Superconductivity emerging from suppressed large MR state in WTe_2

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Acknowledgements

Collaborators:

Material: Prof. YG Shi @ IOP

Theory : Prof. GM Zhang @ Tsinghai University

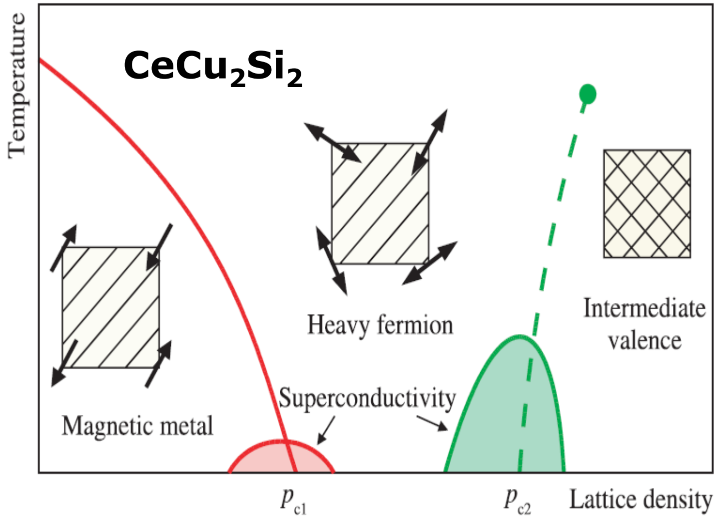
HP-XRD SSRF: Dr. K Yang, Dr. AG Li and Dr. S Jiang

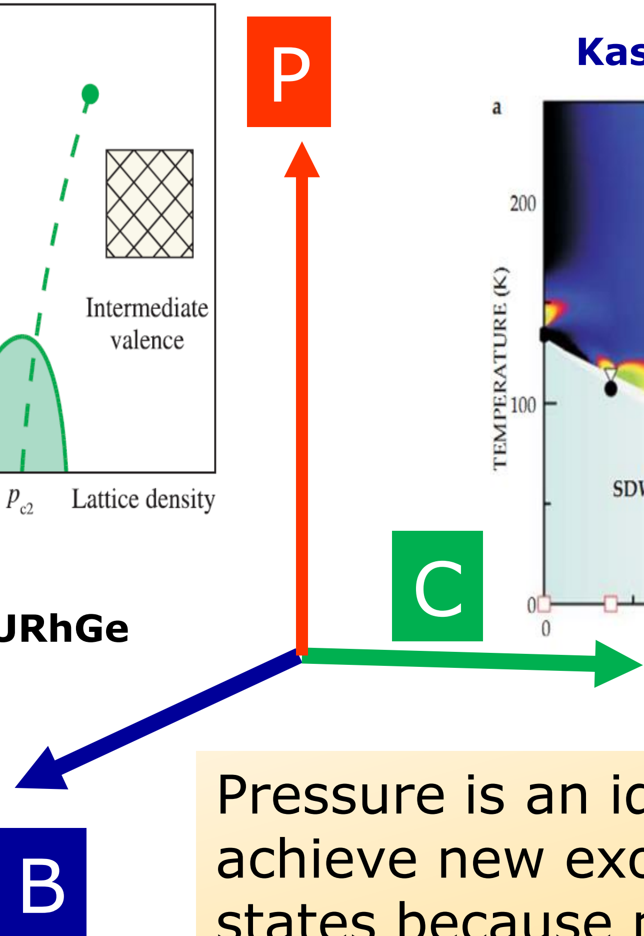
Students who did the experimental work:

DF Kang and YZ Zhou: High pressure transport measurements at IOP

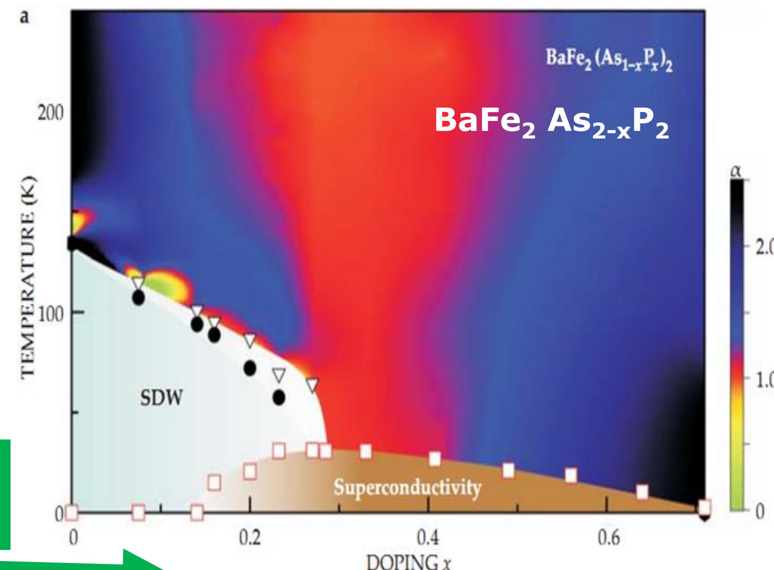
Tuning methods of SC state

Yuan et al Science 2005



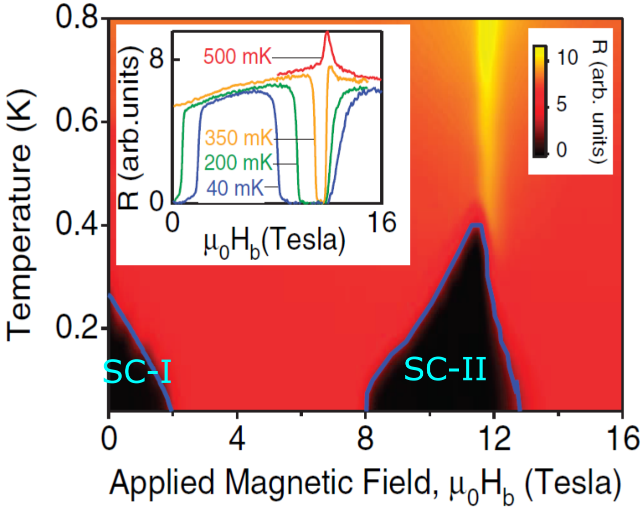


Kasahara et al PRB 2010



Levy et al, Science 2005

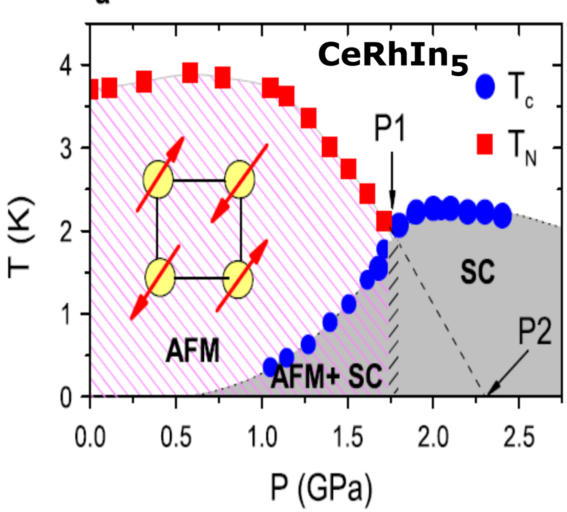
URhGe



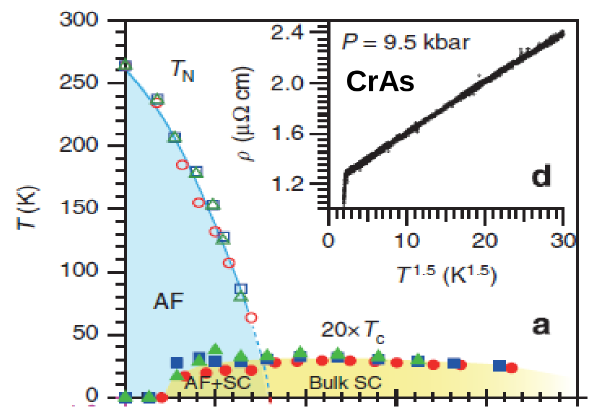
Pressure is an ideal means to achieve new exotic electronic states because pressure can promote changes of energy bands.

SC state emerges from different states

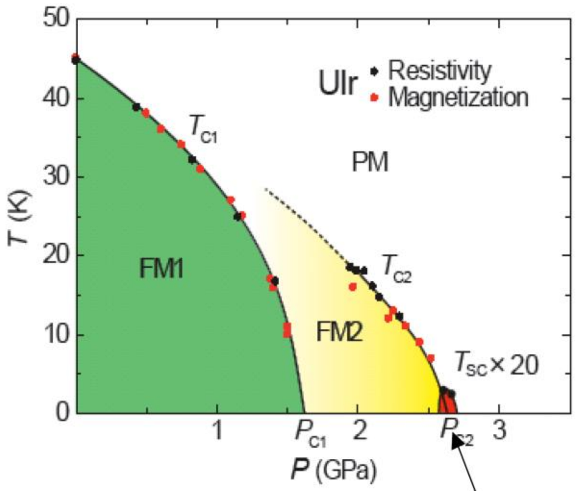
Park et al , PRL 2008



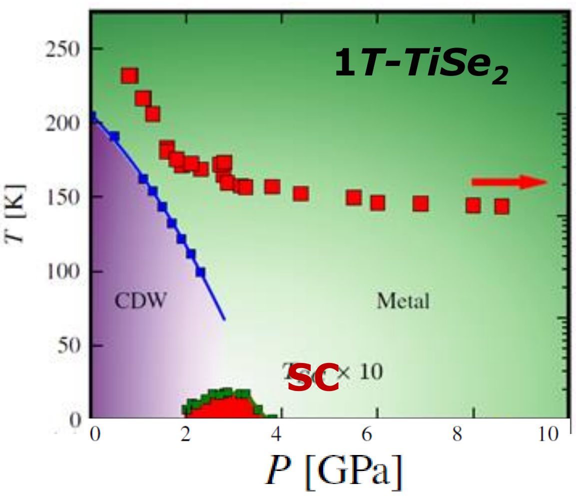
Wu et al , Nat Commni 2014



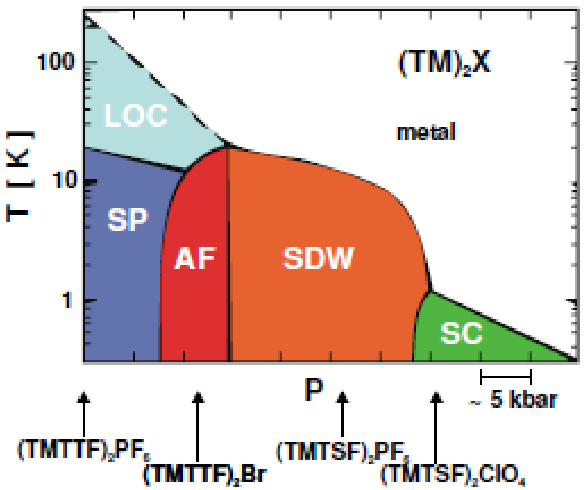
Akazawa et el, JPSJ 2004



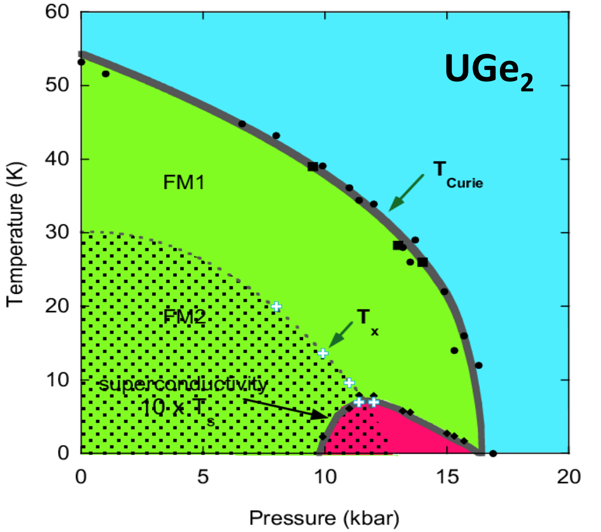
Joe et al, Ph.D thesis 2014



Andres et al, PRB 2003

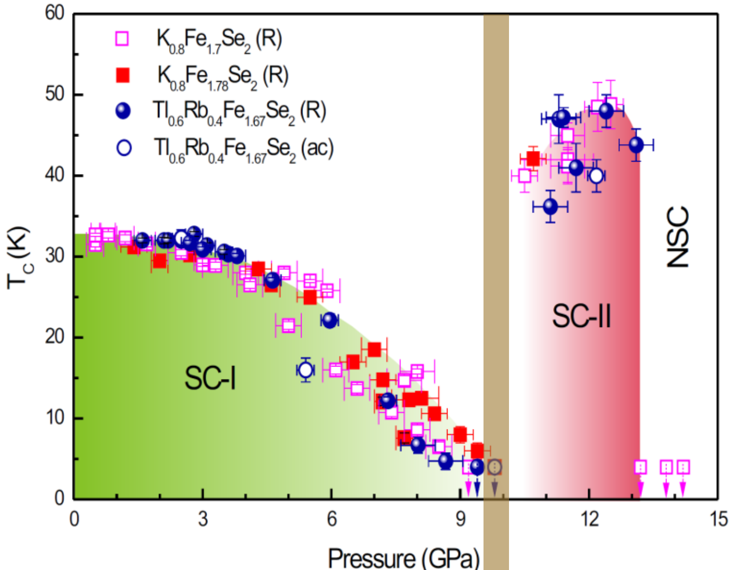


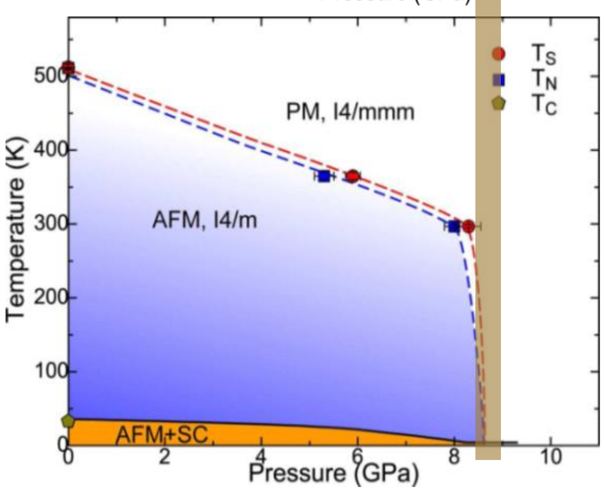
Saxena et al , Nature 2000



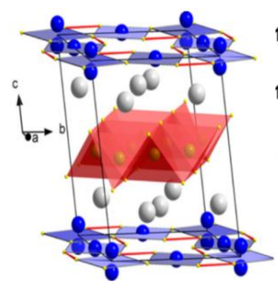
SC state emerges from different states

Sun et al , Nature 2012

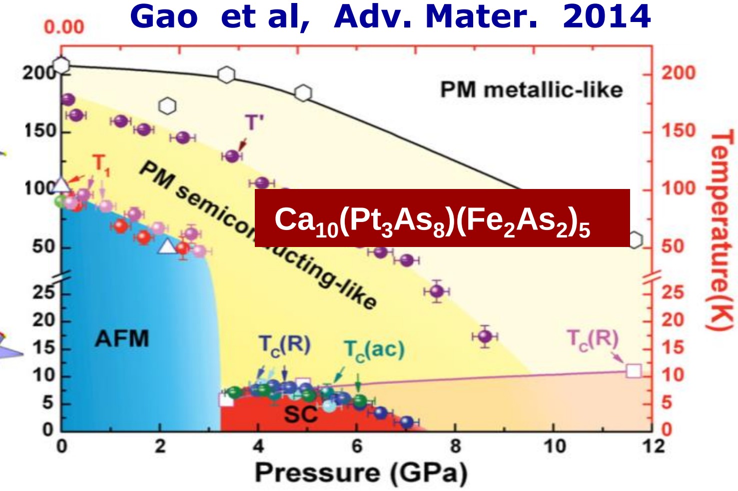


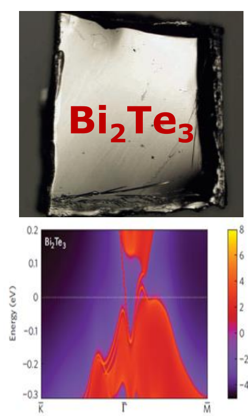


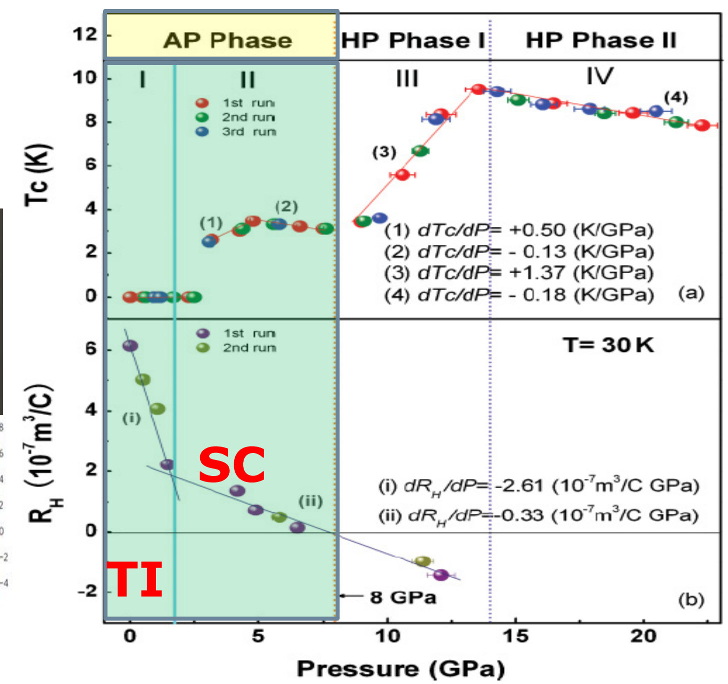
Bao et al , CPL 2014



Gao et al, Adv. Mater. 2014

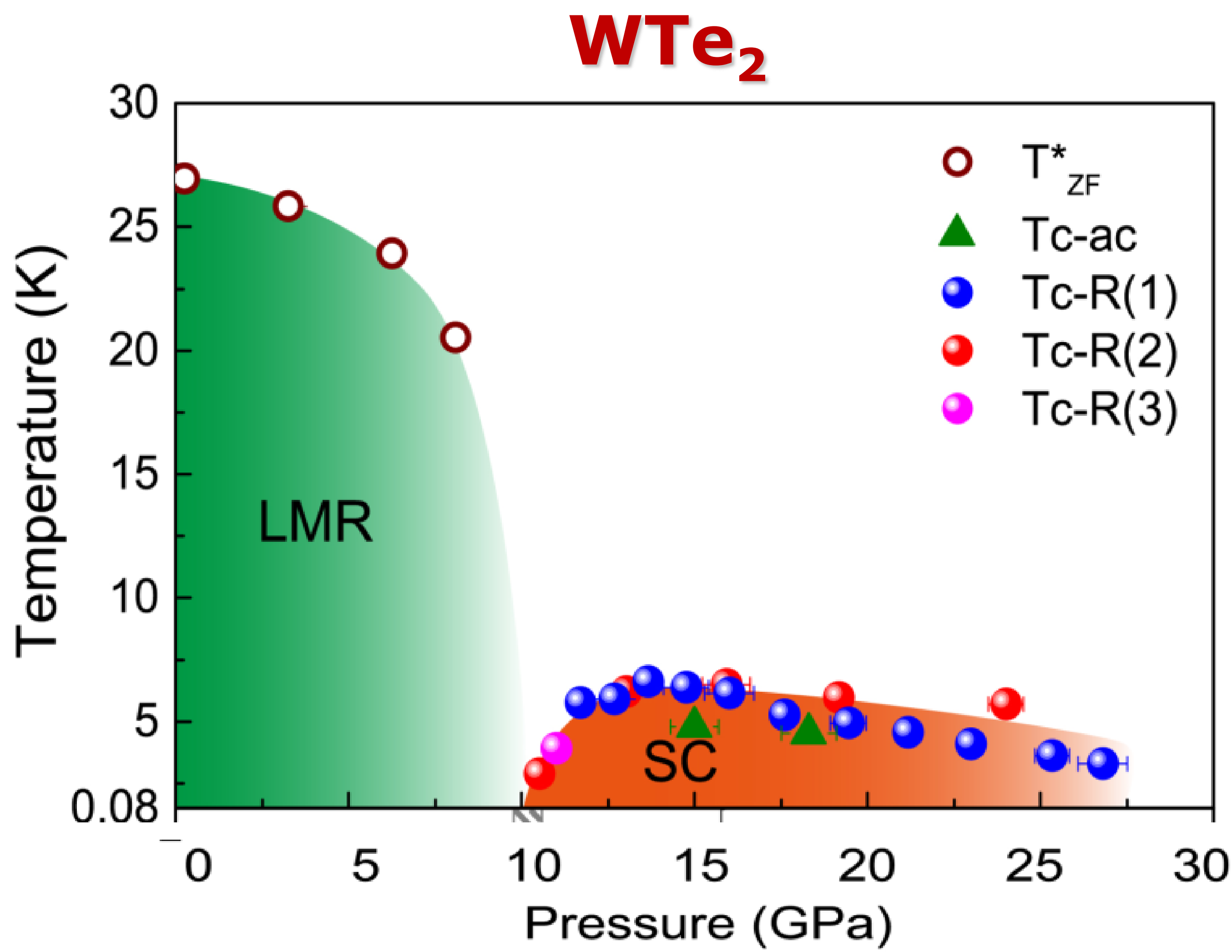






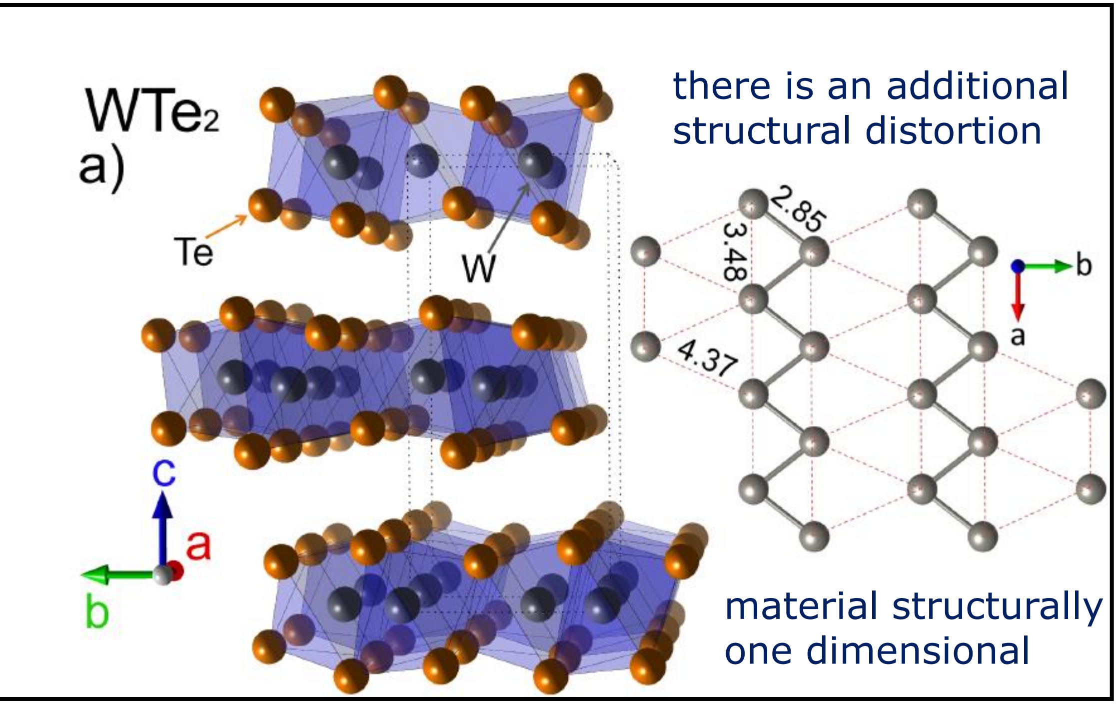
Work done by our group

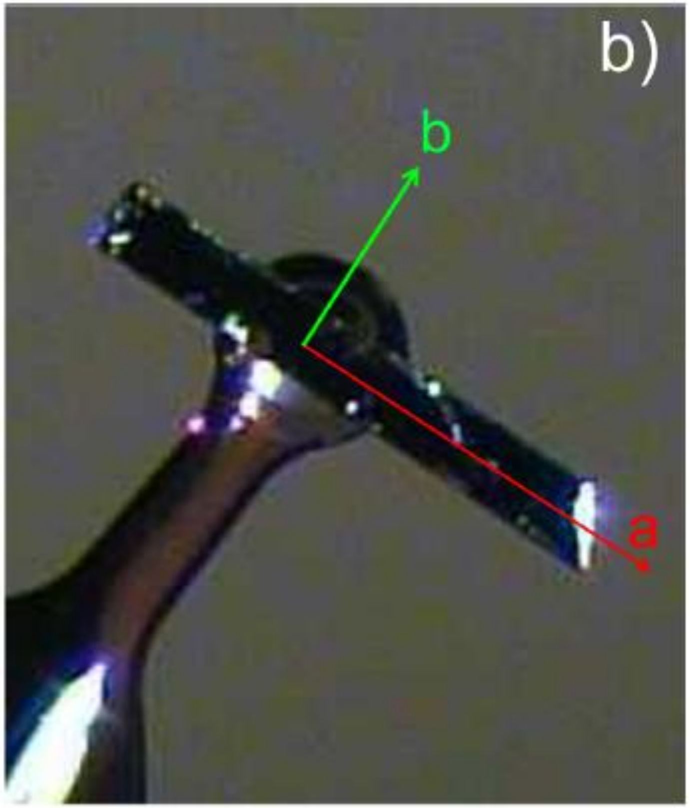
SC state emerges from different states



Basic feature of WTe_2 @ ambient P

Crystal structure (orthorhombic)



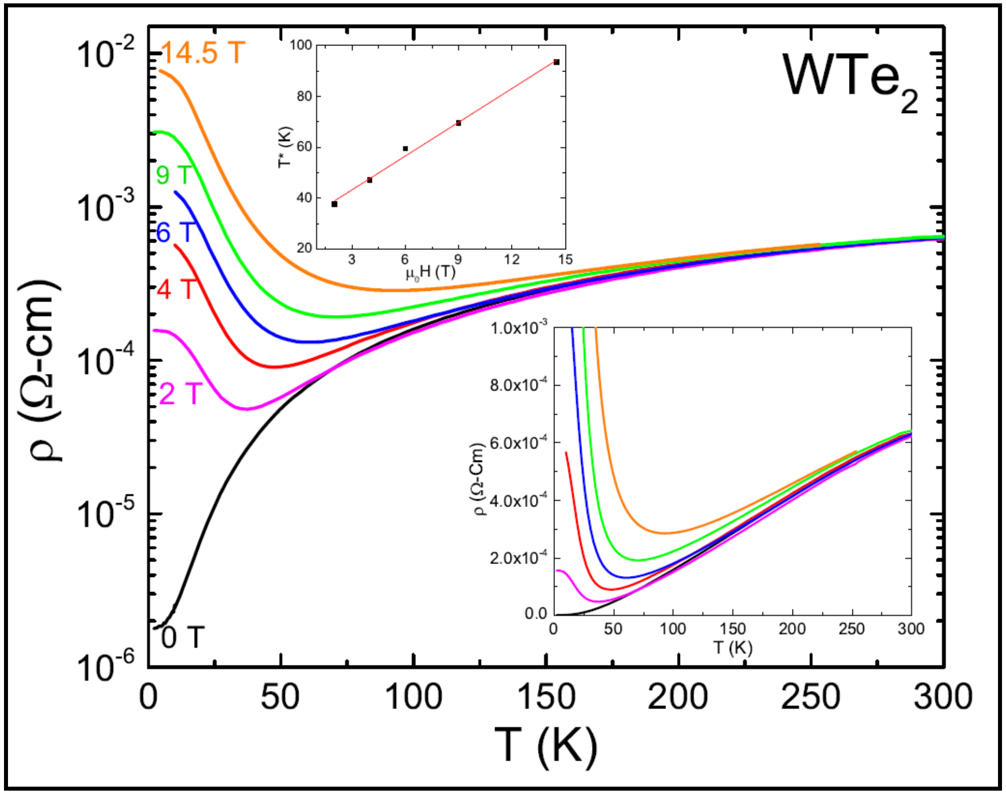


Typical single crystal of WTe_2

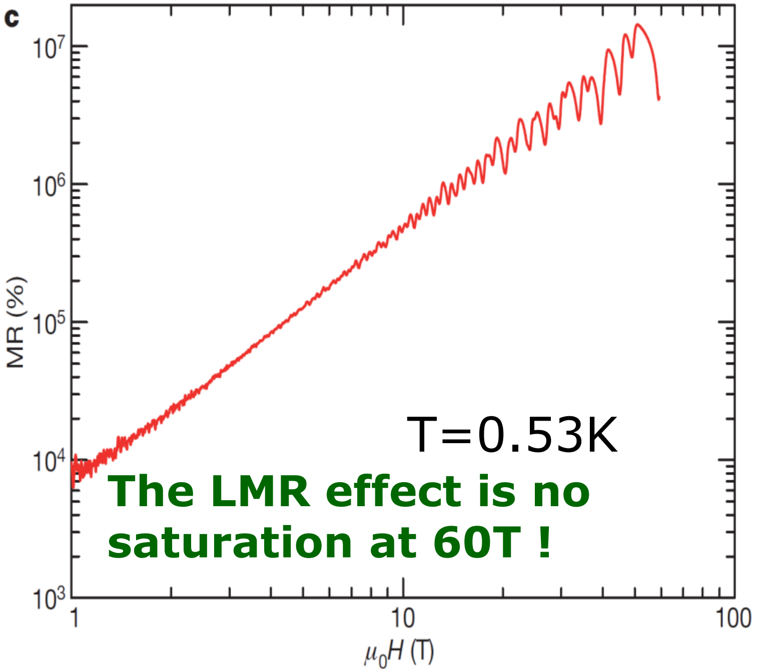
- A classic layered dichalcogenide structure (like MoS_2 and $TiSe_2$)
- The chain of W atoms forms along *a* axis

Properties of WTe_2 @ ambient P

Large magnetroresistance behavior

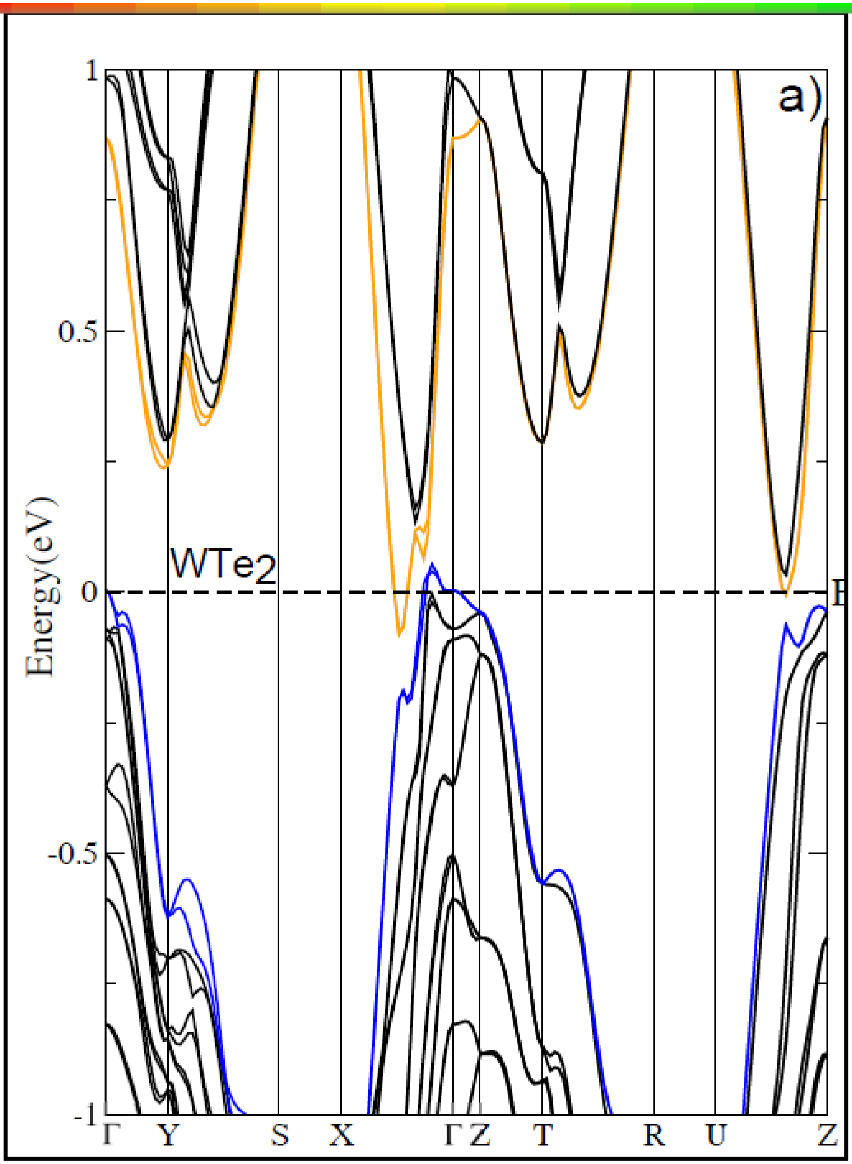


Ali et al, Nature 514 205 (2014)

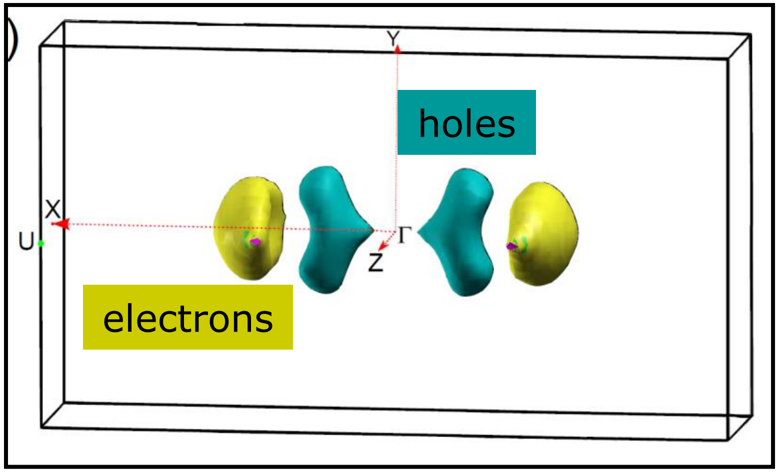


WTe_2 is not magnetic and has no magnetic elements, but show an extremely large magnetoresistance (LMR) at lower temperature in a high field. The LMR state can be enhanced dramatically at higher field

Theoretical calculations



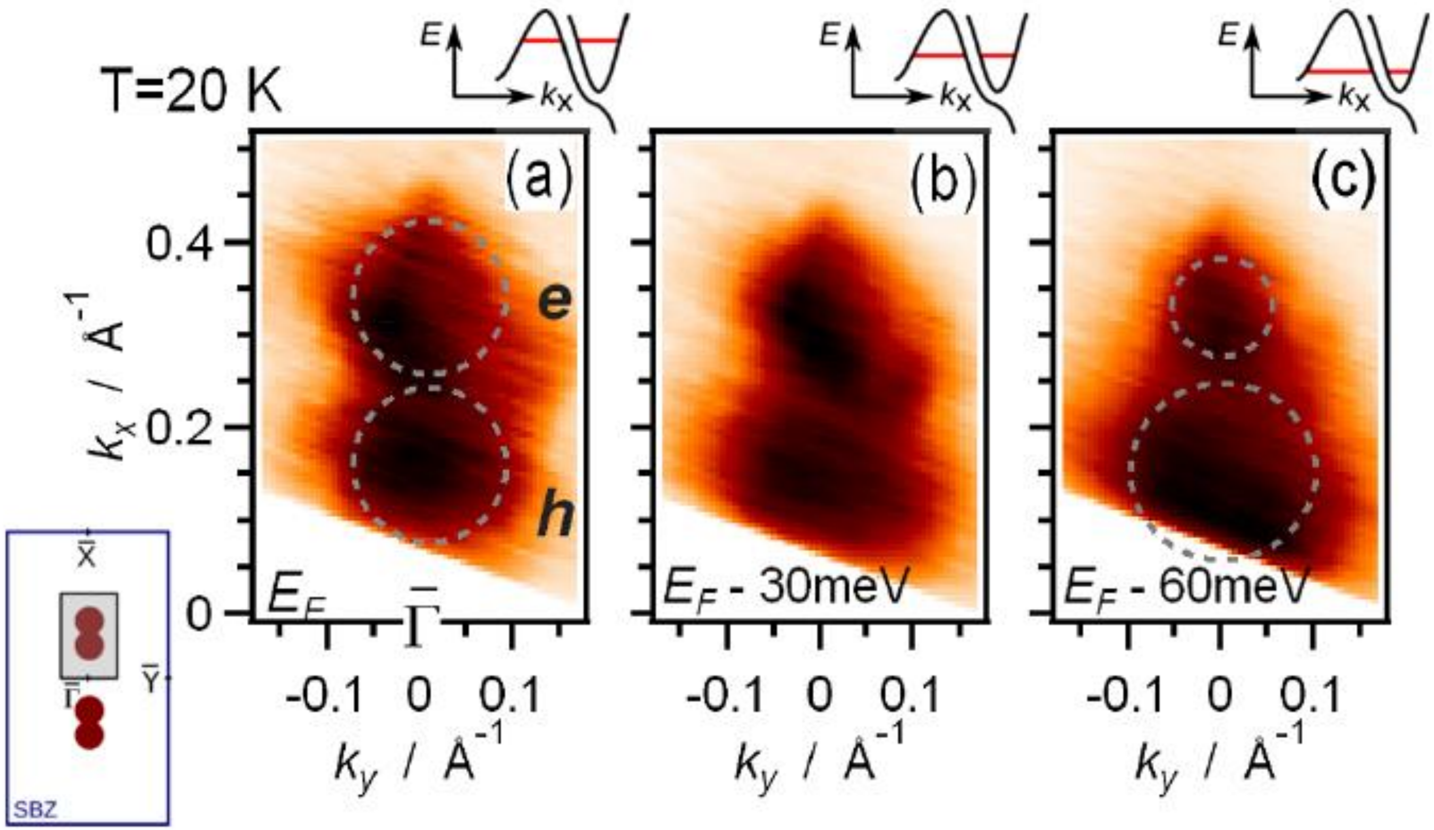
WTe_2 is a delicate semimetal



Calculations indicate that the LMR effect is resulted from the perfect balance between electron and hole Fermi pockets .

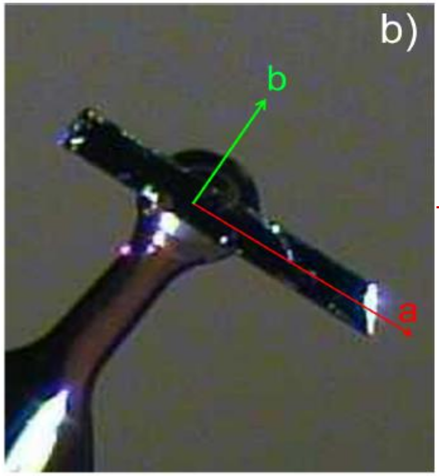
ARPES studies

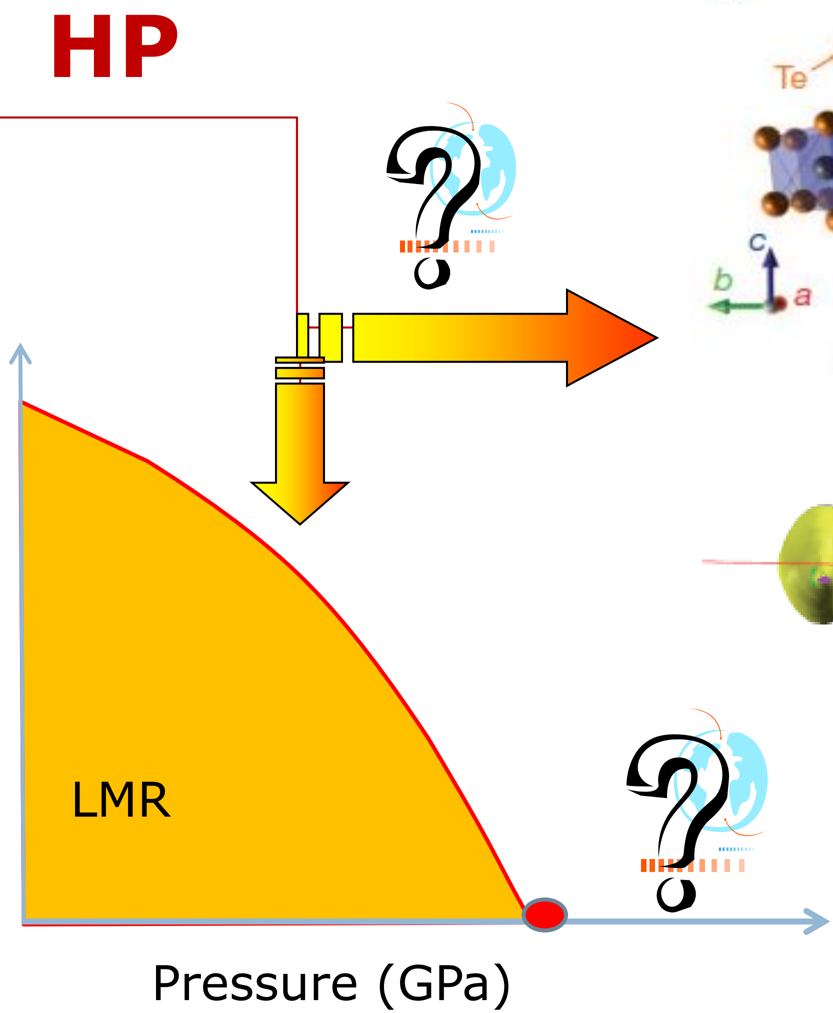
Pleticosic et al. PRL 113, 216601 (2014)

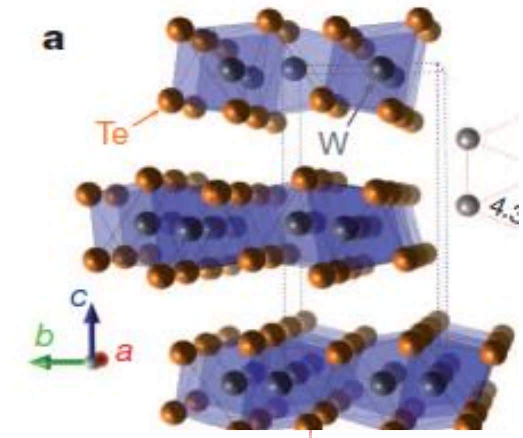


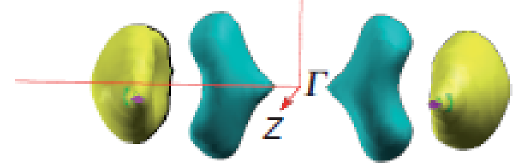
The size of the electronic pocket and hole pocket at Fermi surface is almost same.

What will happen for WTe_2 at HP?







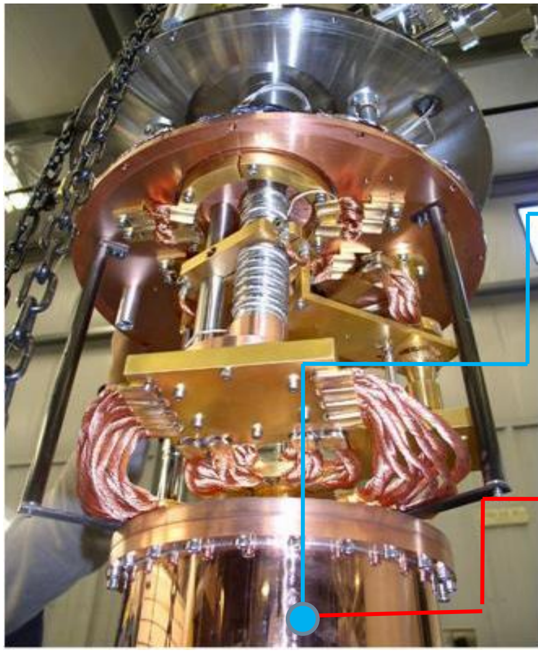


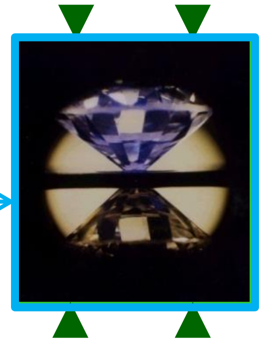
There three things need to be clarified:

1 structure stability
2 e-h balance
3 QCT

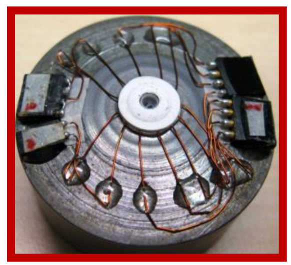
Experimental methods

In-situ HP transport measurements in our lab



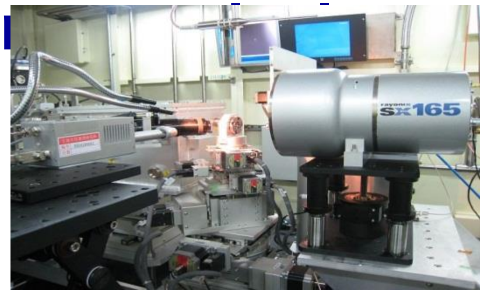


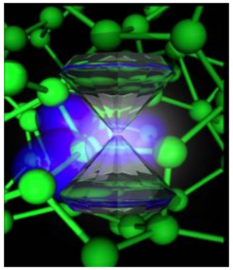
HP-resistance,
HP-magtoresistance
HP- Hall coefficient

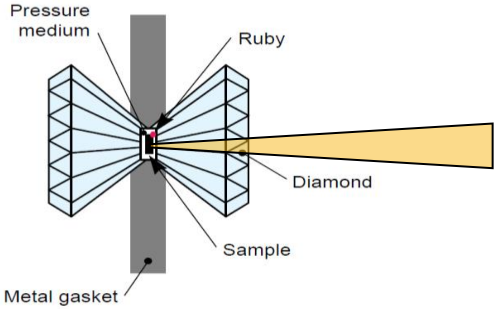


HP- Resistance
HP-specific heat

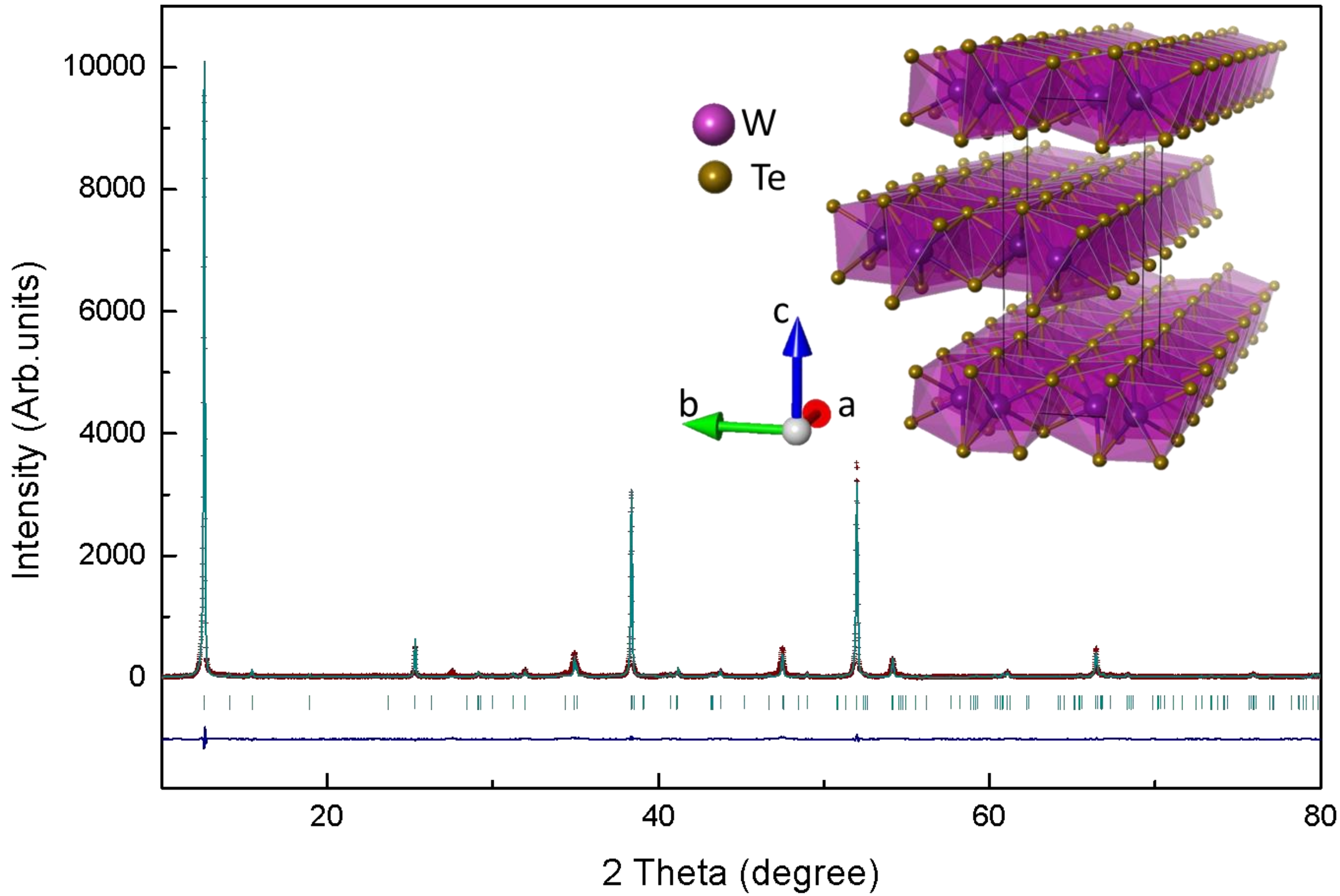
In-situ HP-XRD measurements at SSRF and BSRF





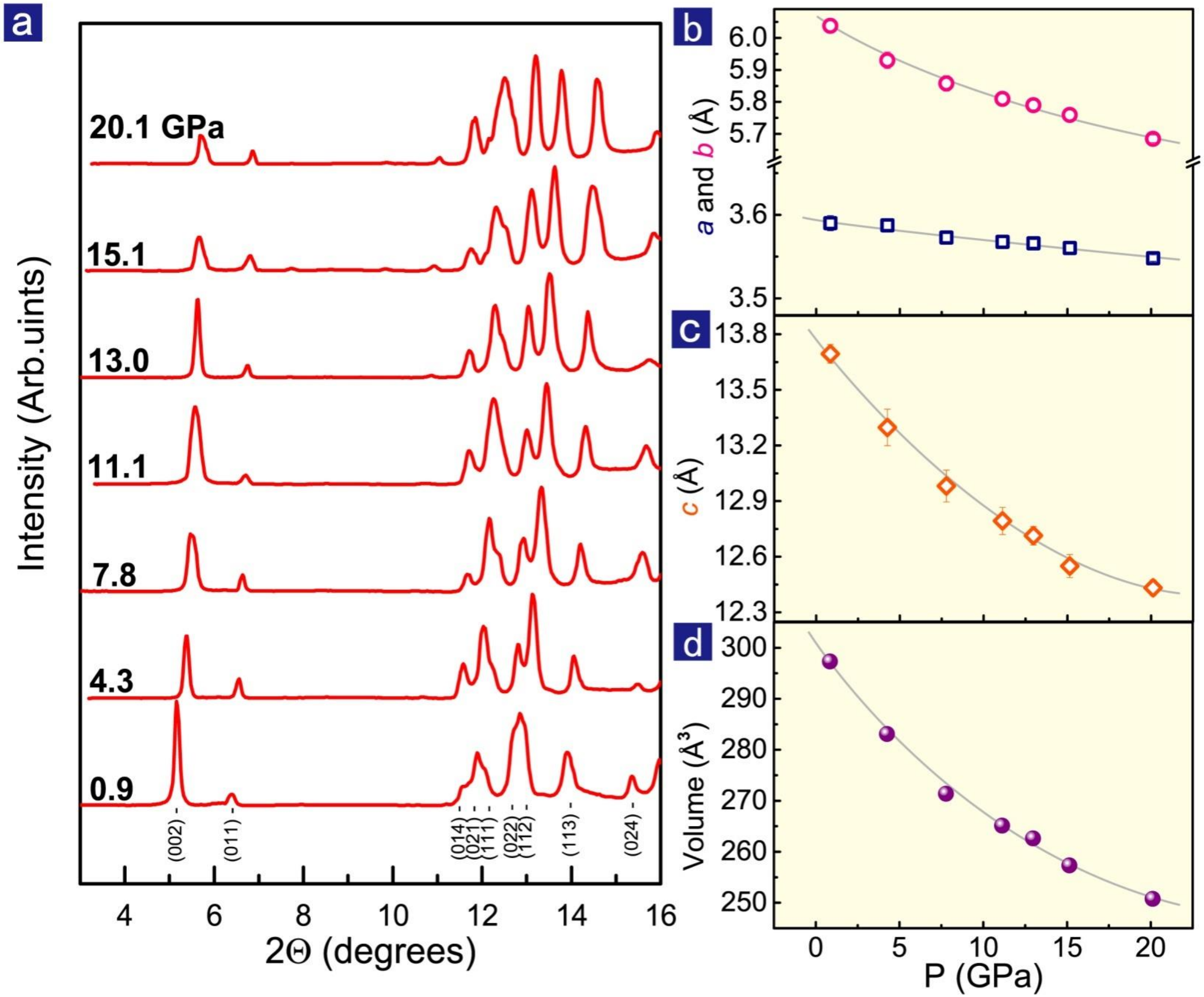


XRD collected at ambient pressure



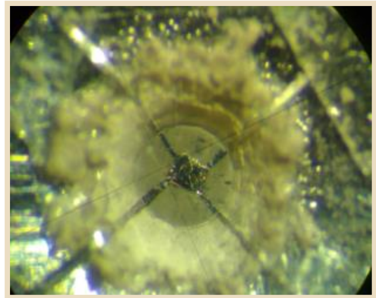
All peaks in the pattern can be well indexed by orthorhombic structure, indicating that the sample's quality is high.

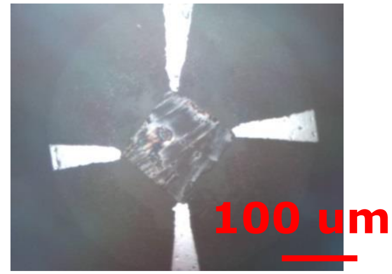
In-situ HP XRD measurements



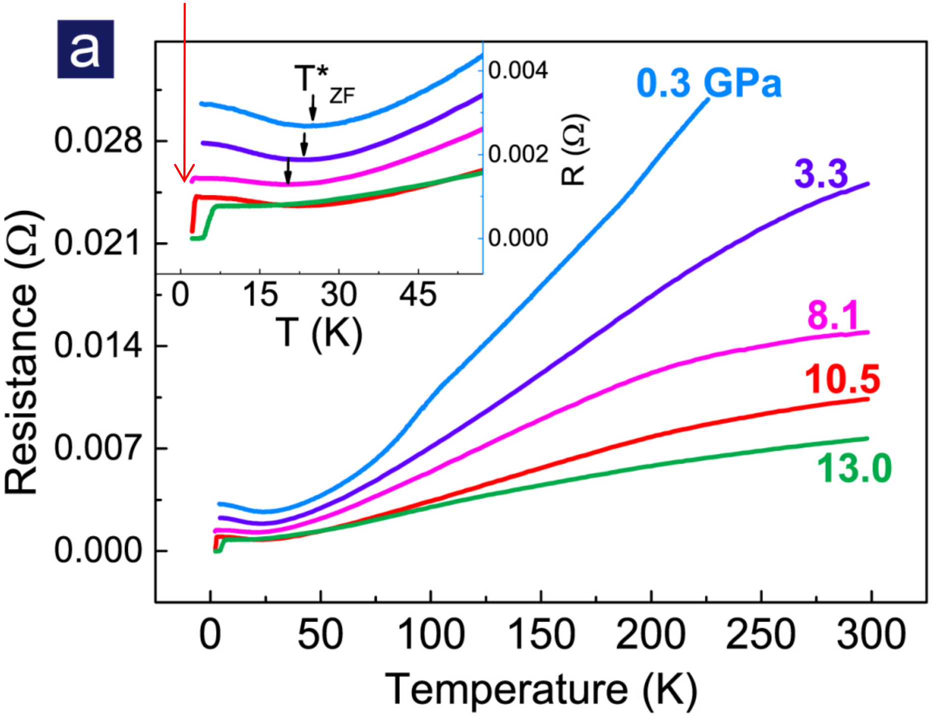
No first-order structure phase transition under pressure up to 20.1 GPa.

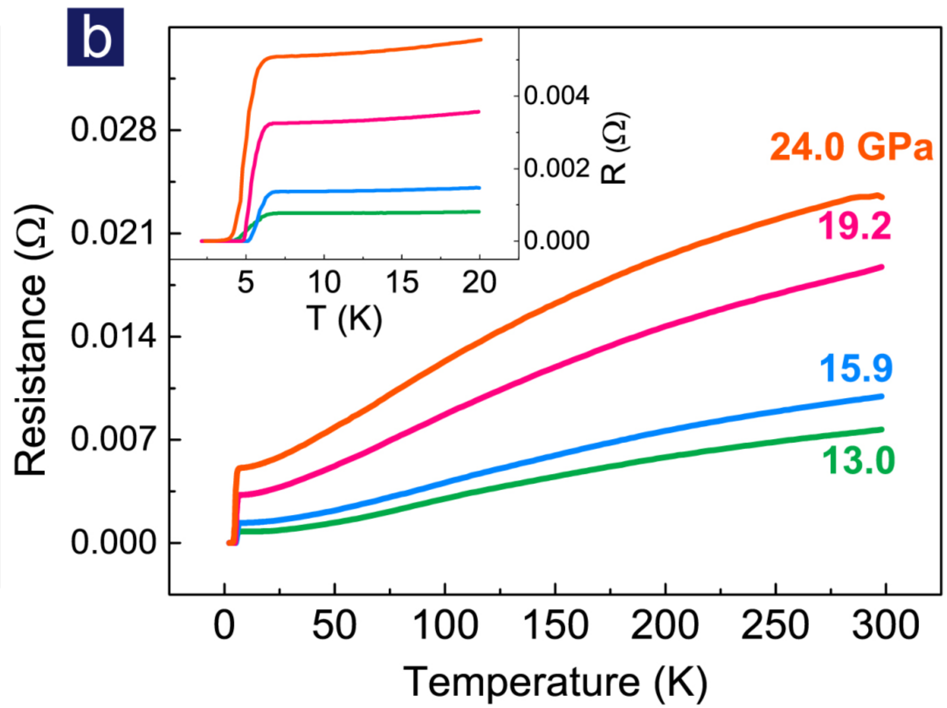
In-situ HP resistance measurements





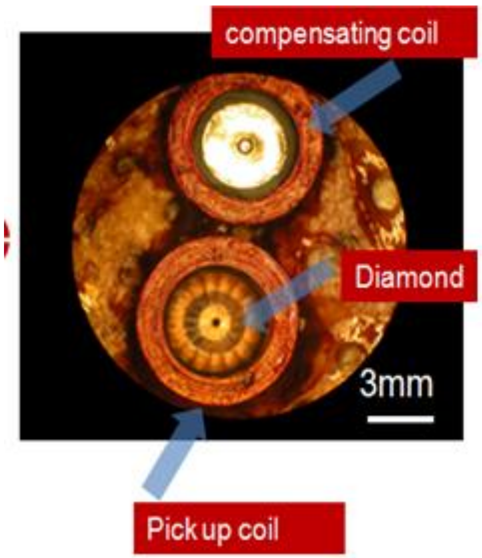
2.8K @ 10.5 GPa

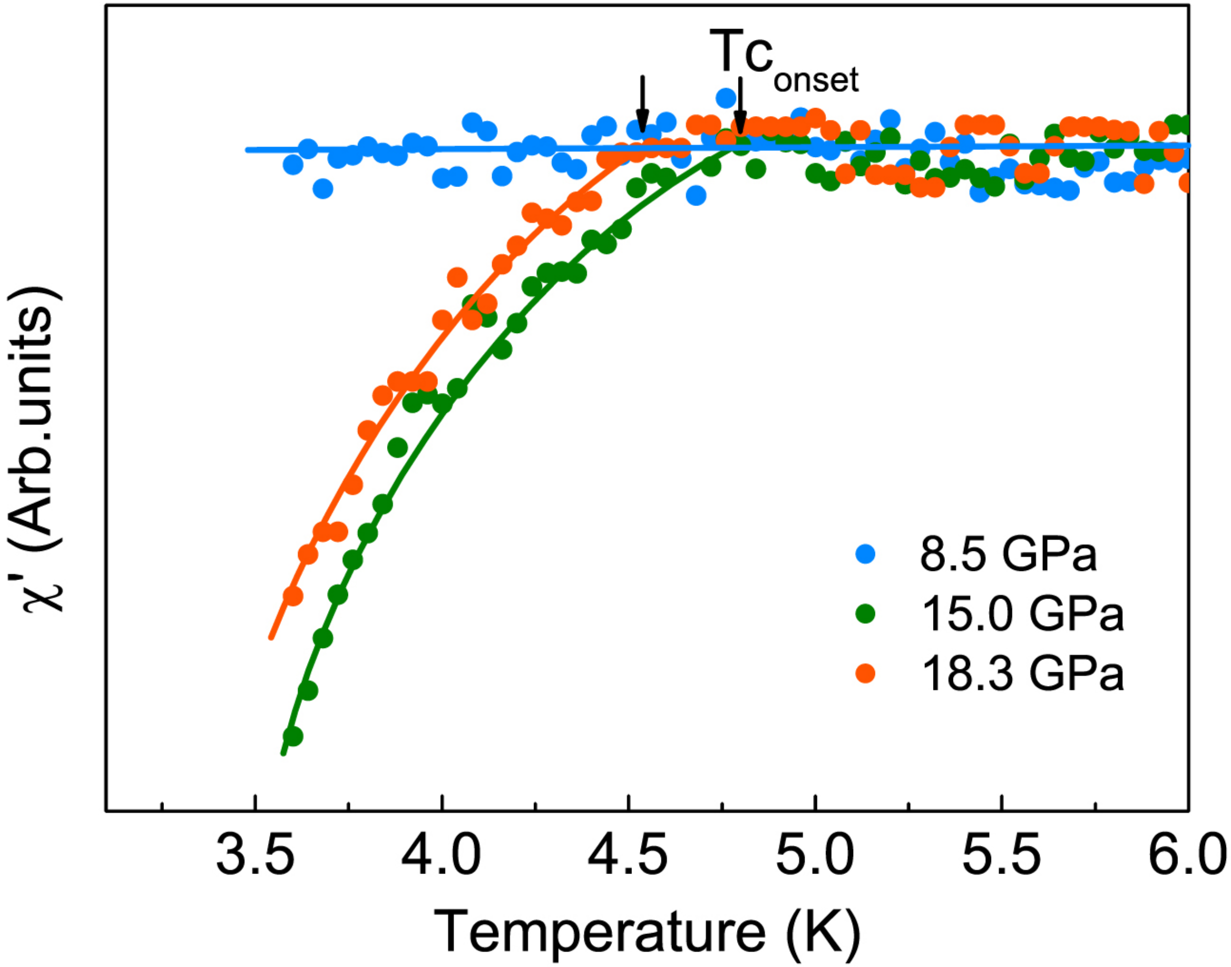




We found a resistance drops suddenly at 2.8 K and 10.5 GPa. Such a drop becomes more pronounced at HP, and the R_0 is achieved at higher pressure.

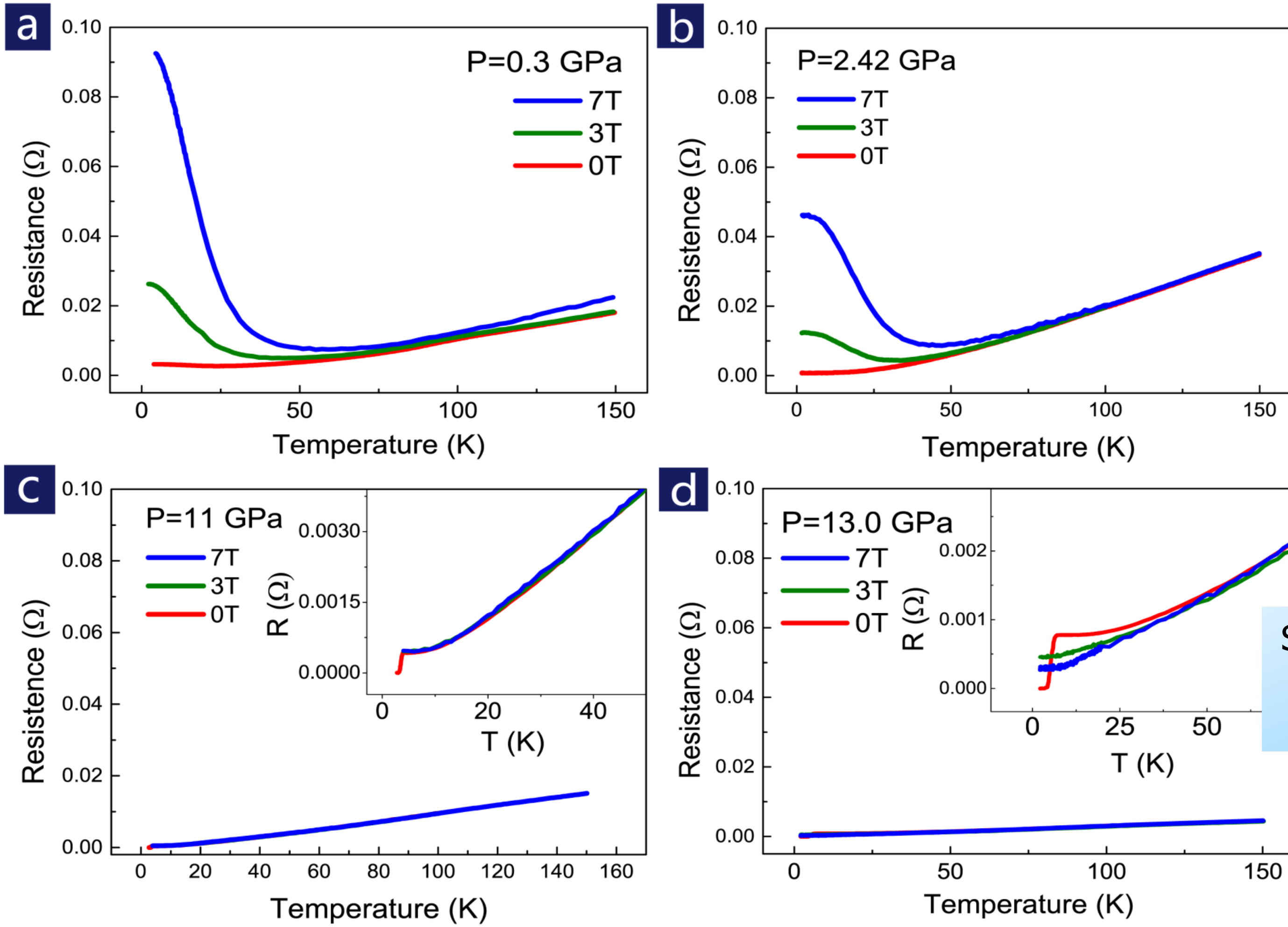
HP *ac* susceptibility measurements





The Meissner effect is observed at the selected pressures, confirming that pressure induces a superconducting transition in WTe_2.

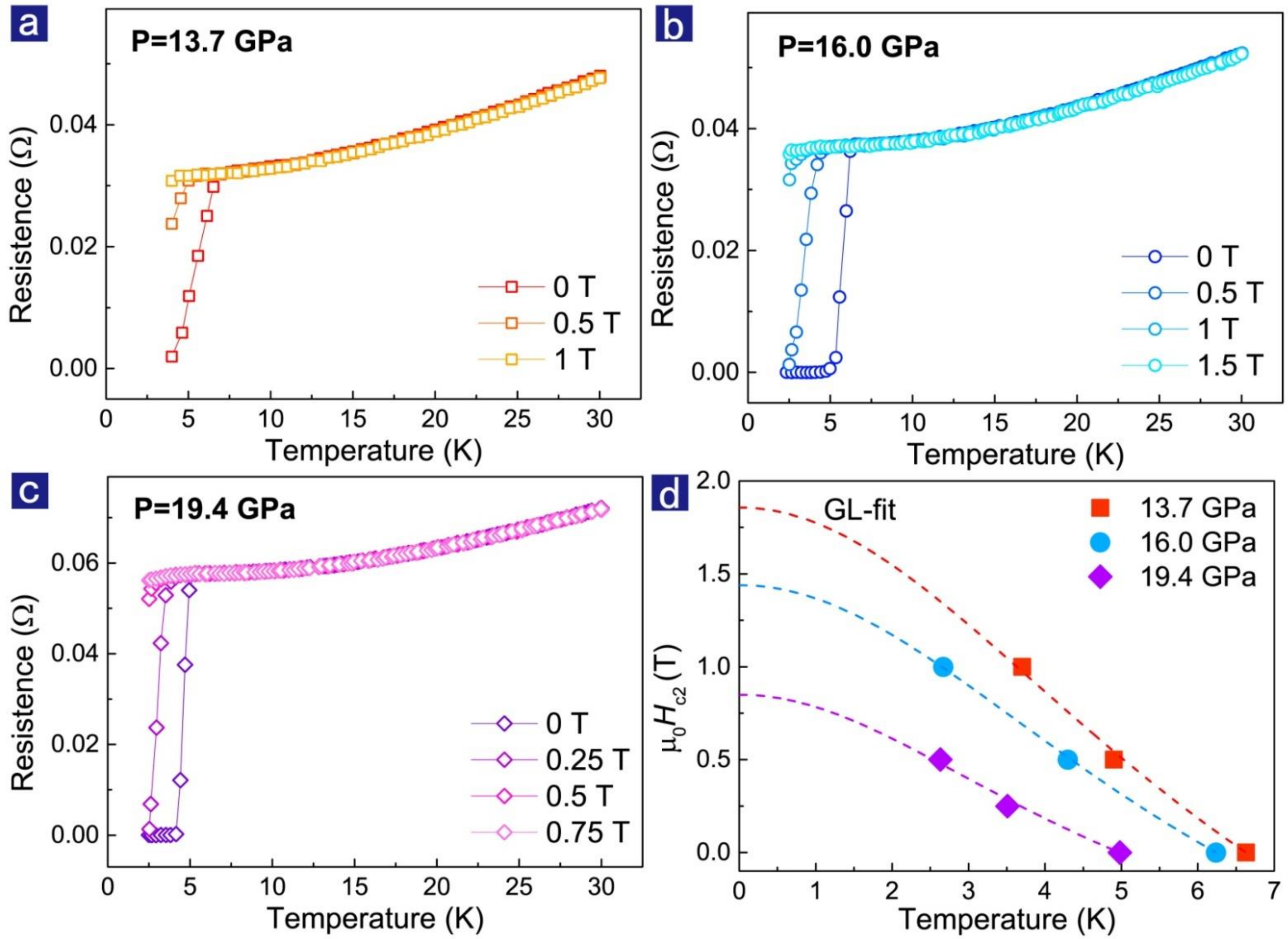
LMR evolution with pressure



SC disappears at 13.0 Gpa under 3T and 7T

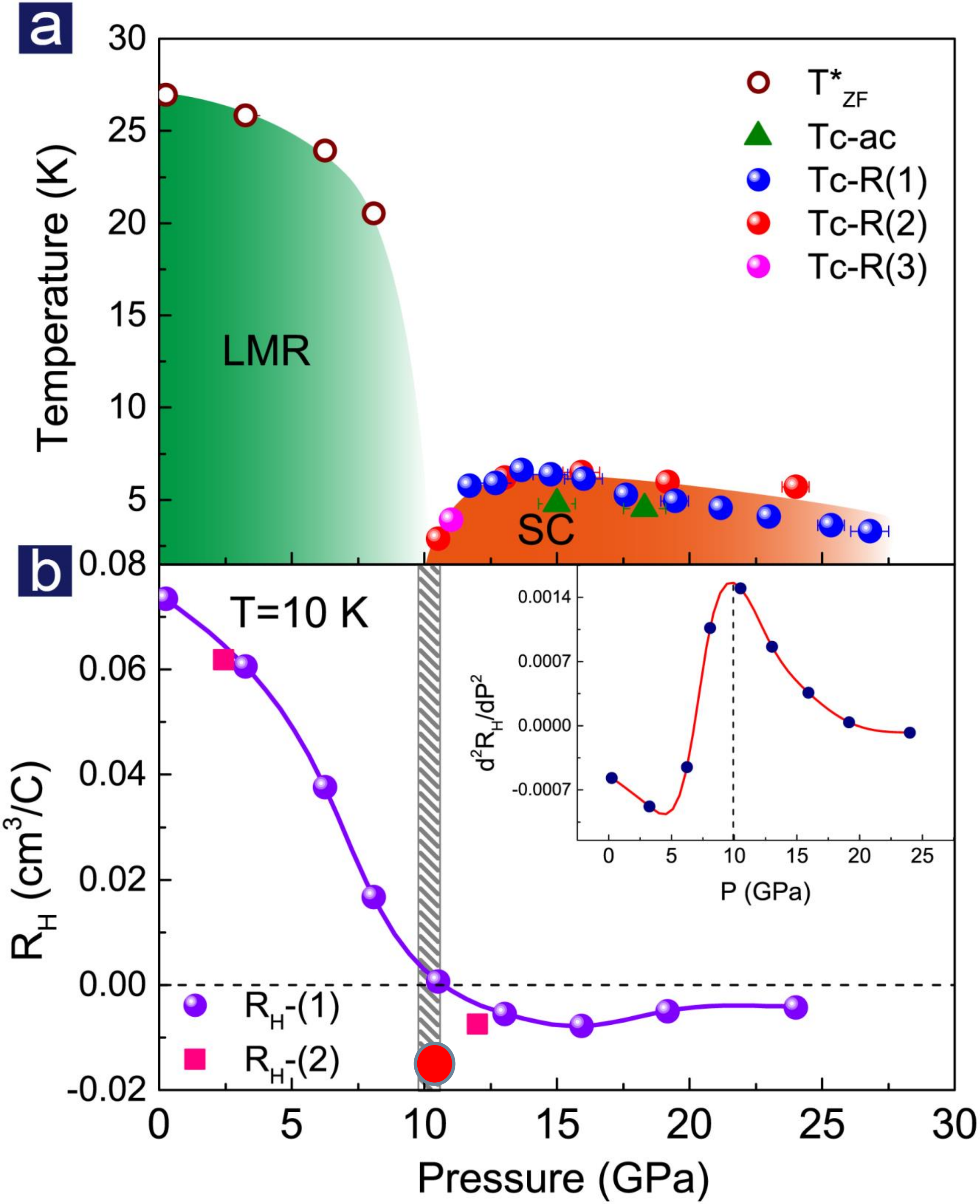
- The positive LMR effect can be suppressed by HP and turned off at 11 GPa.
- The superconductivity appears at 11 GPa and above.

Estimation of upper critical field



1.9 T
1.4T
0.9T

Using the Ginzburg-Landau formula to fit the experimental data, we estimate the value of Hc_2 at zero temperature.



We found:

➢ The positive LMR effect can be gradually suppressed and turned off at 10.5 GPa, where SC emerges.

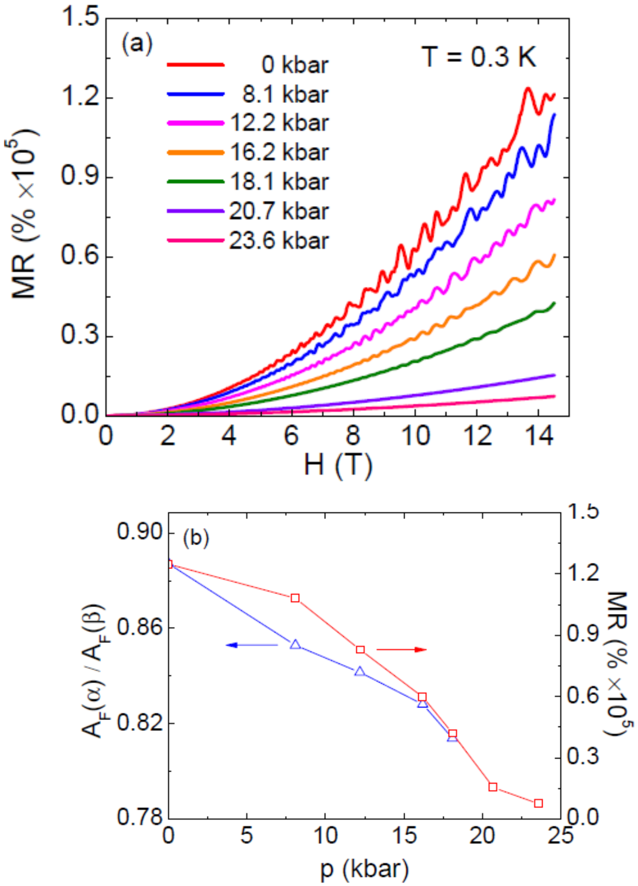
➢ Tc reaches to 6.5 K at ~ 13 GPa and then decreases to 2.6 K at ~ 24 GPa.

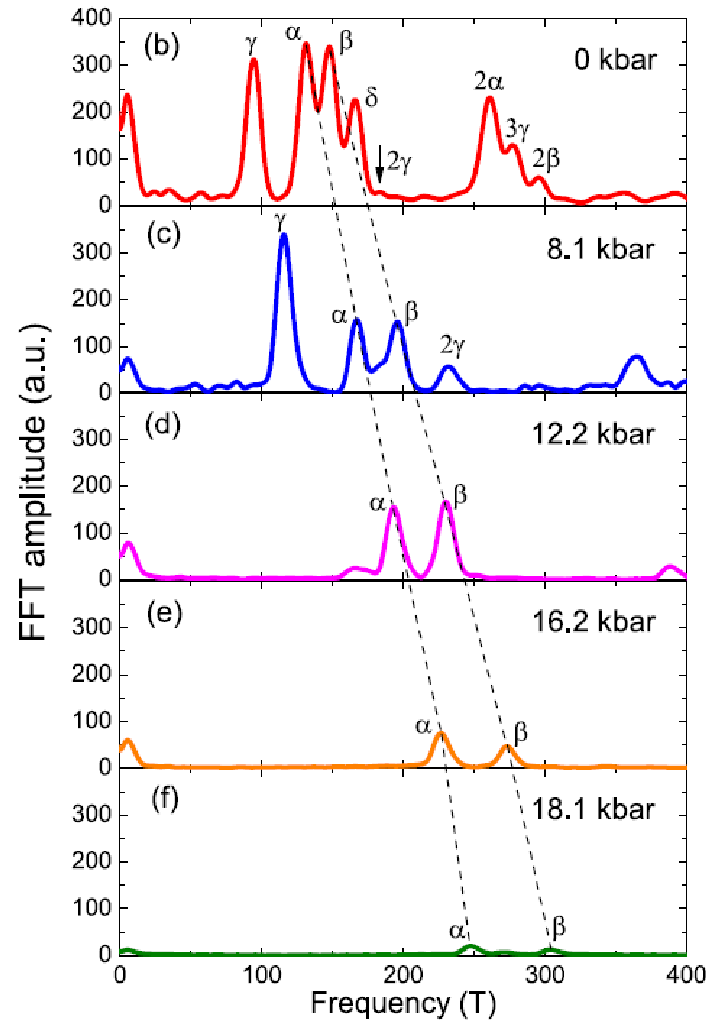
➢ Hall measurements at low T demonstrate that elevating pressure decreases hole carriers but increases electron ones.

➢ At the Pc, a sign change in the Hall coefficient is observed, indicating a quantum phase transition of the Fermi surface reconstruction.

Reconstruction of FS under pressure

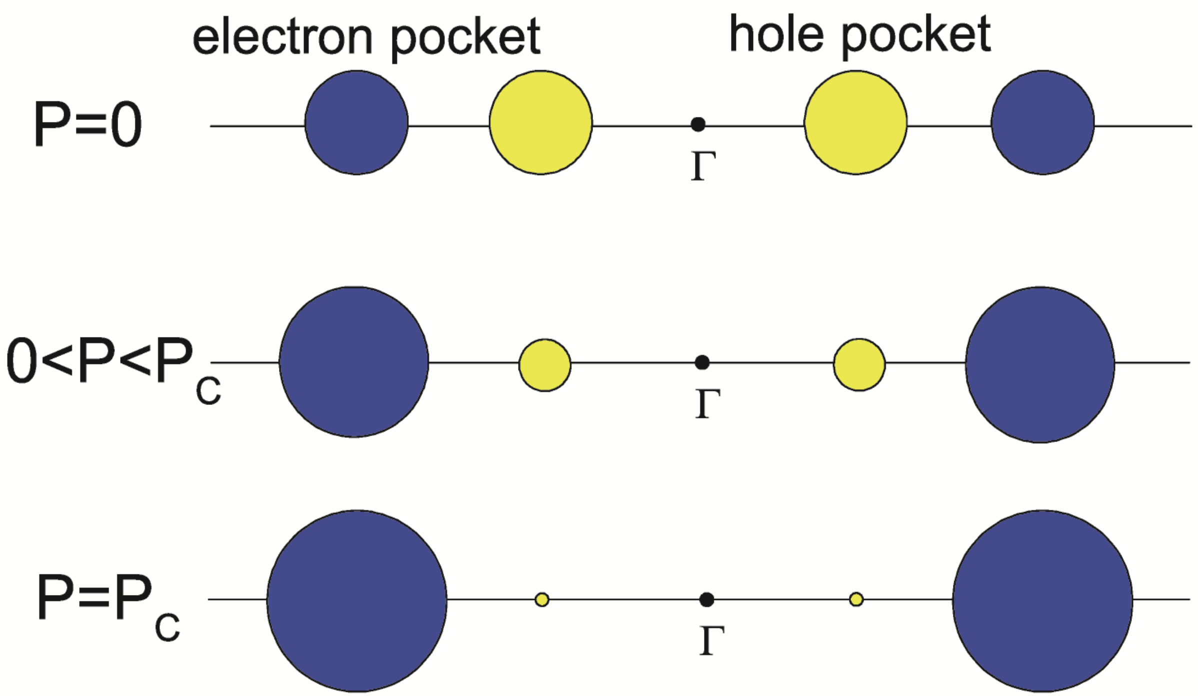
arXiv 1412.8298





The reconstruction of the FS in WTe_2 has been identified by Shubnikov-de-Hass oscillation measurements under pressure.

Carton picture of evolution of electron and hole pockets with pressure



h=e LMR,

h<e WLM

h<<e NLM
SC appears

Our HP results support the scenario that the perfect balance between h and e pockets are responsible for the LMR effect.

Summary

1. Superconductivity frequently emerges in the proximity of different electronic ground states. Pressure is an ideal method to tune the electronic state from one to the other, and reveal new phenomena.

2. The LMR effect in WTe_2 can be fully suppressed at 10.5 GPa and superconductivity emerges accordingly. This is the first example to be pressurized to superconductivity from a suppressed LMR state under pressure, which enriches route to explore superconductivity in materials.

Thank you very much for your attention!