Multigap Superconductivity in Chiral Noncentrosymmetric $TaRh_2B_2$

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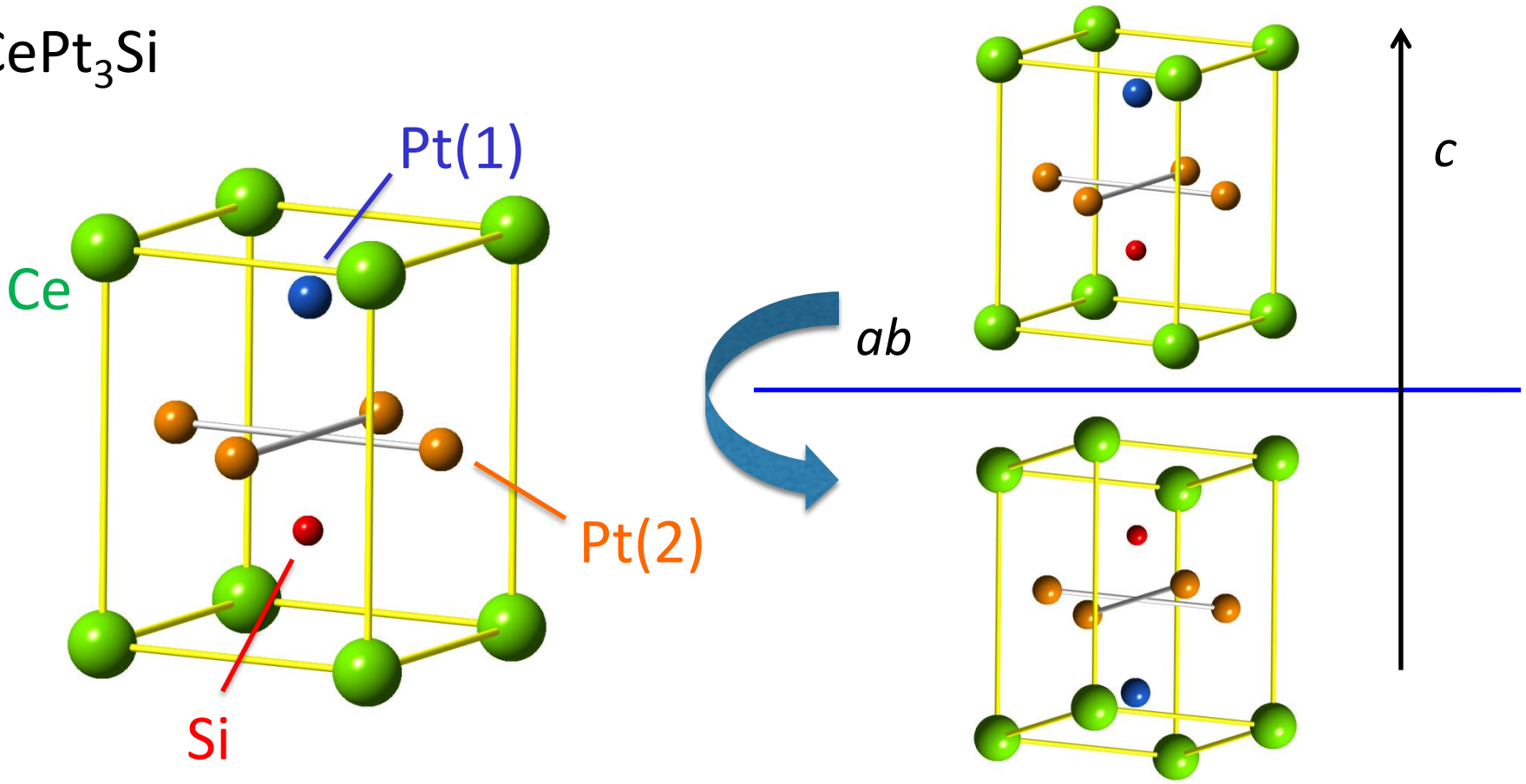
Inversion Symmetry

(or lack thereof…)

$(x, y, z) \rightarrow (-x, -y, -z)$ not a symmetry of the crystal.

$CePt_3Si$



E. Bauer *et al.*, Phys. Rev. Lett. **92**, 027003 (2004).

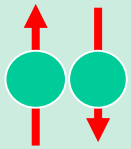
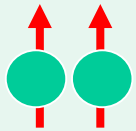
Superconductivity

The gap function of a superconductor has the form

$$\hat{\Delta}(\boldsymbol{k}) = \begin{bmatrix} 0 & \Delta_0 \\ -\Delta_0 & 0 \end{bmatrix} + \begin{bmatrix} -d_x + id_y & d_z \\ d_z & d_x + id_y \end{bmatrix}$$

Singlet Triplet

If the crystal has inversion symmetry then we have:

	Spin part	Orbital part
Singlet	antisymmetric 	Symmetric (s, d…)
Triplet	symmetric 	Antisymmetric (p, f…)

But what if the crystal lacks a centre of inversion?

Noncentrosymmetric Superconductivity

Rashba-type antisymmetric spin-orbit coupling (ASOC) allows degeneracy of the Fermi surfaces.

Parity no longer a good quantum number.

	Centrosymmetric	Noncentrosymmetric
Cooper pair		

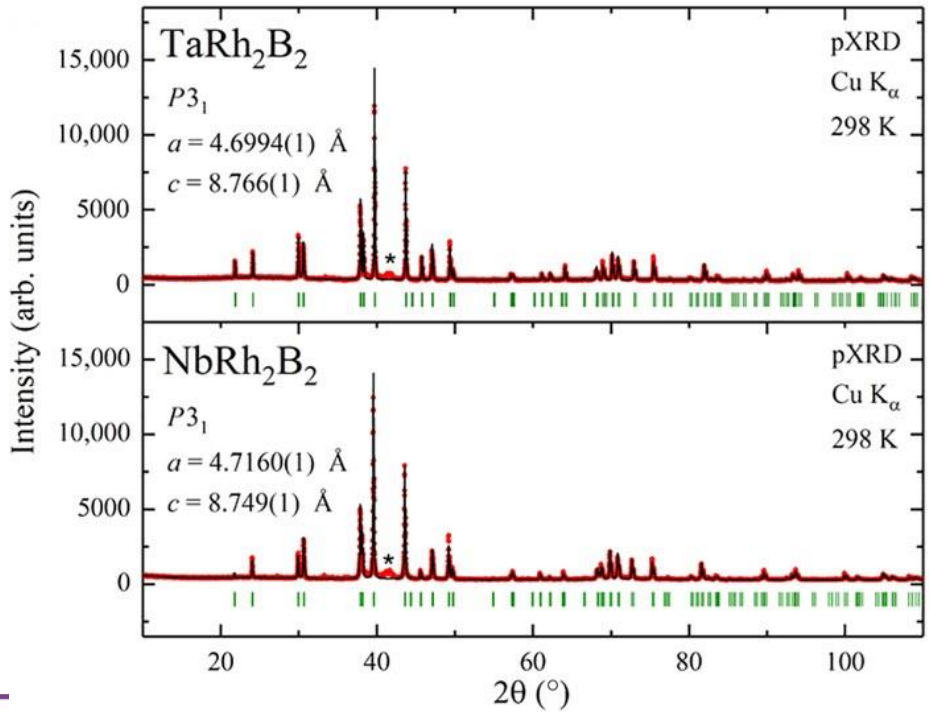
Cooper-pair wave function may now be a MIXTURE of spin-singlet and spin-triplet pairing.

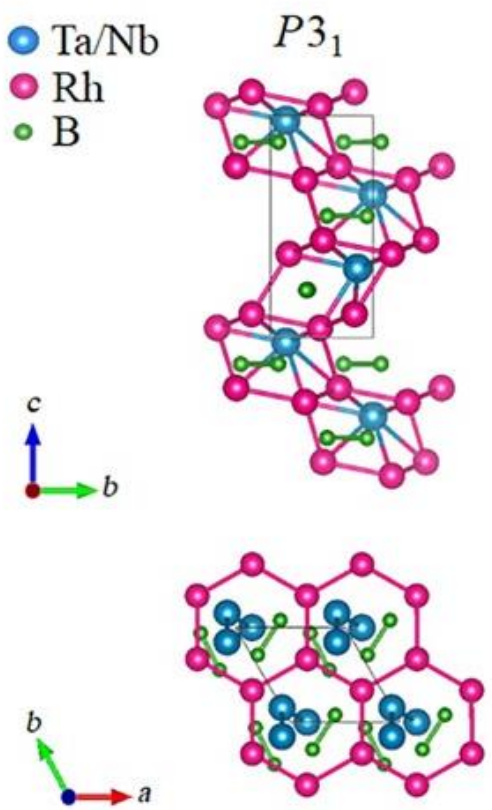
L. P. Gor'kov and E. I. Rashba, Phys. Rev. Lett. **87**, 037004 (2001).

$TaRh_2B_2$ and $NbRh_2B_2$

$TaRh_2B_2$ and $NbRh_2B_2$ crystallizes in chiral noncentrosymmetric crystal structure.

- Space group: $P\ 3_1$
- Polar & Asymmorphic

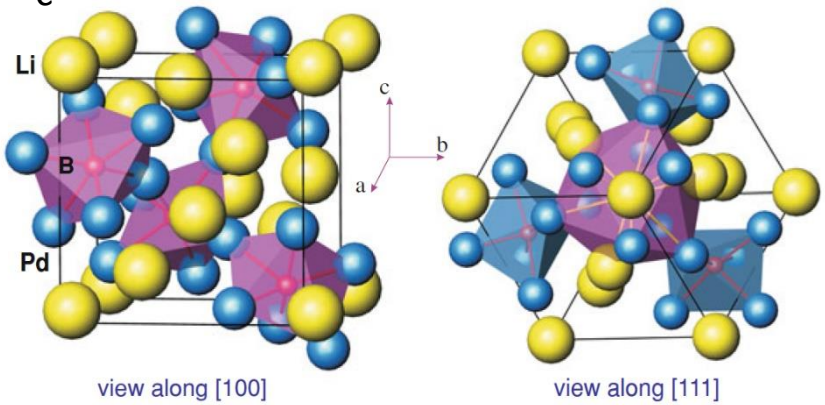




E. M. Carnicom *et al.* Science Advances **4**, eaar7969 (2018).

Chirality in Superconductors

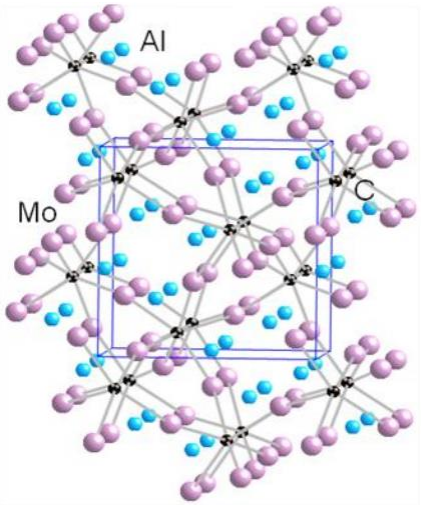
$Li_2Pd_{1-x}Pt_xB$
T_c ~ 2.7 - 7 K



Space group: $P4_332$.
s-wave (Pd) to line nodal gap (Pt).

H. Q. Yaun *et al.* Phys. Rev. Lett. **97**, 017006 (2006).

Mo_3Al_2C
T_c ~ 9 K



Space group: $P4_132$.
Nodal gap.

A. B. Karki *et al.* Phys. Rev. B **82**, 064512 (2010).

Both noncentrosymmetric with chiral crystal structure.

Experimental Methods

Polycrystalline samples prepared by pressing mixed powder into a pellet and heating in high vacuum furnace at 1200 ^{o}C for 6 hours.

Powder XRD confirm:

- structure.
- no impurities including oxides.

Magnetization, heat-capacity, and resistivity.

Muon spectroscopy.

Muon Spin Relaxation/Rotation (μSR)

Zero-field, longitundinal-field and transverse-field studies were carried out using MuSR spectrometer at ISIS-RAL.

Powder samples mounted on a Ag plate.

^{3}He cryostat $0.3 \leq T \leq 10$ K.

Stray fields cancelled to level of 1 μT.

$TaRh_2B_2$

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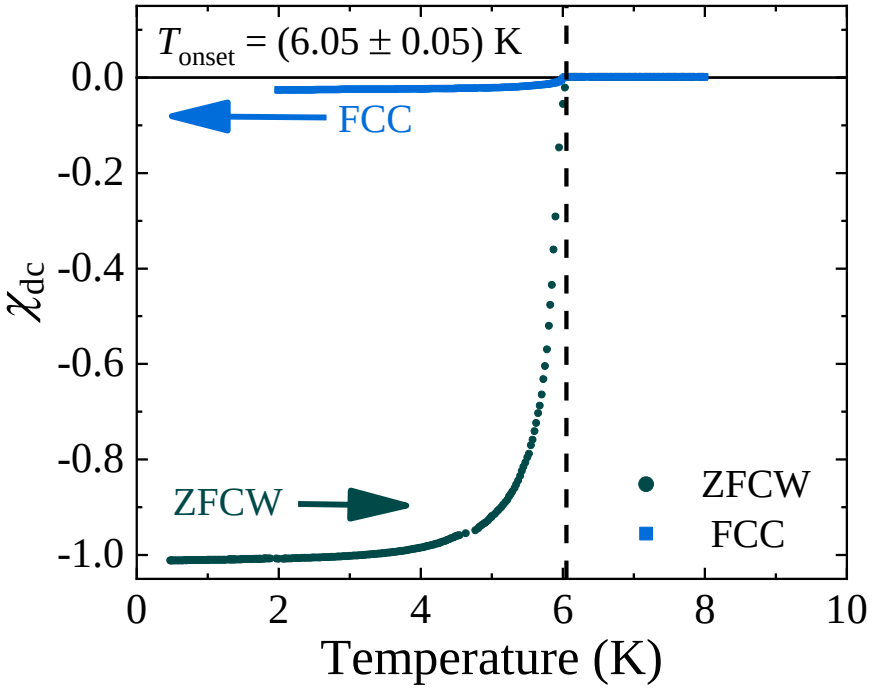
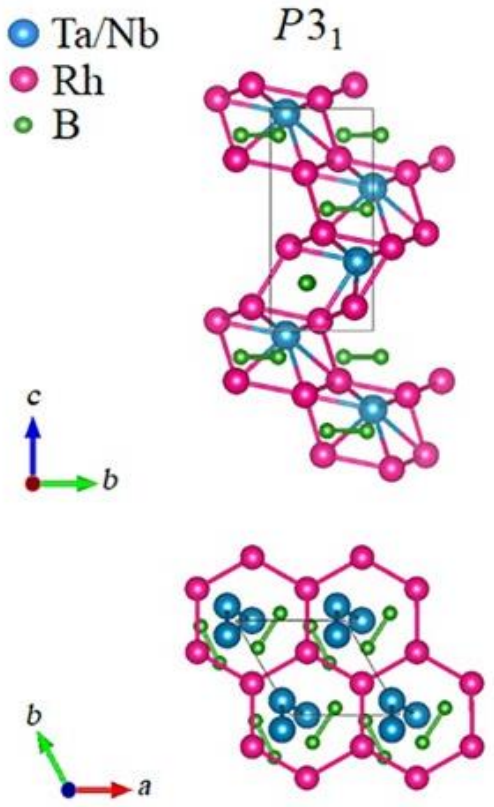




E. M. Carnicom *et al.* Science Advances **4**, eaar7969 (2018).

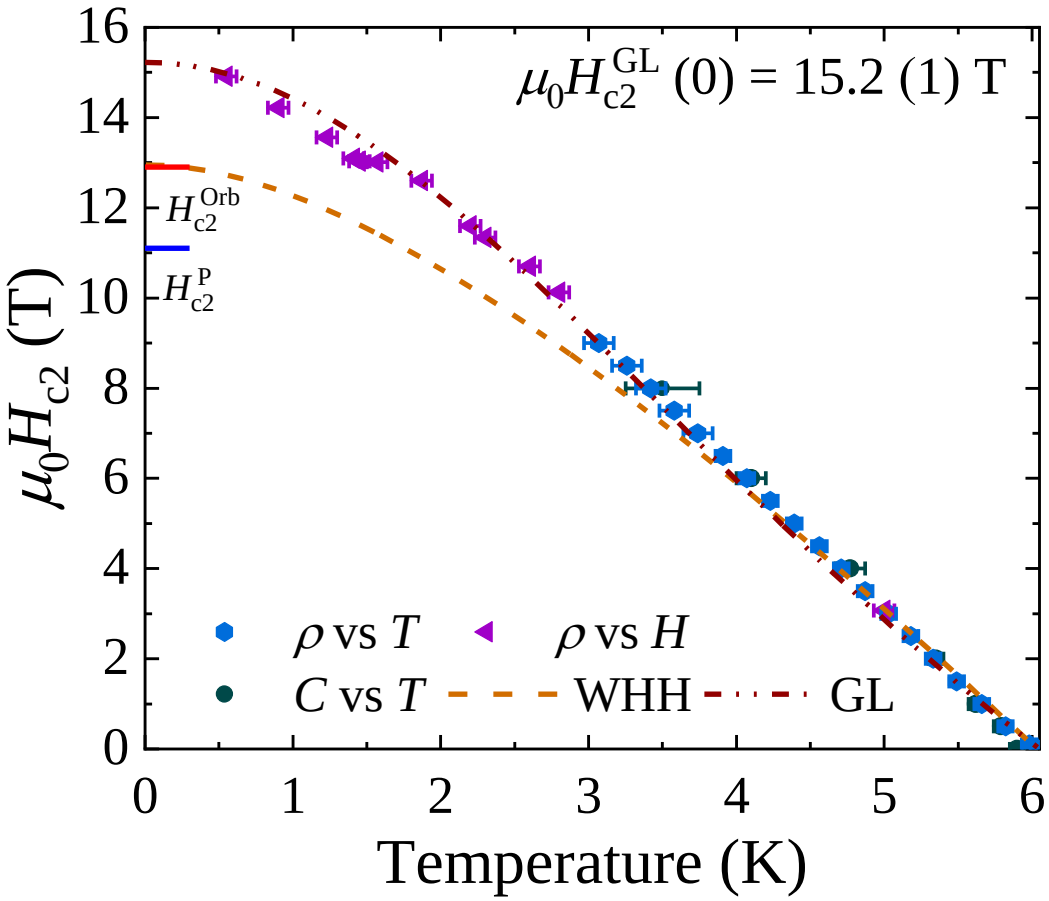
D. A. Mayoh *et al.* Physical Review B. **98**, 014502 (2018).

Upper Critical Field

$$\mu_0 H^{\mathrm{P}} = 1.85 \times T_c$$

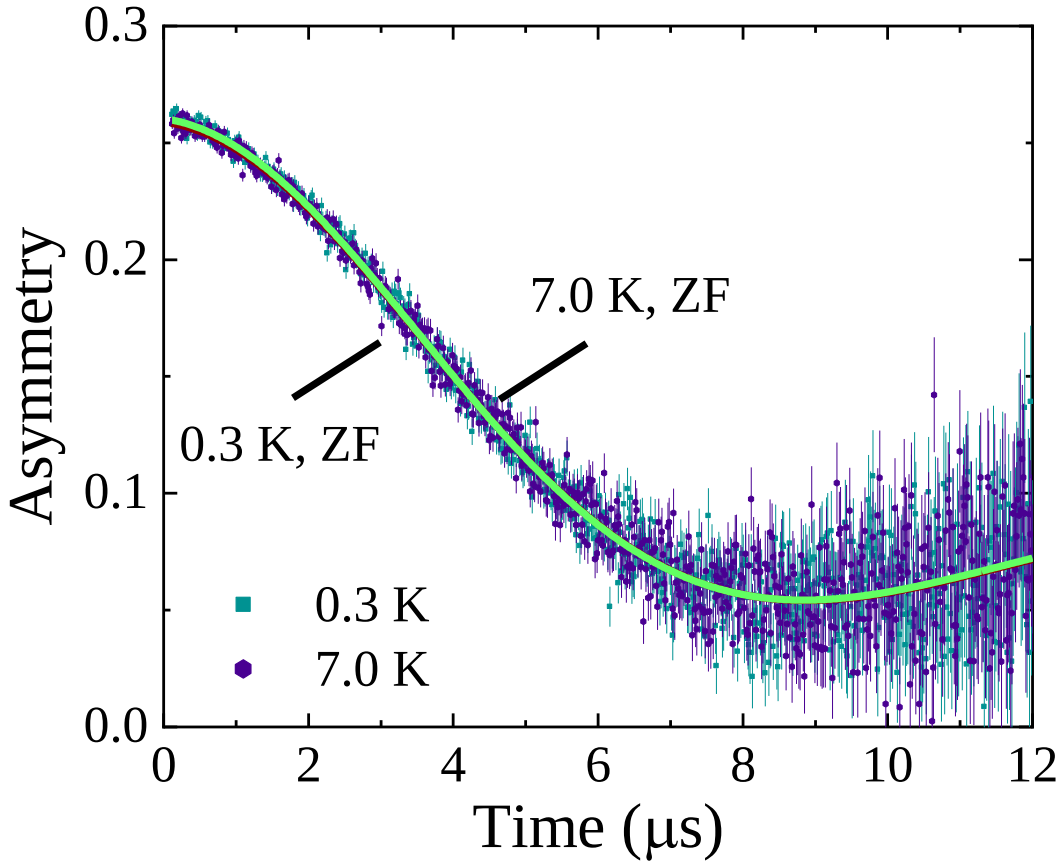
$$\mu_0 H^{\mathrm{P}} = 11.1\ (1)\ \mathrm{T}$$

Pauli Limit Violation



D. A. Mayoh *et al.* Physical Review B. **98**, 014502 (2018).

Zero-field μSR



No time-reversal symmetry breaking.

D. A. Mayoh *et al.* Physical Review B. **98**, 014502 (2018).

Transverse-field μSR

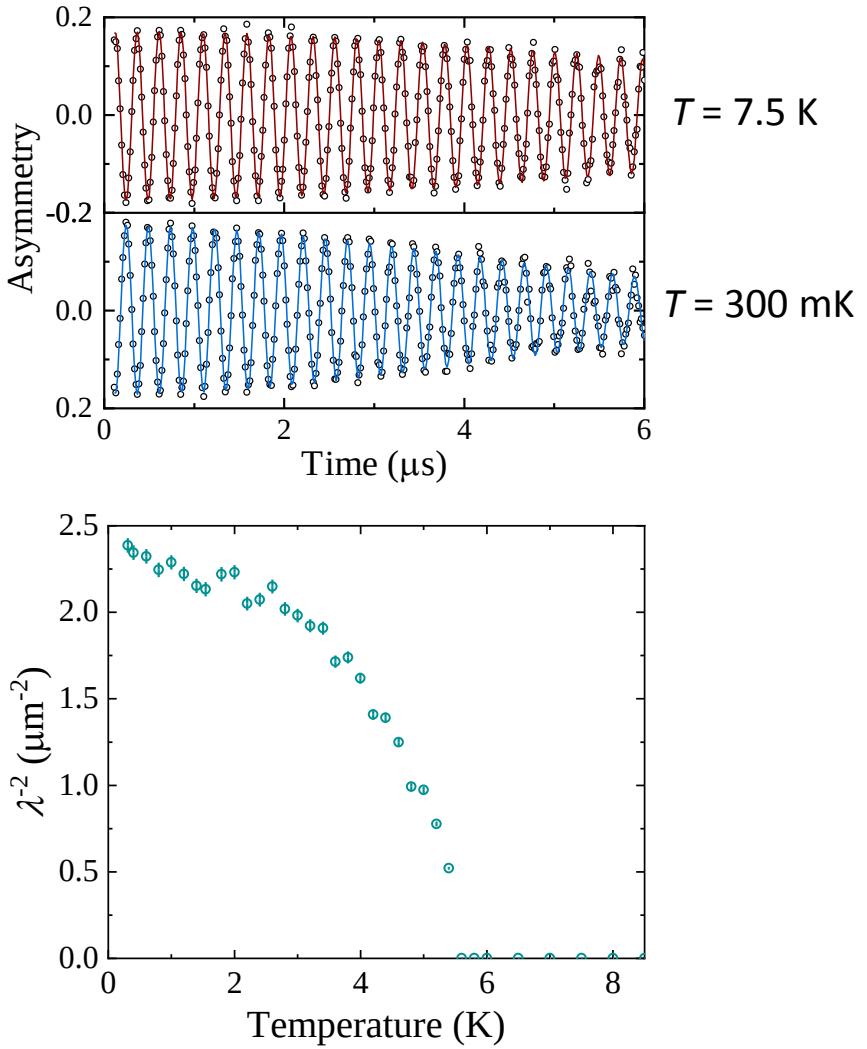
TF-spectra in 30 mT.

Muons implanted in the silver sample holder do not depolarize.

Spectra fitted with Gaussian relaxation,

$$G(t) = A_1 \exp\left(\frac{-\sigma_{sc}^2 t^2}{2}\right)\cos(2\pi\upsilon_1 t + \phi_1) + A_2 \cos(2\pi\upsilon_2 t + \phi_2).$$

σ_{sc} directly related to superfluid density.

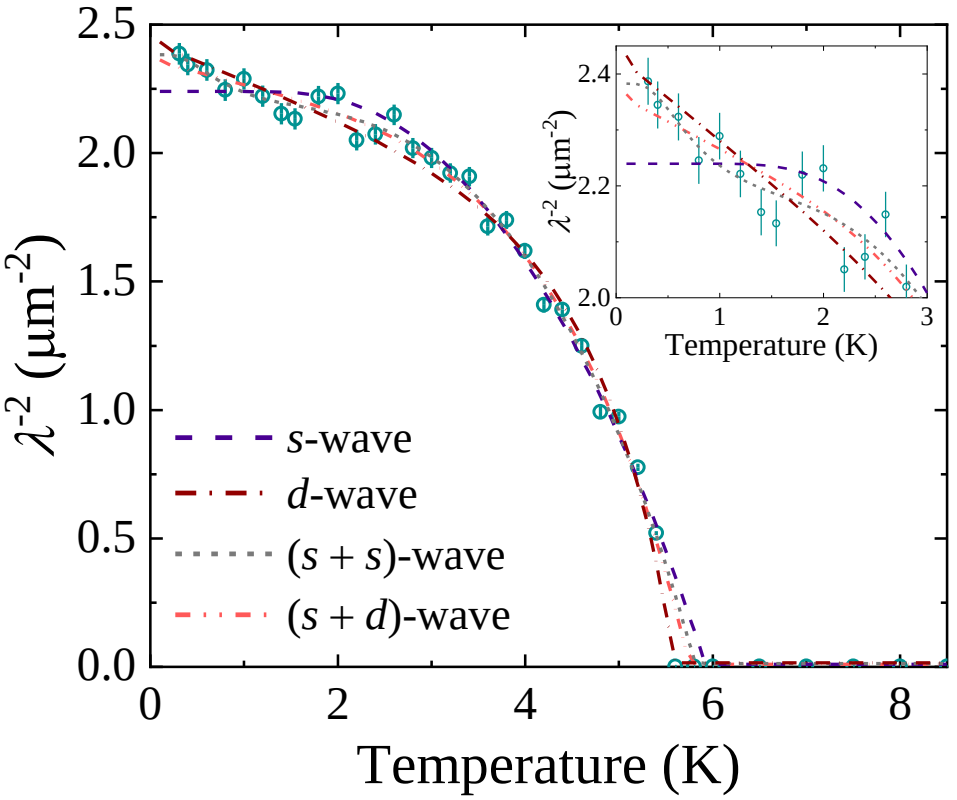


D. A. Mayoh *et al.* Physical Review B. **98**, 014502 (2018).

Transverse-field μSR

$$\left[\frac{\lambda^{-2}(T,\Delta_0)}{\lambda^{-2}(T,\Delta_0)}\right] = w\left[\frac{\lambda^{-2}(T,\Delta_0)}{\lambda^{-2}(T,\Delta_0)}\right] + (1-\mathrm{w})\left[\frac{\lambda^{-2}(T,\Delta_0)}{\lambda^{-2}(T,\Delta_0)}\right]$$

	d-wave	(*s*+*s*)-wave	(*s*+*d*)-wave
$\frac{\Delta_{0,1}}{k_B T_c}$	3.78 (14)	2.28 (8)	2.56 (11)
$\frac{\Delta_{0,2}}{k_B T_c}$	---	0.27 (9)	2.83 (9)
w	1	0.89 (2)	0.51 (2)
χ^2_{norm}	1.81	1.18	1.35



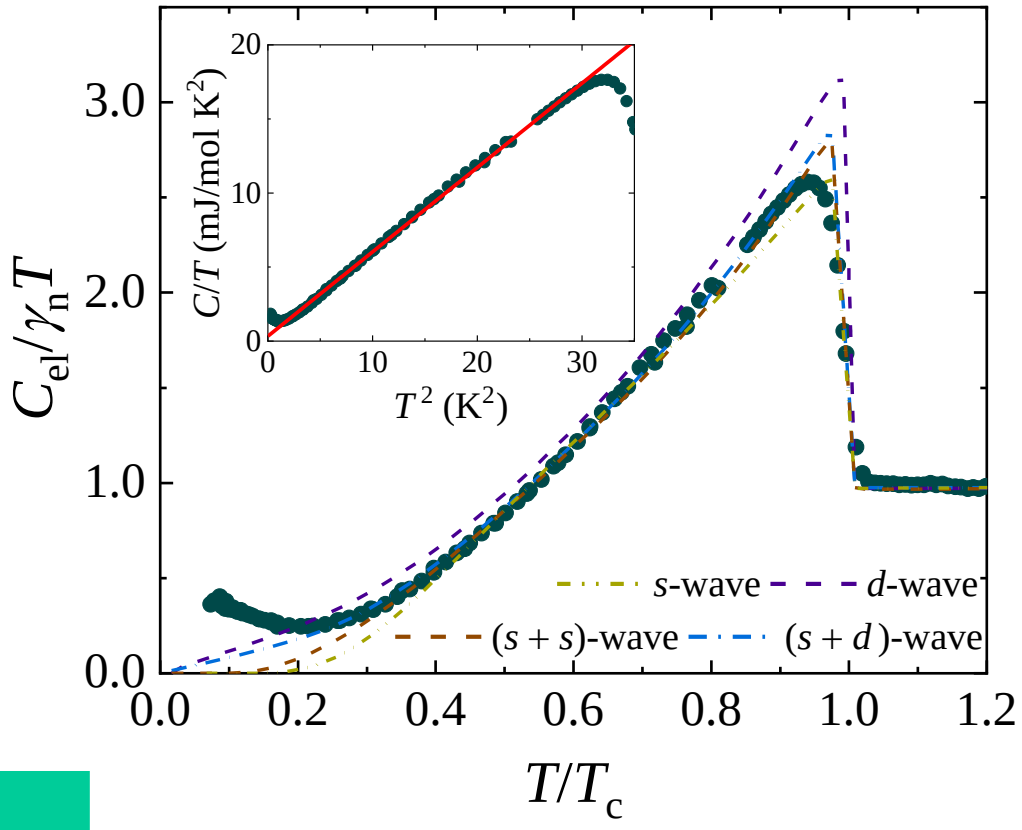
cf. BCS value 1.77.

D. A. Mayoh *et al.* Physical Review B. **98**, 014502 (2018)

Heat Capacity

Complicated by hyperfine contribution

Clearly not *s*-wave.



(s+s)- wave:

$\frac{\Delta_{0,1}}{k_B T_c}$	$\frac{\Delta_{0,2}}{k_B T_c}$	w
2.19 (12)	1.1(3)	4:1

$$\frac{\Delta C}{\gamma_n T_c} = 1.57(2) > 1.43$$

D. A. Mayoh *et al.* Physical Review B. **98**, 014502 (2018).

Conclusion

- New chiral noncentrosymmetric superconductor.
- Strong evidence of multigap superconductivity in $TaRh_2B_2$.
- Large upper critical field well above Pauli limit.