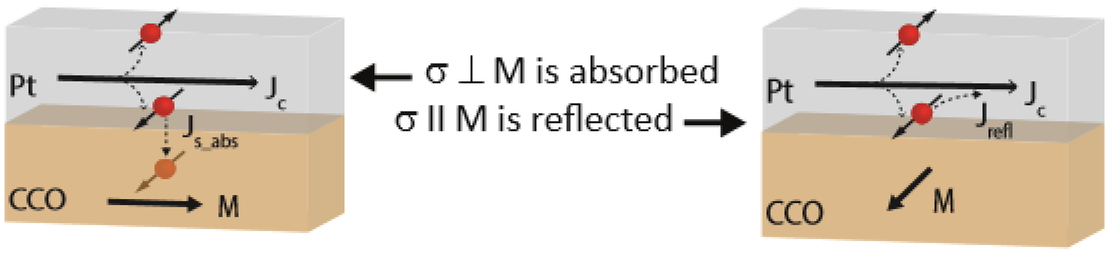
Spin-Hall magnetoresistance

A charge current through Pt creates a spin accumulation by spin-Hall effect (SHE). This spin accumulation can be absorbed or reflected by rotationg the magnetization M of CCO [1].

Direction of J_s, J_e and spin polarization (σ), is given by: $J_e \propto (J_s \times \sigma)$

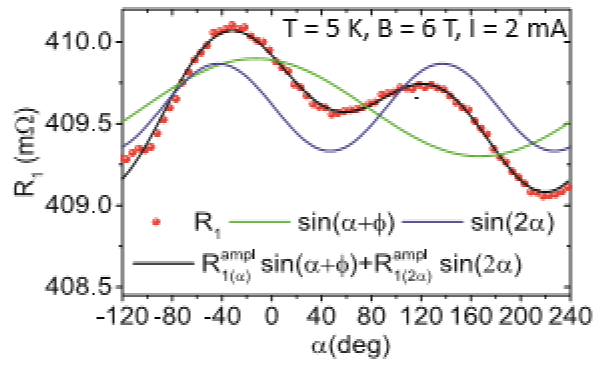


R_1: 1st harmonic response of transverse Pt resistance

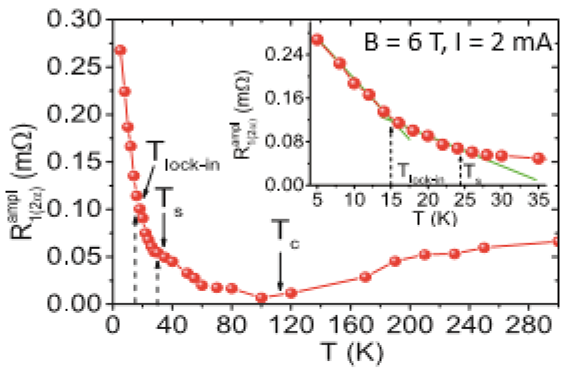
Change in R_1 by rotation of in-plane magnetization M

R_1: combination of

1. Hall effect (R_H) $\propto$ I, sin(α)
2. SMR (R_{SMR}) $\propto$ I, θ_{SH}, sin(2α)



T-dependence of SMR (R_{SMR}) in Pt on CCO



Below T_c in YIG, $R_{SMR} \propto$ M. However in CCO, unlike bulk magnetization M,

$$R_{SMR} \propto T^{-1}$$

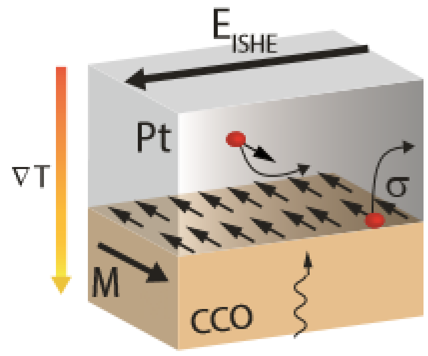
SMR signal in paramagnetic state above T_c, can be related to high interface susceptibility.

Spin-Seebeck effect

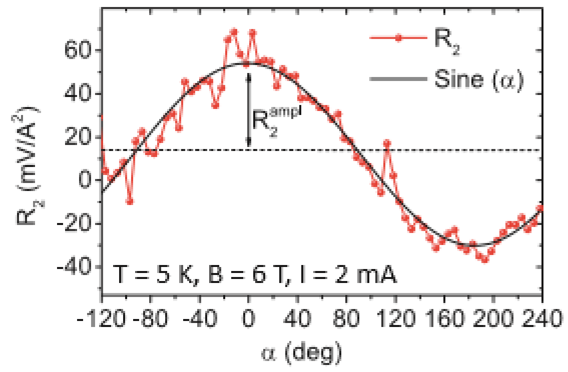
A temperature gradient due to current induced heating over Pt/CCO interface, results in a spin current pumped into the Pt layer, electrically detected by ISHE [3].

R_2: 2nd harmonic response of transverse Pt resistance measurement

$R_2 \propto I^2$, θ_{SH}, sin(α)



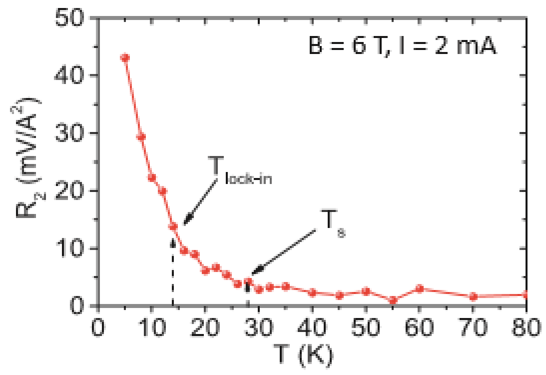
Change in R_2 by rotation of in-plane magnetization M as expected for SSE

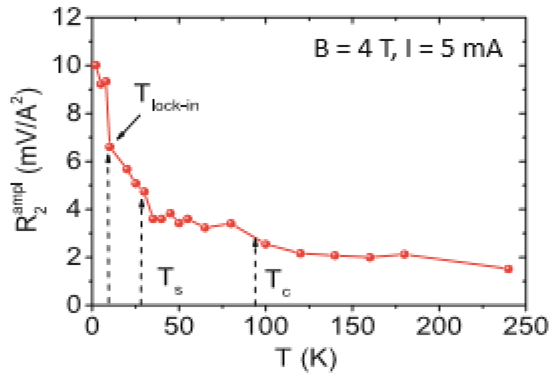


T-dependence of SSE (R_2) in Pt on CCO

Distinct slope change of SSE (R_2) signal below spin-spiral (T_s) and spin lock-in ($T_{lock-in}$) transition temperatures.

Finite SSE signal exsists above T_c at high currents (I > 2 mA) through Pt Hall-bar.





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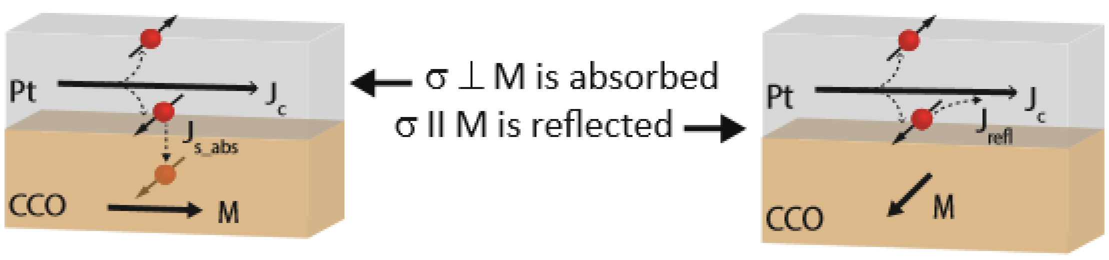

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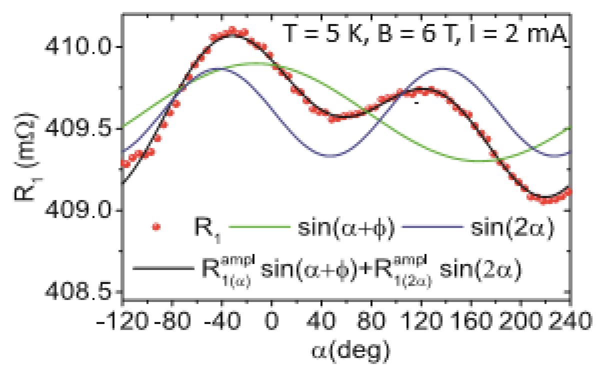

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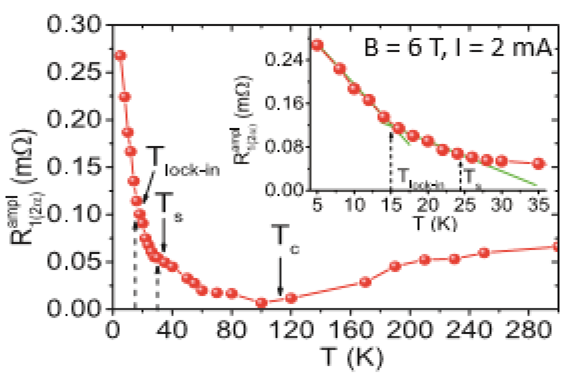

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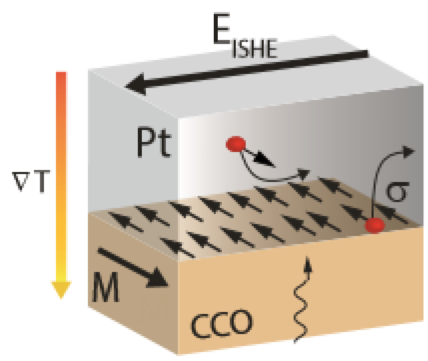

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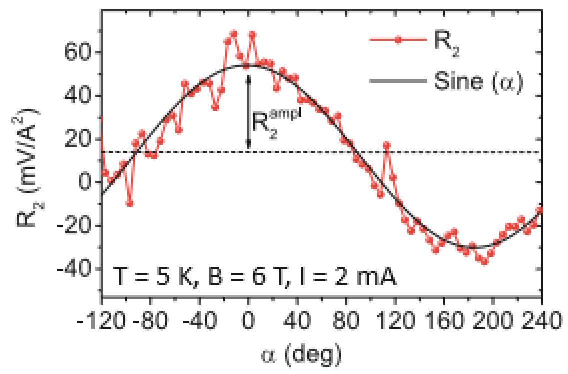

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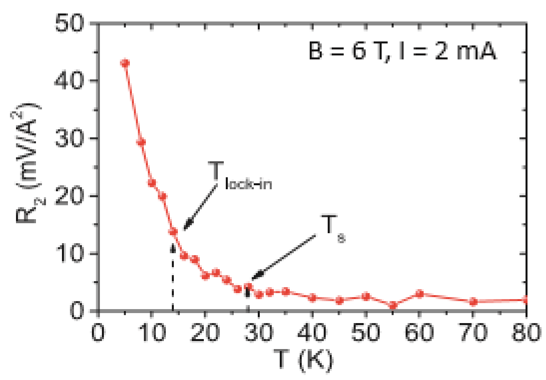

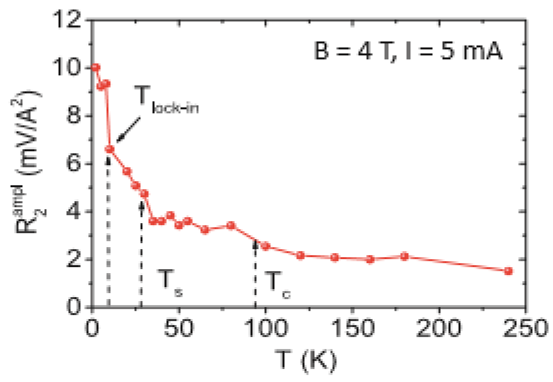

Summary

- The temperature dependence of the SMR and, though less so, the SSE, exposes distinct anomalies at the magnetic phase transitions.
- The SMR is more than one order of magnitude larger at $T < T_{lock-in}$ as compared to the signals around T_c.
- We relate the observed enhancement of the SMR below T_s to contributions from the cycloidal spiral, projected onto the spin accumulation at the Pt/CCO interface.
- Increase in the SSE signal below T_s suggests that the magnons from the complex Cr-sublattice magnetization texture plays a essential role in the observed signal.

References: [1]. N. Vlietstra et al., *Phys. Rev. B* **87**, 184421 (2013). [2]. A. Aqeel, et al., *J. Appl. Phys.* **116**, 153705 (2014). [3]. N. Vlietstra et al., *Phys. Rev. B* **90**, 174436 (2014).

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