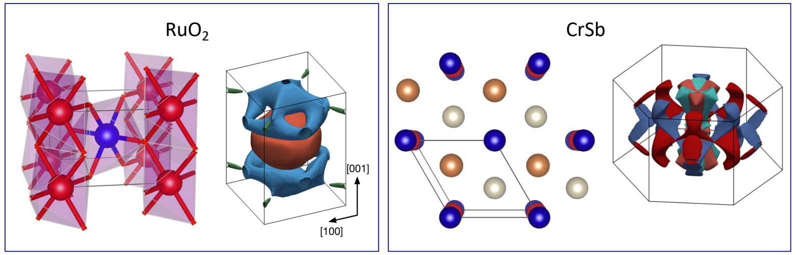
Spin-split Fermi surface in the metallic altermagnet CrSb

F. Malte Grosche
Cavendish Laboratory, Cambridge

Identify altermagnets by measuring their Fermi surface:



- Symmetry idea, spin splitting $\Delta_\mathbf{k} = \varepsilon_\uparrow(\mathbf{k}) - \varepsilon_\downarrow(\mathbf{k})$
- RuO_2: known to be an altermagnet, what does Fermi surface say?
- CrSb: clean metallic altermagnet, spin-split Fermi surface resolved

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[Wu PRX **15,** 031044 (2025), Long Nature **656,** 854 (2026)]

The team studying metallic altermagnet candidates

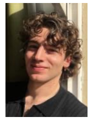
Crystal growth
- *RuO_2:* Shubhankar Paul, Hisakazu Matsuki, **Yoshi Maeno (Kyoto)**
- *CrSb:* Ran Tao, Mengmeng Long, Shitao Qu, **Mads Hansen**

Quantum oscillation measurements
- *Core group:* **Theo Weinberger, Tony Wu, Alex Eaton**
- *Expeditions:* + **Mengmeng Long, Hanyi Chen,** Mridul Shrestha (Cambridge), Dave Graf (Tallahassee), Oleksandr Zheliuk, Uli Zeitler, Yurii Skourski (Rossendorf), Gang Li, Rui Zhou (Beijing SECUF), Zengwei Zhu (Wuhan)
- *Band structure:* **Theo Weinberger**

High pressure CrSb
- *Neutrons, XRD:* **Mads Hansen,** Ran Tao, Shitao Qu


Alex Eaton


Tony Wu


Theo Weinberger

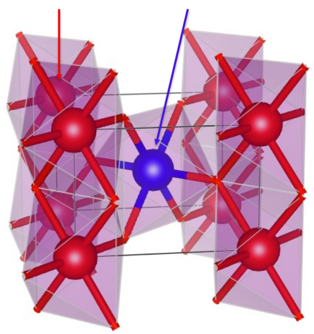

Mads Hansen

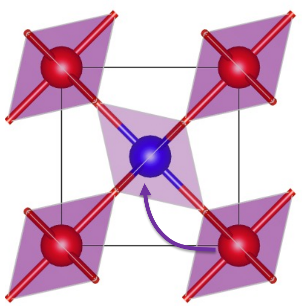

Mengmeng Long


Hanyi Chen

RuO_2 – a prototypical metallic altermagnet?

red = spin up   blue = spin down RuO_2 along *c*





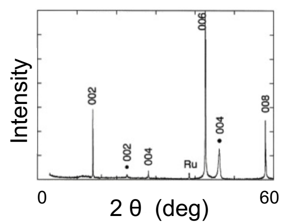
RuO_2 (O not shown) assuming it is magnetically ordered

Combine rotation+translation in real space with spin-flip to map spin-up onto spin-down sublattice

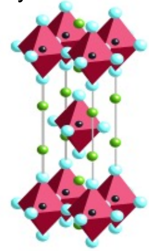
Rotation (+translation) required to map one spin sublattice onto the other $\rightarrow$ spin-up Fermi surface is mapped onto spin-down Fermi surface by a rotation as well $\rightarrow$ **spin-split Fermi surfaces.**

Resolving Fermi surfaces using high-field quantum oscillations

x-ray spectrum

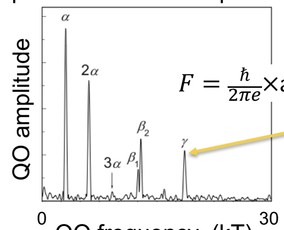


crystal structure



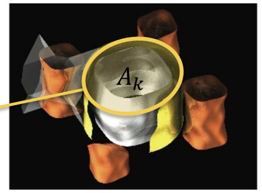
Sr_2RuO_4

quantum oscillation spectrum



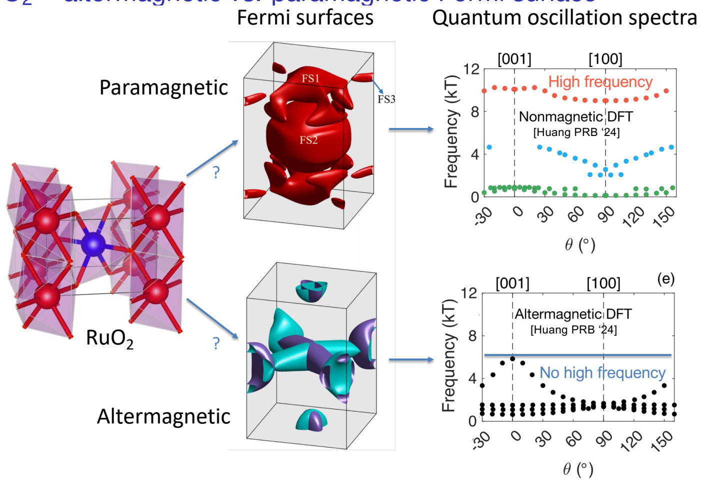
$F = \frac{\hbar}{2\pi e}\times$area A_k

electronic structure



Track cross-section vs. angle: map out Fermi surface

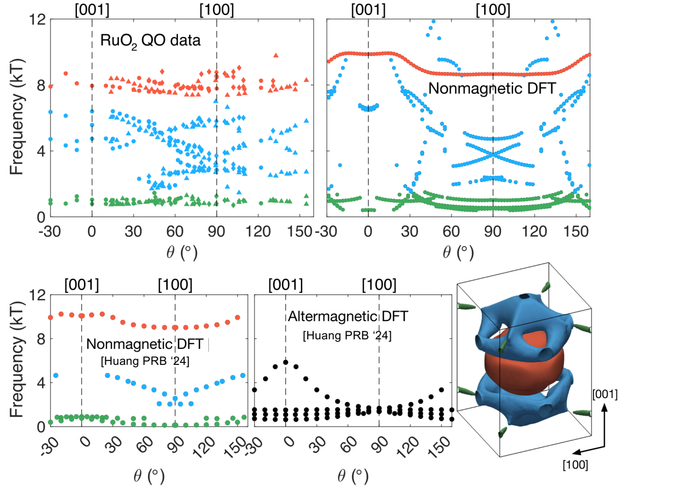
RuO_2 – altermagnetic vs. paramagnetic Fermi surface



Band structure: high frequency branch in the paramagnetic state.
No high frequencies in the altermagnetic state.

[Huang PRB **110,** 144410 (2024)]

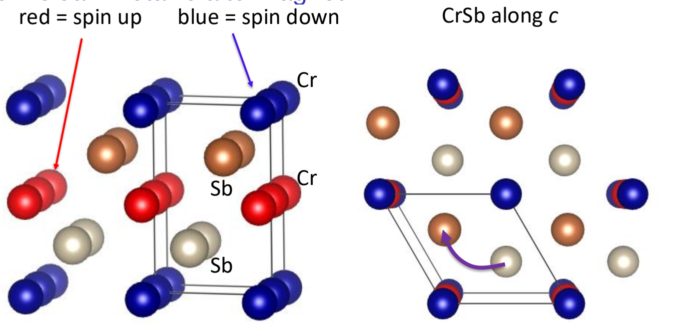
RuO_2 – Quantum oscillations rule out altermagnetic Fermi surface



High-frequencies from 'orange' pocket not expected in altermagnet →
RuO_2 is a paramagnet, not an altermagnet.

[**Wu PRX 15, 031044 (2025)**, Huang PRB **110,** 144410 (2024)]

CrSb – clean metallic altermagnet?!



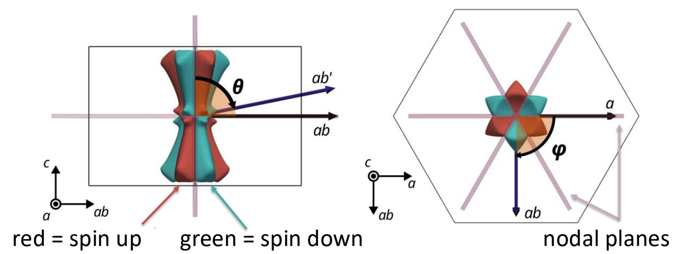
CrSb in magnetically ordered state detected by neutron scattering

Combine 60° rotation + vertical translation with spin-flip to map spin-up onto spin-down

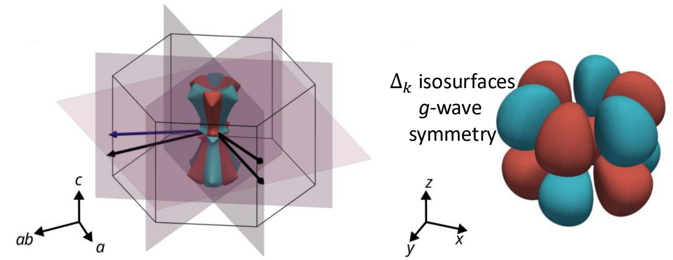
Rotation (+translation) required to map one spin sublattice onto the other → spin-up Fermi surface is mapped onto spin-down Fermi surface by a rotation as well → **spin-split Fermi surfaces.**

[Long Nature **656,** 854 (2026)]

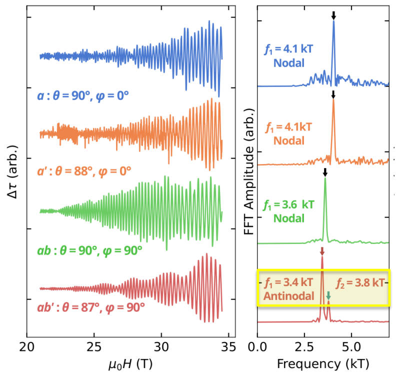
CrSb – spin splitting, nodal and antinodal planes



Wavevector dependent spin splitting $\Delta_{\mathbf{k}} = \varepsilon_{\uparrow}(\mathbf{k}) - \varepsilon_{\downarrow}(\mathbf{k})$
$\Delta_{\mathbf{k}} = 0$ where Fermi surface pockets intersect: **nodal planes**



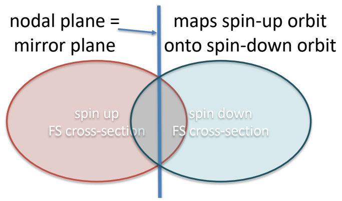
CrSb – spin-splitting vanishes for fields in nodal planes



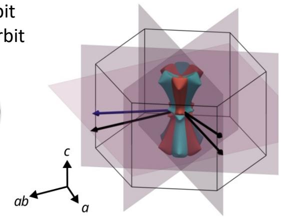
- Observe single frequency for B along a or ab
- $k_z = 0$ is nodal plane
- Frequencies split for B turned away from ab, but not a
- Because a is in nodal plane, ab is in antinodal plane.

nodal plane = mirror plane

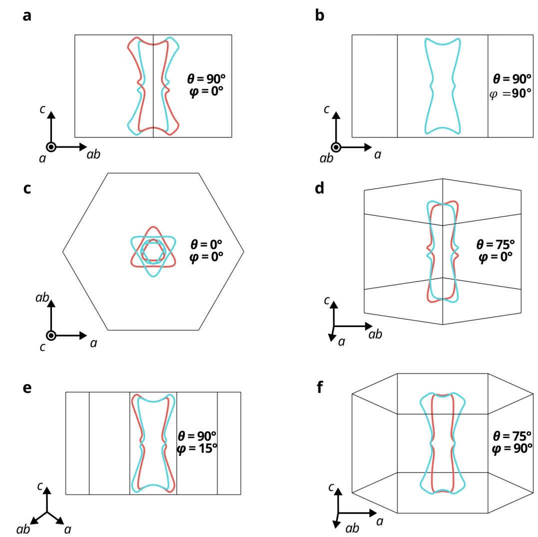
maps spin-up orbit onto spin-down orbit



⇒ equal areas = equal QO frequencies for fields in nodal plane



CrSb – QO orbits for different field directions



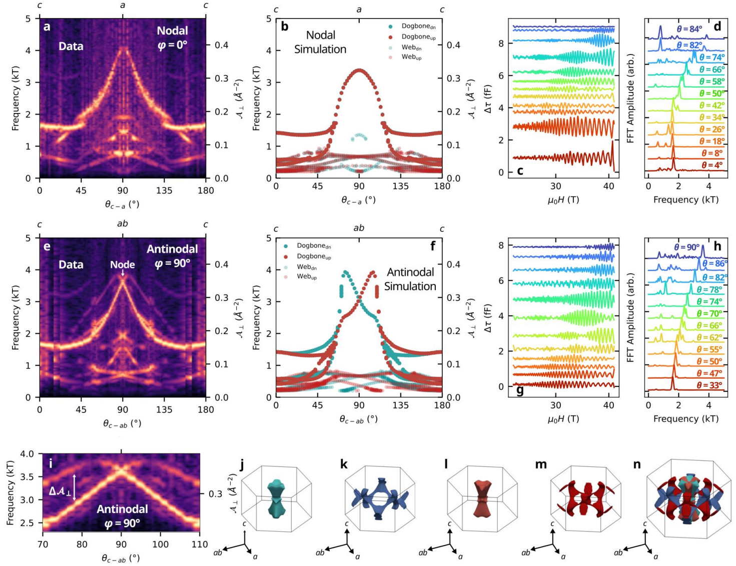
- Fields in nodal plane: equal up- and down-spin orbit areas
- Fields in antinodal plane: splitting of areas

Fermi surfaces in altermagnets

TEMM '26

Altermagnetism
RuO_2
CrSb altermagnet
Structure
Spin splitting
Results
CrSb under pressure
Summary

CrSb – mapping out spin-split surfaces, rotating B towards c



Splitting of main 'dogbone' sheet follows expectations from band structure. Additional 'web' sheet produces lower frequency spaghetti

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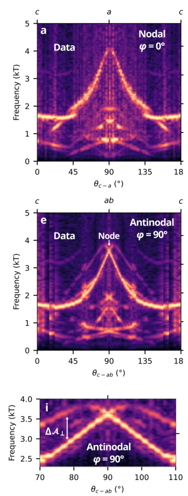
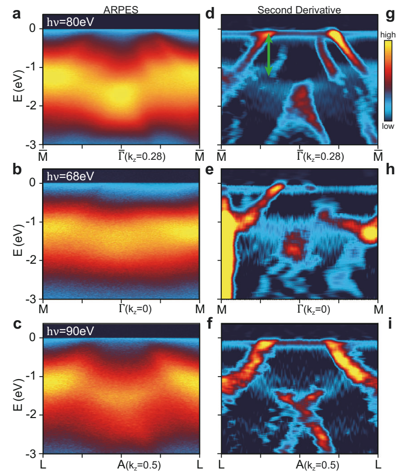
Comparison with ARPES

Quantum oscillations



ARPES evidence for spin splitting



[Yang Nature Comms **16**, 1442 (2025)]

Spin splitting also observed in ARPES data

[Long Nature **656,** 854 (2026), Yang Nature Comms. **16,** 1442 (2025)]

Fermi surfaces in altermagnets

TEMM '26

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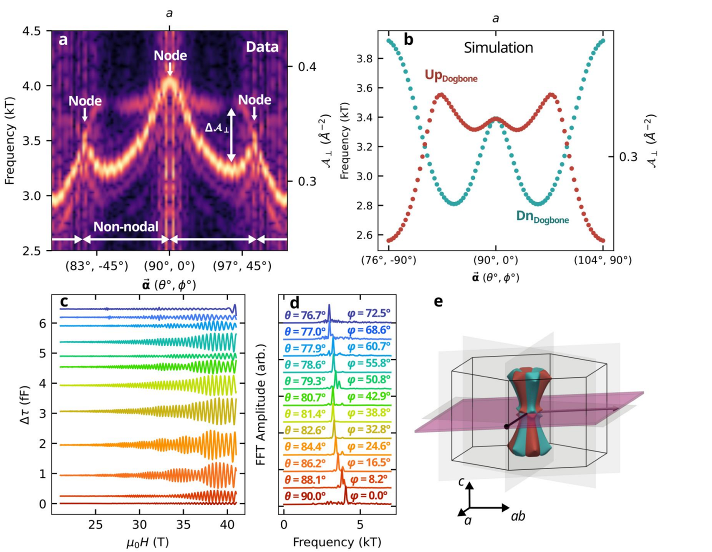
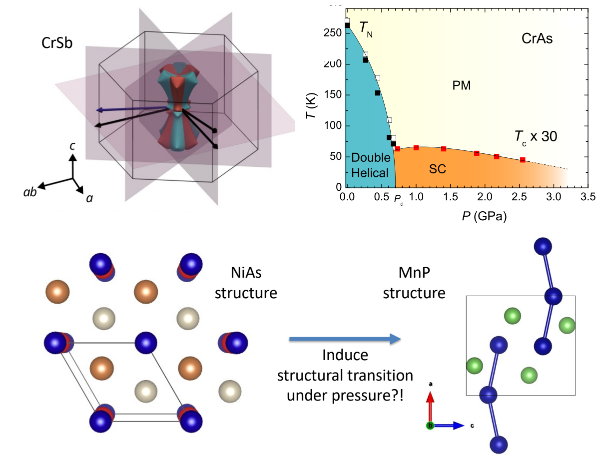
CrSb – rotating B around c resolves periodicity of spin-splitting



Track 120° periodicity in splitting of main 'dogbone' sheet

***g*-wave altermagnetic spin-splitting unambiguously resolved**

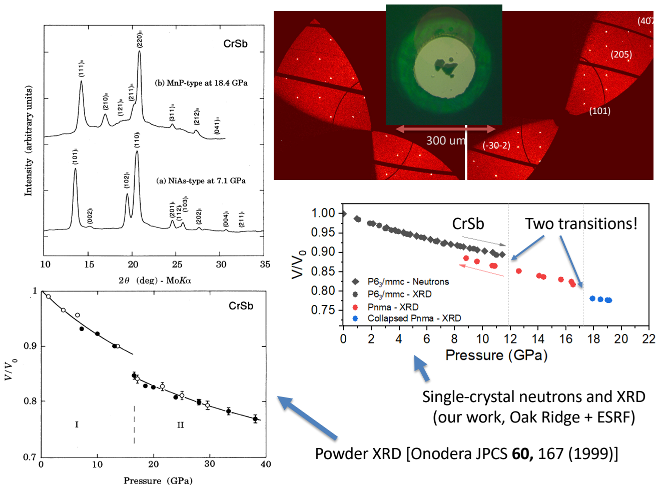
Drive CrSb altermagnetism to zero with pressure? CrSb vs. CrAs



CrAs structure is different from that of CrSb. Incommensurate helical magnetic order. Superconductivity emerges under pressure.

- Suppress CrSb altermagnetism **before** the structural transition?
- If the structural transition happens first, can we induce CrAs-like superconductivity in CrSb?

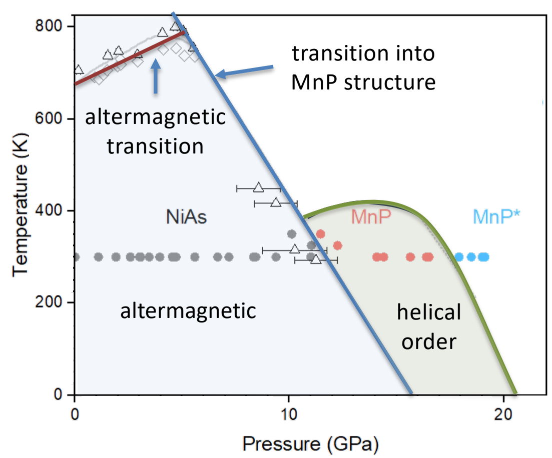
High pressure diffraction in CrSb



High pressure diffraction: **two structural transitions** in CrSb

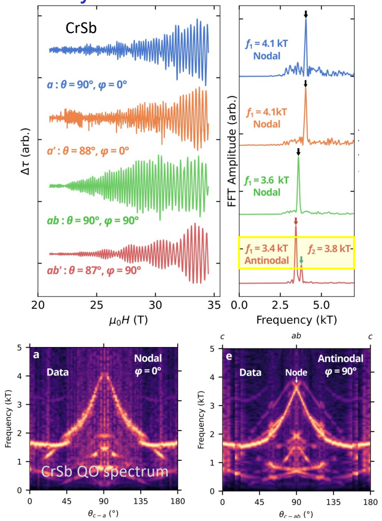
1. Hexagonal → orthorhombic, strongly hysteretic.
2. Isostructural, volume change

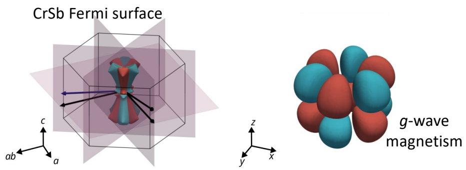
Working hypothesis for CrSb high pressure phase diagram

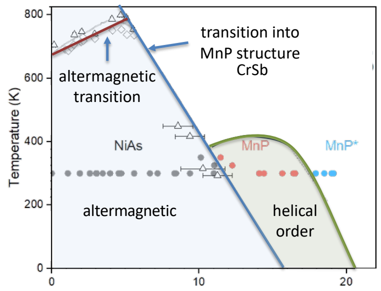


1. Low pressure structure hosts altermagnetism
2. Change to MnP structure, which hosts CrAs helical order

Summary







Quantum oscillations resolve g-wave spin splitting in CrSb
High pressure CrSb changes into MnP structure
What can be expected at an altermagnetic quantum critical point?