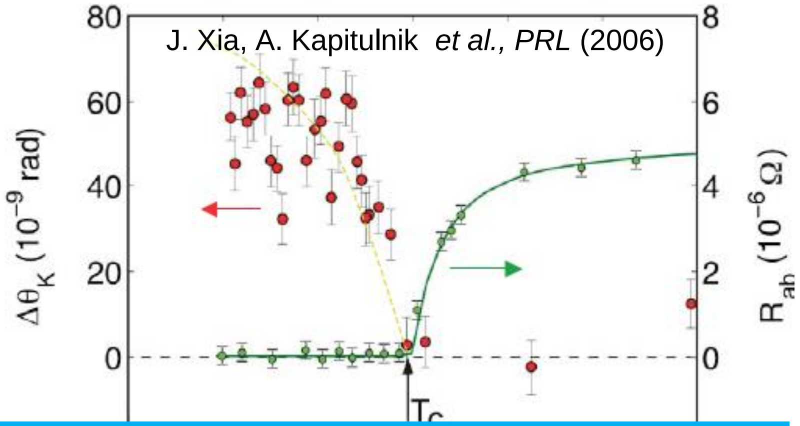
Some experimental evidences for multicomponent order parameter in Sr_2RuO_4

Enhanced muon spin relaxation rate below T_c → spontaneous magnetic fields



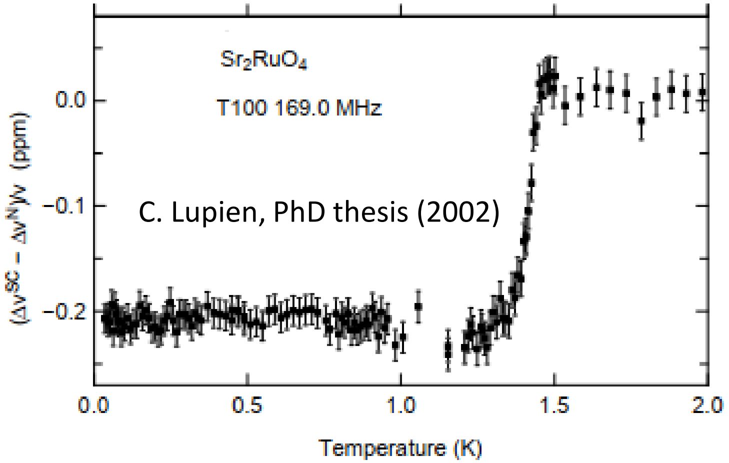
Luke, G. M. et al. Nature 394, 558–561 (1998)

Polar Kerr effect



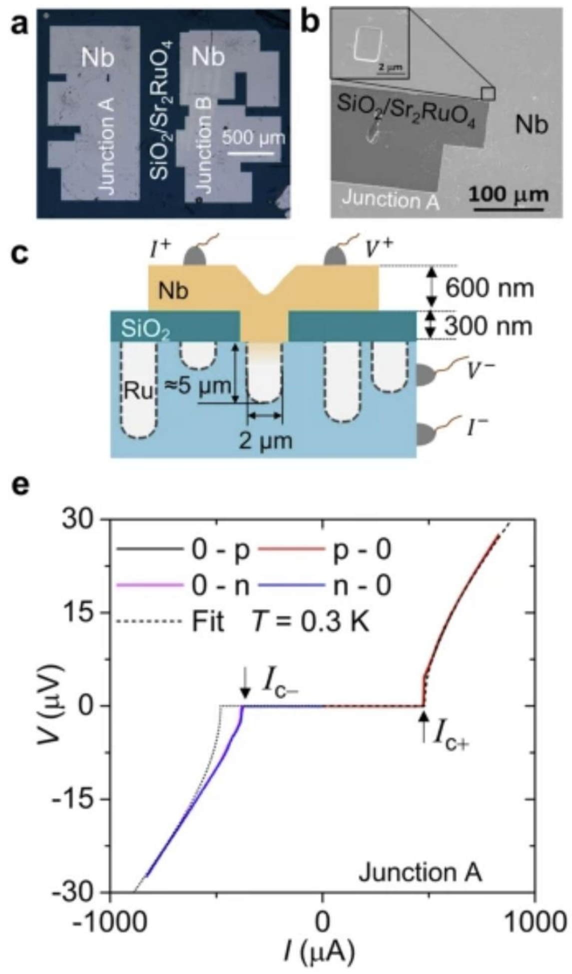
Altogether these experiments are consistent with chiral state.

Jump in transverse sound viscosity at T_c, -> indication for 2D order parameter.



S .Ghosh *et al.*, *Nat. Physics* (2020) , S. Benhabib et al., *Nat. Physics* (2020)

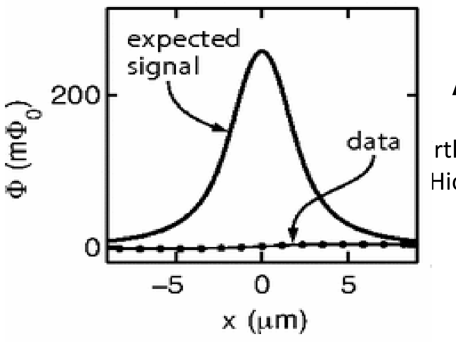
Superconducting diode effect in ZF



M.S Anwar et al., Commun Phys 6, 290 (2023).

Evidences against chiral superconductivity in Sr_2RuO_4

Scanning SQUID microscopy



Absence of edge currents?

rtley, *et al*., Phys. Rev. B **76,** 014526 (2007)
Hicks *et al*., Phys. Rev. B **81,** 214501 (2010)

Problems with interpretation Josephson effect:
S. Kashiwaya et al., PRB **100**, 094530, S.-I. Suzuki et al., PRB **101**, 054505 (2020), ….

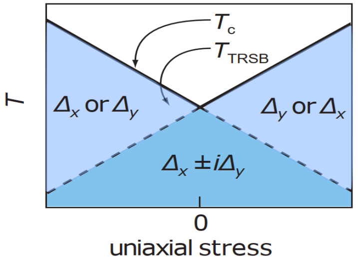
The negative result can be explained by the suppression of superconductivity through surface reconstruction and surface magnetism.

C. A. Marques *et al*., arXiv:2005.00071
A. Kreisel *et al*., arXiv:2103.06188
R. Fittipaldi *et al*., Nat Commun. 12, 5792 (2021).

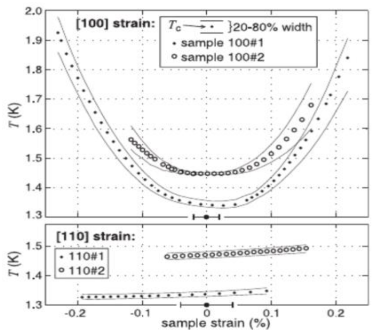
Are T_c and T_{TRSB} transitions split under uniaxial strain?

Missing cusp in T_c under strain

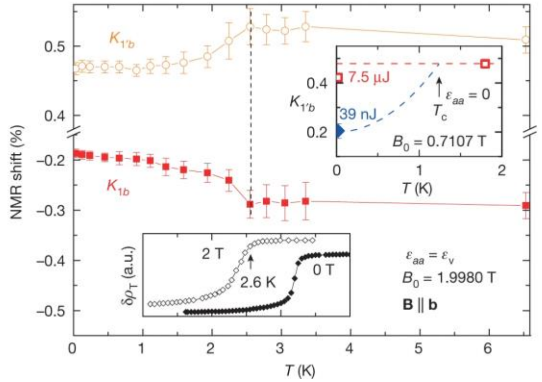
Theory



Experiment



C. W. Hicks *et al*., *Science* **344,** 283-285 (2014).
A. Steppke, *et al*., *Science* **355**, eaaf9398 (2017).



The reduction of the NMR Knight shift below T_c

A. Pustogow *et al*., *Nature* **574**, 72 (2019).

Non-chiral p-wave!?

Sr_2RuO_4 is multiband superconductor

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Variety of possible superconducting order parameters in Sr_2RuO_4

Multi-band nature of the Fermi surface results in a possibility of mixed pairing states with the pairing mediated by spin fluctuations, candidates: *s+id, d+ig, s+ip*

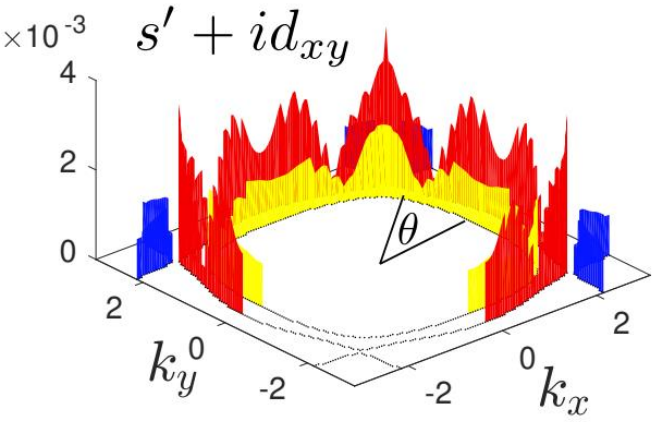
A. T. Rømer, et al., PRL 123, 247001 (2019); PRB
S. A. Kivelson, *et al.*, npj Quantum Mat. 5, 43 (20

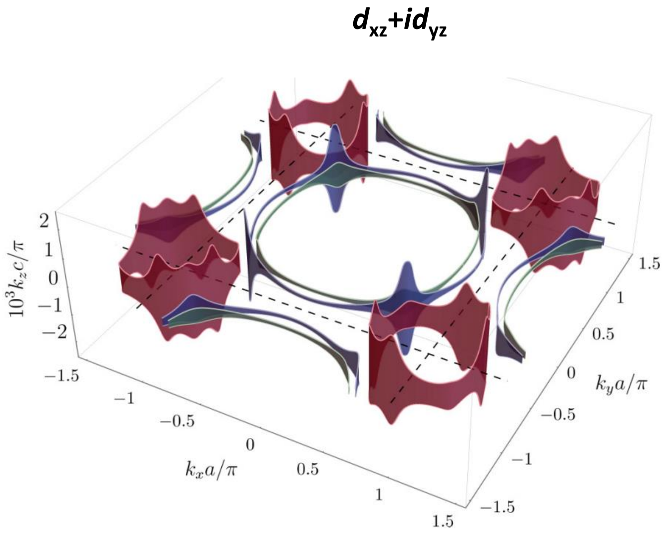
Mixed pairing or chiral

?

Alternatively, the orbital degree
pairing originated from local inte

A. Ramires, and M. Sigrist, *Physical Review B* (2(
H. G. Suh *et al.*,Phys. Rev. Research **2**, 032023(F
A. Ramires, arXiv:2110.10621.





A chiral p-wave is excluded according to the NMR Knight shift measurements:

A. Pustogow *et al.*, *Nature* **574**, 72 (2019).
K. Ishida, *et al.*, J. Phys. Soc. Jpn. **89**, 034712 (2020).
A. Chronister *et al.*, PNAS **118** (25) e2025313118 (2021).

How can we distinguish between chiral and non-chiral superconductivity using μSR?

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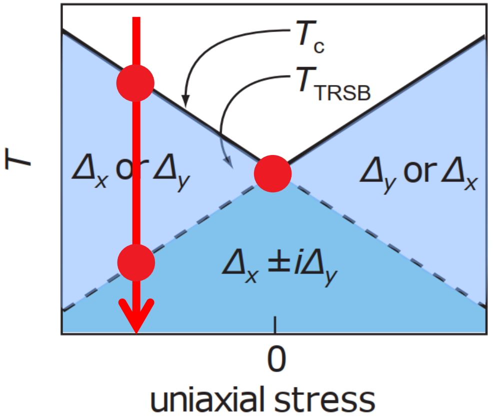
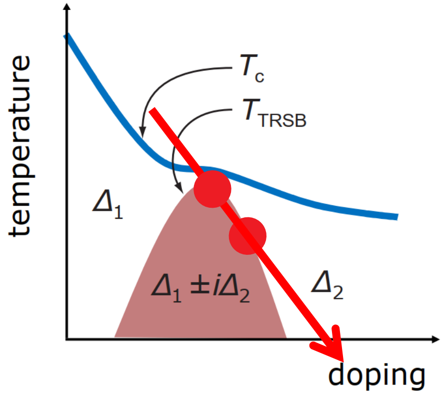
$\tilde{\Gamma}_7 = E_g$: chiral d-wave **($d_{xz} \pm id_{yz}$)**

- T_c and T_{BTRS} transitions must split under symmetry breaking uniaxial strain.
- Do not split with the hydrostatic pressure and isotropic disorder.



Accidentally degenerated sates:

$$\tilde{\Gamma}_1 = A_{1g} \oplus A_{2g} : \quad s + ig\text{-wave}$$
$$\tilde{\Gamma}_2 = A_{1g} \oplus B_{1g} : \quad s + id\text{-wave}$$
$$\tilde{\Gamma}_3 = A_{1g} \oplus B_{2g} : \quad s + id'\text{-wave}$$
$$\tilde{\Gamma}_4 = B_{1g} \oplus A_{2g} : \quad d + ig\text{-wave}$$
$$\tilde{\Gamma}_5 = B_{2g} \oplus A_{2g} : \quad d' + ig\text{-wave}$$
$$\tilde{\Gamma}_6 = B_{1g} \oplus B_{2g} : \quad d + id'\text{-wave}$$

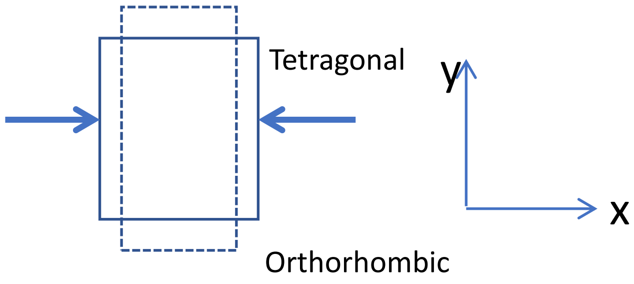


- T_c and T_{BTRS} transitions must split under uniaxial strain.
- Do split with the hydrostatic pressure and disorder.

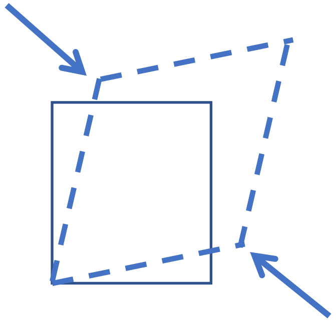
V. Grinenko *et al.*, Nat Commun 12, 3920 (2021).

Uniaxial pressure

(100) direction

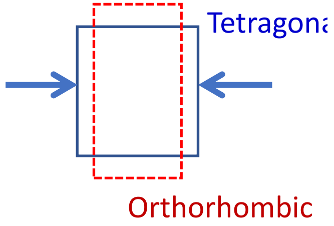


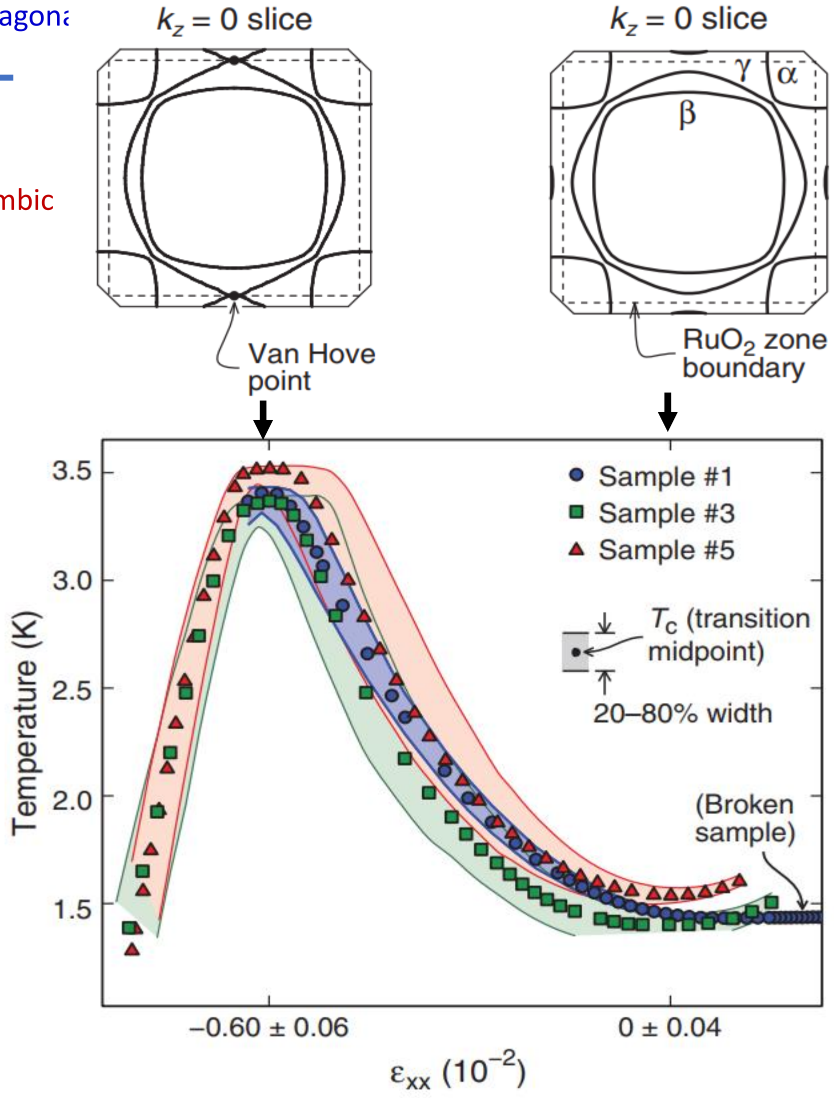
(110) direction



- **Splitting of T_c and T_{BTRS} is expected for both: chiral and accidentally degenerated orders.**
- **Important demonstration that T_c and T_{BTRS} are related to a different phase transitions.**

Sr_2RuO_4 under the (100) strain

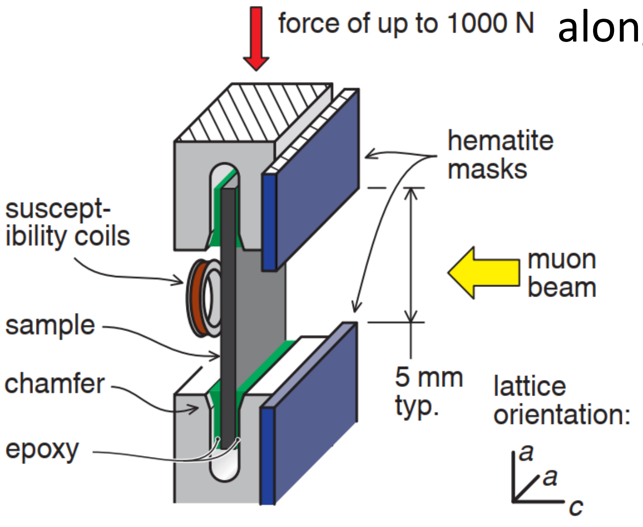




A. Steppke, *et al.*, *Science* **355**, eaaf9398 (2017).

- What is the effect of van Hove on BTRS state?
- Can van Hove induce magnetism?

Experimental setup for the μSR:



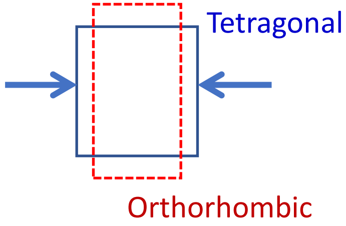
along (100)

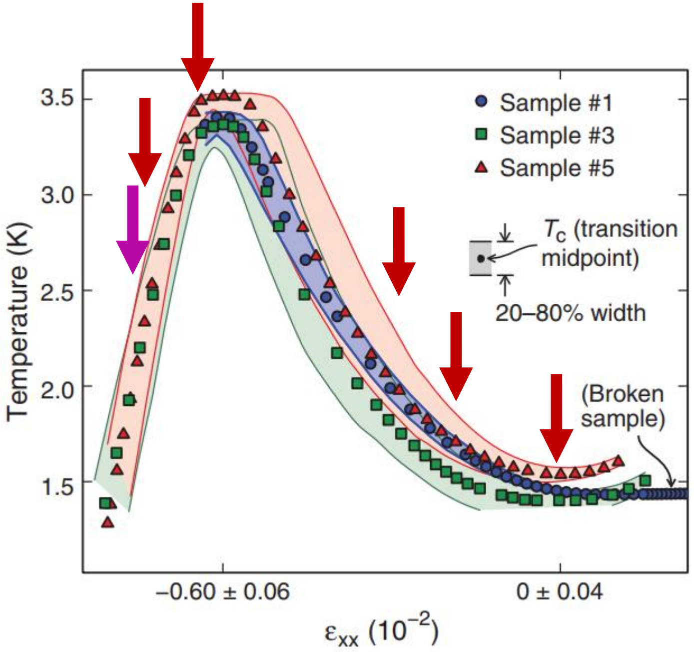
S. Ghosh *et al.*, Review of Scientific Instruments **91**, 103902 (2020).

V. Grinenko, S. Ghosh *et al.* *Nat. Phys.* **17**, 748–754 (2021).

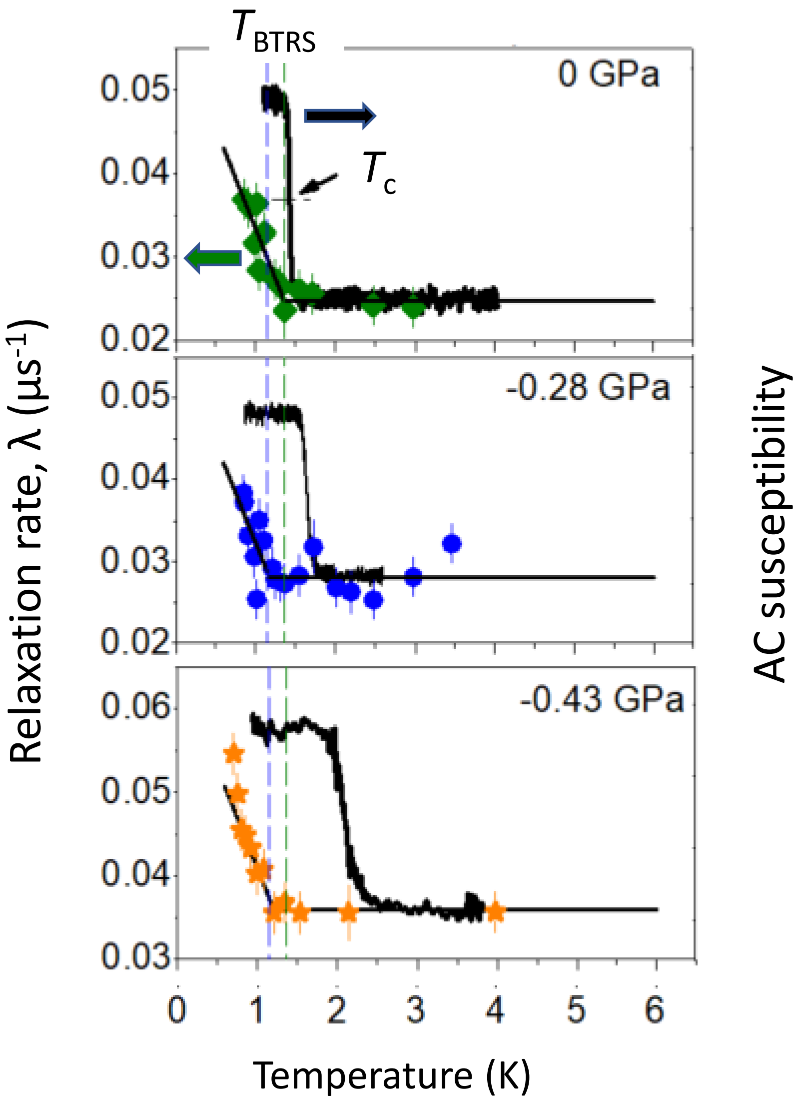
- T_c is measured by AC susceptibility.
- T_{BTRS} by zero-field μSR.

BTRS superconductivity of Sr_2RuO_4 under the (100) strain

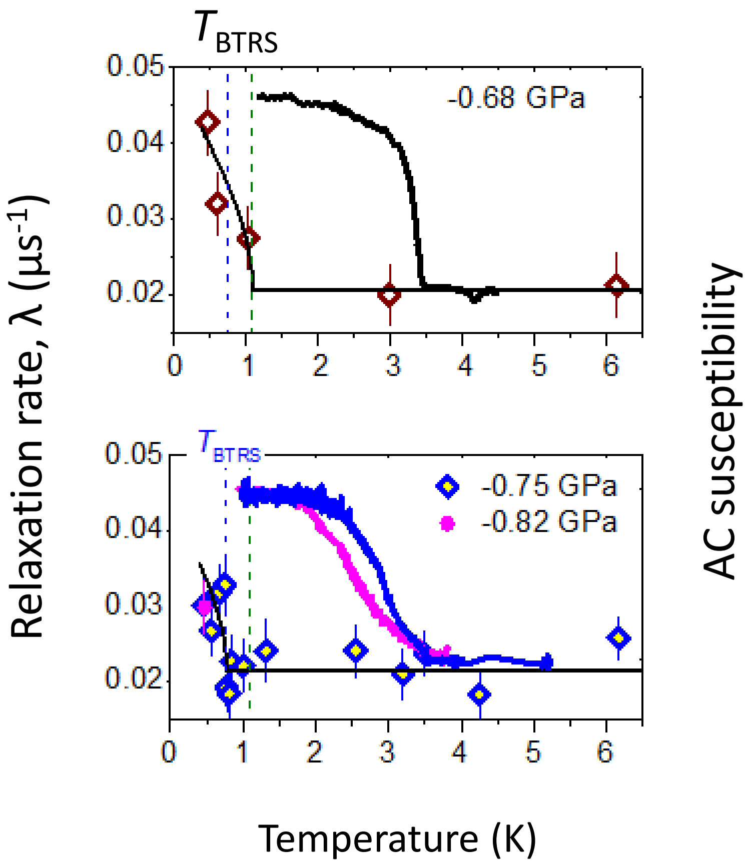




A. Steppke, *et al.*, *Science* **355**, eaaf9398 (2017).

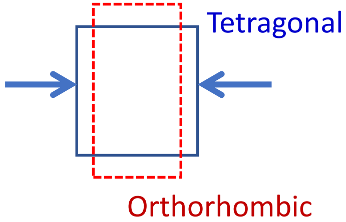


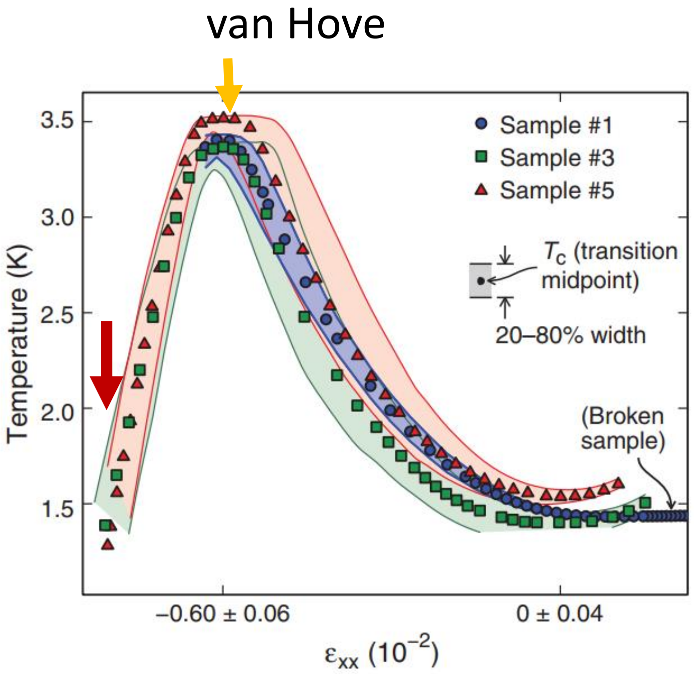
V. Grinenko *et al.*, *Nat. Phys.* **17,** 748–754 (2021)



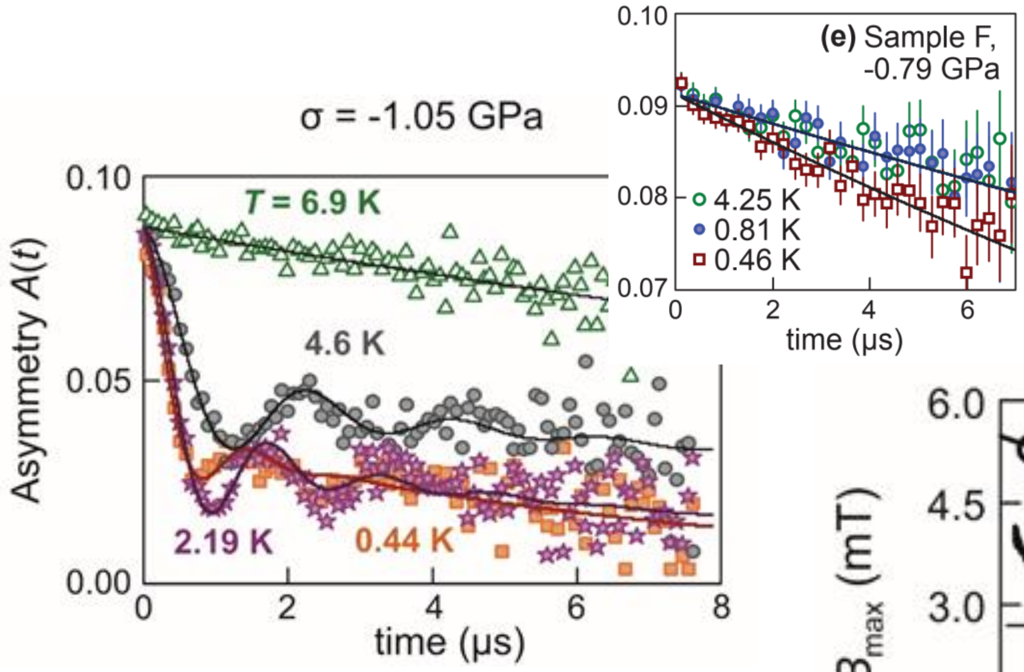
- ✓ **Significant splitting of T_{BTRS} and T_c!**
- ✓ **BTRS state exists above van Hove singularity!**

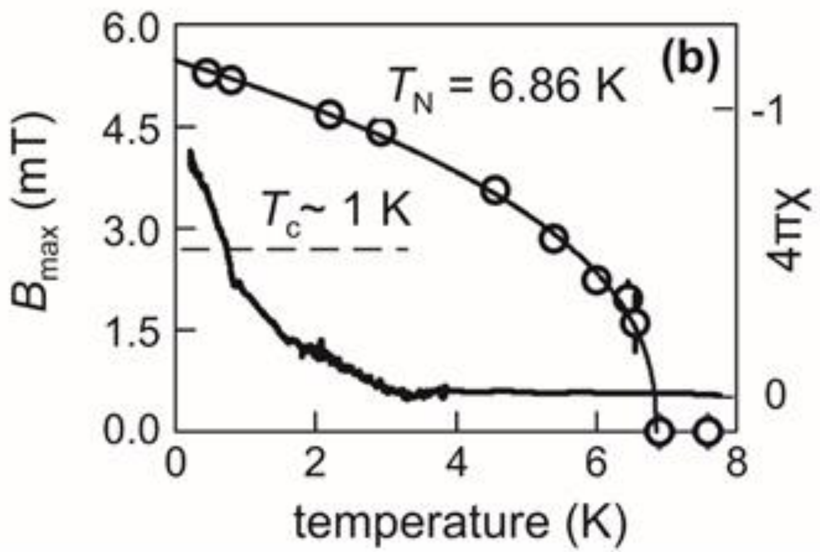
Strain induced SDW phase in Sr_2RuO_4





A. Steppke, *et al*., *Science* **355**, eaaf9398 (2017).



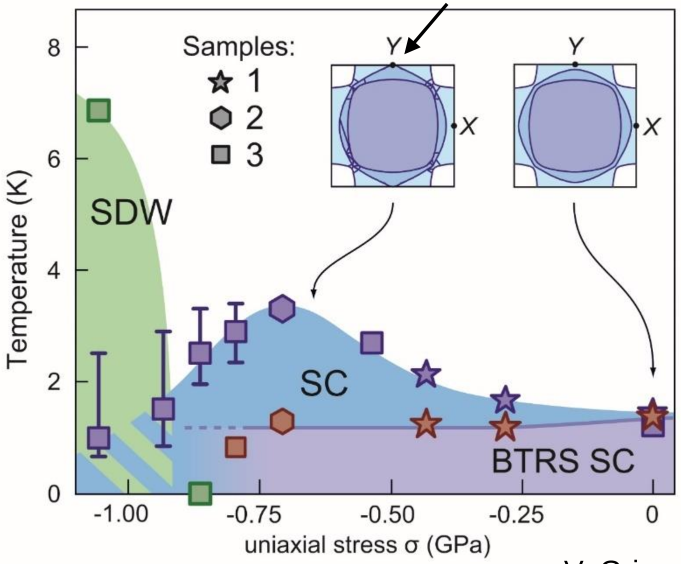


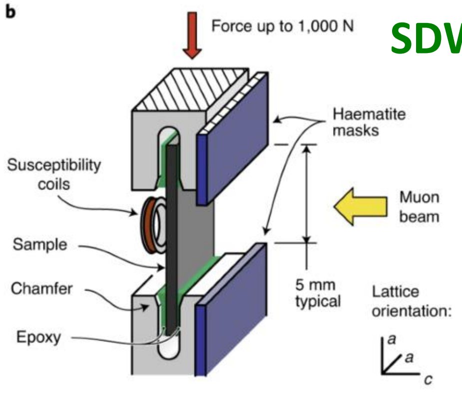
V. Grinenko *et al*., *Nat. Phys.* **17,** 748–754 (2021)

- An incommensurate **SDW phase** well **above the van Hove singularity** with $\boldsymbol{T_N}$ **~ 7 K**;
- Small internal magnetic fields correspond roughly to **0.1** $\boldsymbol{\mu_B}$ (similar to $Sr_3Ru_2O_7$);
- The SDW internal field is **100 times stronger than spontaneous fields due to BTRS superconductivity.**

μSR measurements of Sr_2RuO_4 under uniaxial strain

Lifshitz transition

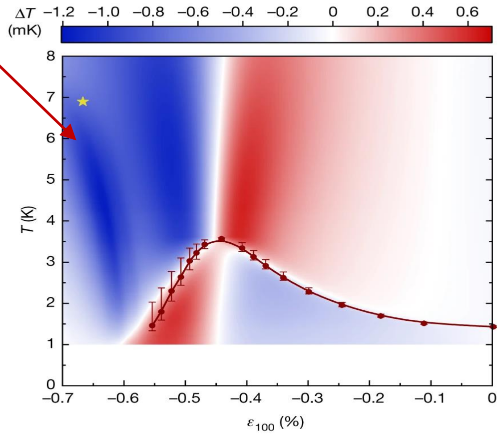




V. Grinenko et al., *Nat. Phys*. **17,** 748–754 (2021).

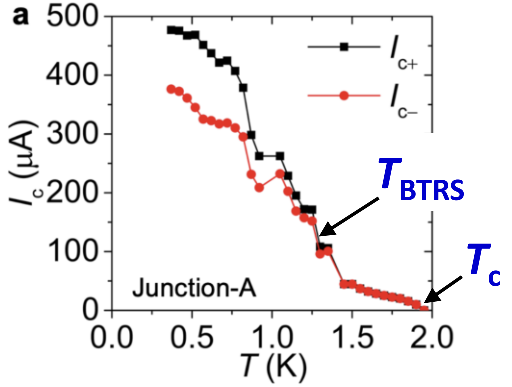
Elastocaloric effect

SDW state



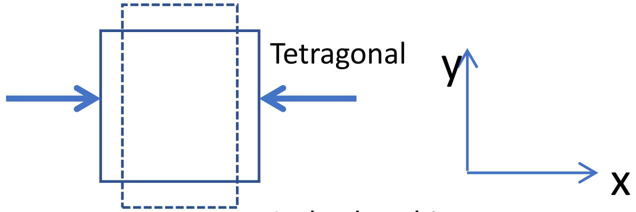
YS. Li *et al., Nature* **607**, 276–280 (2022).

Spontaneous superconducting diode effect



M. S. Anwar et al., arXiv:2211.14626v1

- ➢ **Superconducting T_c and T_{BTRS} split by uniaxial strain → two distinct phases!**

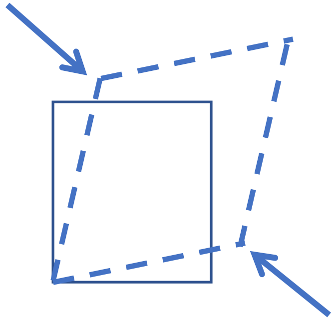


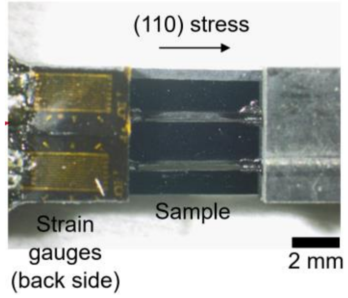
- ✓ SDW phase detected by μSR is confirmed by elastocaloric effect measurements.
- ✓ Split T_c and T_{BTRS} is confirmed by spontaneous superconducting diode effect measurements.

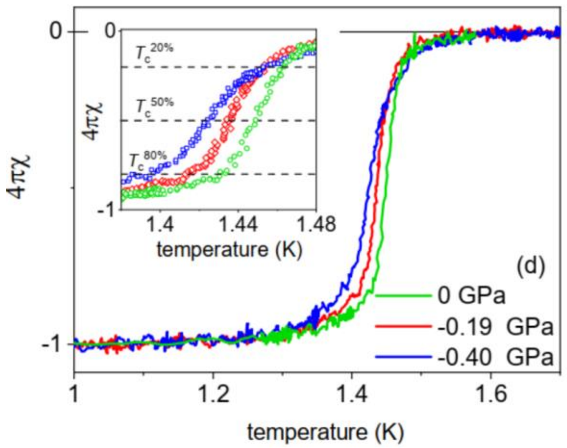
What is the evidence from other probes in favor of the μSR phase diagram?

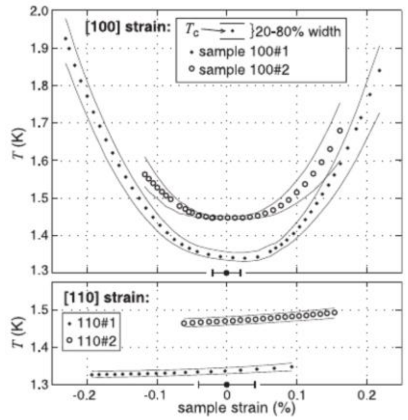
- ➢ Uniaxial strain induces spin density wave order (SDW) above the Lifshitz transition in odd with early theoretical predictions.

Sr_2RuO_4 under the (110) strain, Sample A

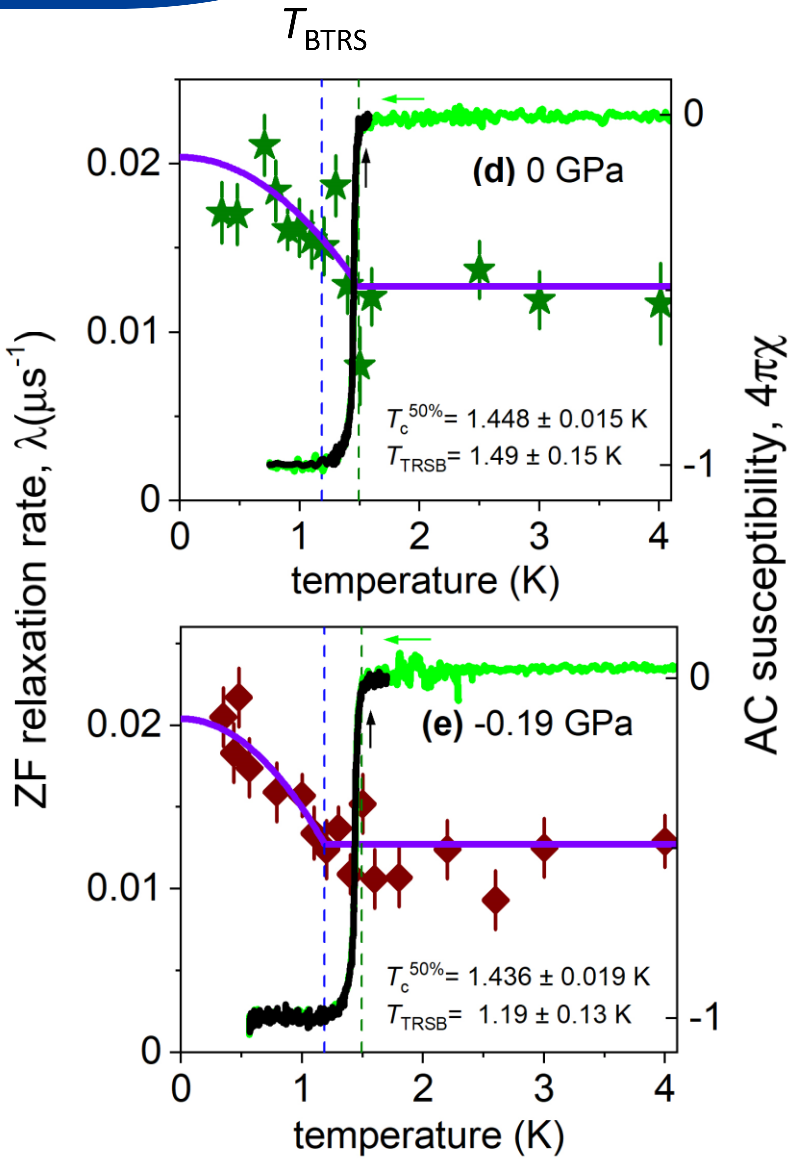








C. W. Hicks *et al.*, *Science* **344,** 283-285 (2014).



Very weak suppression of T_c by the (110) strain consistent with previous studies.

Splitting of T_{BTRS} and T_c under the strain!

V. Grinenko et al., Phys. Rev. B **107**, 024508 (2023).

Summary: splitting between T_c and T_{TRSB} under uniaxial strain

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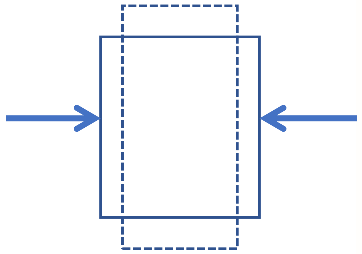
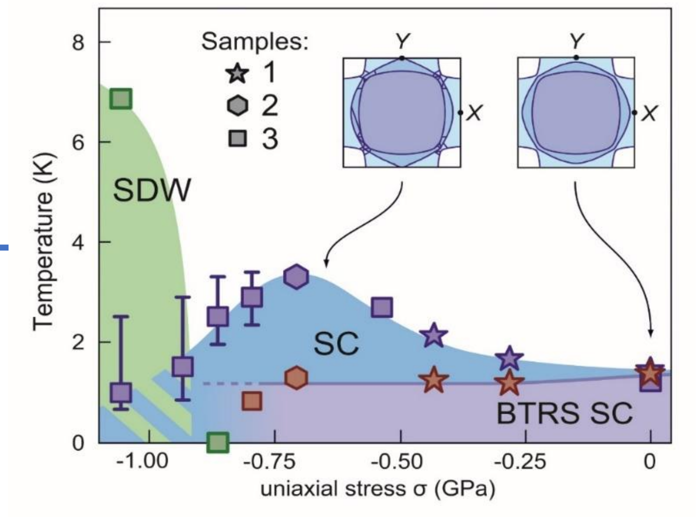
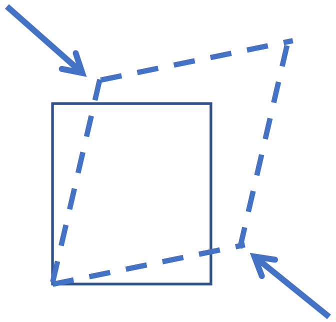
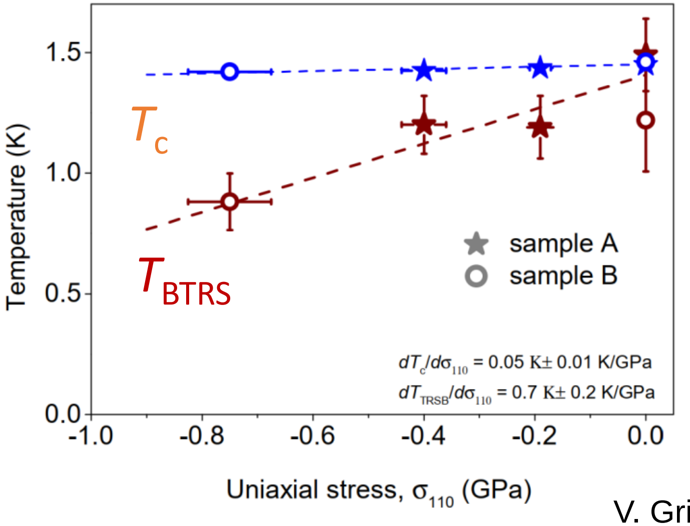




Electronic structure is very sensitive to <100> strain → difficult to perform a quantitative analysis of the strain dependencies of T_c and T_{BTRS}.

- The electronic structure is less affected by <110> strain → the splitting is due to lifted degeneracy between the components.





- Fast suppression of T_{TRSB} under <110> stress indicates that the condensation energy associated with the TRSB phase can be small:

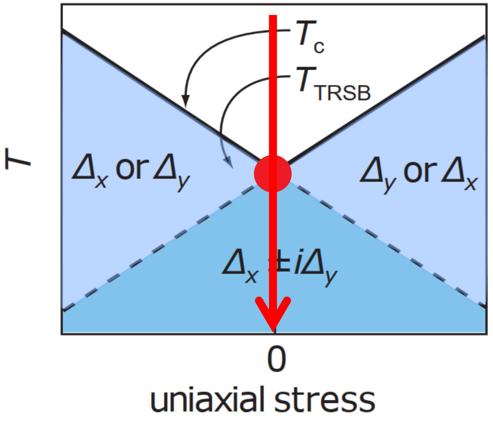
$$\frac{\Delta C_1}{T_c}\frac{dT_c}{d|\sigma|} = -\frac{\Delta C_2}{T_{BTRS}}\frac{dT_{BTRS}}{d|\sigma|}$$

V. Grinenko et al., Phys. Rev. B **107**, 024508 (2023).

How can we distinguish between chiral and non-chiral superconductivity using μSR?

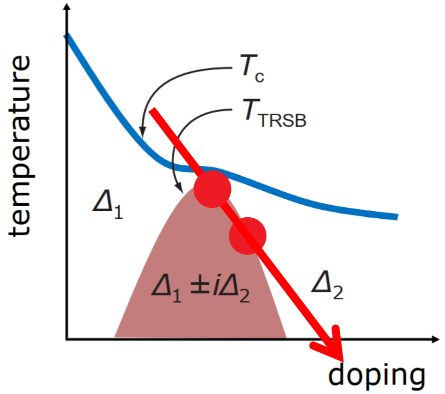
$\tilde{\Gamma}_7 = E_g$: chiral d-wave (**$d_{xz} \pm id_{yz}$**)

- T_c and T_{BTRS} transitions must split under symmetry breaking uniaxial strain.
- Do not split with the hydrostatic pressure and isotropic disorder.



Accidentally degenerated sates:

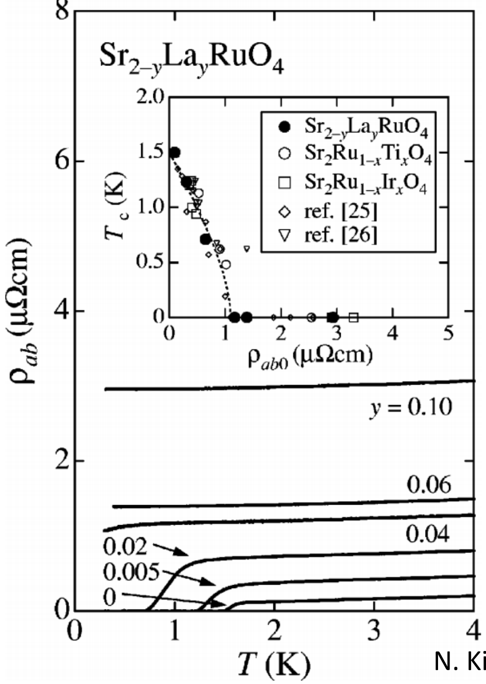
$$
\begin{aligned}
\tilde{\Gamma}_1 &= A_{1g} \oplus A_{2g} : \quad s + ig\text{-wave} \\
\tilde{\Gamma}_2 &= A_{1g} \oplus B_{1g} : \quad s + id\text{-wave} \\
\tilde{\Gamma}_3 &= A_{1g} \oplus B_{2g} : \quad s + id'\text{-wave} \\
\tilde{\Gamma}_4 &= B_{1g} \oplus A_{2g} : \quad d + ig\text{-wave} \\
\tilde{\Gamma}_5 &= B_{2g} \oplus A_{2g} : \quad d' + ig\text{-wave} \\
\tilde{\Gamma}_6 &= B_{1g} \oplus B_{2g} : \quad d + id'\text{-wave}
\end{aligned}
$$



- T_c and T_{BTRS} transitions must split under uniaxial strain.
- Do split with the hydrostatic pressure and disorder.

V. Grinenko *et al.*, Nat Commun 12, 3920 (2021).

Disorder effect on T_c



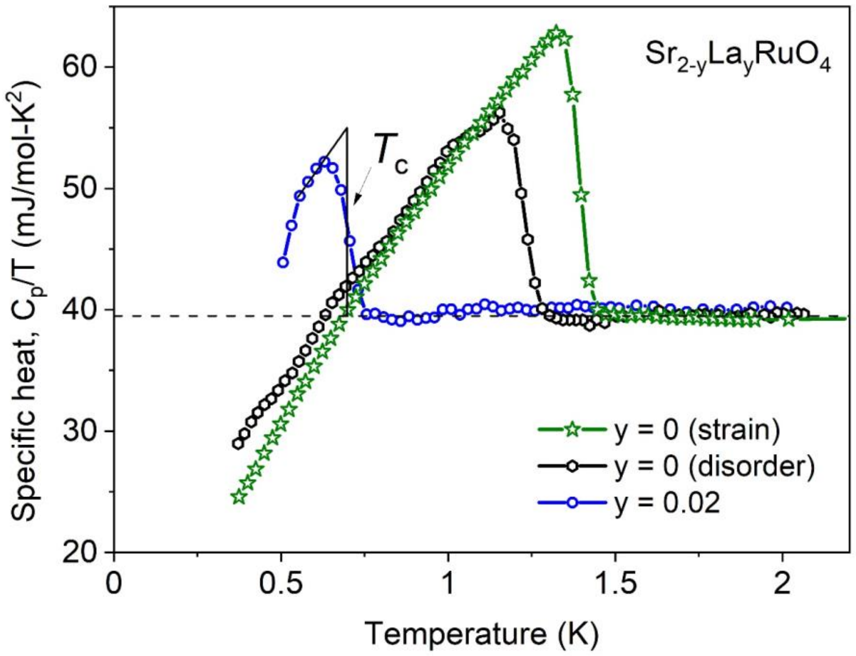
N. Kikugawa et al., Phys. Rev. B **70**, 060508(R) (2004)

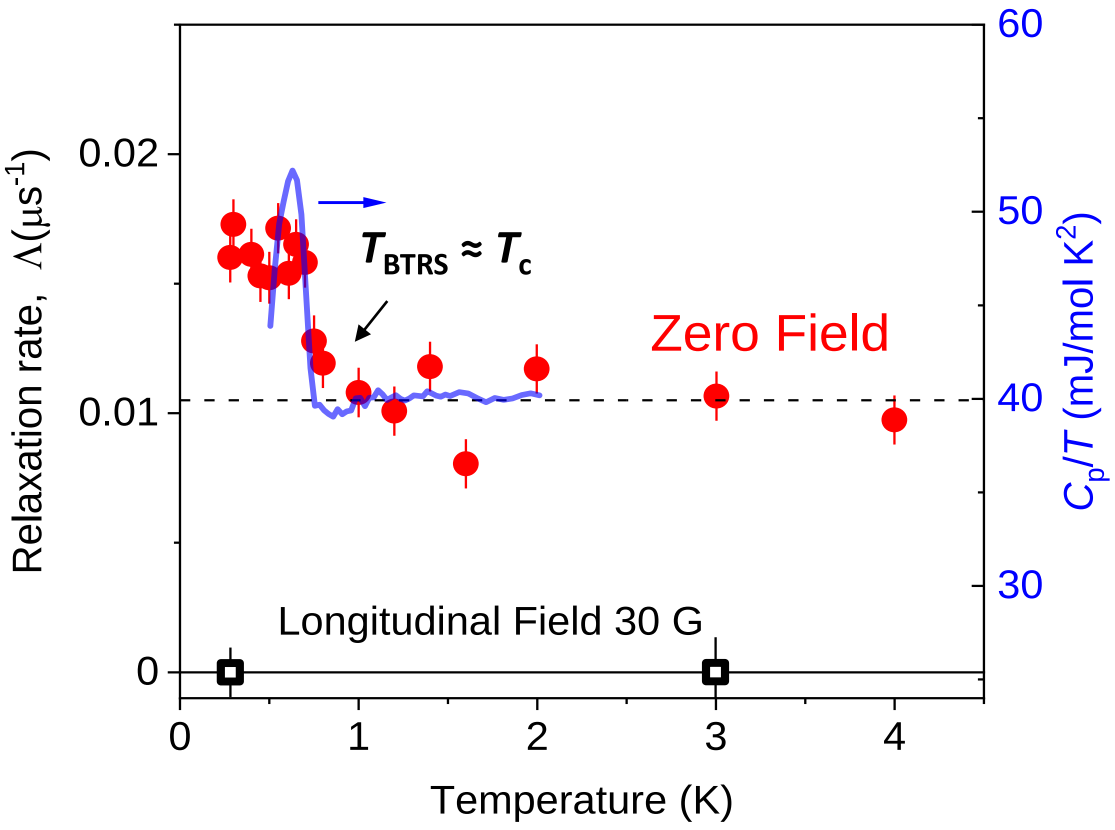
- At small concentrations the dominant effect of La on T_c is related to a pair breaking effect.
- La-doping results in isotropic in-plane disorder without anisotropic internal strain.

La-doping is an ideal tool to study the effect of disorder on T_c and T_{BTRS}

Time reversal symmetry breaking in $Sr_{2-y}La_yRuO_4$

1% of La doping suppresses T_c by 50% as compared with a impurity free T_{c0}





- The normal state electronic specific heat is nearly the same for all samples, $\gamma_n \approx 40$ mJ/mol-K^2 -> the DOS are unchanged.
- Sharp superconducting transition -> homogeneous suppression of superconductivity by a pair braking effect.

T_{BTRS} = T_c in the sample with **a half of the disorder free T_{c0};**

Together with the splitting between T_{BTRS} and T_c under uniaxial strain

→ **evidence in favor of a chiral superconductivity in Sr_2RuO_4**

V. Grinenko et al., Nat Commun 12, 3920 (2021).

Theory: Splitting of the T_c and T_{TRSB} under disorder for accidentally degenerated orders

李政道研究所 Tsung-Dao Lee Institute

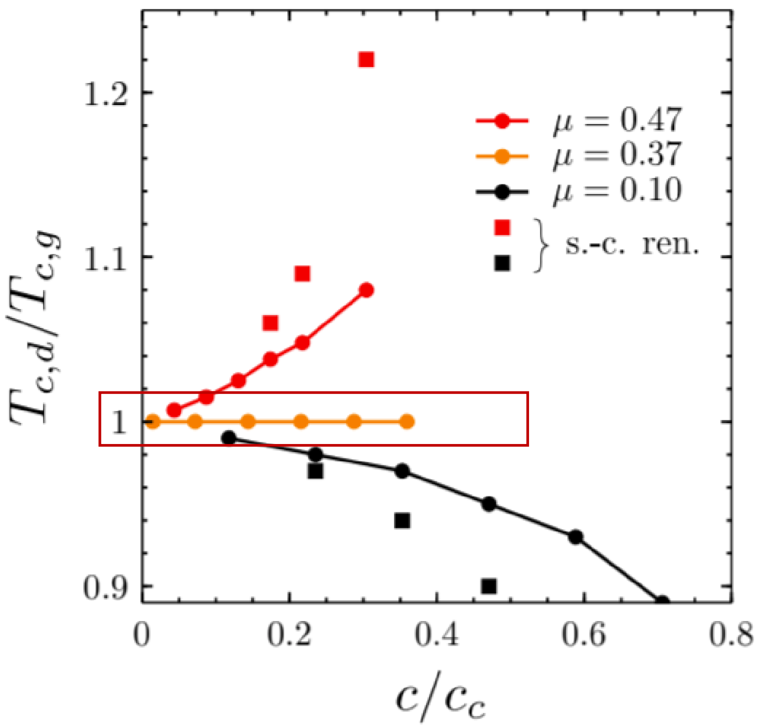
Accidentally degenerated sates:

$$\begin{aligned}
\tilde{\Gamma}_1 &= A_{1g} \oplus A_{2g} : \quad s + ig\text{-wave} \\
\tilde{\Gamma}_2 &= A_{1g} \oplus B_{1g} : \quad s + id\text{-wave} \\
\tilde{\Gamma}_3 &= A_{1g} \oplus B_{2g} : \quad s + id'\text{-wave} \\
\tilde{\Gamma}_4 &= B_{1g} \oplus A_{2g} : \quad d + ig\text{-wave} \\
\tilde{\Gamma}_5 &= B_{2g} \oplus A_{2g} : \quad d' + ig\text{-wave} \\
\tilde{\Gamma}_6 &= B_{1g} \oplus B_{2g} : \quad d + id'\text{-wave}
\end{aligned}$$

- T_c and T_{BTRS} transitions must split under uniaxial strain.
- Do split with the hydrostatic pressure and disorder.

V. Grinenko *et al.*, Nat Commun 12, 3920 (2021).

***d*+*ig* state**



B. Zinkl. & M. Sigrist, arXiv:2009.10089 (2020).

Manfred Sigrist

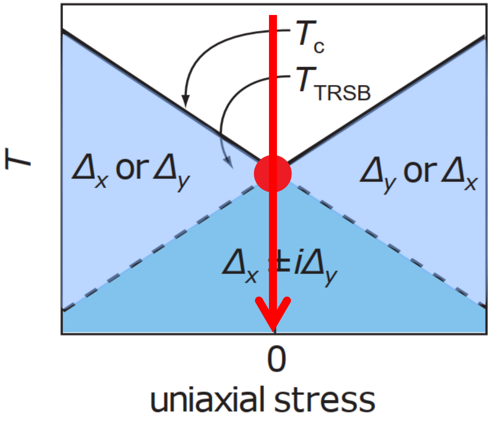
Fine-tuning is possible that transitions do not split with disorder.

Therefore, additional experiments are needed!

How can we distinguish between chiral and non-chiral superconductivity using µSR?

$\tilde{\Gamma}_7 = E_g$: chiral d-wave **($d_{xz} \pm id_{yz}$)**

- T_c and T_{BTRS} transitions must split under symmetry breaking uniaxial strain.
- Do not split with the hydrostatic pressure and isotropic disorder.



Accidentally degenerated sates:

$$
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\tilde{\Gamma}_1 &= A_{1g} \oplus A_{2g} : \quad s + ig\text{-wave} \\
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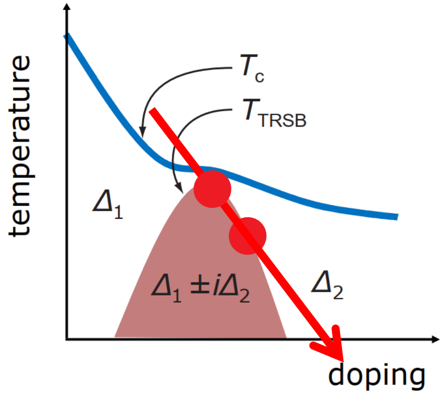
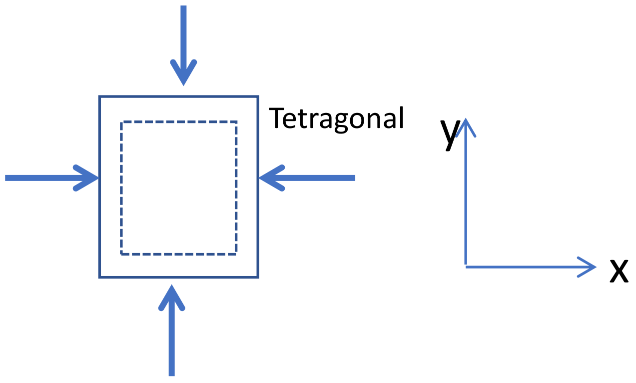
\tilde{\Gamma}_4 &= B_{1g} \oplus A_{2g} : \quad d + ig\text{-wave} \\
\tilde{\Gamma}_5 &= B_{2g} \oplus A_{2g} : \quad d' + ig\text{-wave} \\
\tilde{\Gamma}_6 &= B_{1g} \oplus B_{2g} : \quad d + id'\text{-wave}
\end{aligned}
$$

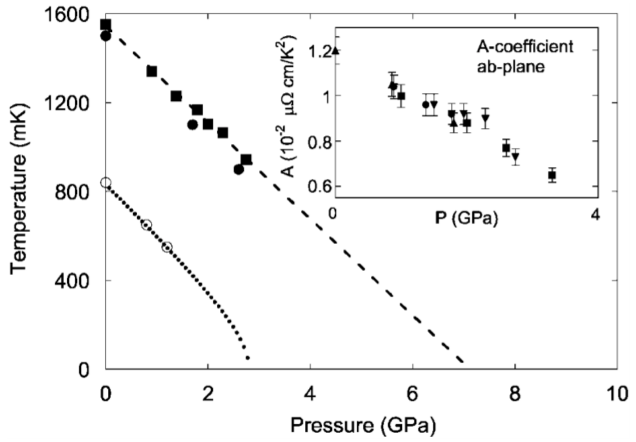


- T_c and T_{BTRS} transitions must split under uniaxial strain.
- Do split with the hydrostatic pressure and disorder.

V. Grinenko *et al*., Nat Commun 12, 3920 (2021).

Hydrostatic pressure preserves tetragonal symmetry *a* = *b*





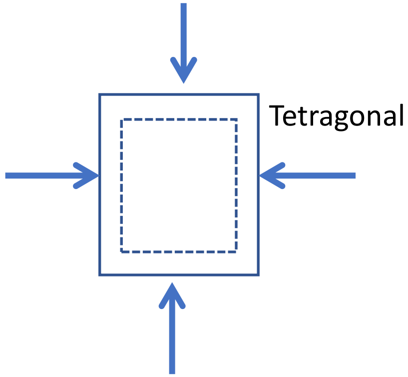
D. Forsythe *et al*., Phys. Rev. Lett. 89, 166402 (2002)
N. Shirakawa *et al*., Phys. Rev. B 56, 7890 (1997)

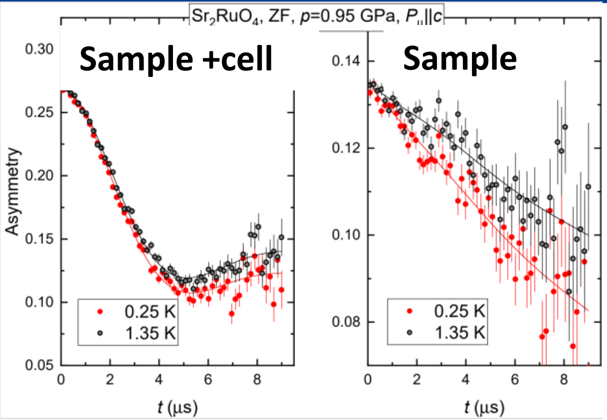
***"Fine tuning"* is impossible for both disorder and hydrostatic pressure!**

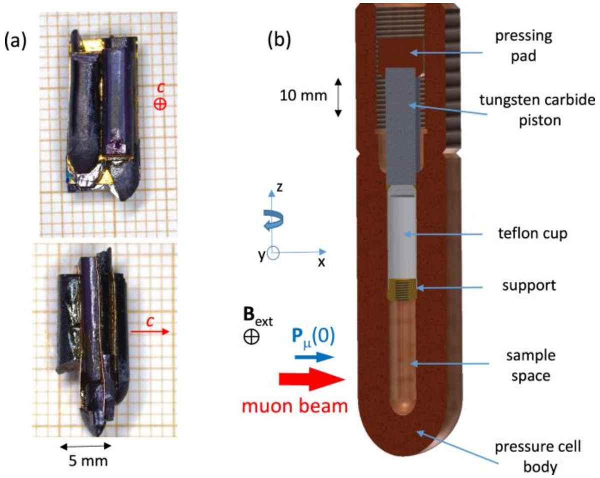
The first μSR measurements of BTRS superconductivity under pressure

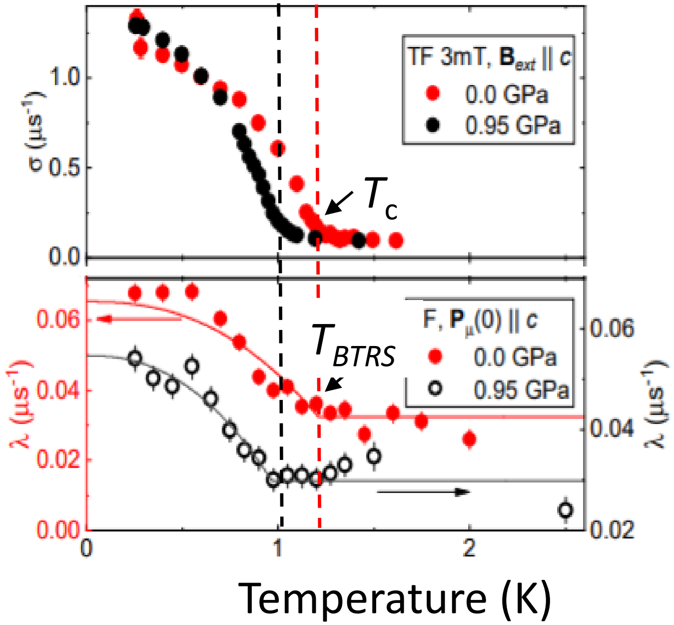
李政道研究所 TSUNG-DAO LEE INSTITUTE

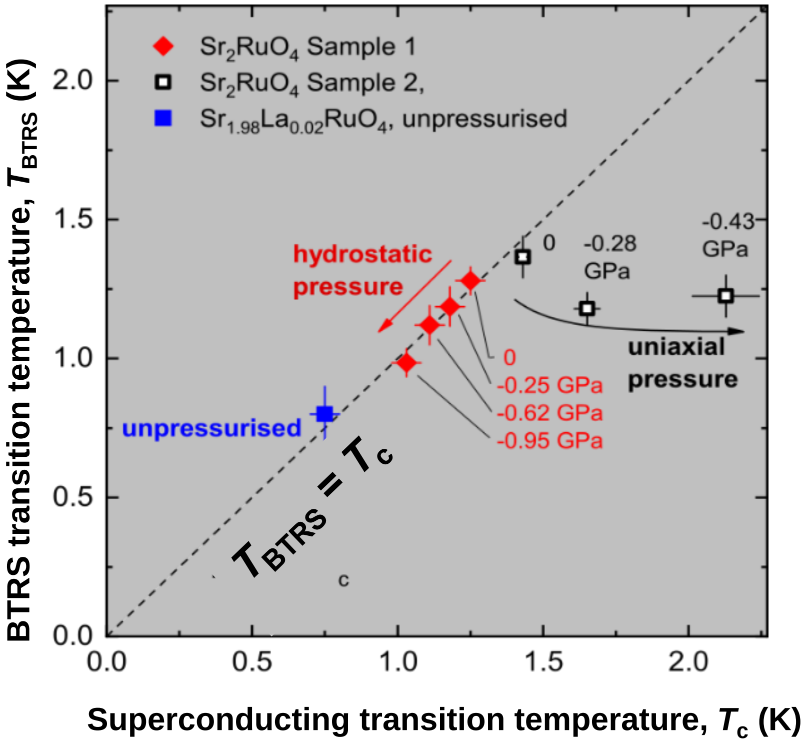
Rustem Khasanov











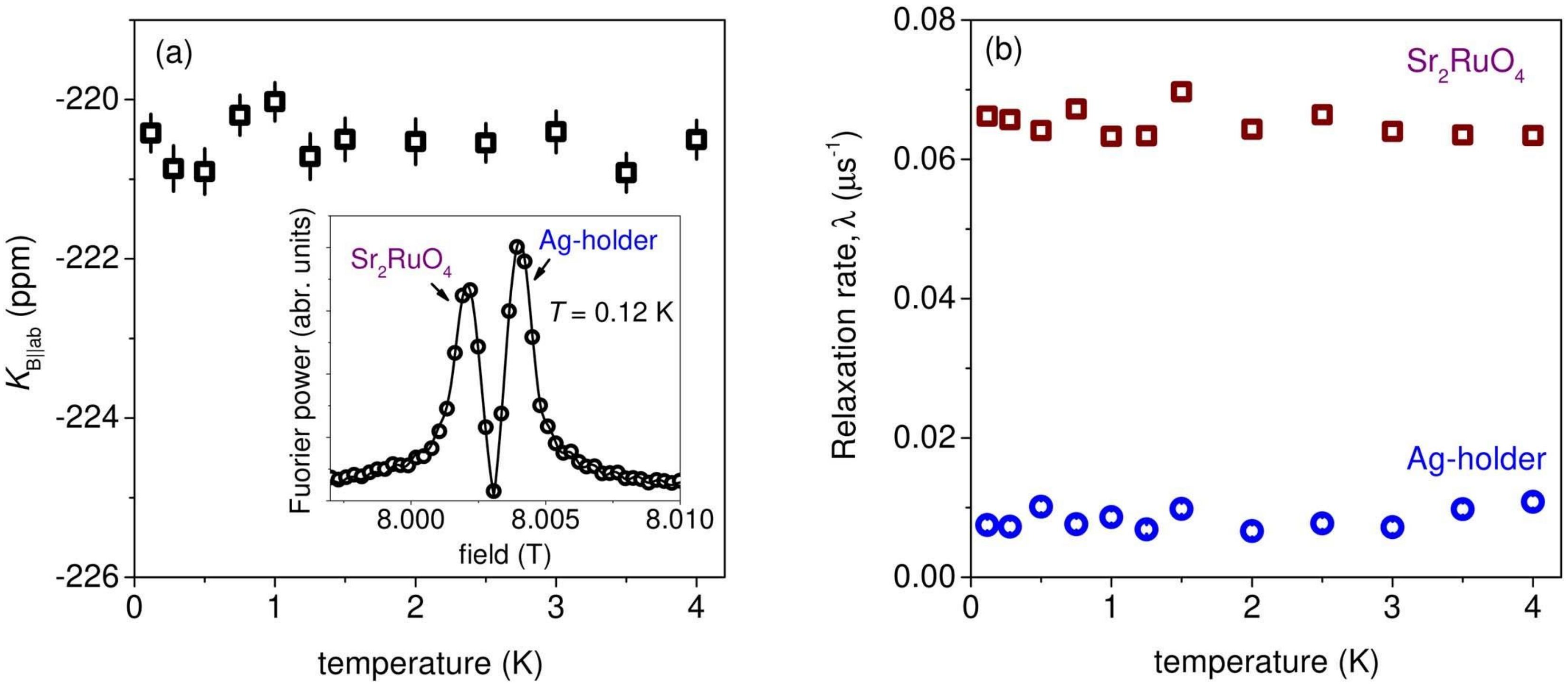
$T_{BTRS} \approx T_c$ due disorder and under hydrostatic pressure

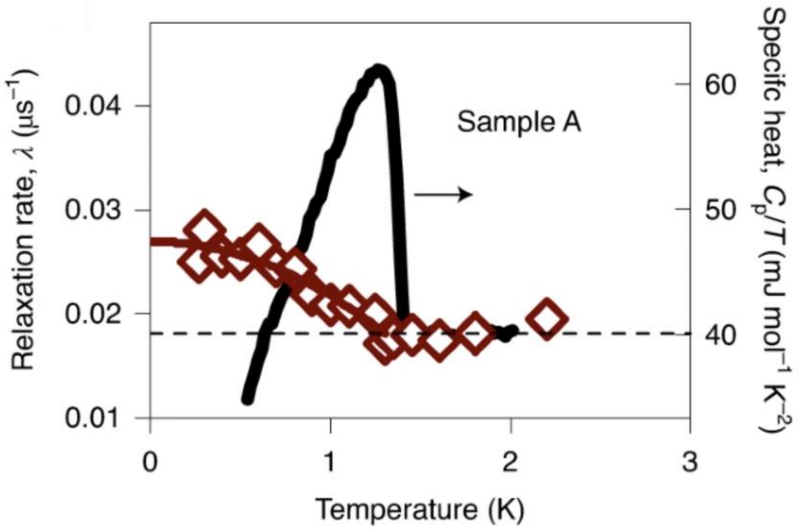
Suppression of superconductivity and time-reversal symmetry breaking under pressure.

Evidence for two component chiral superconductivity in Sr_2RuO_4.

V. Grinenko et al., *Nat Commun* **12**, 3920 (2021)

Magnetic field effect on the BTRS state



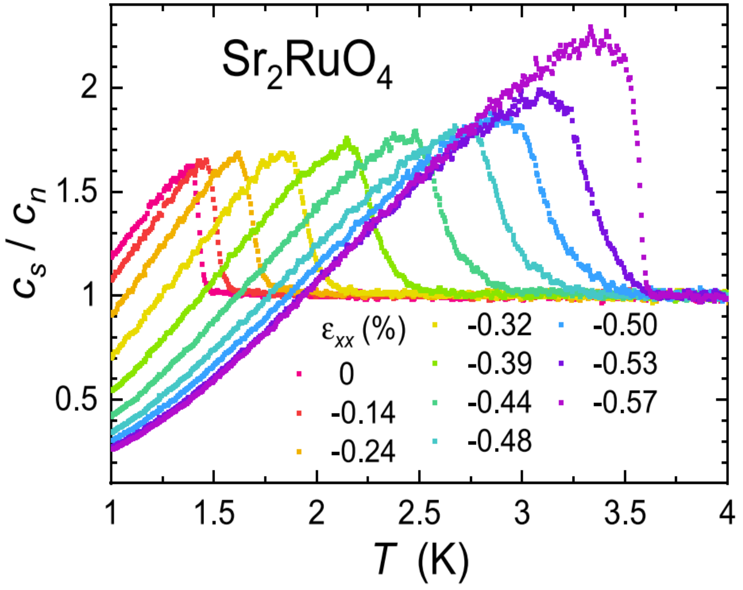


V. Grinenko, S. Ghosh *et al*., *Nat. Phys.* **17,** 748–754 (2021).

- The BTRS transition is not seen in the applied magnetic field above H_{c2} in both Knight shift and muon depolarization rate.
- The new measurements Y. Maeno *et al*., shows that in magnetic fields $T_c \sim T_{BTRS}$ up to H_{c2}.

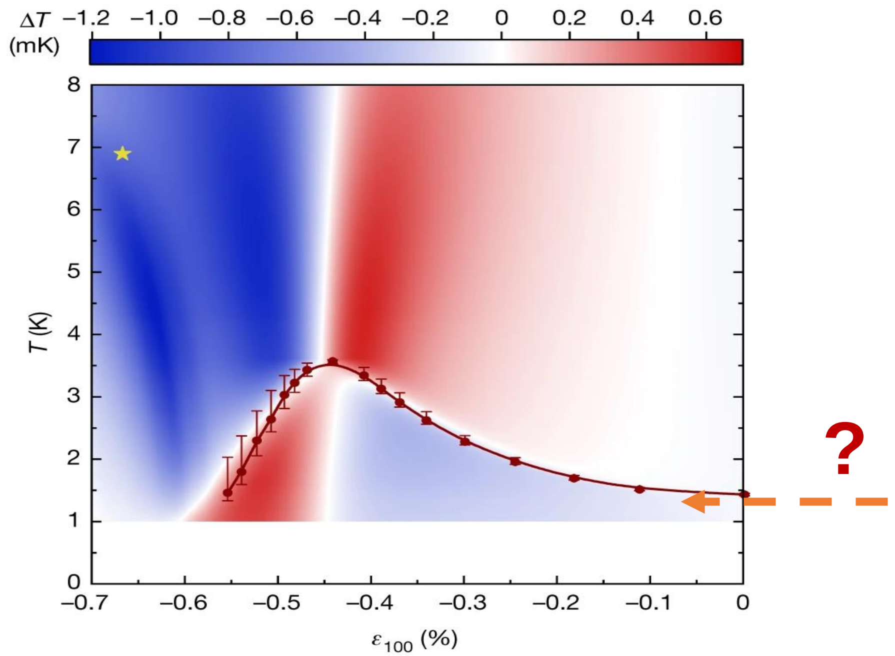
Evidence against BTRS superconductivity in Sr_2RuO_4

Missing anomaly at T_{TRSB} in the specific heat under uniaxial strain



Y.-S. Li *et al.*, PNAS **118** (10) e2020492118 (2021)

Elastocaloric effect

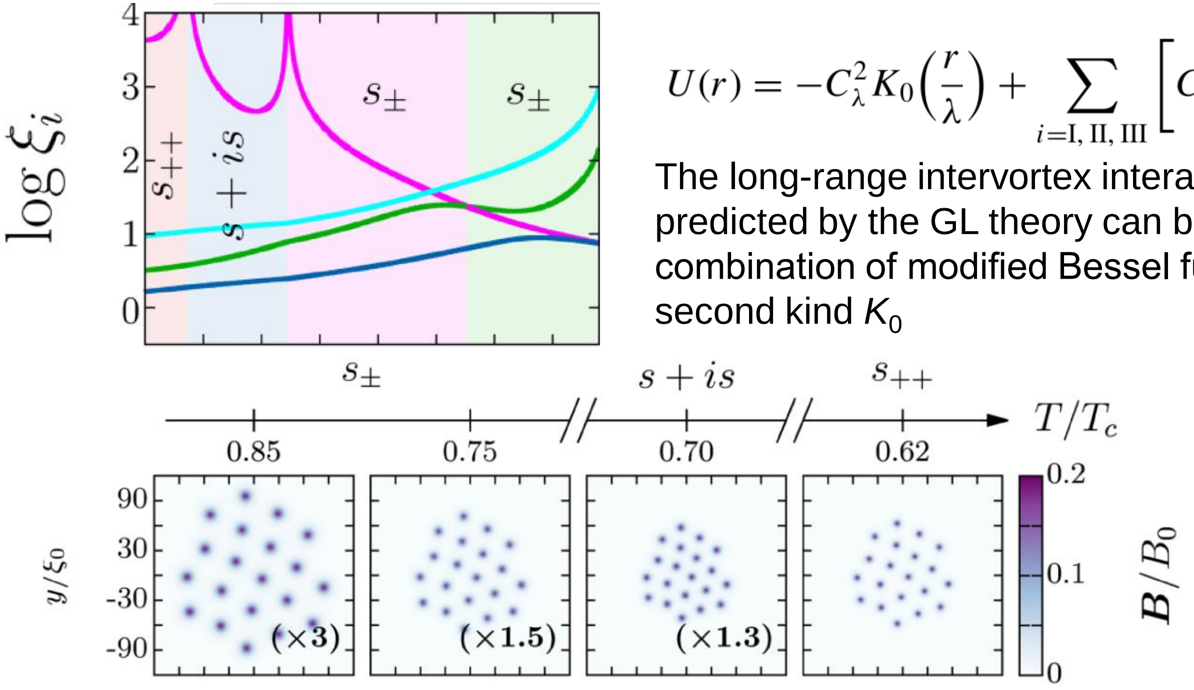


YS. Li *et al., Nature* **607**, 276–280 (2022).

No evidence for the BTRS transition in the specific heat and electrocaloric effect measurements under uniaxial strain.

Is the enhanced relaxation seen in μSR related to superconductivity at all?

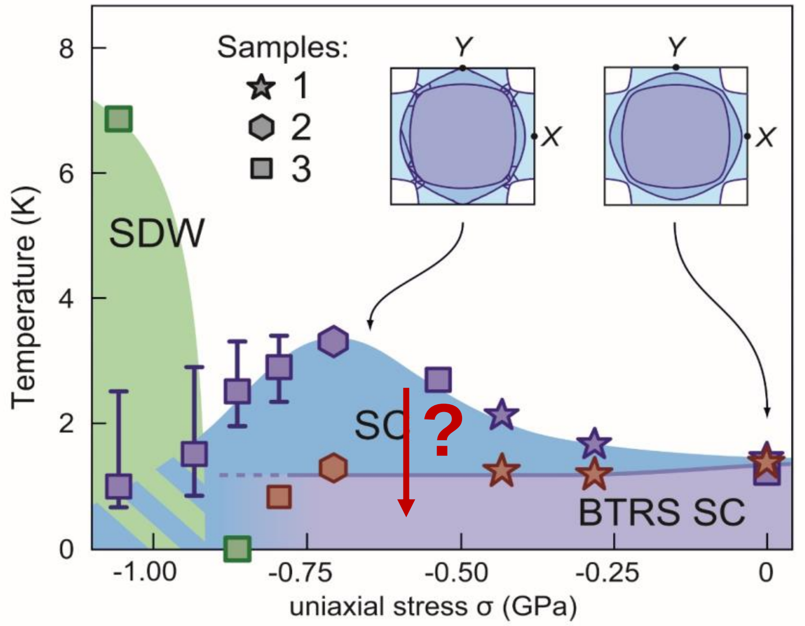
Can μSR provide a thermodynamic evidence for BTRS ?



$$U(r) = -C_\lambda^2 K_0\left(\frac{r}{\lambda}\right) + \sum_{i=\mathrm{I,\,II,\,III}} \left[C_i^2 K_0\left(\frac{r}{\xi_i}\right)\right]$$

The long-range intervortex interacting potential predicted by the GL theory can be expressed as a combination of modified Bessel functions of the second kind K_0

J. Garaud et al., PRB 98, 014520 (2018)



Is the BTRS transition affects the vortex distribution in the sample when T_c and T_{BTRS} are split?

- The hypothesis is that divergent TRSB coherence length at T_{TRSB} results in long-range intervortex attraction, while a short-range interaction, mediated by superconducting coherence length, is always repulsive. This should lead to vortex clustering, which can be observed in the field distribution probed by muons for sufficiently weak pinning and low vortex density (more noticeable in smaller fields).

What do we expect from a regular vortex lattice?

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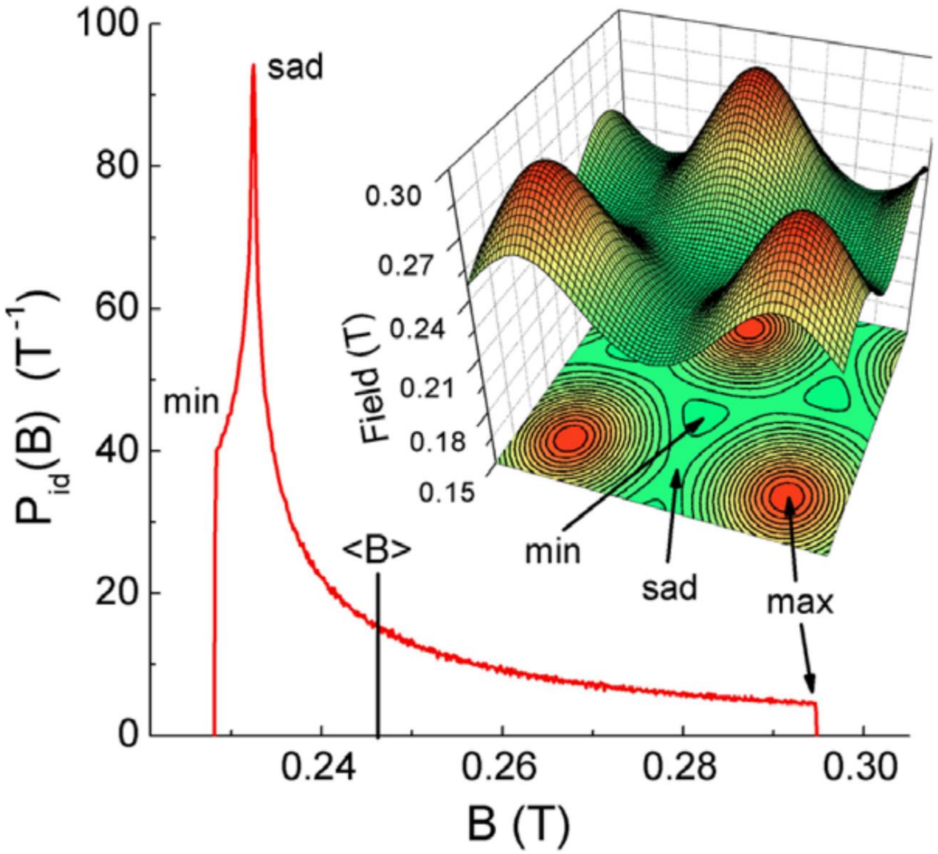


Figure 1. Example of a spatial distribution of the magnetic field $B(\mathbf{r})$ and the corresponding local magnetic field distribution $P_{\mathrm{id}}(B)$ for an ideal hexagonal FLL determined by the NGL method. The parameters used for the calculations are $\lambda = 50$ nm, $\xi = 20$ nm, and $\langle B\rangle = 0.3B_{c2} \simeq 246.8$ mT, and intervortex distance $a = 69.5$ nm.

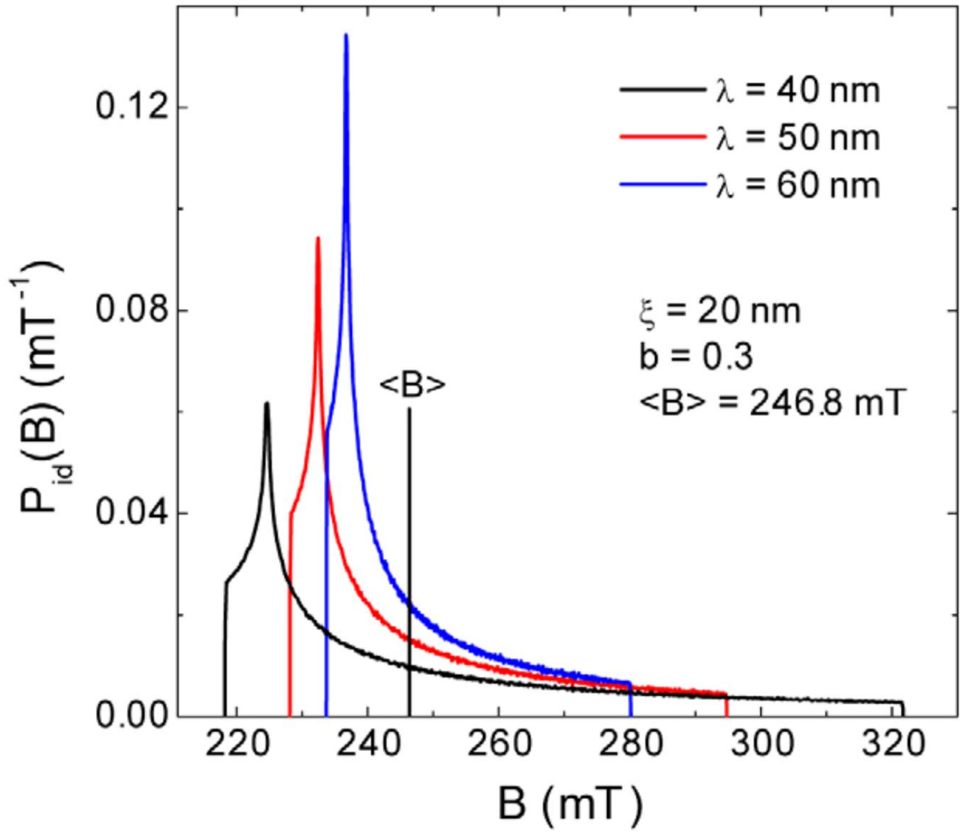
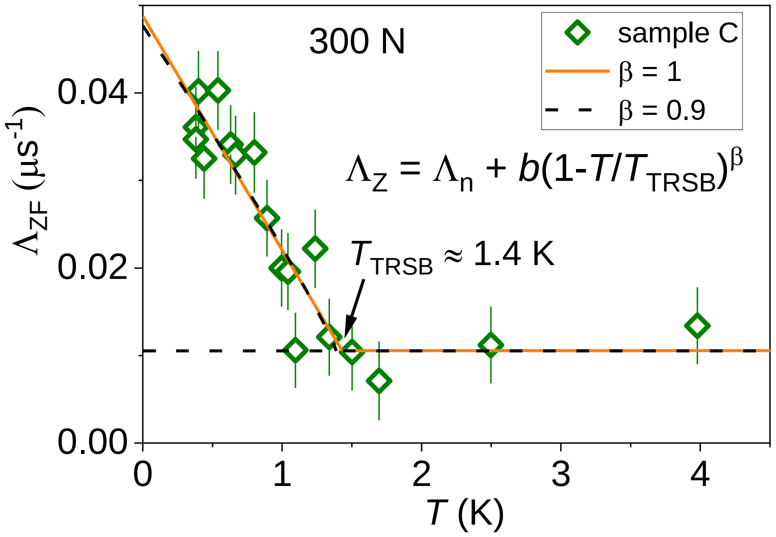
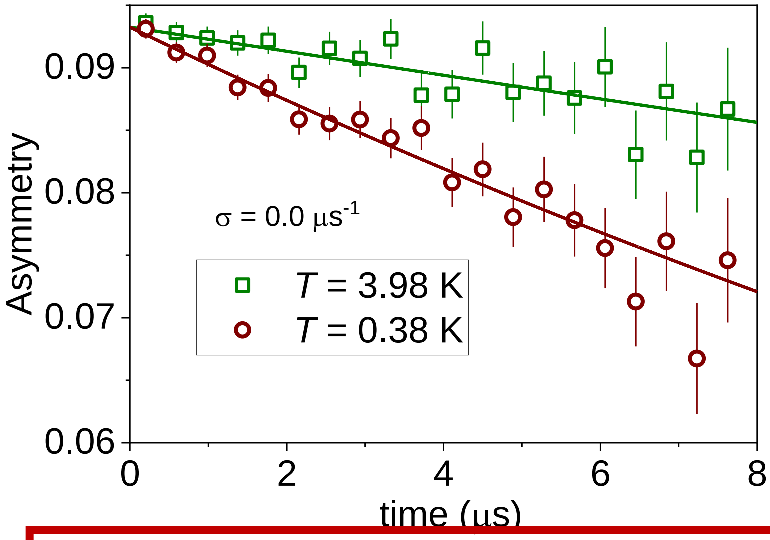
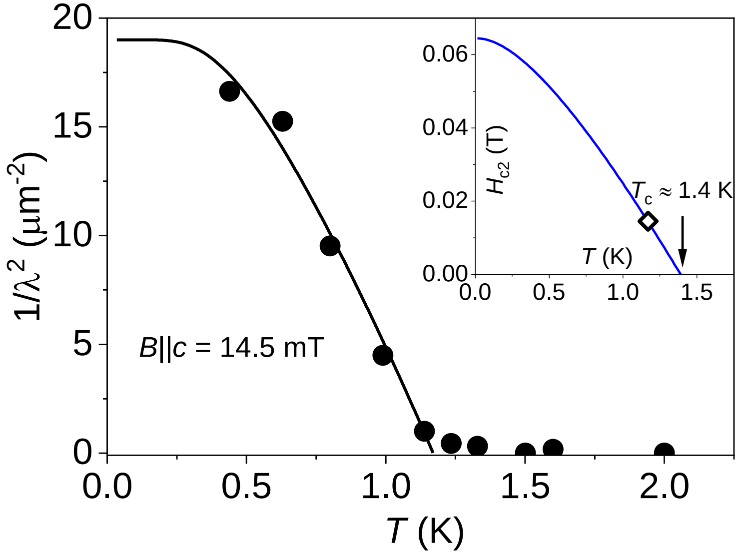


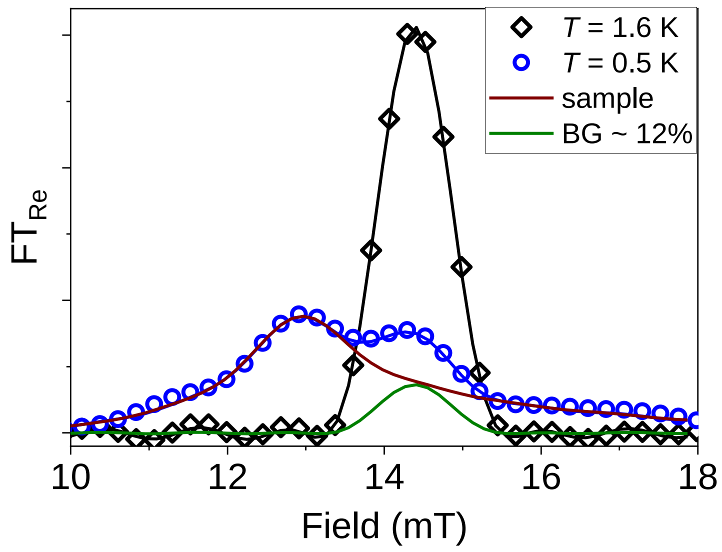
Figure 2. Local magnetic field distribution $P_{\mathrm{id}}(B)$ for an ideal hexagonal FLL obtained using the NGL model for different values of λ, at fixed ξ and applied field $B_{\mathrm{app}} \simeq \langle B\rangle$. The curves are normalized so that $\int P_{\mathrm{id}}(B)\,\mathrm{d}B = 1$. Note that the shape of $P_{\mathrm{id}}(B)$ strongly depends on λ.

Sample C (spring cell nominally 300N)









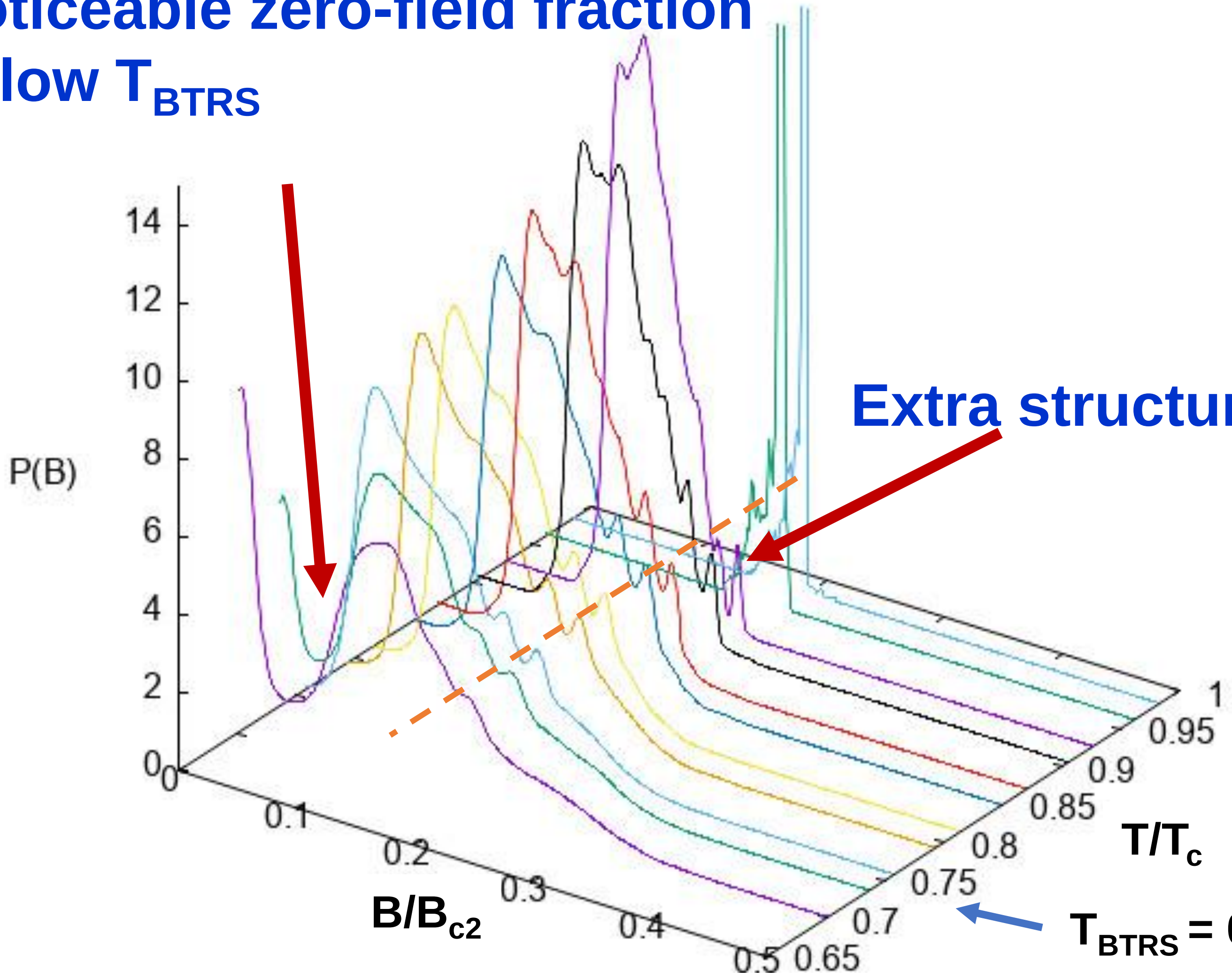
At the beginning we had troubles to apply strain.

The spectra in TF looks as expected for the samples with T_c ~ T_{BTRS}!

What do we expect from in the case $T_{BTRS} < T_c$?

Noticeable zero-field fraction below T_{BTRS}

Tow-band GL model applicable for s+is and s+id or s+ig states.

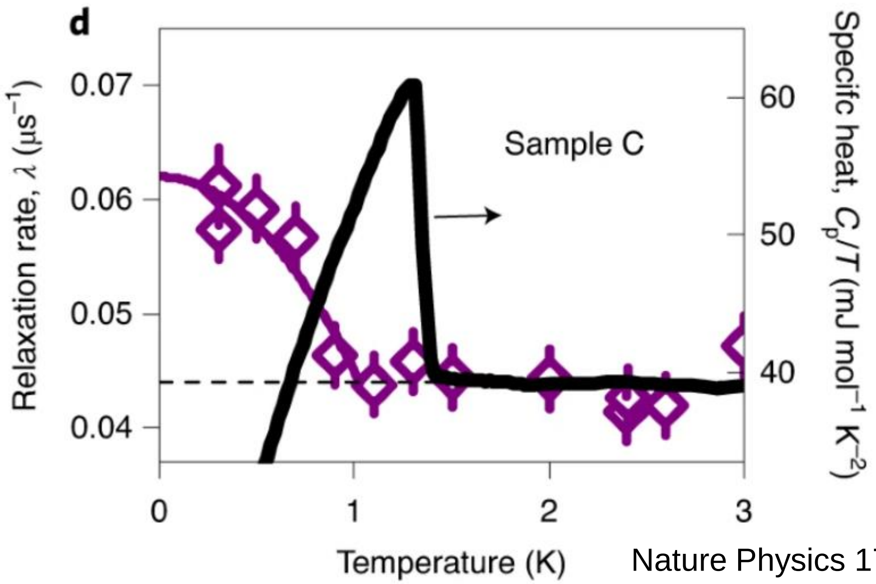


Extra structure in the spectra

$T_{BTRS} = 0.75\ T_c$

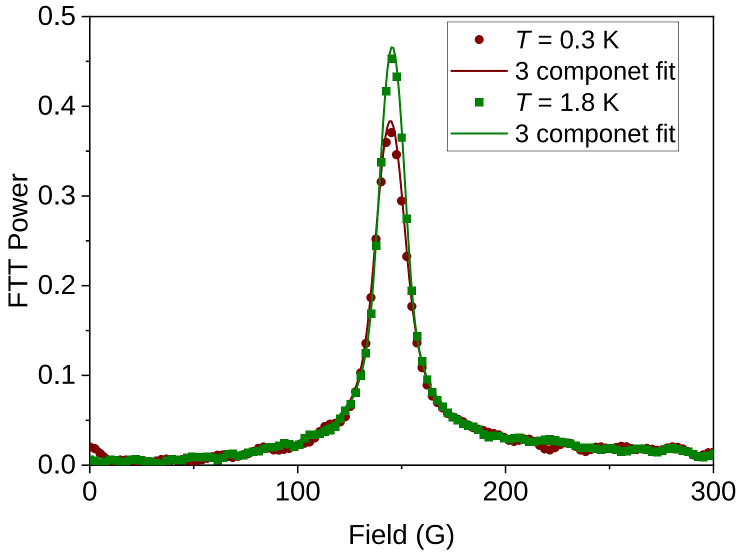
Julien Garaud

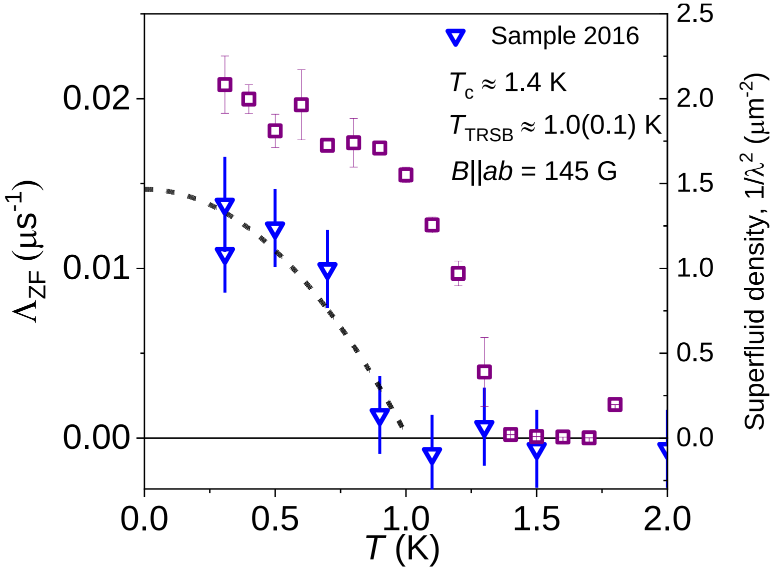
Sample with naturally split transitions at zero strain, zf and B||ab



Nature Physics 17, 748–754 (2021)

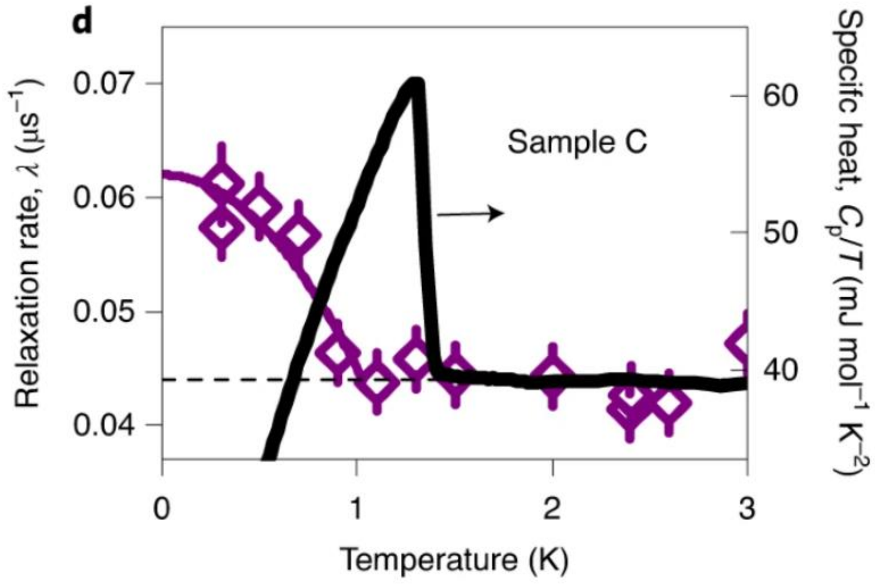
B||ab

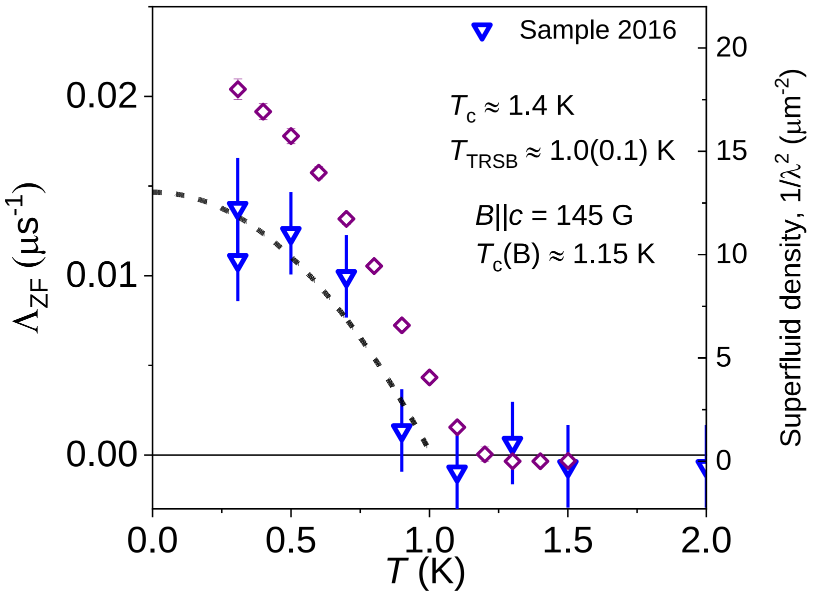




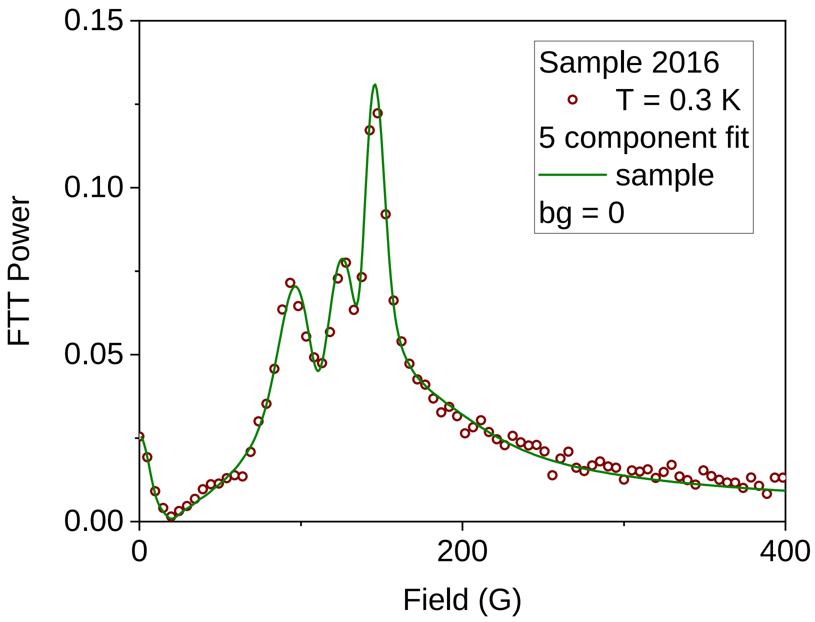
- The significant splitting about ΔT ~ 0.4 K at zero stain;
- The measurements without pressure cell -> bg ~ 0;
- For the field applied in the *ab*-plane the spectra don't show apparent anomalies around T_{TRSB}.

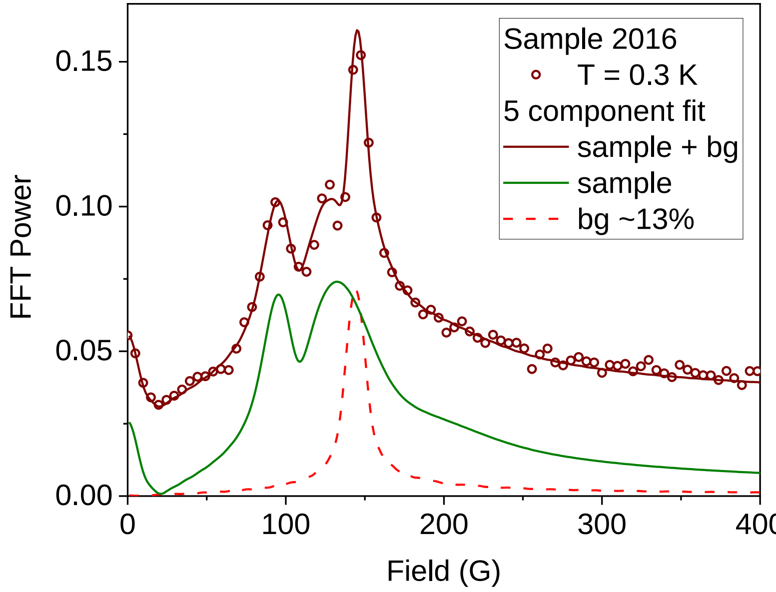
Sample with naturally split transitions at zero strain, zf and B||c





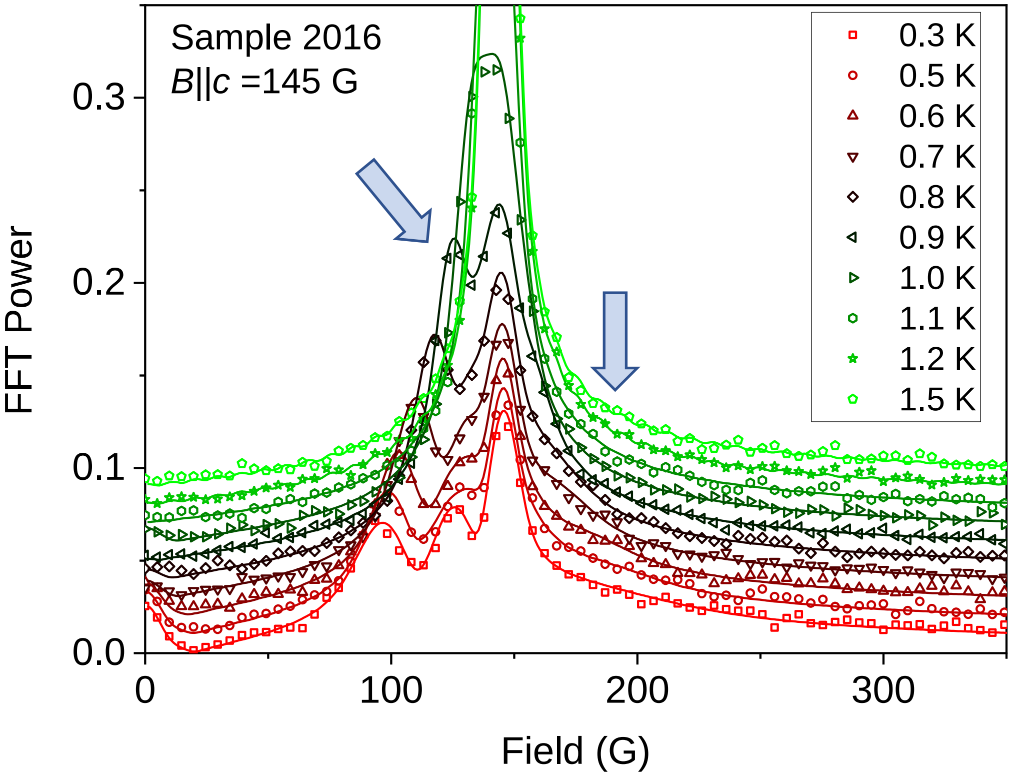
B||c

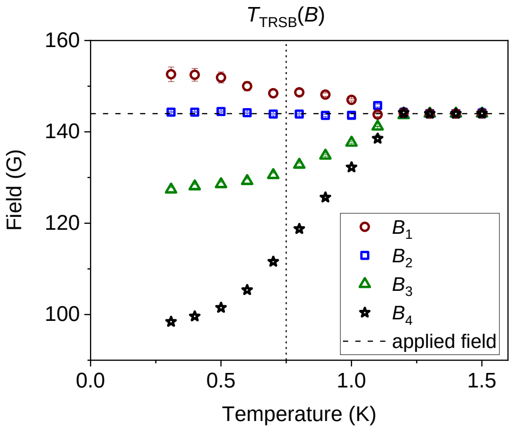


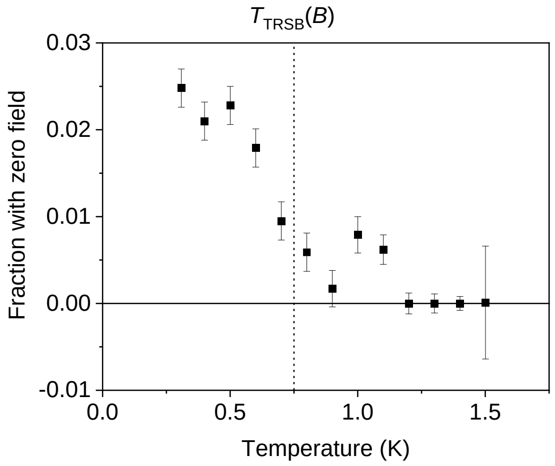


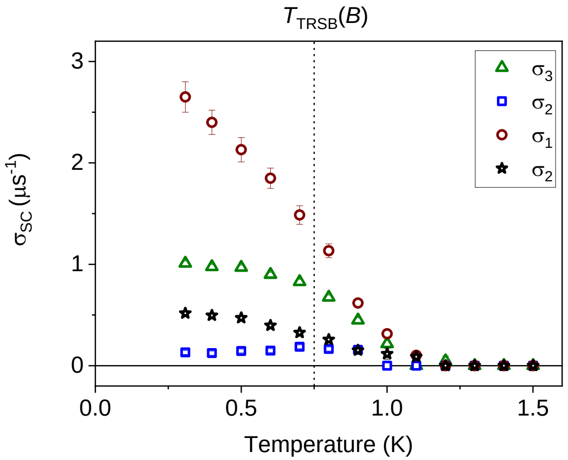
- $B||c$ = 145 G suppresses T_c by 0.25 K;
- We suppose that T_{TRSB} ~ 0.75 K at $B||c$ = 145 G ;
- The field distribution is similar for 2024 sample under strain, but with even more pronounced multi-peak behavior.
- We expect that the vortex clustering tendency is stronger in samples with lower T_c due to sampler Ginzburg-Landau parameter.

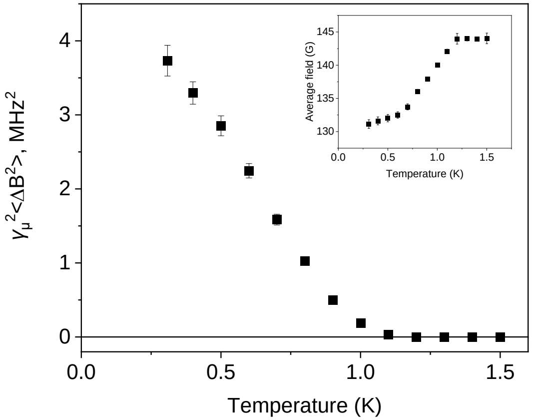
Sample with split transitions at zero strain, B||c





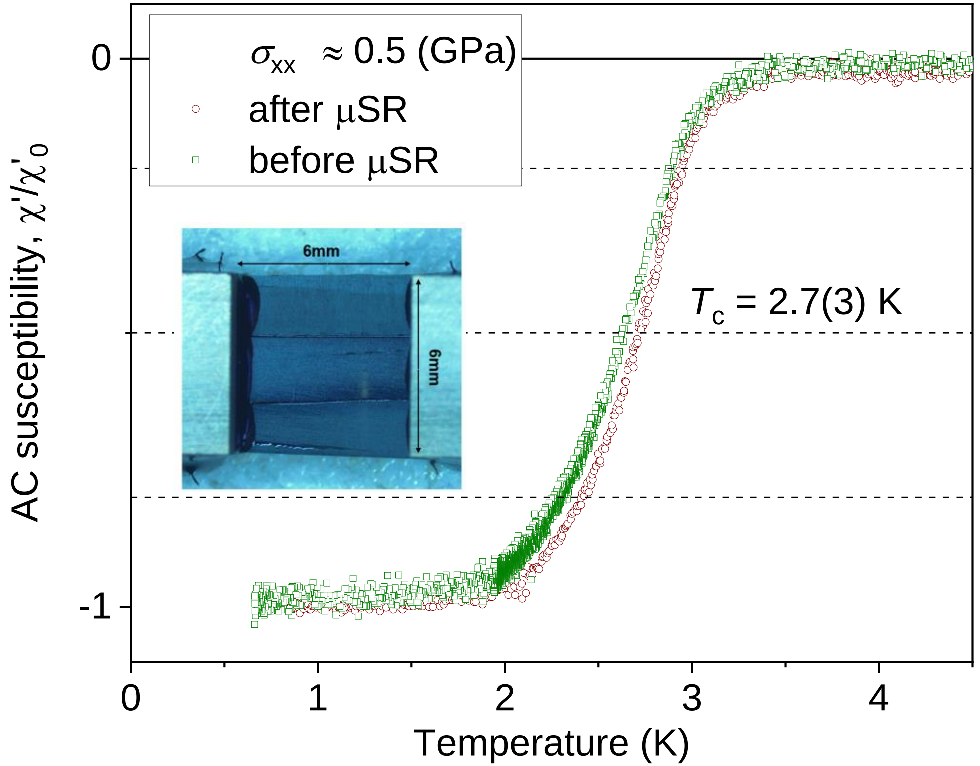


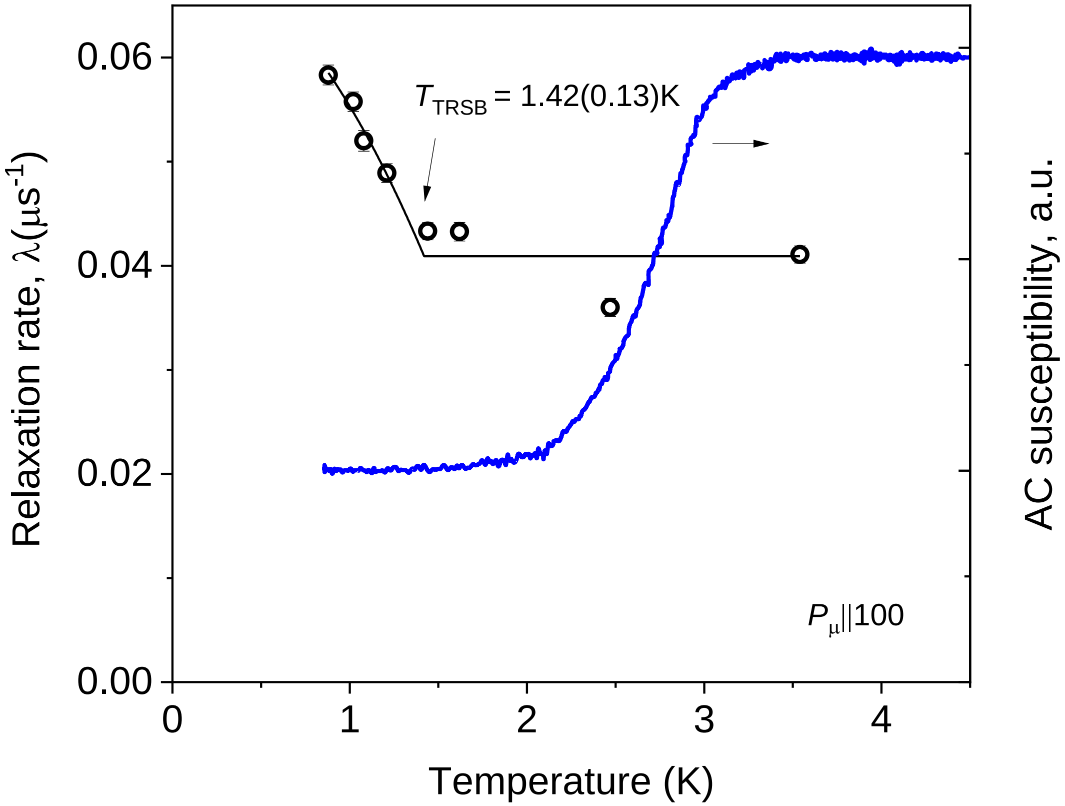




- We observe an increase of the field of the high-field component and the fraction with zero field close to the expected T_{TRSB} in applied field.
- In addition double structure of the spectra appears close to T_{TRSB} with noticeable high-field shoulder.

Zero-field measurements of Sr_2RuO_4 under uniaxial strain





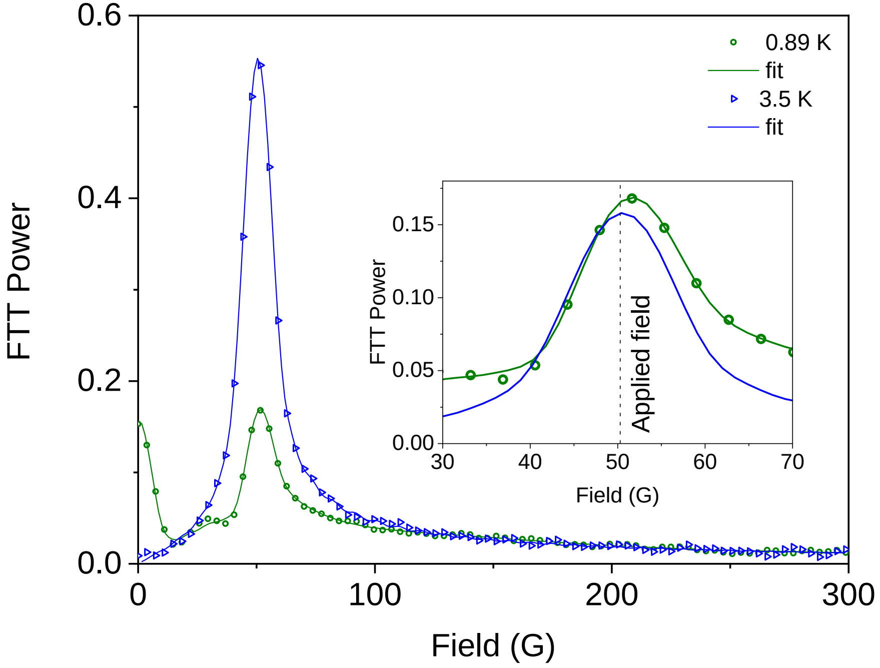
- The applied uniaxial pressure ~ 0.5GPa with $T_c^{50\%}$ ~ 2.7K;
- TRSB transition temperature, T_{TRSB} ~ 1.4 K.

Can we verify under uniaxial strain the observation obtained on the sample with the split transitions?

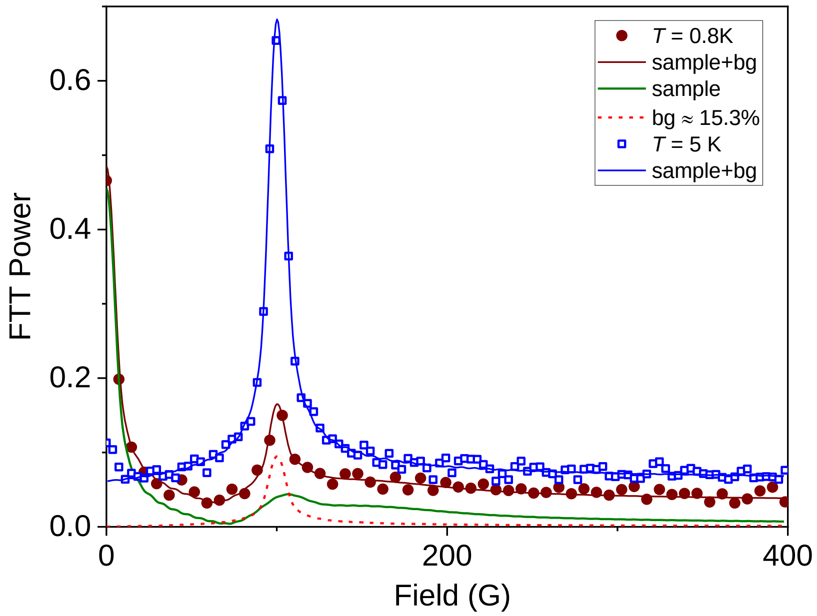
Analysis of the sample volume fraction using TF measuremnts

李政道研究所
TSUNG-DAO LEE INSTITUTE

Standard experiment: The field is applied above T_c, the sample is cooled to the base temperature, and the measurements are performed in steps while heating.



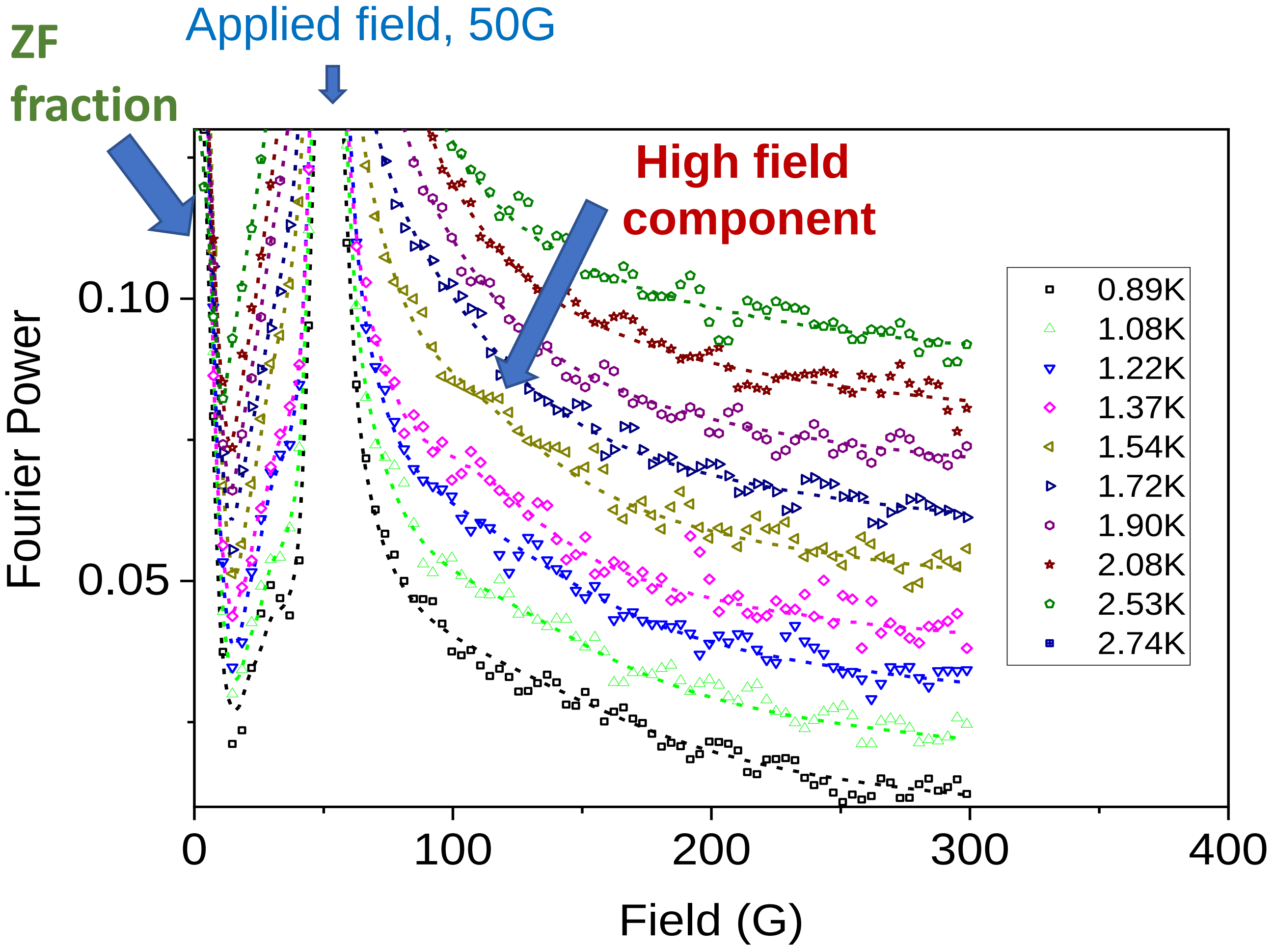
Pinning experiments:
ZF cooling to T = 0.8K application B||c = 120 G, changing to 100 G and measuring.

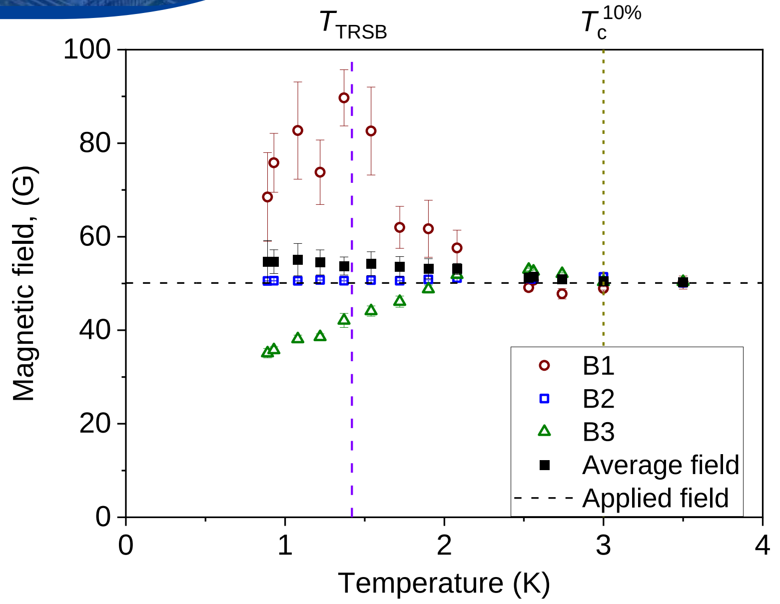


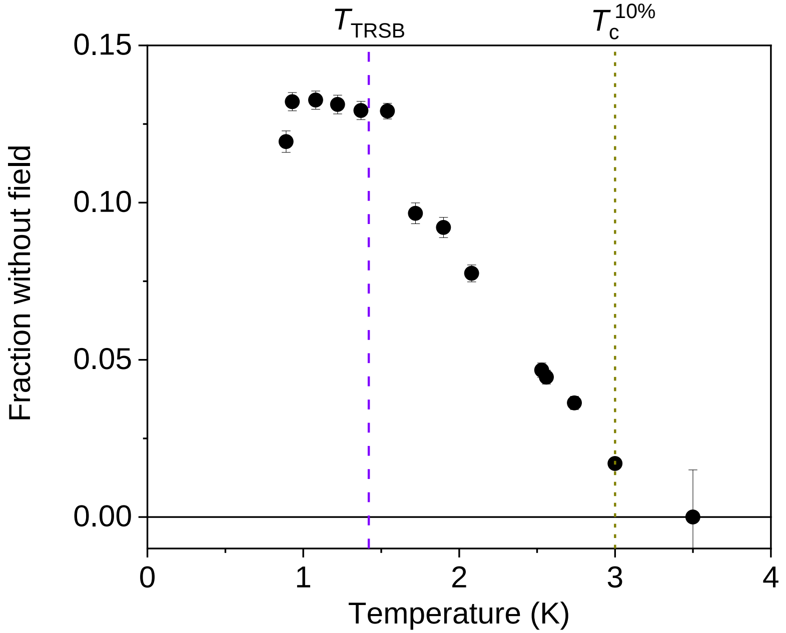
The central peak close to the applied field is not related to the background since it’s position shifts systematically with the temperature.

The background contribution estimated from the pinning experiments is about of 15% of the signal amplitude.

50 G || the c-axis under uniaxial strain, T_c ~ 3 K, T_{BTRS} = 1.4 K

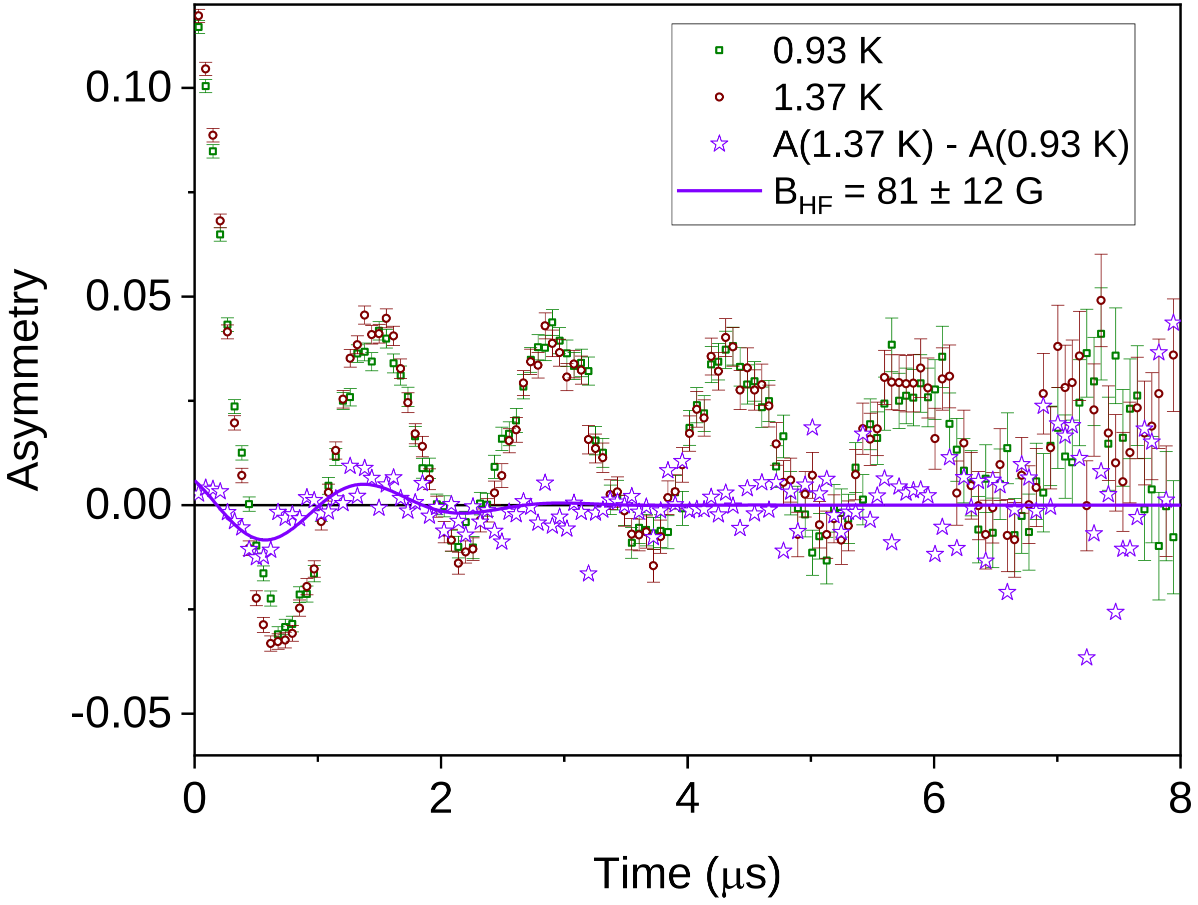


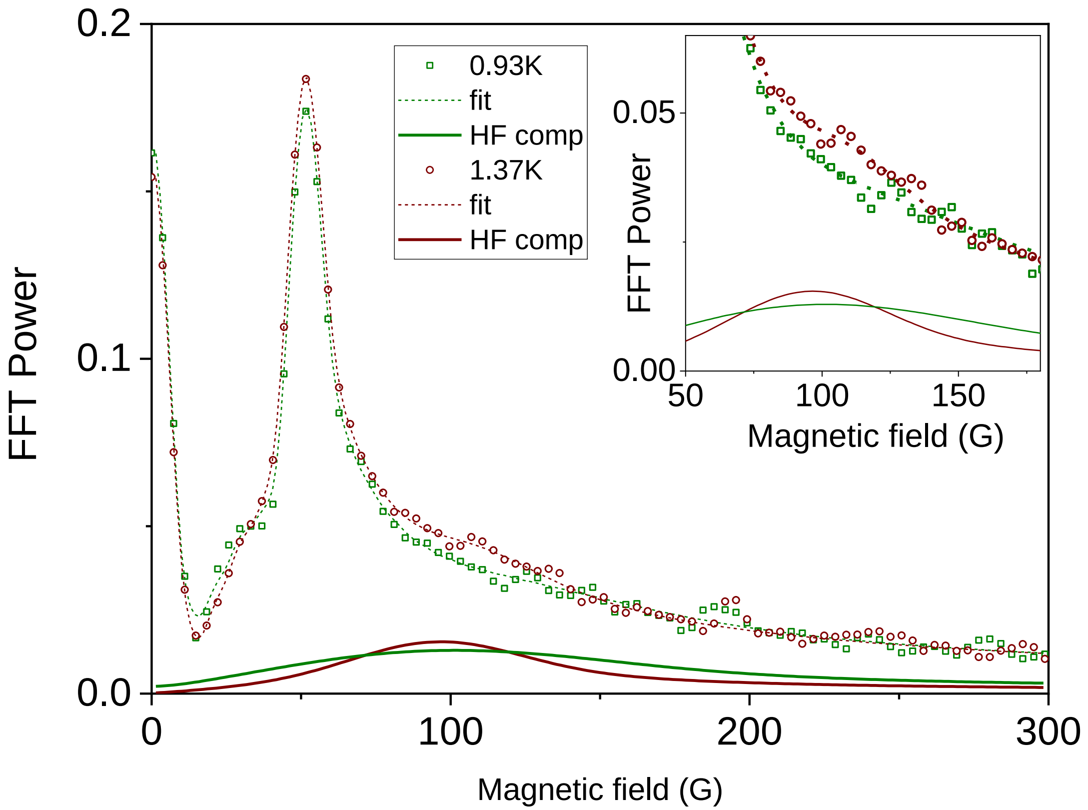




- ✓ The high-field component moved to the highest field near T_{TRSB} ≈ 1.4 K.
- ✓ Around this temperature, there is a jump at zero field fraction.

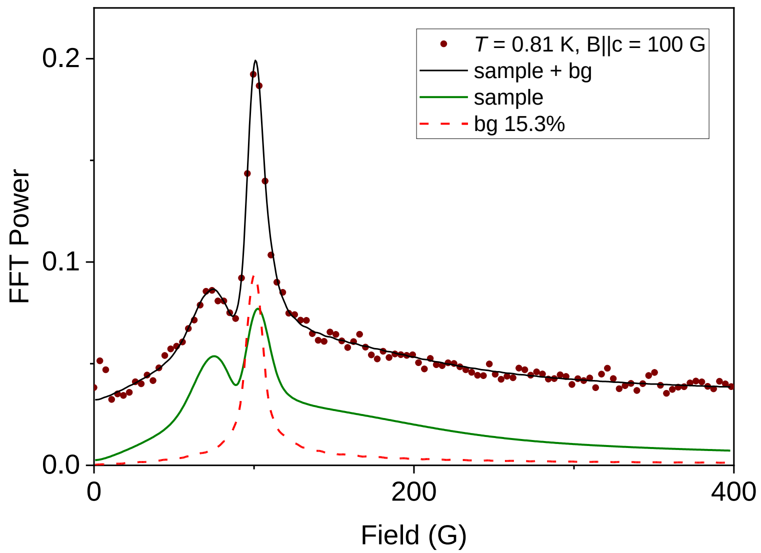
High-field fraction is not an artifact of Fourier transform

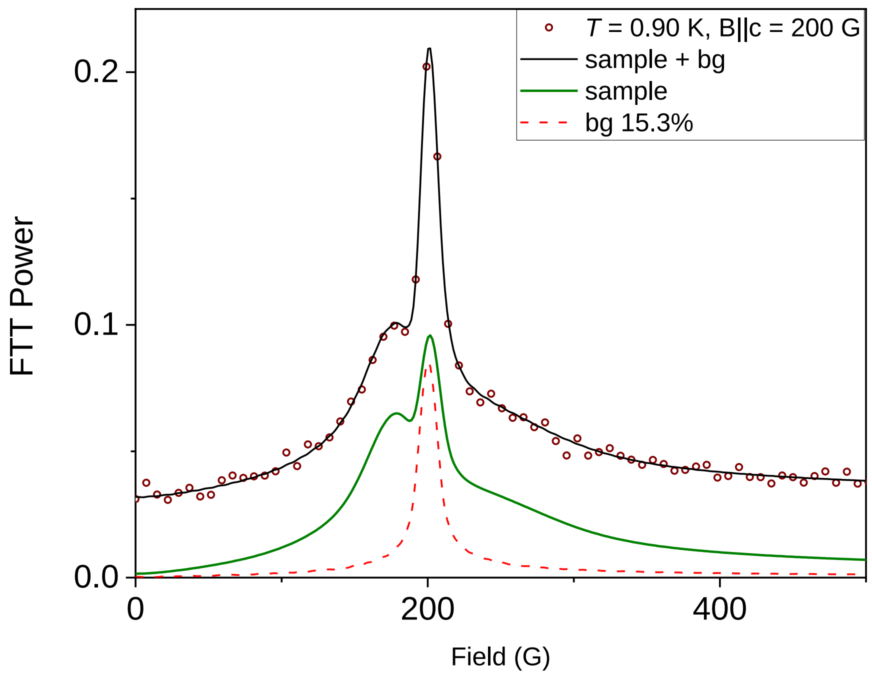


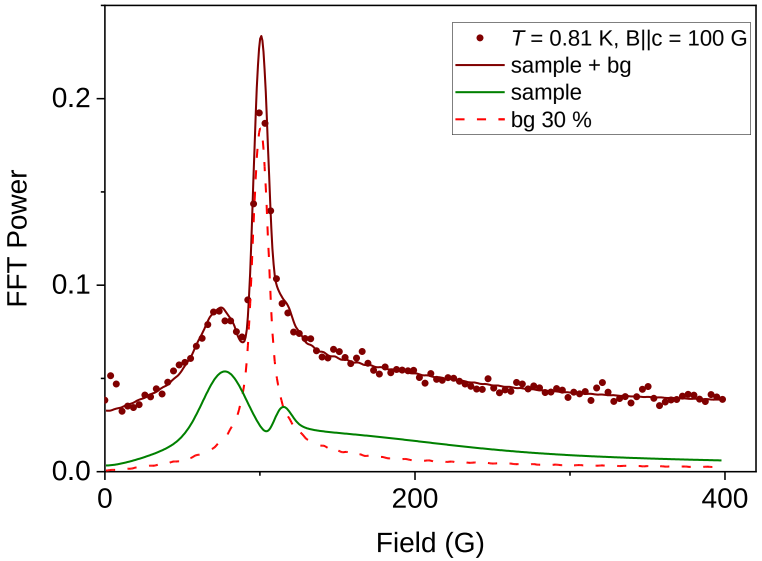


- The high-field component is not an artifact of fit or Fourier Transform;
- The well defined high-field component is absent at lower temperatures.

TF-μSR data in 100 and 200 G applied fields ||c

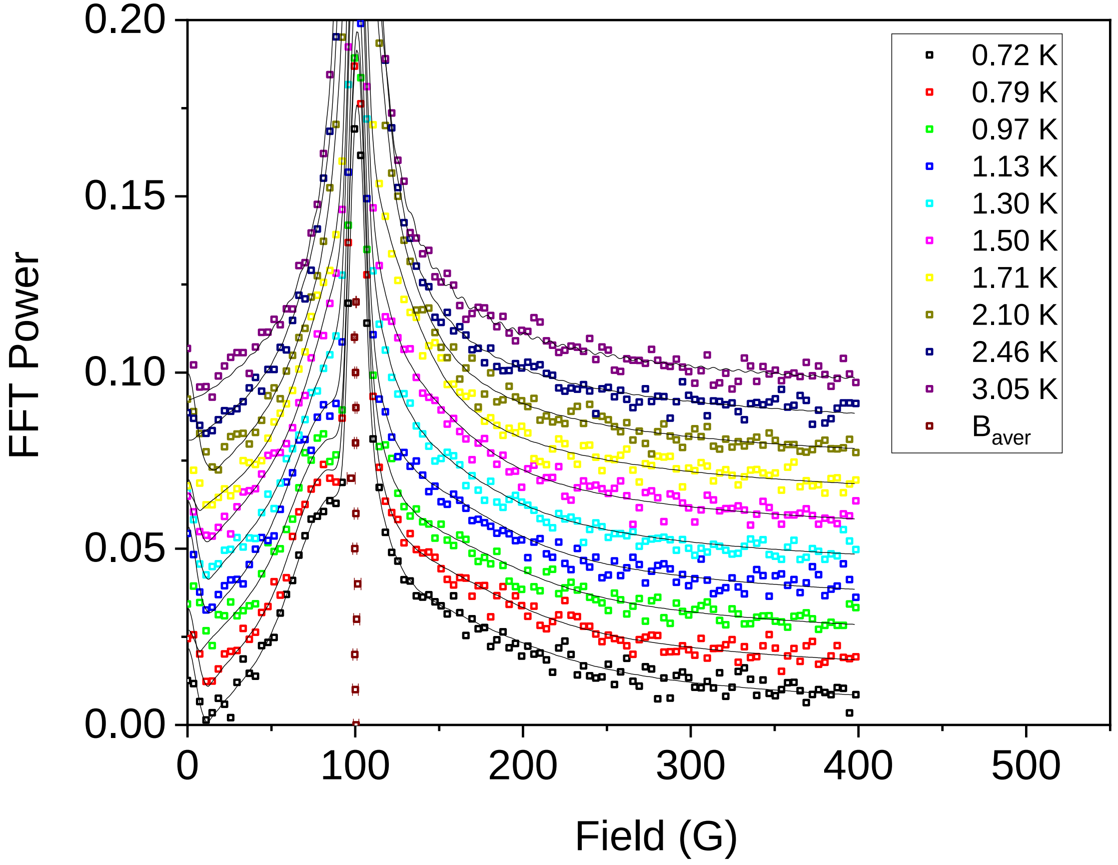


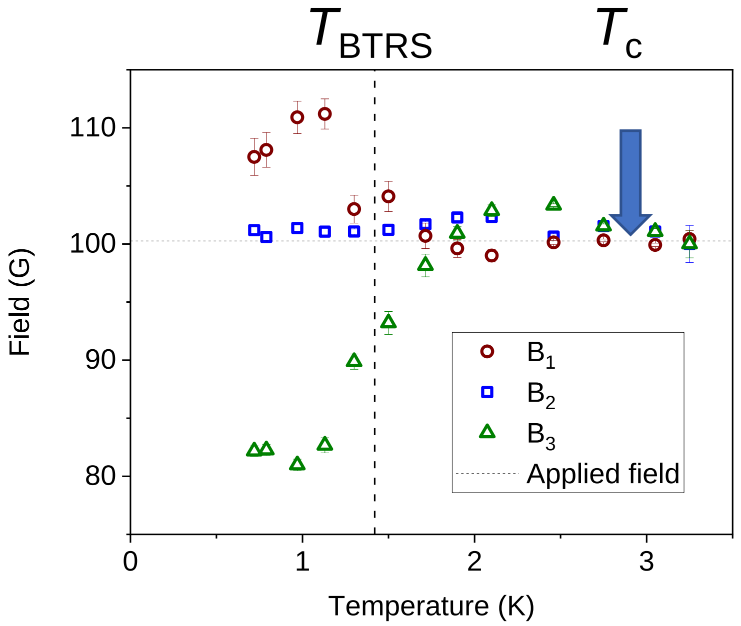


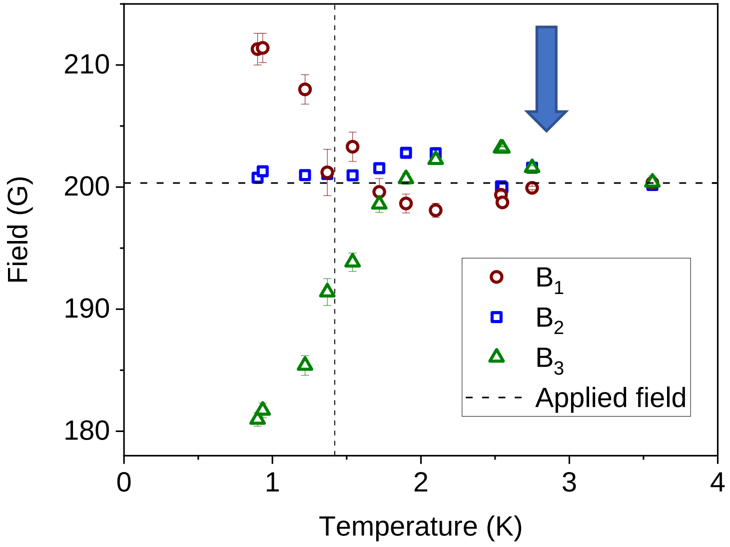


- The background contribution cannot account the two-peak structure of the signal;
- Both peaks coming from the sample indicating two well-defined regions with different intervortex distances.

TF-μSR data in 100 G applied fields ||c

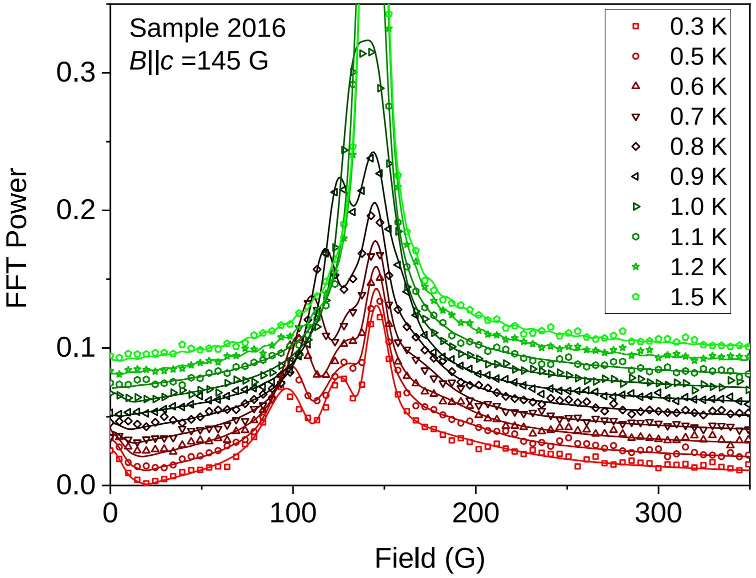


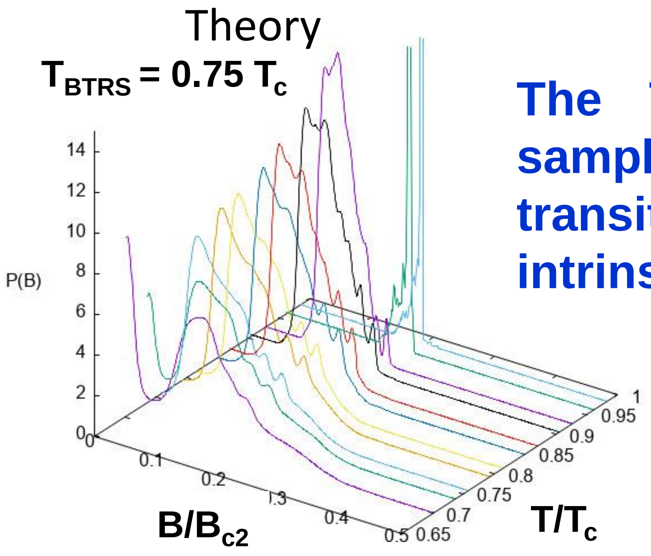




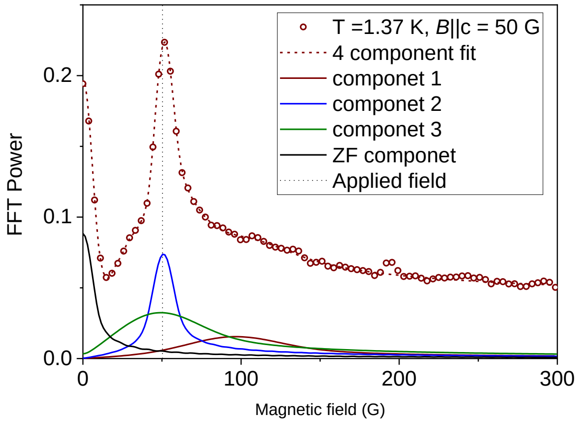
- 2 peak structure develops around BTRS transition.

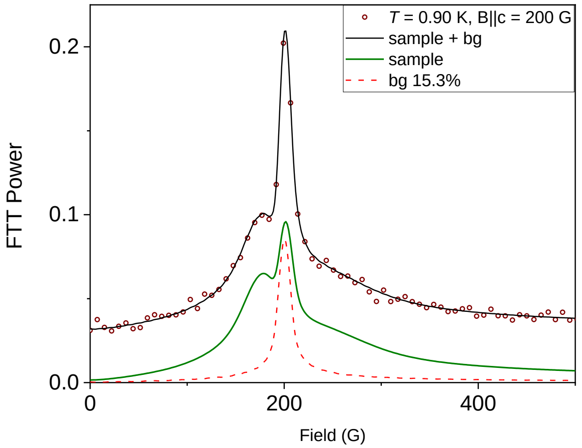
Summary

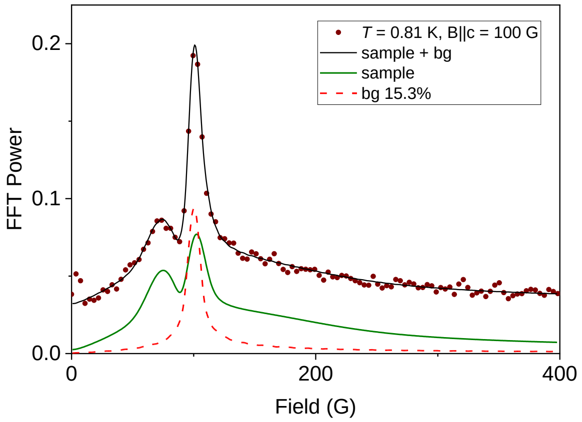




The TF data obtained on the Sr_2RuO_4 samples with the split T_c and T_{BTRS} transitions suggest that BTRS state is intrinsic to superconductivity.







Looking for postdocs and PhD students!

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