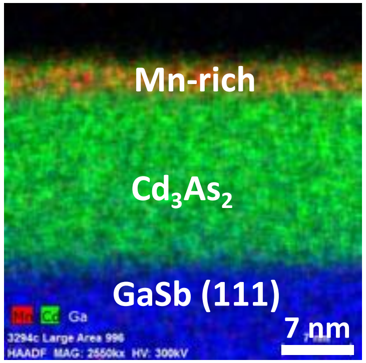
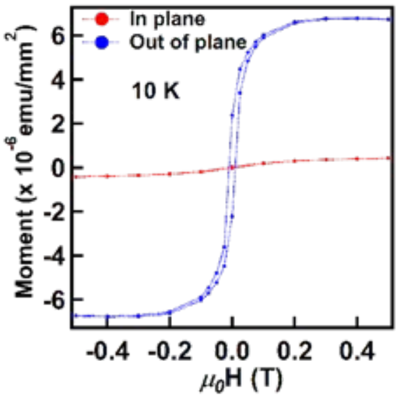
Interfacing a Dirac semimetal with magnetism
Institute for Quantum Matter EFRC DE-SC0019331

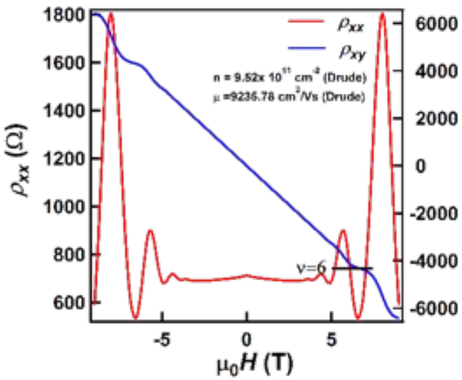
STEM image



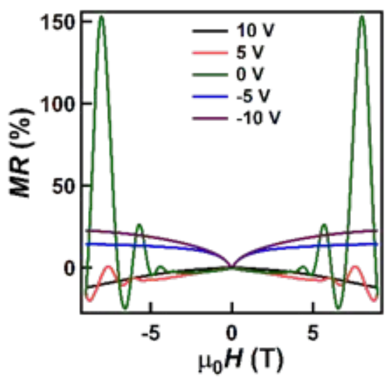
SQUID magnetometry



Quantum transport



Gated Q transport



Scientific Achievement

We have measured Fermi-energy-dependent quantum transport in electrostatically-gated thin films of the Dirac semimetal Cd_3As_2 interfaced with a ferromagnet.

Significance and Impact

Introducing magnetism into a Dirac semimetal breaks time-reversal symmetry and is an important step along the path to realizing a monopole superconductor.

Research Details

- MBE growth of Mn-Cd_3As_2 on (111) GaSb
- Mn-dopant acts a surfactant, segregating near surface in a ferromagnetic phase with out-of-plane magnetic anisotropy.
- Quantum transport in Cd_3As_2 remains intact and is studied as function of Fermi energy.

R. Xiao, A. Mitra, W. Yanez, Y. Fang, J. Held, J. Chamorro, A. Mkhoyan, T. McQueen, B. Ramshaw, N. Samarth, in preparation

IQM-EFRC research performed at Cornell , Penn State, and Johns Hopkins as part of the topological superconductivity thrust.

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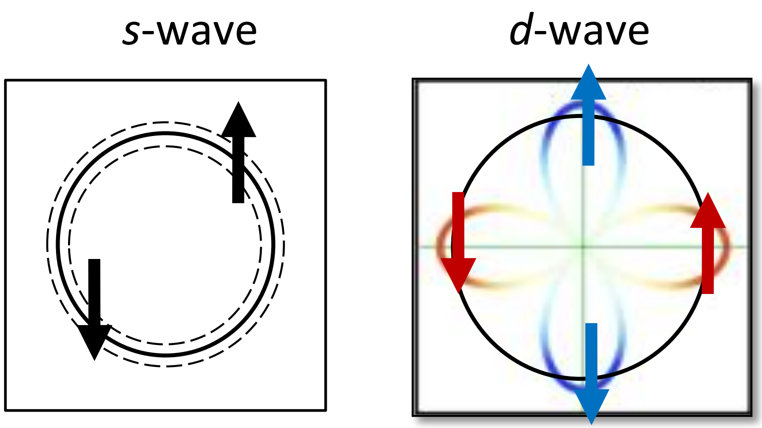
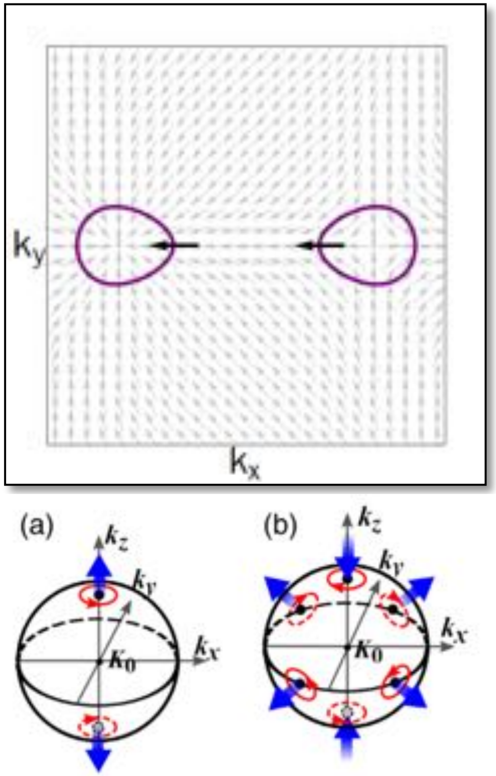
Monopole superconductors are classified by topology

Conventional



Conventional superconductors are classified by the point-group symmetry of the Cooper pairs

Monopole



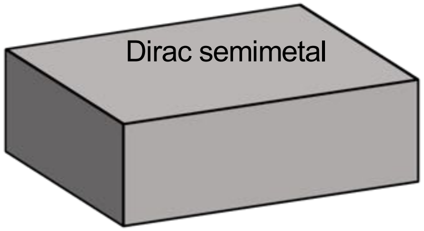
Nodal structure enforced by topology of bands, not by symmetry of pairing.

Theory [**Li**]

Thin-films as a flexible platform

✓ Growth + measurement of Dirac semimetal

[Samarth, McQueen, Ramshaw]

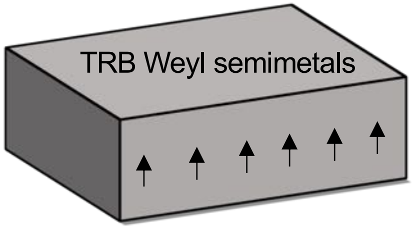


✓ Introduce magnetism

[Samarth]

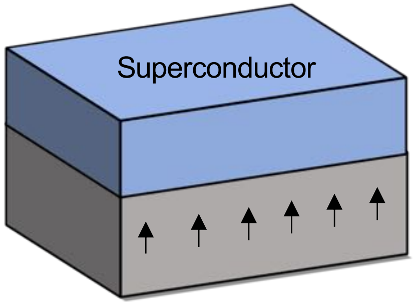
Realization of time reversal breaking (TRB) Weyl semimetals

[Samarth, Ramshaw, Li, Vanderbilt]



❑ Induced superconductivity by the proximity effect

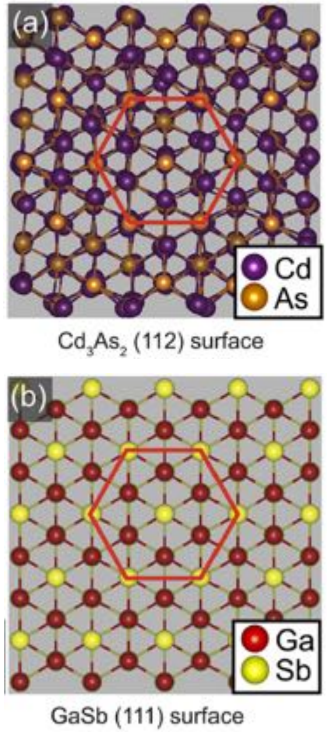
[Samarth, Li, Vanderbilt]

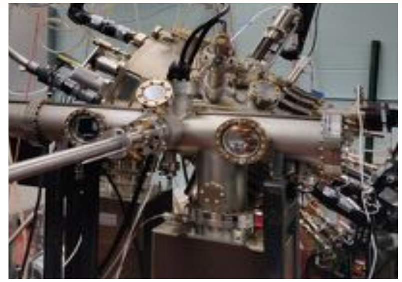


❑ Detection of monopole superconductivity

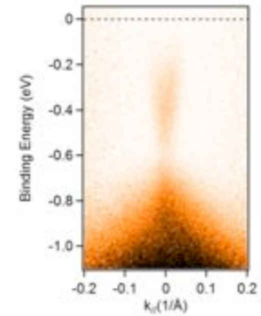
[Samarth, Ramshaw, Your Name Here]

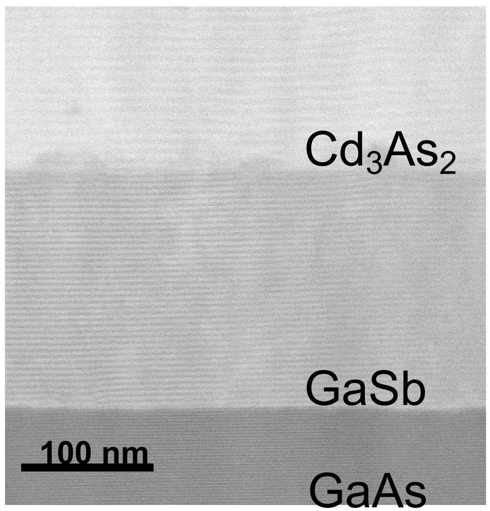
MBE growth and characterization of Cd_3As_2

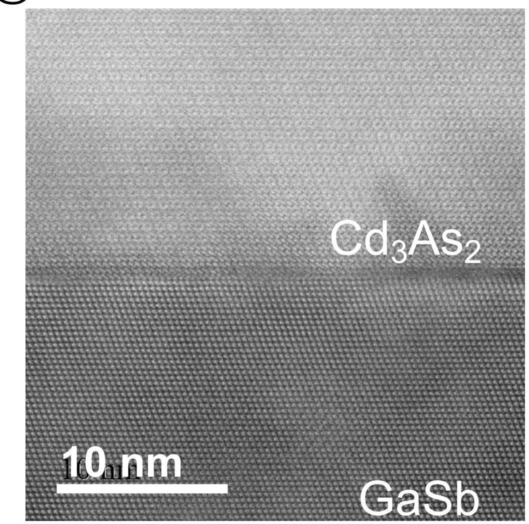


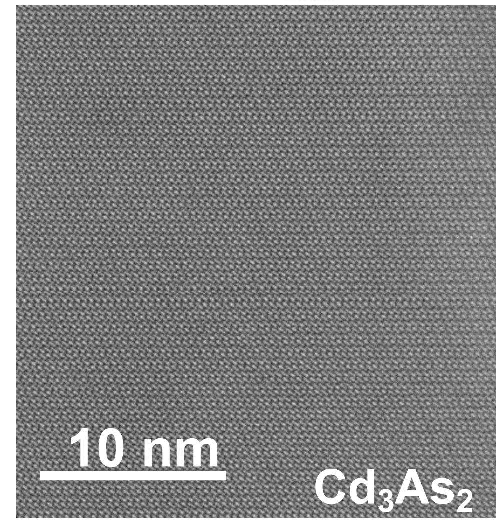


MBE @ Penn State









For prior work: see T. Schumann, *et.al.*, APL Mater. 4, 126110 (2016)

Cd_3As_2 is grown on GaAs(111) substrate with a GaSb buffer layer.

In vacuo ARPES (preliminary) consistent with prior results on cleaved bulk crystals.

Synthesis **[Samarth, McQueen]** Theory **[Vanderbilt, Li]**

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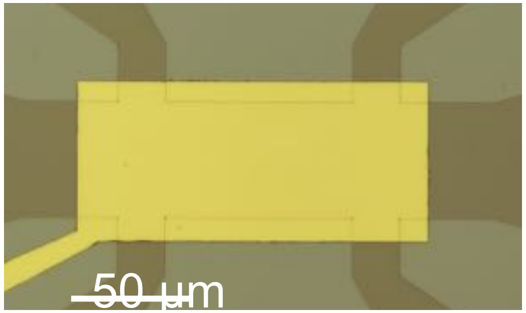
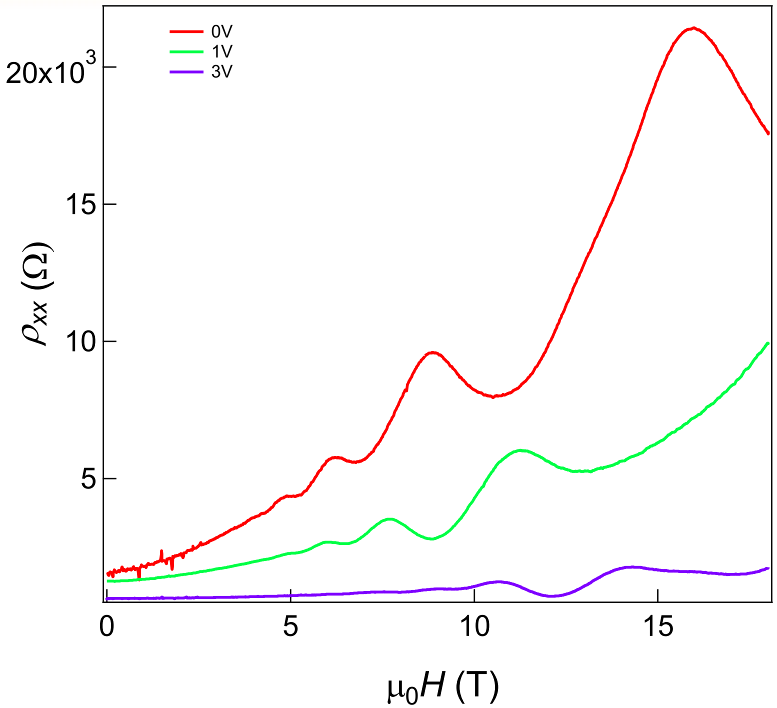
High quantum mobility, tunable carrier density



Transport devices:
Photolithography + Ar etching
Electrostatic top gate via ALD of Al_2O_3 (dielectric) + Ti/Au electrode.

Quantum transport measurements:
Cornell: B < 20 T, T > 270 mK
PSU: B < 8 T, T > 2 K

Typical Drude mobility in range 2200 – 6000 $cm^2/V.s$

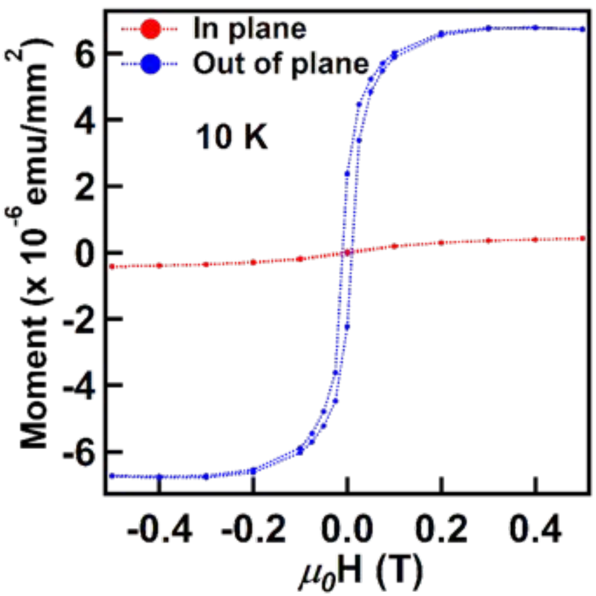


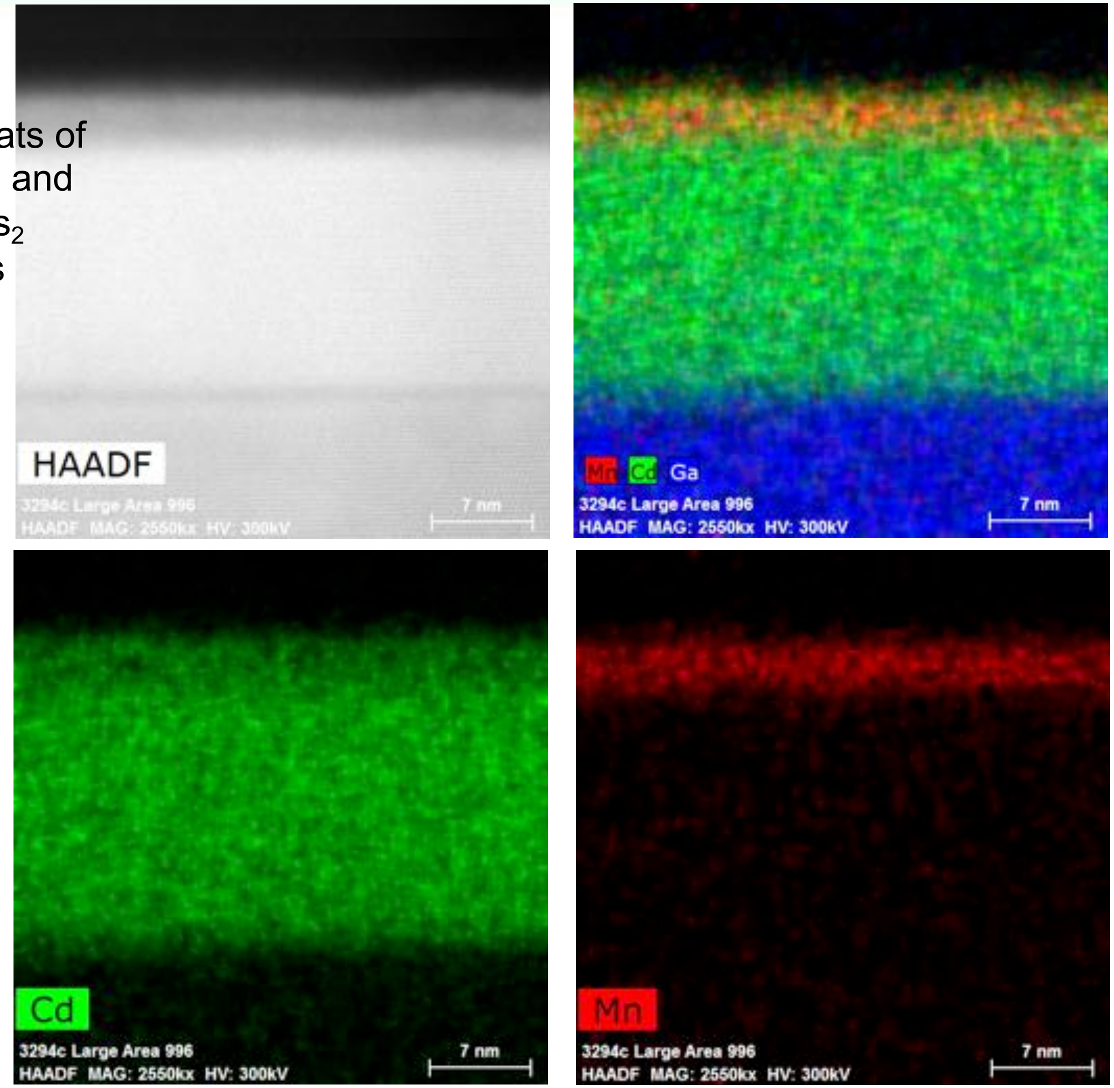
Gate (V)	Frequency (T)	3D carrier density (cm^{-3})	2D carrier density (cm^{-2})	Mobility ($cm^2/V/s$)
0	20.5	1.04E+18	1.57E+12	2654.22
1	25.70	1.47E+18	2.20E+12	2266.67
3	41.13	2.97E+18	4.46E+12	2241.77

15 nm thick Cd_3As_2 sample

Measurements **[Ramshaw, Samarth]**

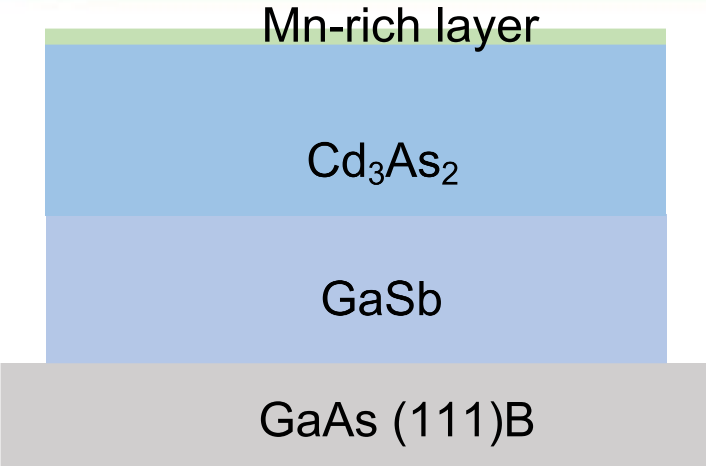
Introduction of magnetism into Cd_3As_2

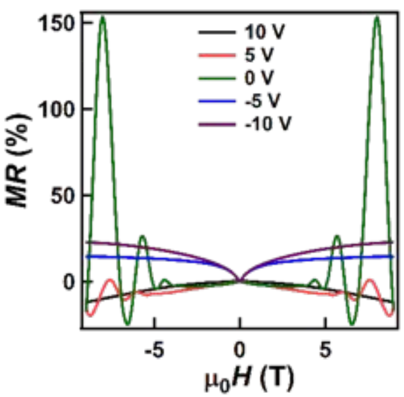


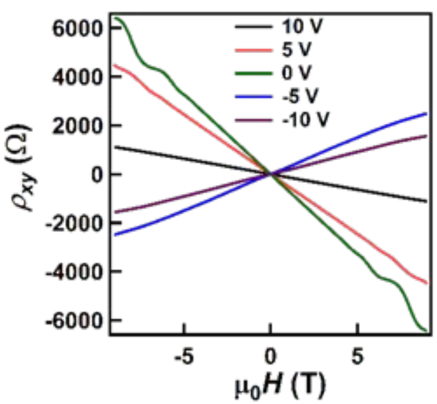


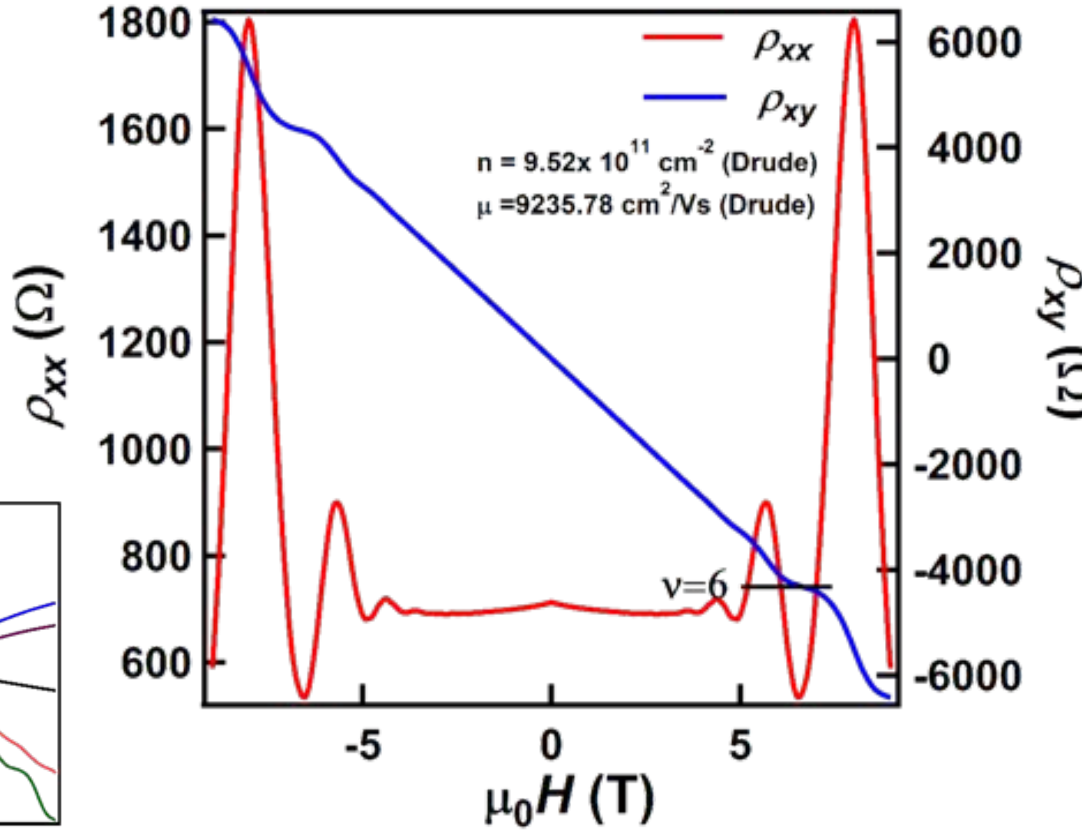
Synthesis and measurement **[Samarth]**

High mobility is retained (improved!) in Mn-capped samples









Mn-rich layer(1 nm)/ Cd_3As_2 (7 nm) at 2K

Measurement **[Samarth]**

The next steps

- Second approach to magnetism: growth on the magnetic semiconductor (Ga,Mn)Sb. **[Samarth]**

- Use Cd_3As_2 source (rather than separate Cd and As) to control vacancies and improve mobility. **[McQueen]**

- High-field angle dependence to determine whether carriers are 2D or 3D, Berry phase. 20 tesla continuous rotation, 35 tesla pulsed in-house. **[Ramshaw]**

- Determine electronic structure in magnetically doped samples. **[Li, Vanderbilt]**

- Introduction of superconductivity and detection of topologically enforced nodal quasiparticles with 3ω thermal transport and penetration depth. **[Samarth, Ramshaw,…]**