

Fermi Arcs Protection in TaAs & Their Susceptibility in $\text{Co}_3\text{Sn}_2\text{S}_2$

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Weizmann Institute of Science



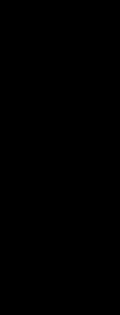
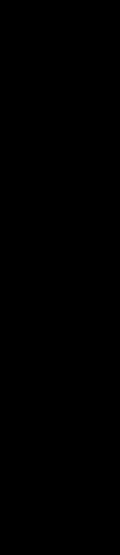
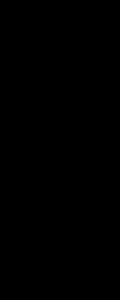
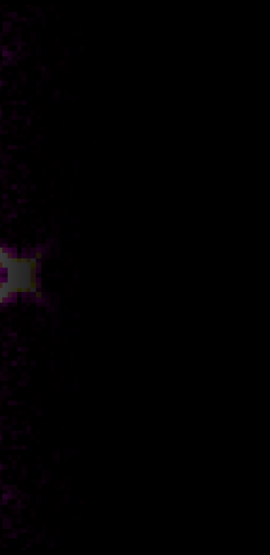
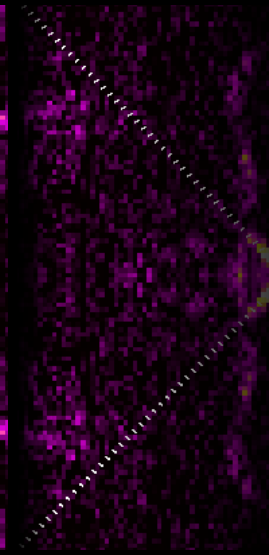
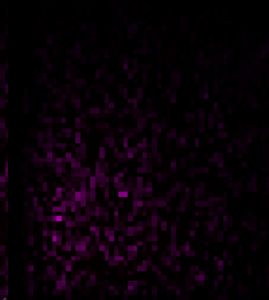
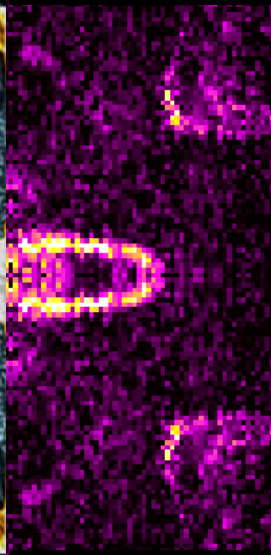
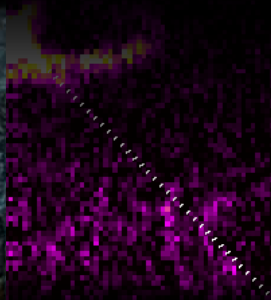
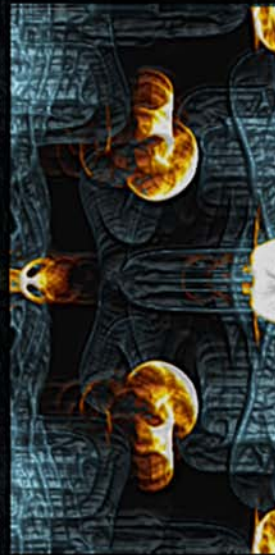
KITP, Nov 2019

Weizmann
Atomic
Scale
Physics lab



Fermi Arc Protection in TaAs

Fermi arcs QPI
Bloch wavefunction
Weyl dominated



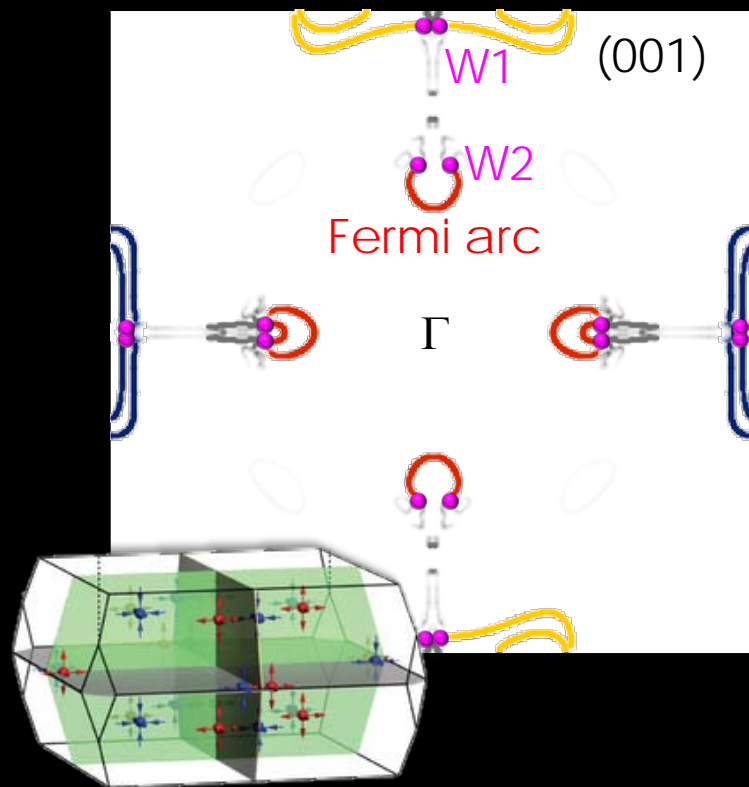
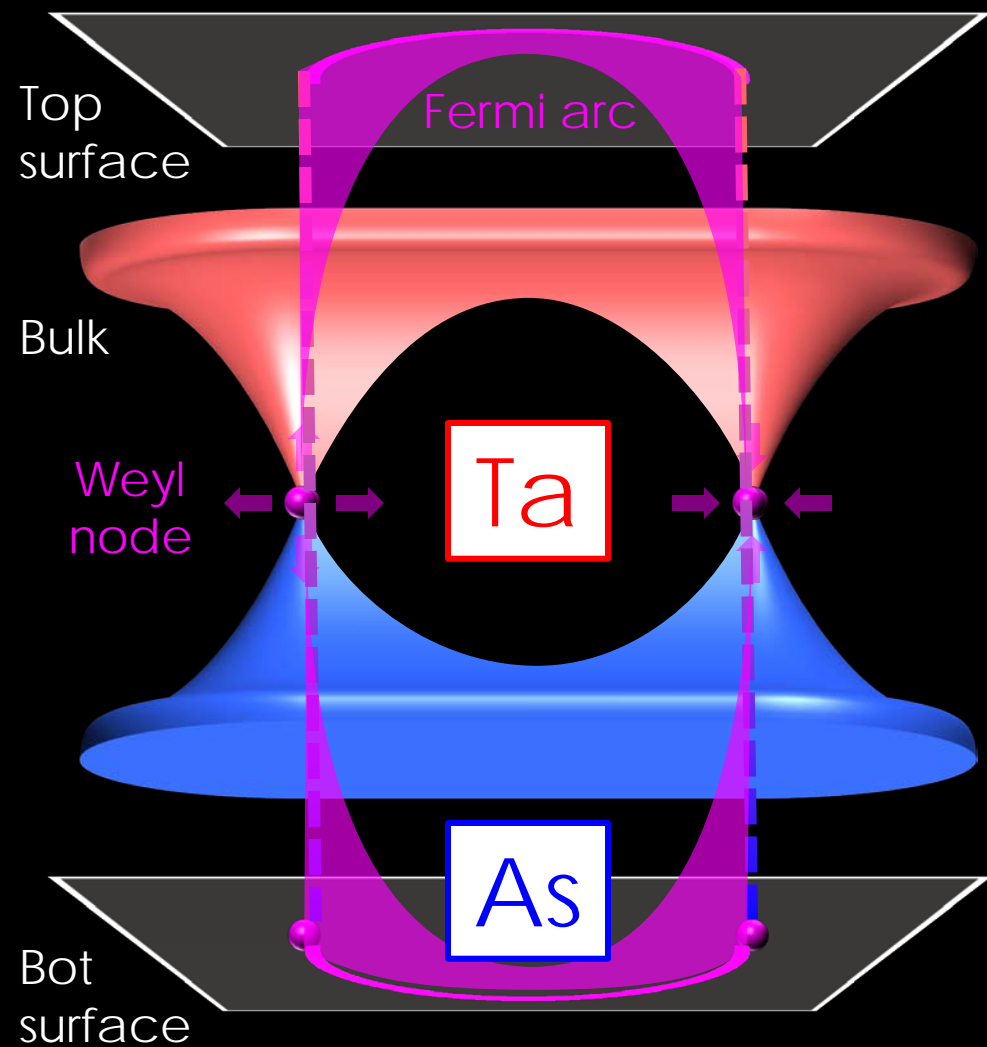
TaAs – Inversion Symmetry broken Weyl Semimetal

Theory H Weng *PRX* (2015)

ARPES SY Xu *Science*; BQ Lv *PRX*; LX

Yang *Nat Phys* (2015)

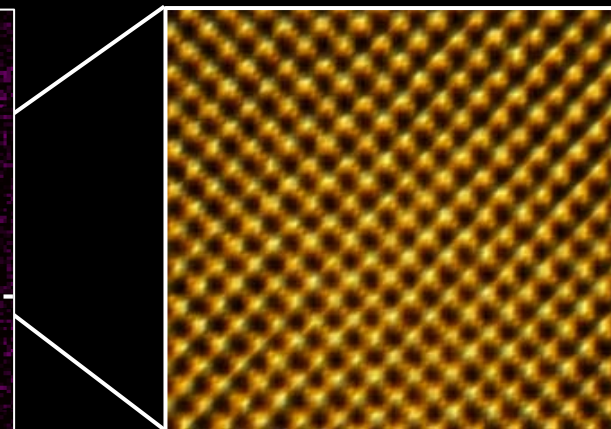
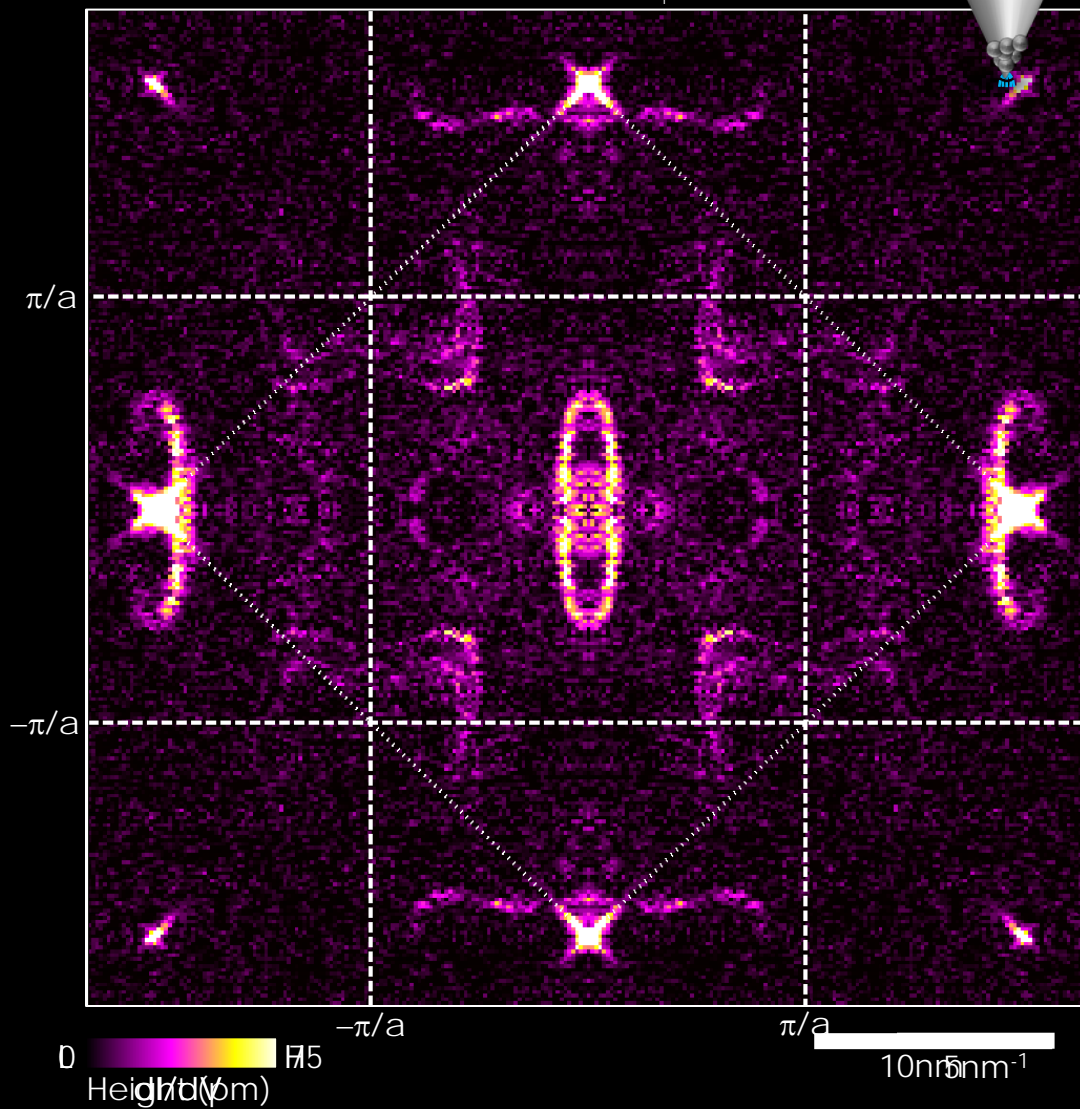
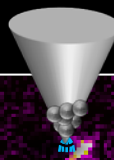
STM R Batabyal, HB *Sci Adv*; H Inoue
Science (2016)



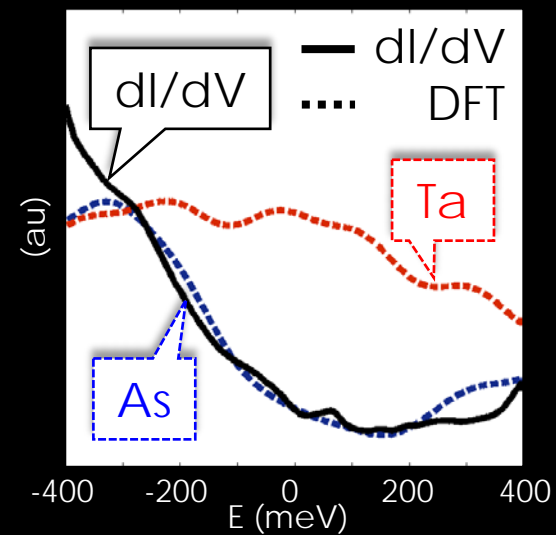
24 Weyl nodes!

Quasi Particle Interference

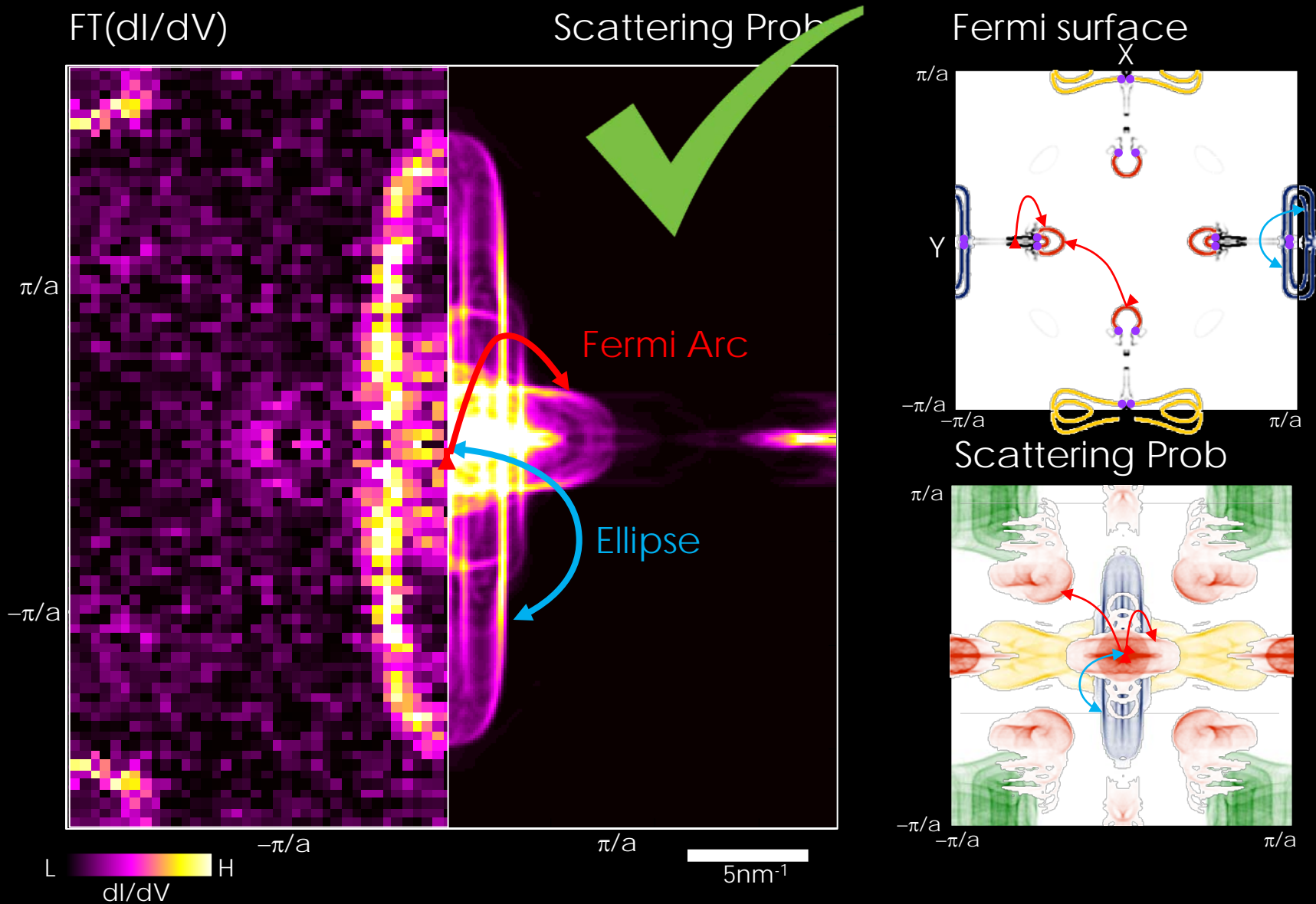
$$I(z) \sim e^{-z/\xi} \int_{E_F}^{E_F+V} \text{DOS}(E) dE$$



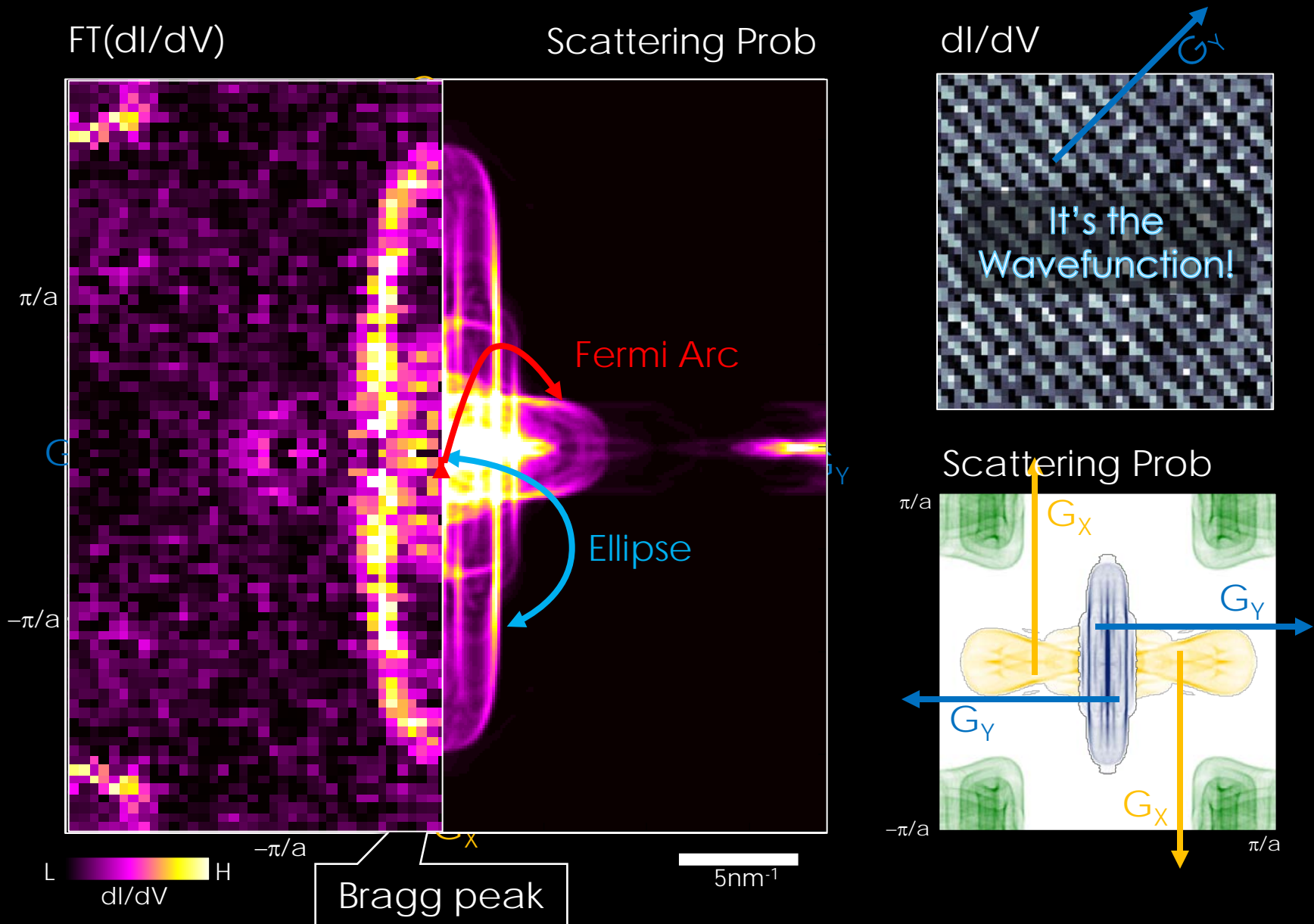
$dI/dV \sim \text{DOS}(E)$



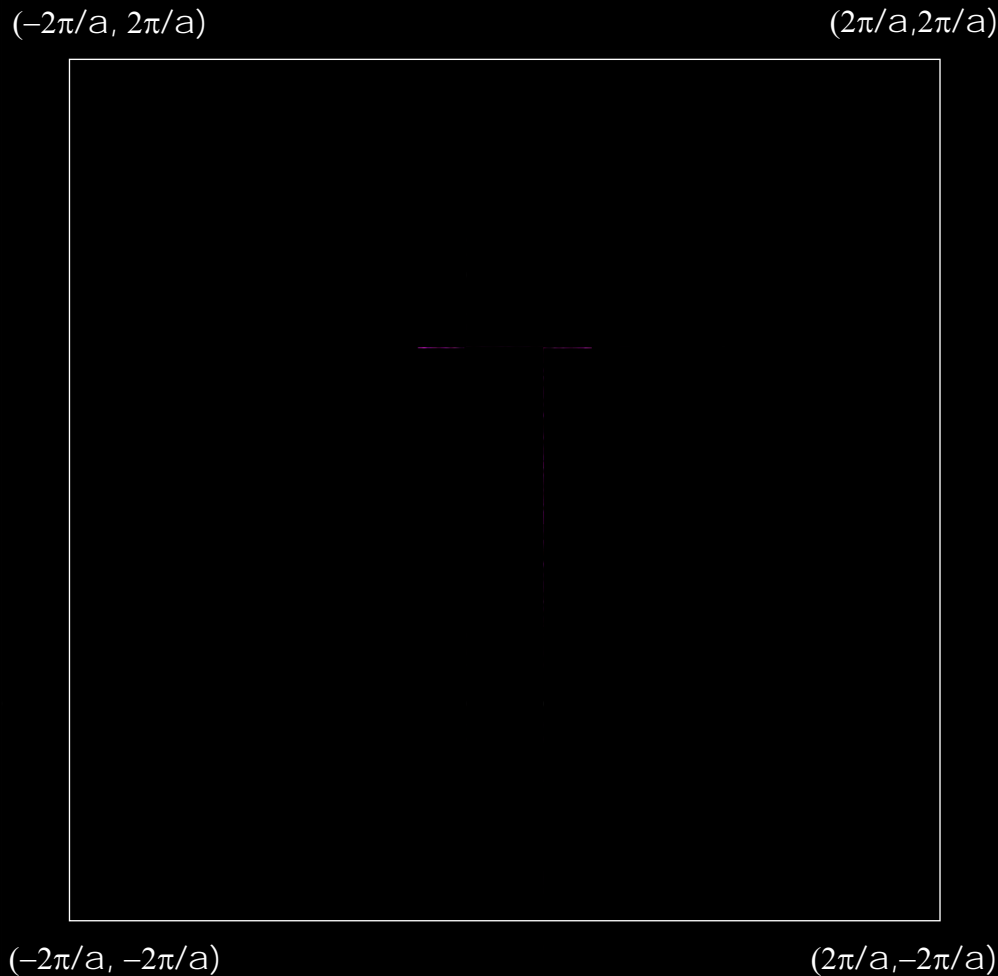
Surface Fermi arcs in TaAs



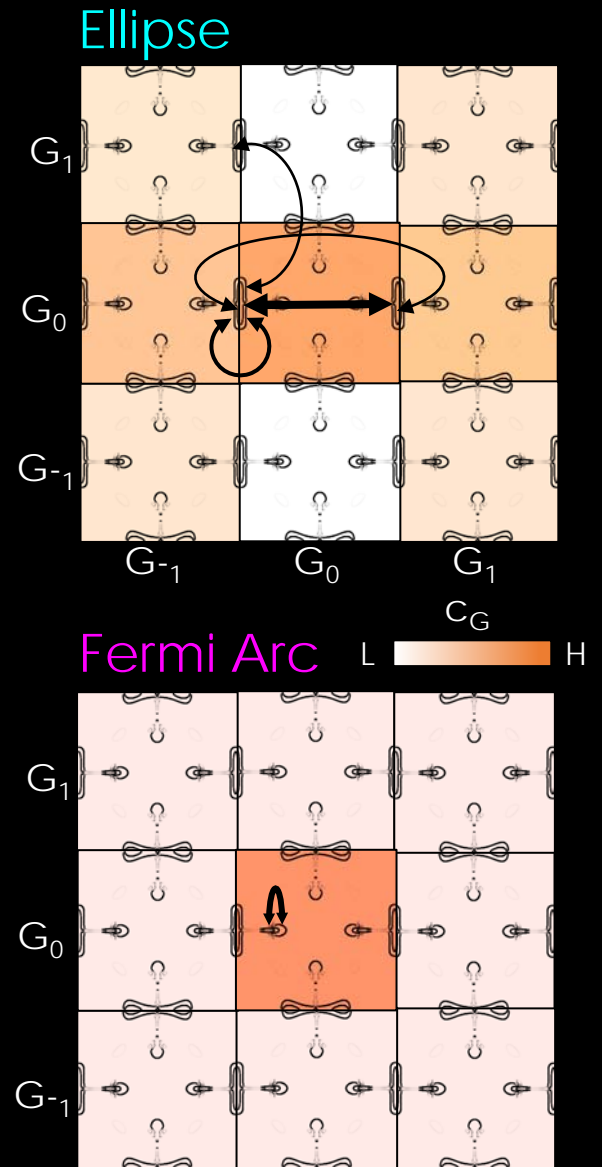
Replicated Quasi Particle Interference



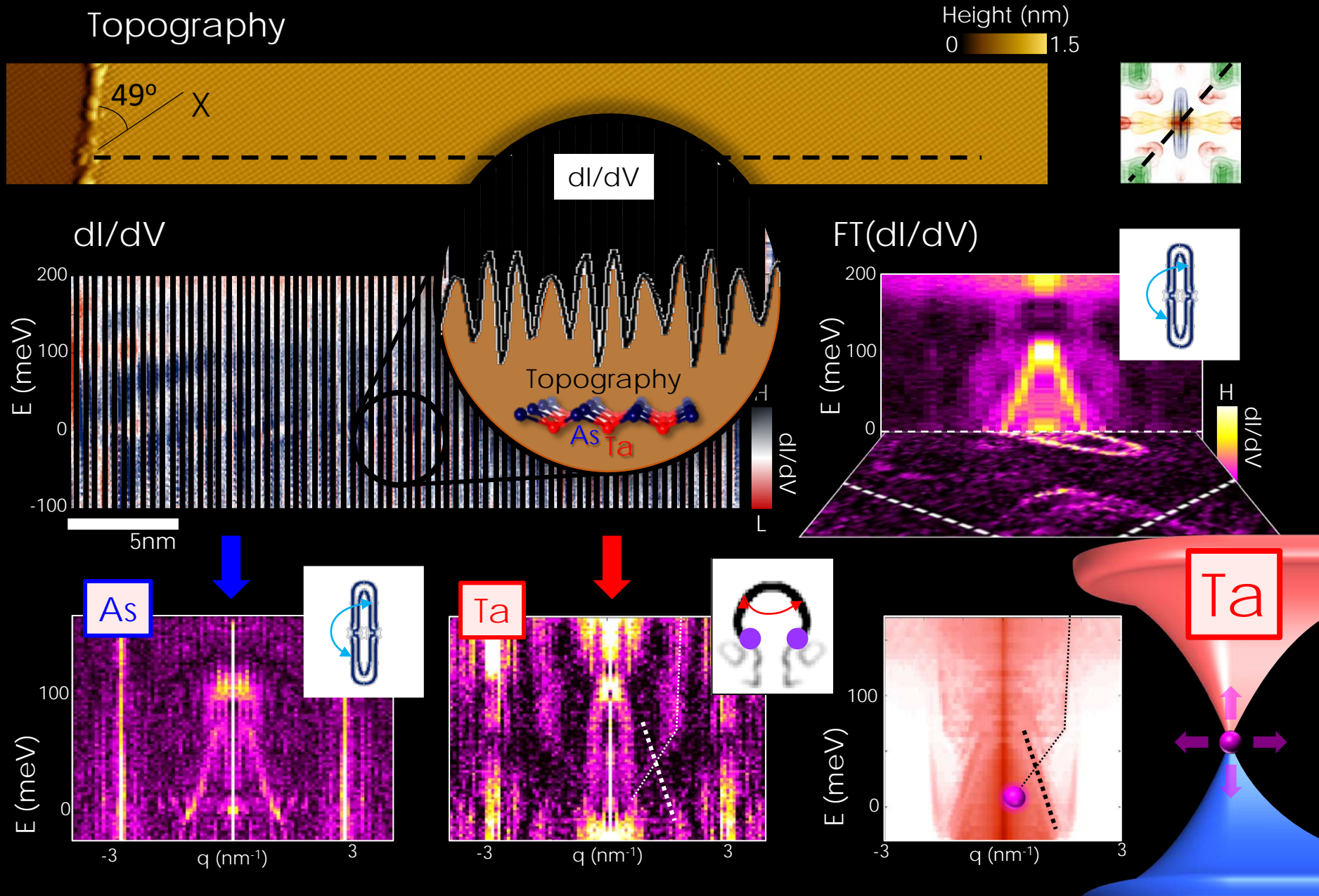
Bloch wavefunction: Trivial vs Fermi arc



Trivial surface bands – complex Bloch
Fermi arc bands ~ plane wave like



Atomically resolved Fermi arcs



Fermi Arc Susceptibility in $\text{Co}_3\text{Sn}_2\text{S}_2$

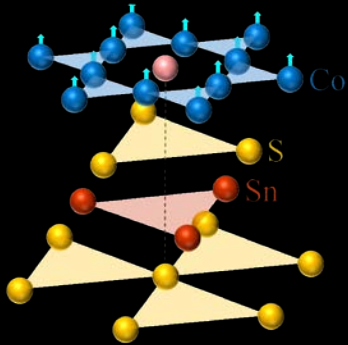
Fermi arcs QPI
TRS breaking in QPI
Rewired Fermi arcs



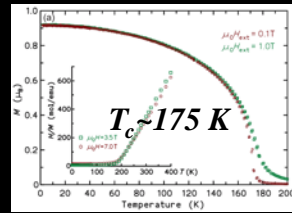


Ferromagnetic Weyl Semimetal

Kagome Lattice

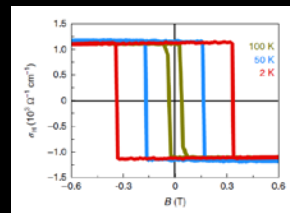


Ferro-
magnetic



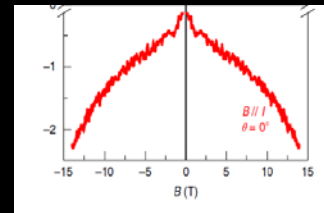
Schnelle, W. et al. PRB(2013)

Anomalous
Hall Effect

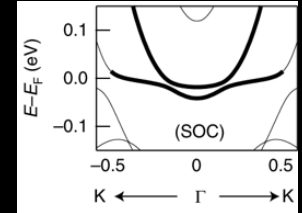


Enke Liu et. al. Nat. Phys.(2018)

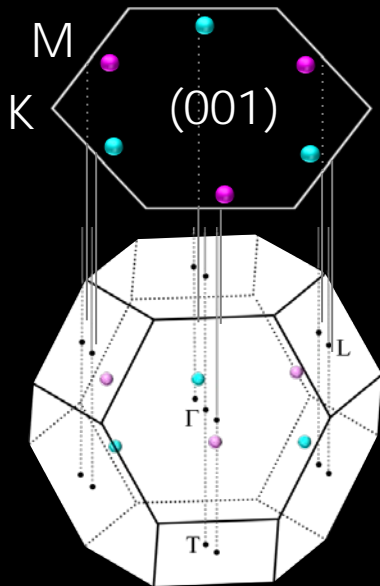
Chiral
Anomaly



Flat
band



JX Yin et al. Nat. Phys.(2019)



Q Xu et. al. PRB.(2018)

"Weyl"ing away time-reversal symmetry

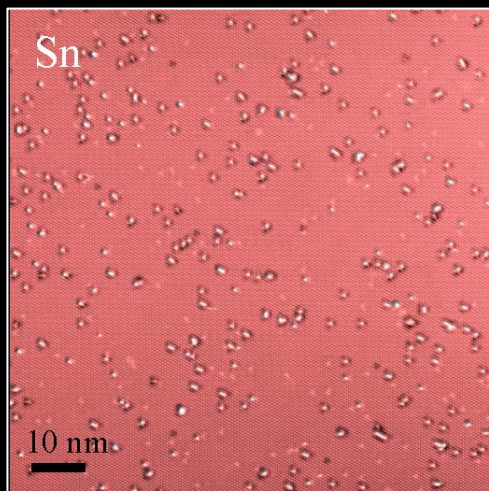
Science Vol 365

(also in *PhysicsWorld, Phys.Org*)

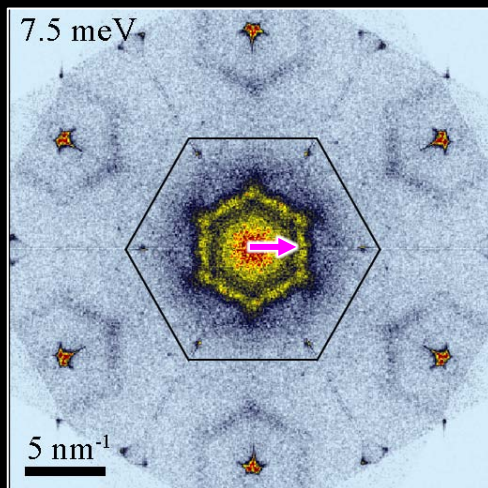
- Ferromagnetic WSM lines in Co_2MnGa (ARPES)
I Belopolsky et al. (Pp 1278)
- Ferromagnetic WSM in $\text{Co}_3\text{Sn}_2\text{S}_2$ (ARPES)
DF Liu et al. (Pp 1282)
- Ferromagnetic WSM in $\text{Co}_3\text{Sn}_2\text{S}_2$ (STM)
N Morali et al. (Pp 1286)

Surface Fermi arcs in $\text{Co}_3\text{Sn}_2\text{S}_2$

Topography

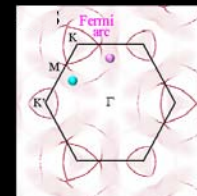
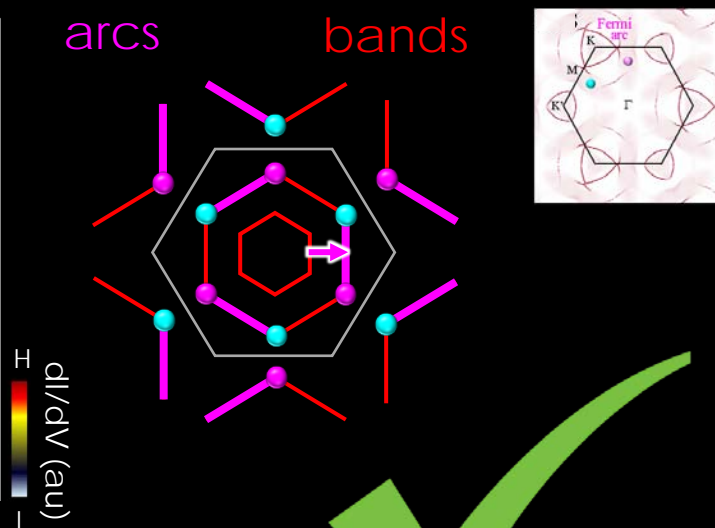


FT(dI/dV)

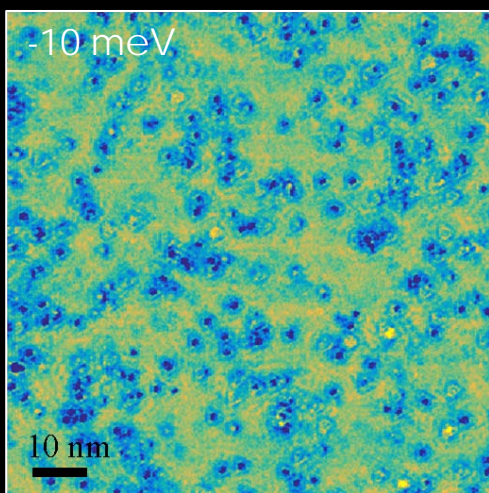


Fermi arcs

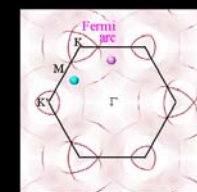
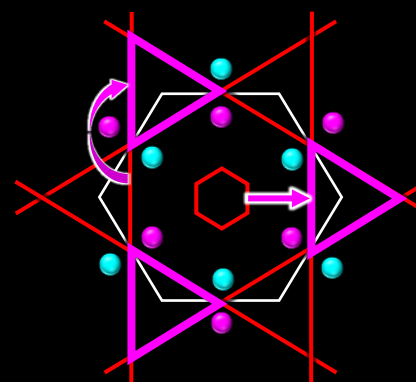
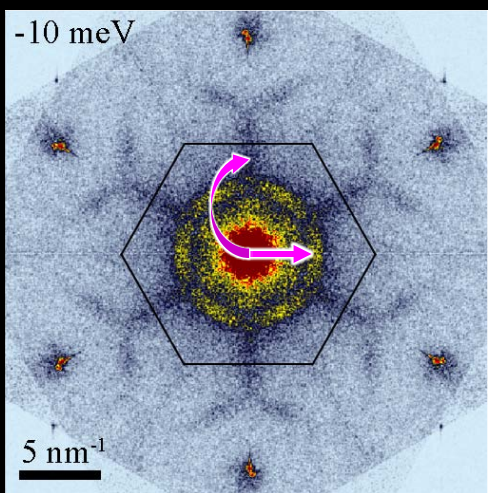
Trivial bands



dI/dV

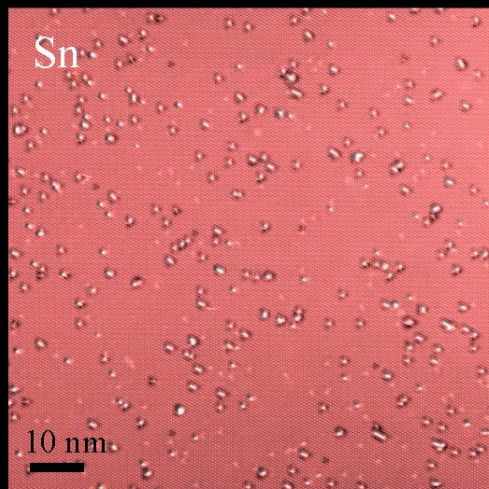


FT(dI/dV)

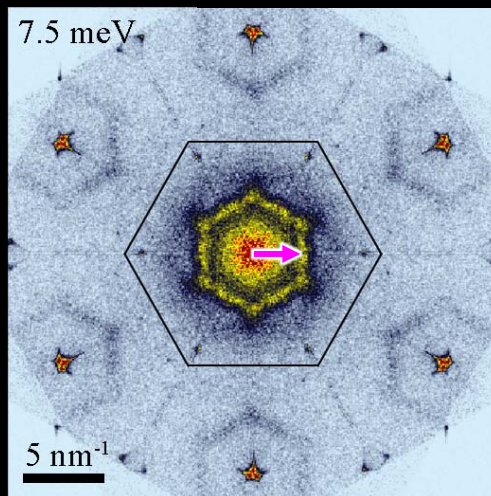


Surface Fermi arcs in $\text{Co}_3\text{Sn}_2\text{S}_2$

Topography

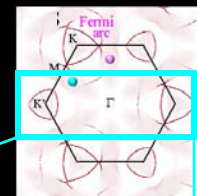


FT(dI/dV)

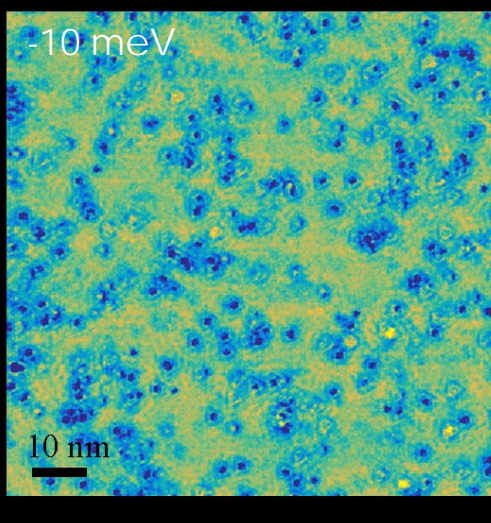


Time Reversal
Symm Breaking

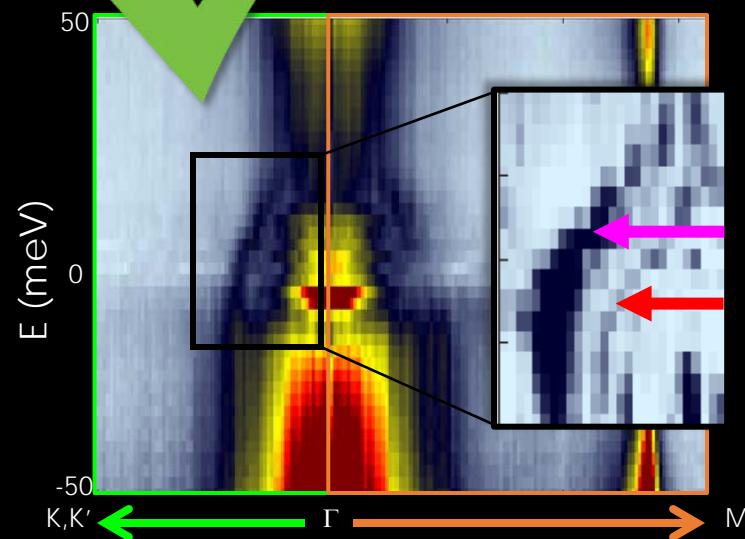
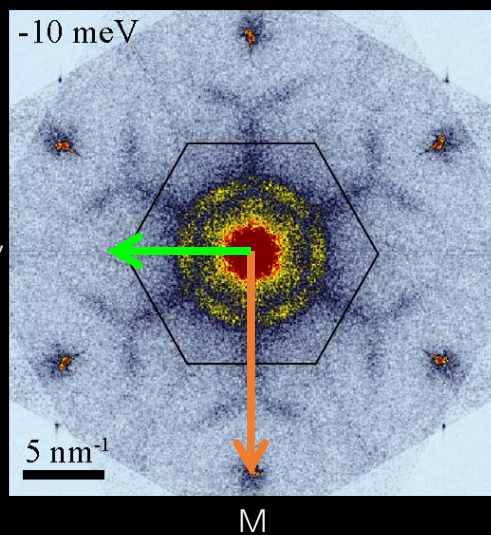
$$H(\mathbf{k}) \neq H(-\mathbf{k})$$



dI/dV

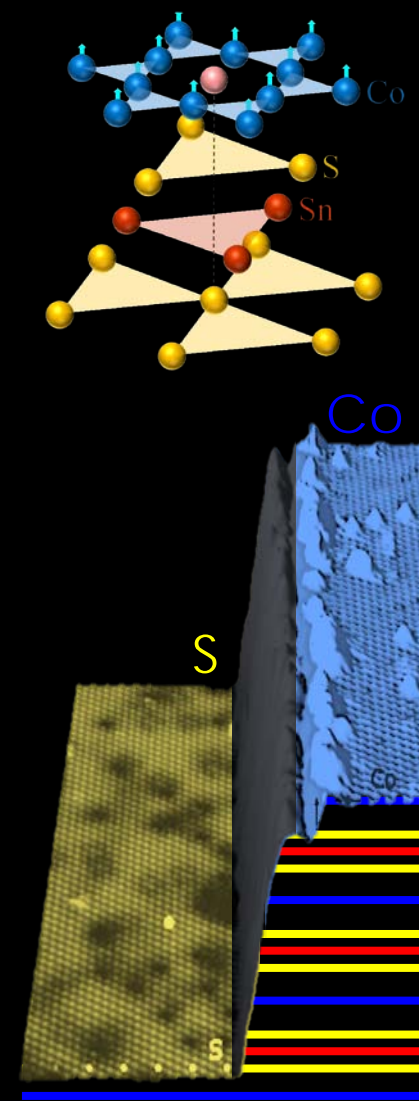
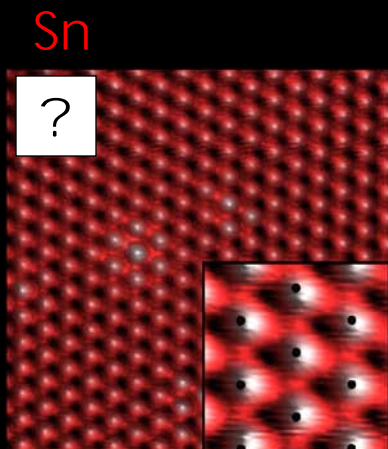


FT(dI/dV)

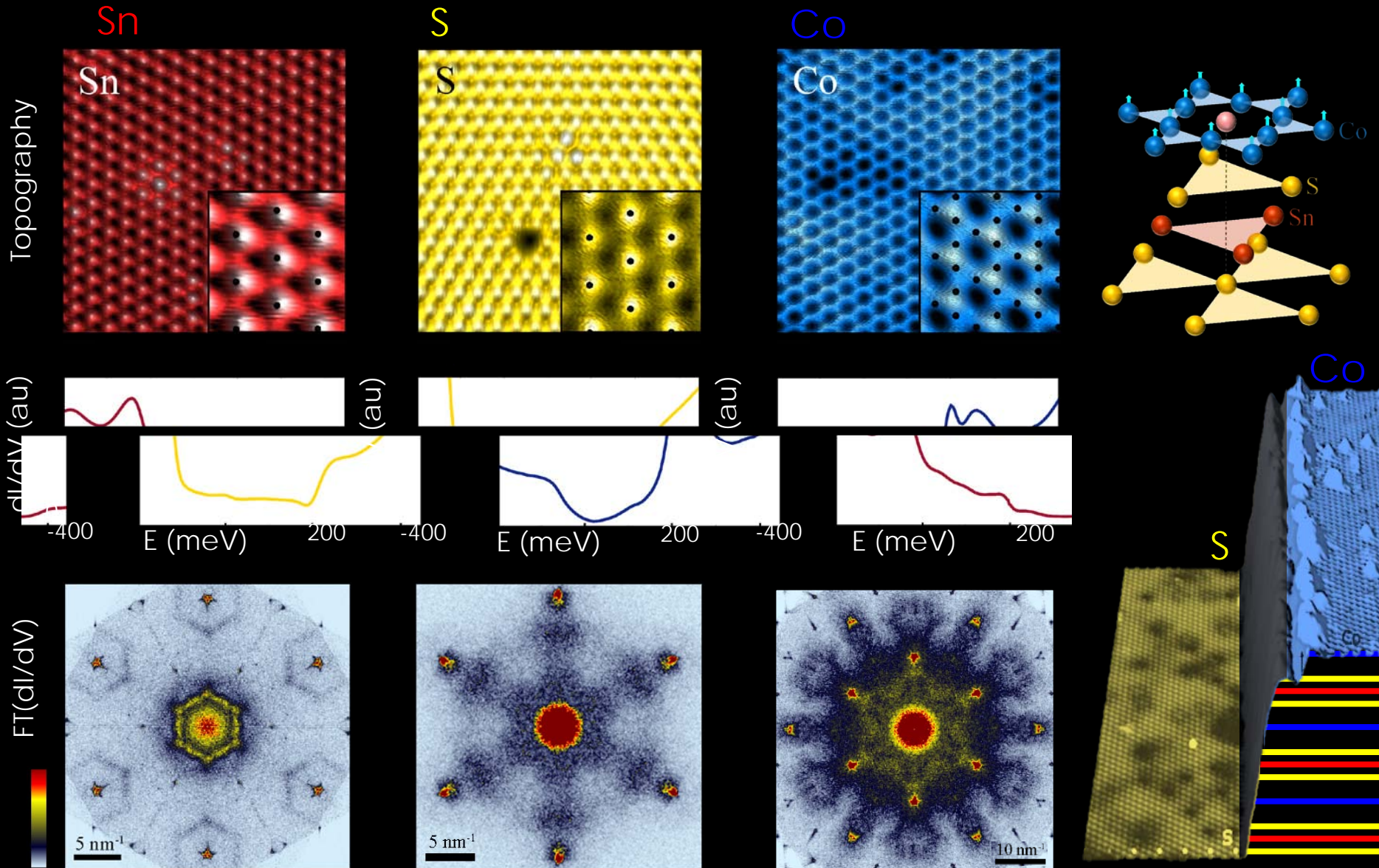


Distinct Surface Terminations

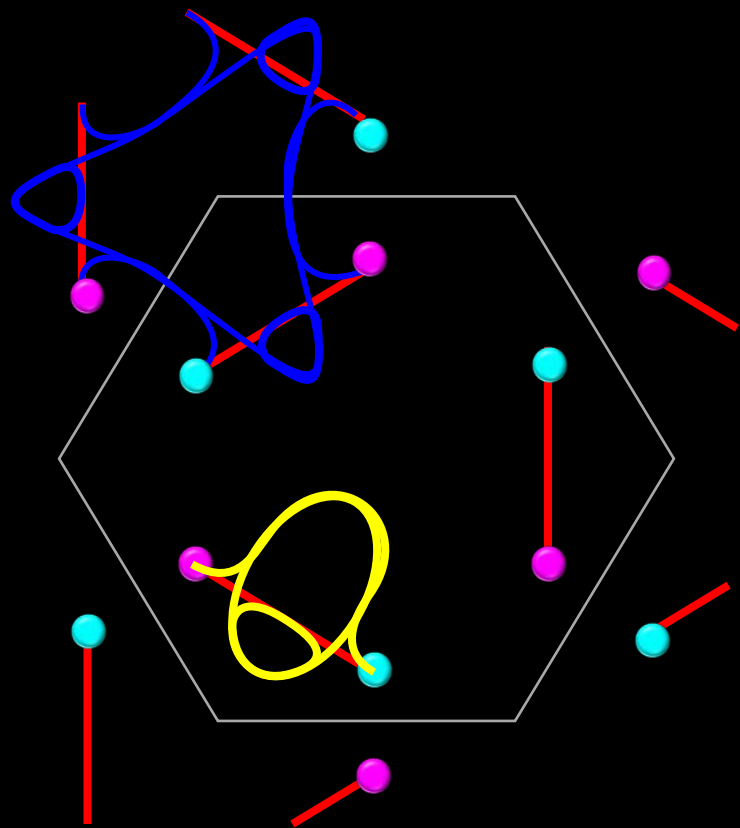
Topography



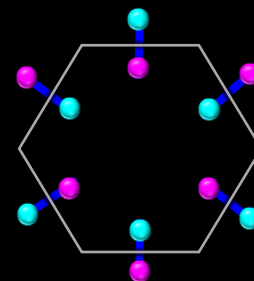
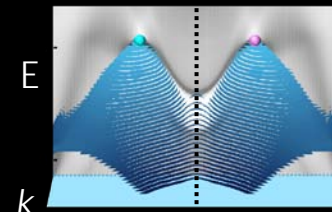
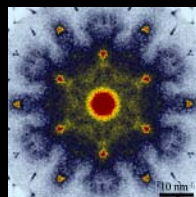
Distinct Surface Spectroscopies



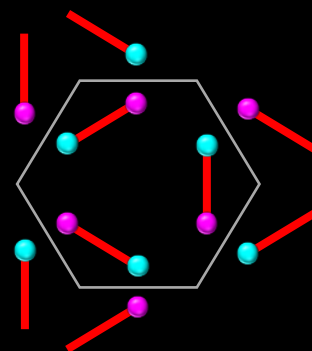
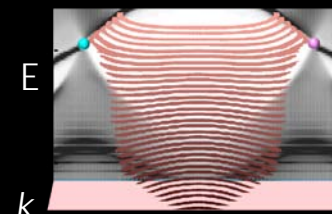
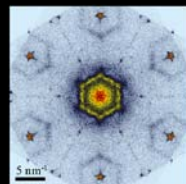
Diverse Fermi arc connectivity in $\text{Co}_3\text{Sn}_2\text{S}_2$



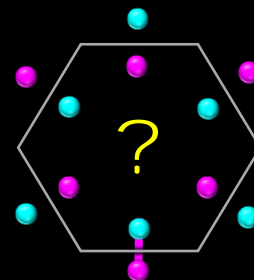
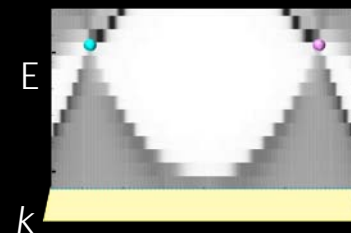
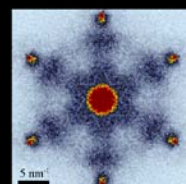
Co – inter BZ



Sn – intra BZ

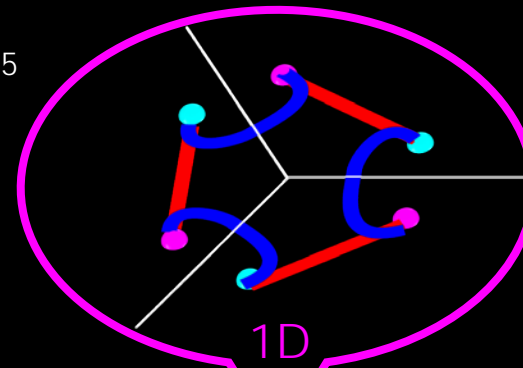
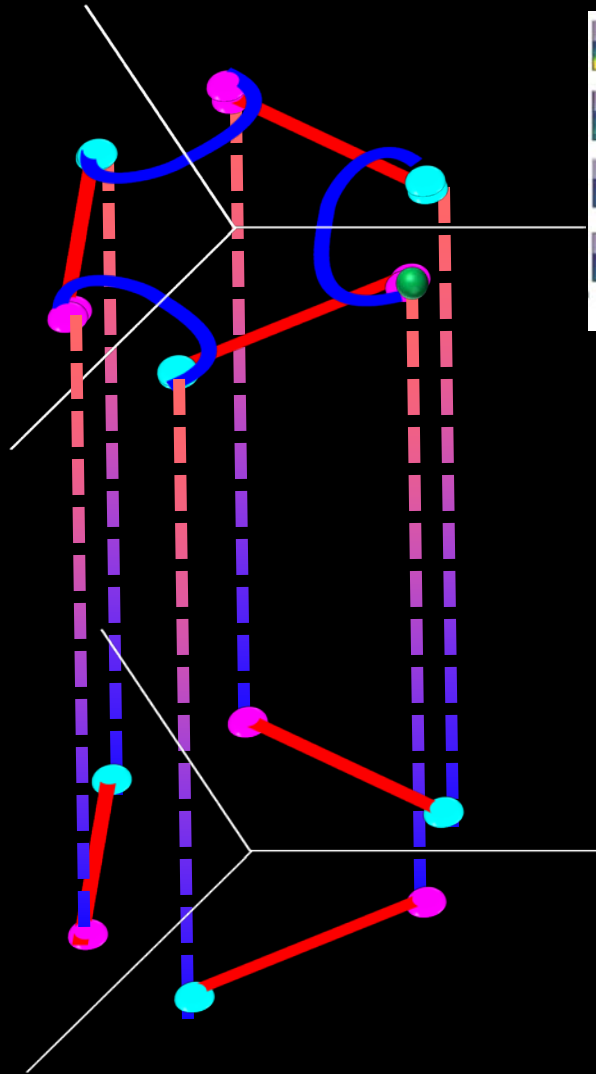
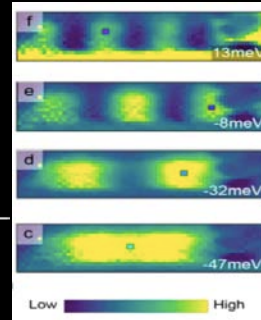


S – ambiguous

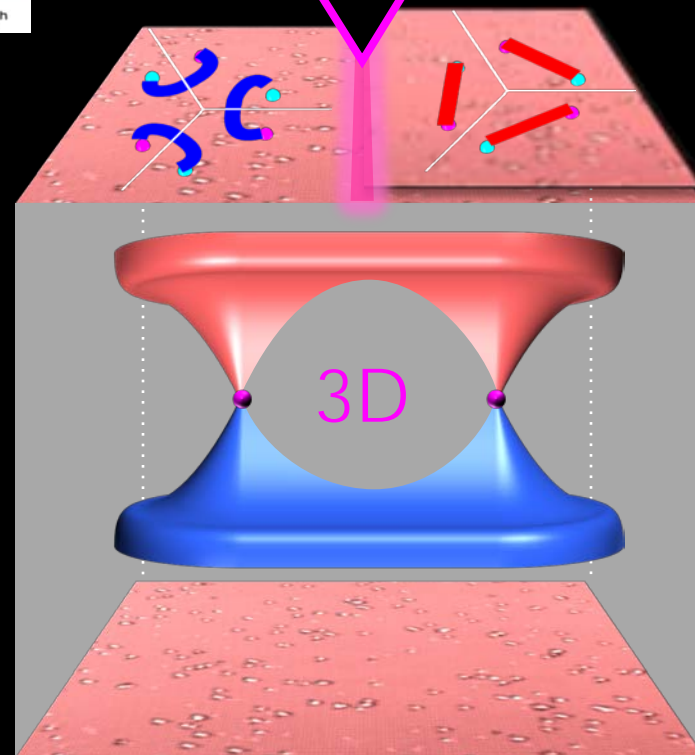


Consequences of Diverse Fermi arc Connectivity

AQH
S Howard 1910.11205



Higher Order Topological Semimetal ?



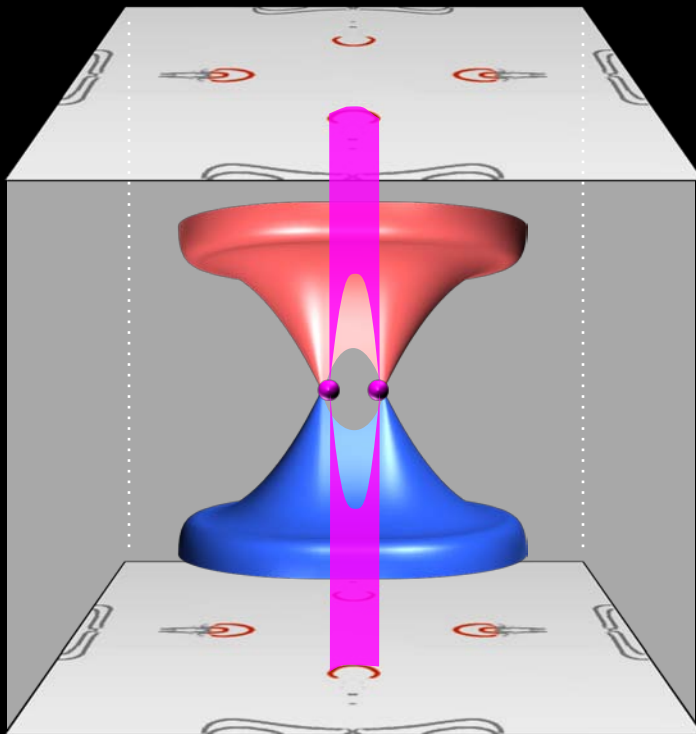
Consequences of Diverse Fermi arc Connectivity

Inversion symmetry broken

Weyl semimetal (TaAs)

Unbound to the atomic
surface

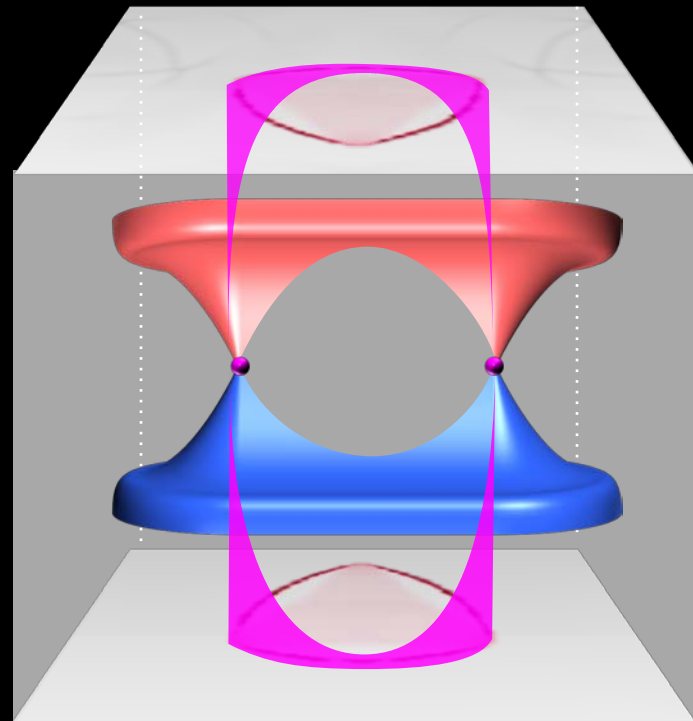
Plane-wave like



Time Reversal symmetry broken

Weyl semimetal ($\text{Co}_3\text{Sn}_2\text{S}_2$)

Varying dispersion &
connectivity



WASP



Nurit Avraham
WASP



Noam Morali
WASP



Rajib Batabyal
Copenhagen



Pranab Kumar-Nag
WASP



Abhay Kumar-Nayak
WASP



Jonathan Reiner
UNSW



Aviram Steinbok
WASP

Theory



Binghai Yan
WIS



Yan Sun
MPI



Qiunan Xu
WIS



Ady Stern
WIS



Raquel Queiroz
WIS



Yuval Oreg
WIS

Chemistry



Claudia Felser
MPI



Chandra Shekhar
MPI



Enke Liu
MPI

Summary

Visualized existence of Fermi arcs in inversion (TaAs) and time reversal ($\text{Co}_3\text{Sn}_2\text{S}_2$) symmetry broken Weyl semimetals

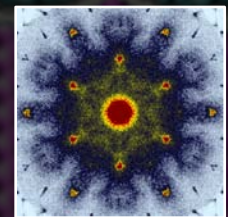
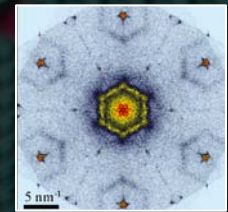
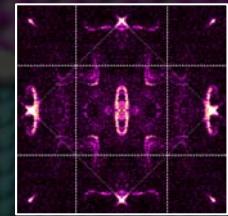
Surface Fermi arcs dominated by bulk Weyl bands (Ta orbitals) rather than by surface (As orbitals)

Fermi arcs have plane-wave like Bloch structure

Time reversal symmetry broken dispersion in $\text{Co}_3\text{Sn}_2\text{S}_2$

Distinct Fermi arc connectivity on Co, Sn & S

Higher order Topological Semimetal?



TaAs

Batabyal Sci. Adv. **2** e1600709(2016)

$\text{Co}_3\text{Sn}_2\text{S}_2$

Morali Science **365**, 1286 (2019)

Thanks