# Temperature Dependence of Quantum Oscillations and Kane-Mele Model in $Fe_3Sn_2$

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## Introduction

The electronic states on the kagome lattice has been proposed as a realization of the Haldane model with Kane-Mele type spin-orbit coupling in the case of $Fe_3Sn_2$ [1]. One essential feature of this type of spin-orbit coupling is the anisotropic evolution of the Dirac electronic states (Fig. 1(a) inset) with the ferromagnetic moment direction. A recent STM study on the same system [2] has pointed out that there exists a strong response in $Fe_3Sn_2$ with respect to the magnetic moment direction.

In our previous quantum oscillation experiments in NHMFL, we have uncovered two branches of the quasi-2D Fermi surfaces which evolves faster than 1/cos$\theta$ (that expected for a simple cylindrical Fermi surface). One hypothesis is that this reflects a change in the band structure as a function of magnetic moment direction. To investigate this further studies of the electronic structure with different magnetic moment direction are of great value.

## Experimental

To further uncover the evolution of the Dirac electronic states with the moment orientation, we measured the temperature-dependent quantum oscillations (Fig. 1(a)) at selected angles in $Fe_3Sn_2$ in the 65 T 25ms pulsed magnets. All quantum oscillations were measured using the piezoresistive torque magnetometry and the temperatures were controlled in $^4$He and $^3$He atmospheres.

## Results and Discussion

From analyzing the magnitude of the torque signal, we infer that the ferromagnetic moment of $Fe_3Sn_2$ follows the external magnetic field above 10 T, validating the analysis of quantum oscillations with a fixed magnetic moment direction [3]. These temperature dependent studies allow a calculation of the effective mass *m**, crucial for understand the evolution of the Dirac states.

Using the angular dependence of this effective mass (Fig. 1(b,c)) quantum oscillation frequency (Fig. 1(c)), and anomalous Hall conductivity (Fig. 1(d)), we were able to calculate the evolution of the Dirac electronic states as a function of magnetic moment without free parameters with results summarized in Fig. 1(e). The Fermi velocity, Dirac gap and Fermi level all decrease considerably as the moment rotates away from the *c*-axis. A model describing the angular evolution of the band parameters (Fig. 1(e)) reasonably reproduces the angular evolutions in Fig. 1b,c,d as think curves. Our results suggest that the Kane-Mele type spin-orbit coupling plays an important role for the Dirac electronic states in $Fe_3Sn_2$ [3].

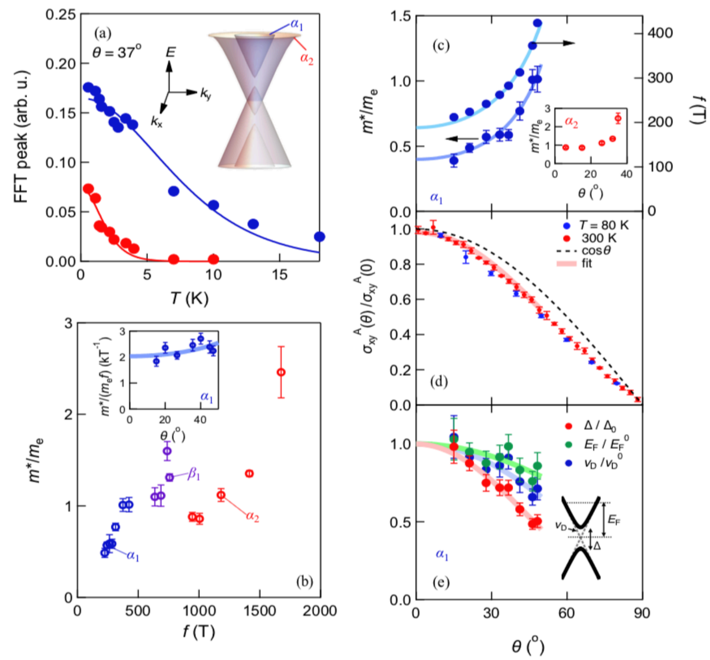


**Fig.1** (a) Typical temperature dependence of oscillation amplitude and Lifshitz-Kosevich fitting of outer ($\alpha_2$) and inner ($\alpha_1$) Dirac dispersion. Inset shows a schematic of the double Dirac spectrum. (b) The observed effective mass versus oscillation frequency for observed Fermi pockets. The inset shows the angular dependence of the ratio $m^*/m_e f$ for $\alpha_1$ along with the massive Dirac model. (c) Angular dependence of effective mass and *f* for the inner Dirac pocket (outer pocket effective mass shown inset), and (d) anomalous Hall conductivity normalized to the zero angle value, with solid curves showing the massive Dirac model. (e) Angular dependence of the massive Dirac band parameters where the gap is normalized to $\Delta_0$ = 32 meV, the Dirac velocity normalized to $v_D^0$=2.2 x $10^5$ m/s and the Fermi energy is normalized to $E_F^0$ = 112 meV with schematic Dirac band shown in inset

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## References

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