Electrical Detection

magnetic Configurations in insulators

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SPIN PHENOMENA INTERDISCIPLINARY CENTER SPICE

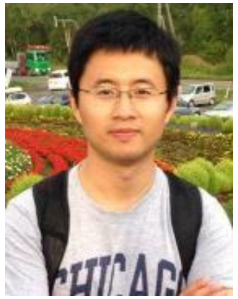
MCQST TUM

Thanks to

Maria Azhar
KIT Karlsruhe

Maxim Mostovoy
Bart J. Van Wees
Thomas Palstra
RUG Netherlands

Nynke Vlietstra
Hans Hübl
TU Munich

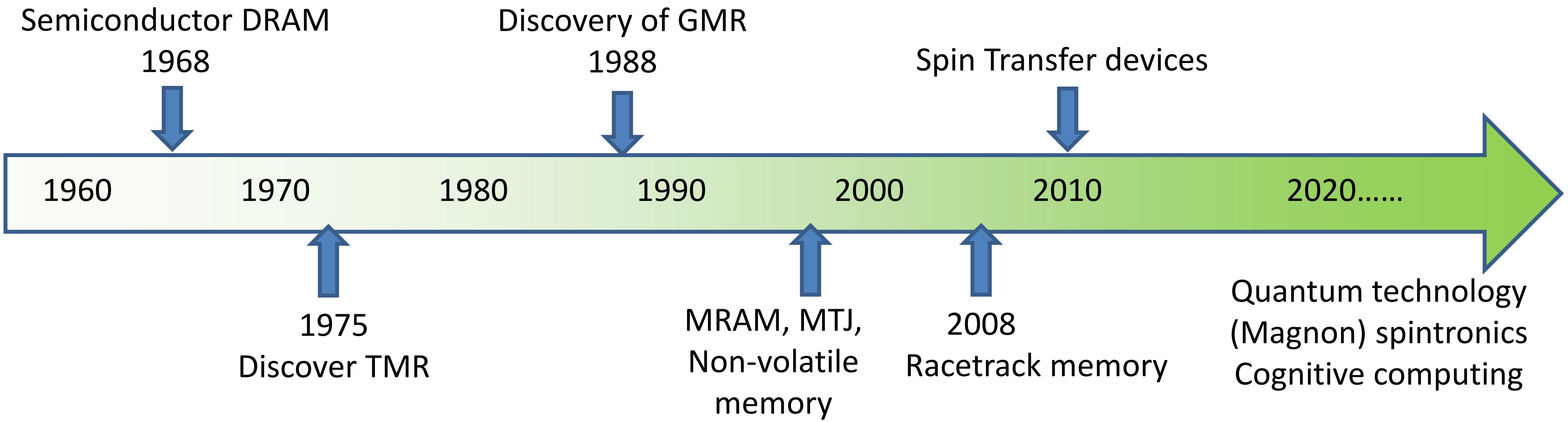










Technology evolution



Going beyond standard charge electronics

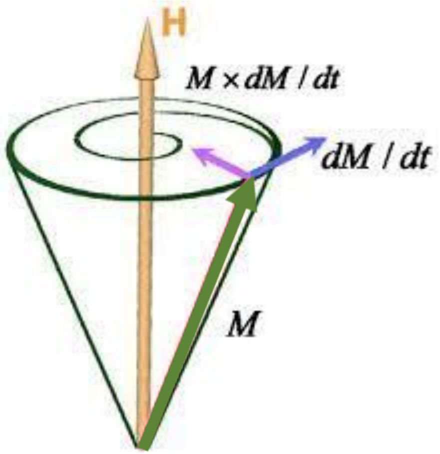
Magnetic insulators?

Magnetic insulators

Yttrium Iron Garnet

YIG - $Y_3Fe_5O_{12}$

Static magnetization



Gilbert damping

α=3×10^{-5}

The lowest!

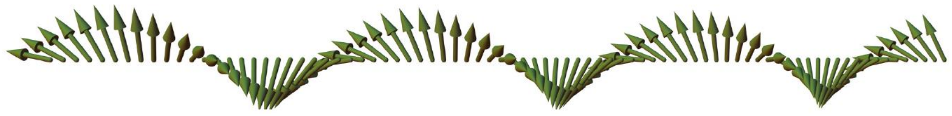
e.g. A. Brataas, B.v. Wees, O. Klein et al. Physics Reports 885 (2020)

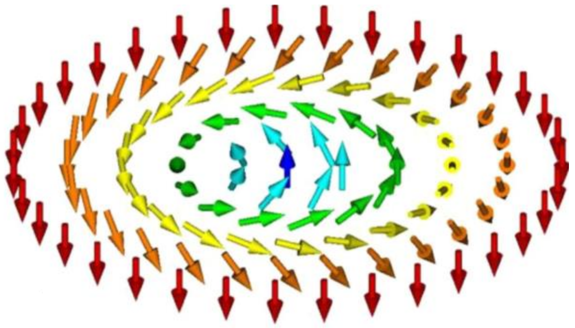
Magnetic insulators

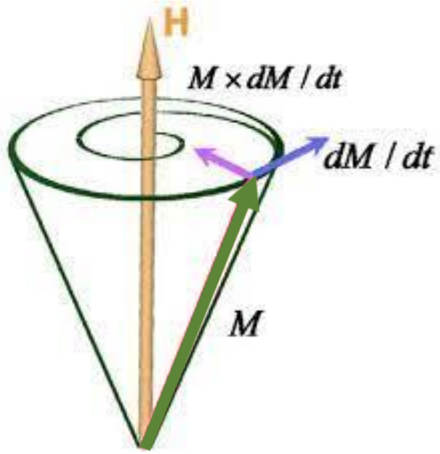
Copper oxy-selenite
Cu_2OSeO_3

Dzyaloshinskii-Moriya (DM)

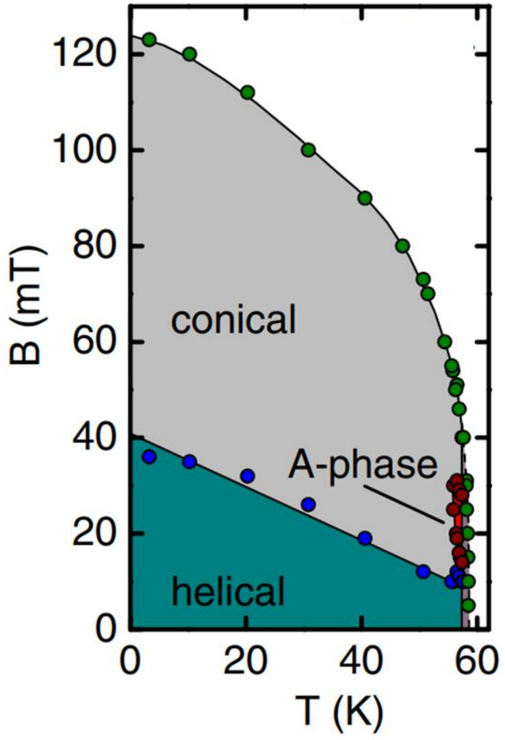
Static magnetization - noncollinear







Gilbert damping
$\alpha \approx 10^{-4}$



Garst et al., J. Phys. D: Appl. Phys. **50** 293002 (2017)

Magnetic insulators

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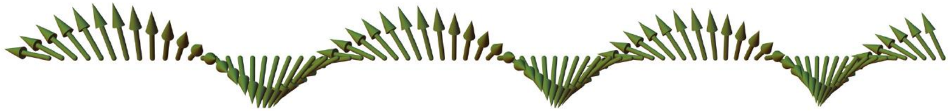

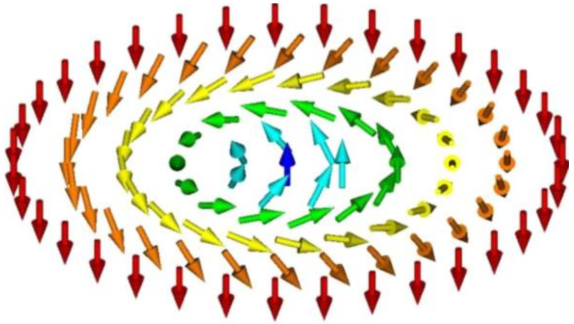

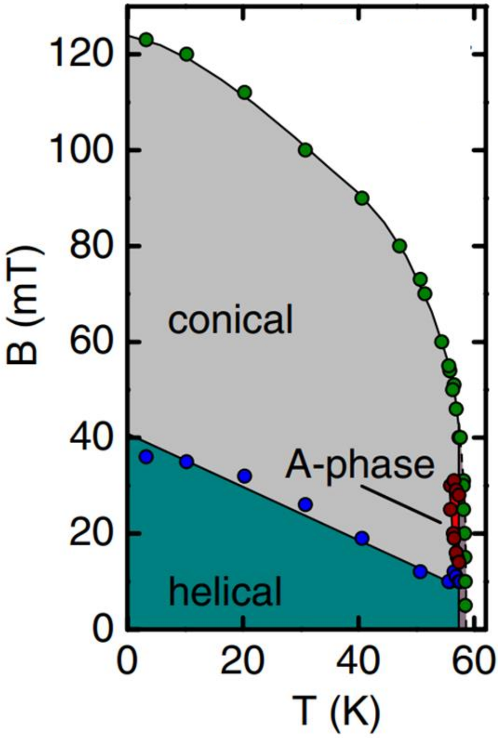

e.g. Tokura, Y. and Seki, S. Adv. Mater., 22 (2010), Leonov and Kézsmárki, Phys. Rev. B **96**, 214413 (2017)

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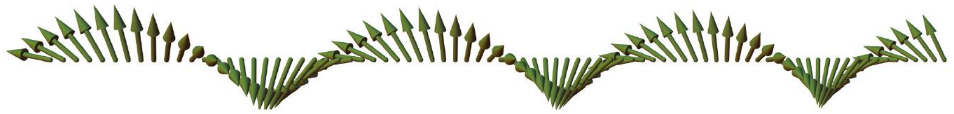
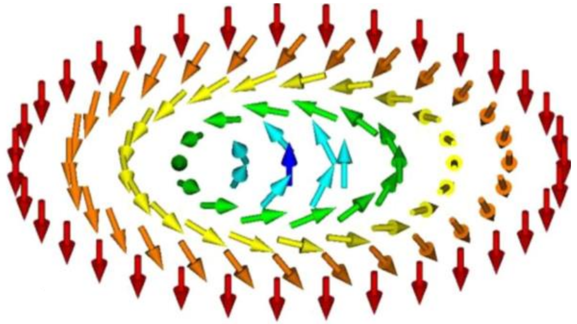
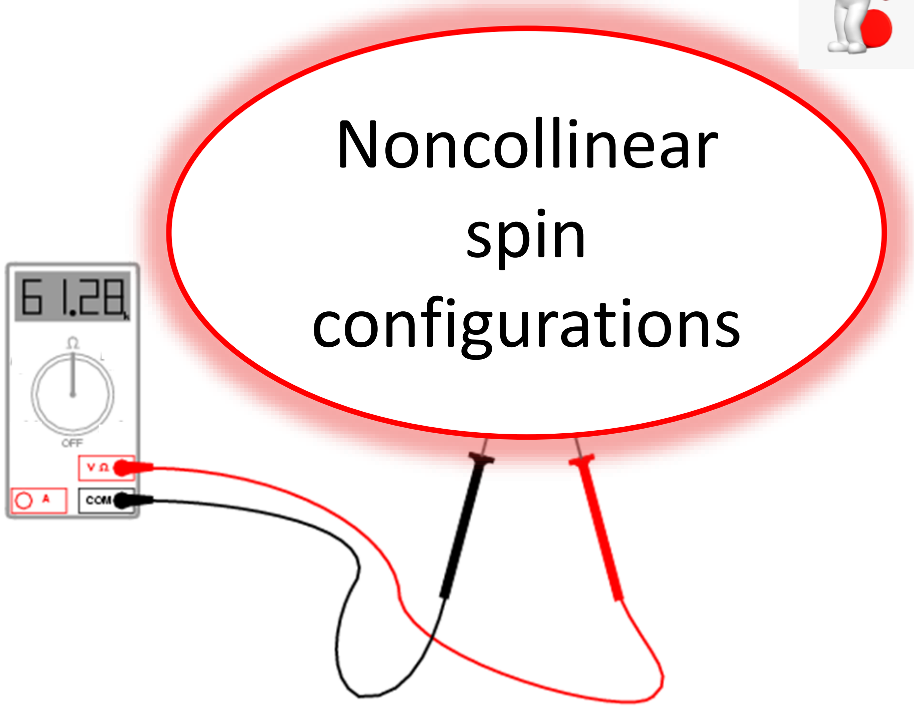






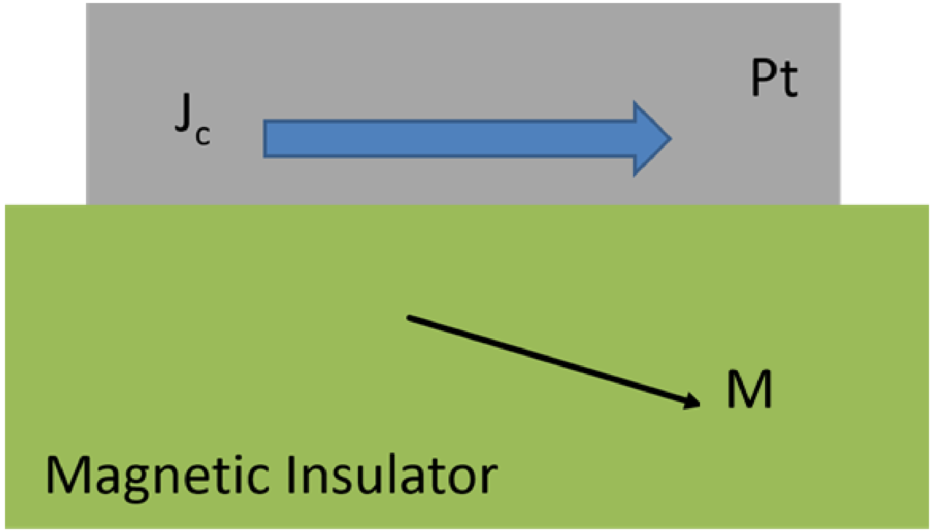
e.g. Tokura, Y. and Seki, S. Adv. Mater., 22 (2010), Leonov and Kézsmárki, Phys. Rev. B **96**, 214413 (2017)

Can we detect magnetic twists electrically?

Part I – Spin-Hall magnetoresistance

Part II – Results in Pt/Cu_2OSeO_3 & Pt/$CoCr_2O_4$

Spin-Hall magnetoresistance (SMR)



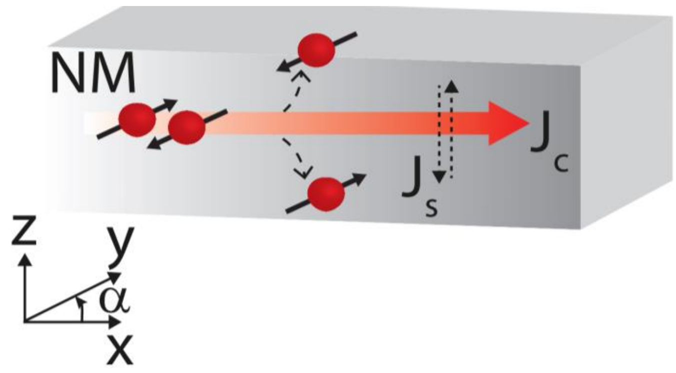
Accidental detection (explained by AMR): M. Weiler *et al.,* Phys. Rev. L. 108, 106602 (2012)

Theory: Y.-T. Chen, *et al.*, Phys. Rev. B **87**, 144411 (2013)

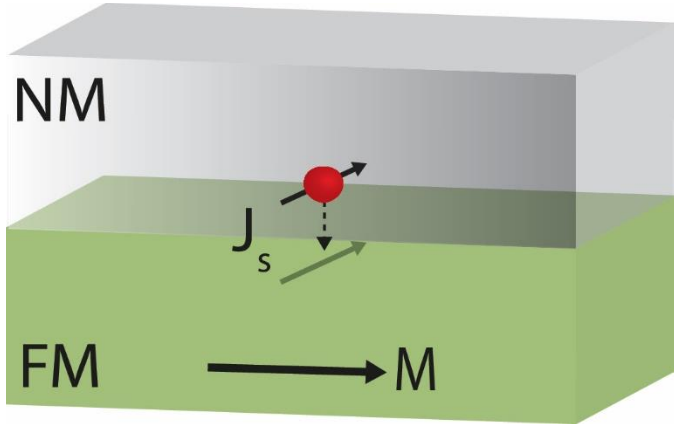
Detection: H. Nakayama *et al.*, Phys. Rev. Lett. 110, 206601 (2013)
N. Vlietstra *et al.*, . Phys. Rev. B 87, 184421 (2013)

Spin-Hall magnetoresistance (SMR)

$$R_L^{SMR} \propto \left(1 - m_y^2\right)$$



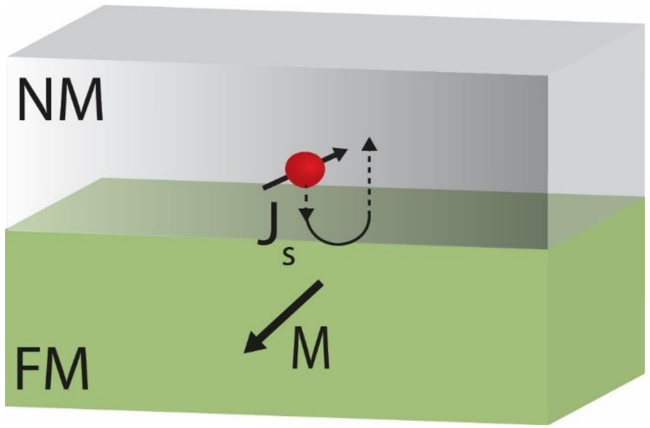
α = 0º
Large R



$\tau_{\mathrm{STT}} \propto M \times (M \times \boldsymbol{s}) \neq 0$

Large dissipation in NM

α = 90º
Small R



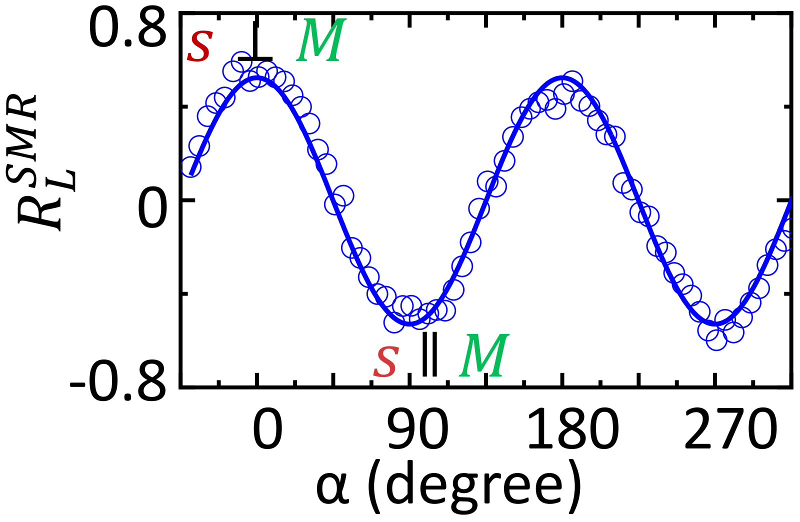
$\tau_{\mathrm{STT}} = 0$

Reduced dissipation in NM

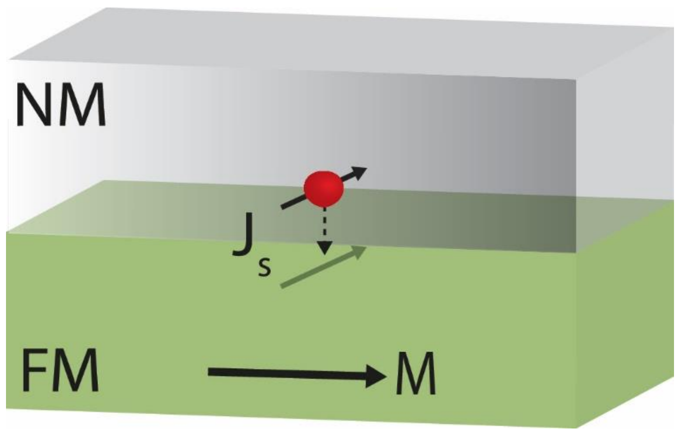
Y.-T. Chen, *et al.*, Phys. Rev. B **87**, 144411 (2013)

Spin-Hall magnetoresistance (SMR)

$$R_L^{SMR} \propto \left(1 - m_y^2\right) = \mathrm{A}\cos^2(\alpha)$$



α = 0º
Large R



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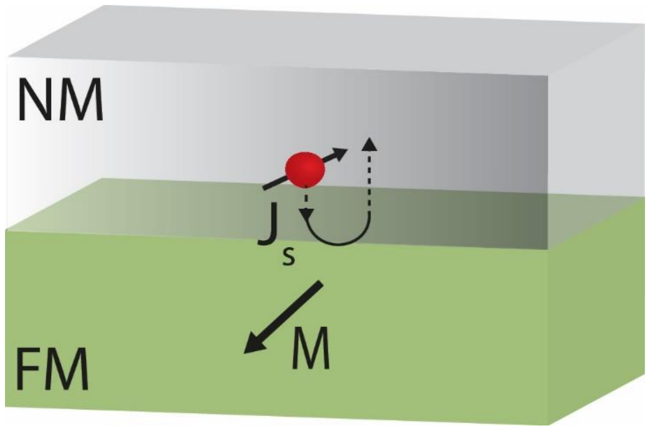


$\tau_{\mathrm{STT}} = 0$

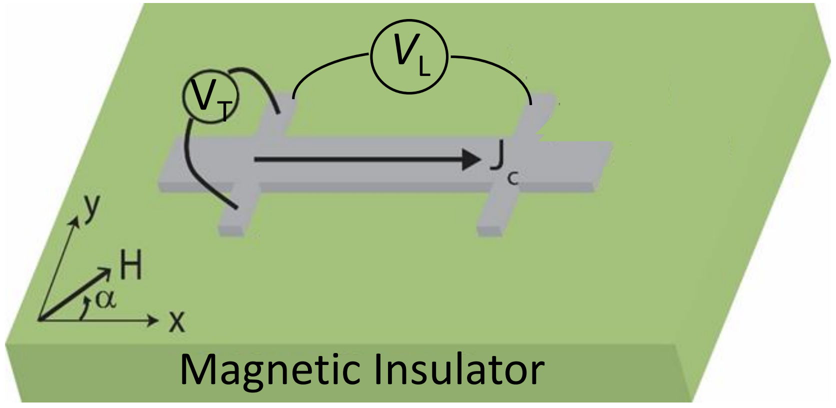
Reduced dissipation in NM

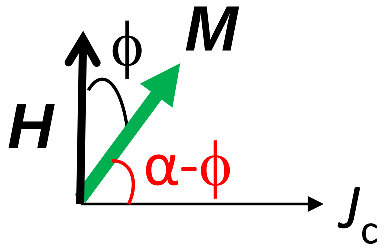
SMR in non-collinear magnets

$$R_L^{SMR} \propto \left(1 - m_y^2\right) = \mathrm{A}\cos^2(\alpha)$$

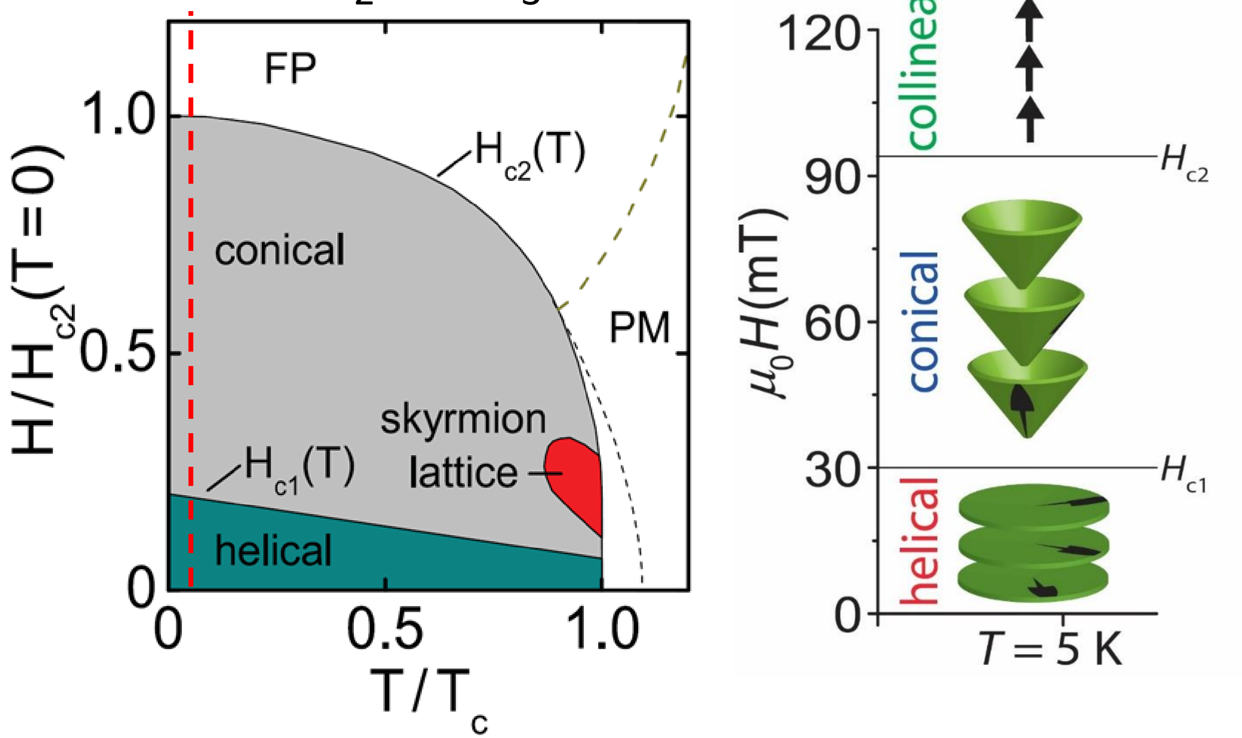
$$R_T^{SMR} \propto m_x m_y = \mathrm{A}\sin(2\alpha)$$

Exp. configuration





Cu_2OSeO_3

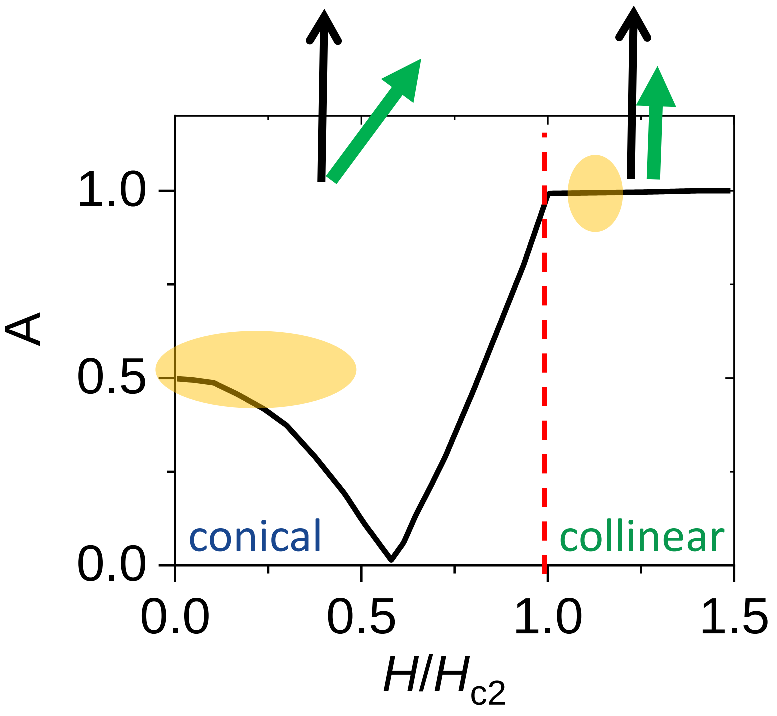


Y.-T. Chen, *et al.*, Phys. Rev. B **87**, 144411 (2013)

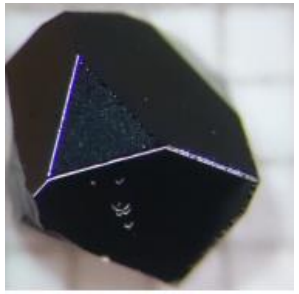
SMR in non-collinear magnets

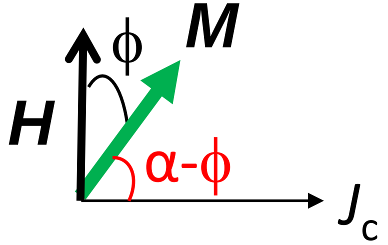
$$R_T^{SMR} \propto \langle m_x m_y \rangle = \mathrm{A}\sin(2(\alpha - \phi))$$

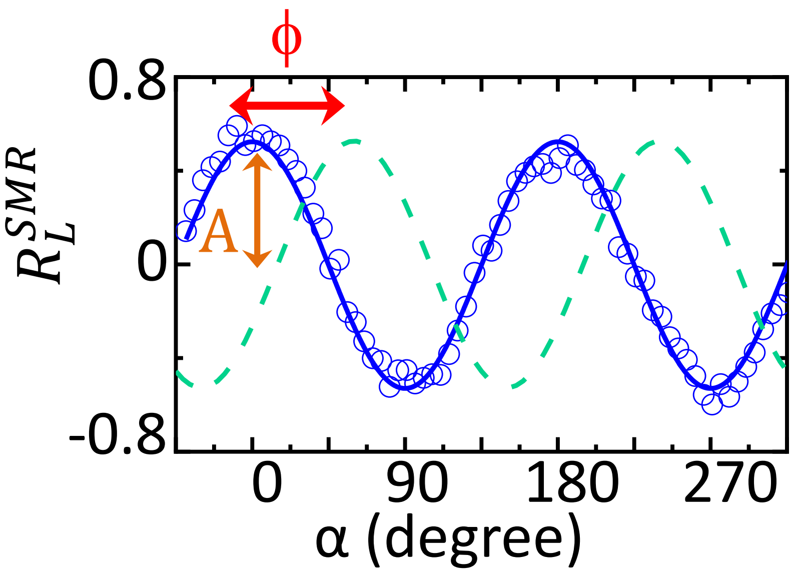
$$\mathrm{A} = R_0 \frac{|3(H/H_{c2})^2 - 1|}{2}$$

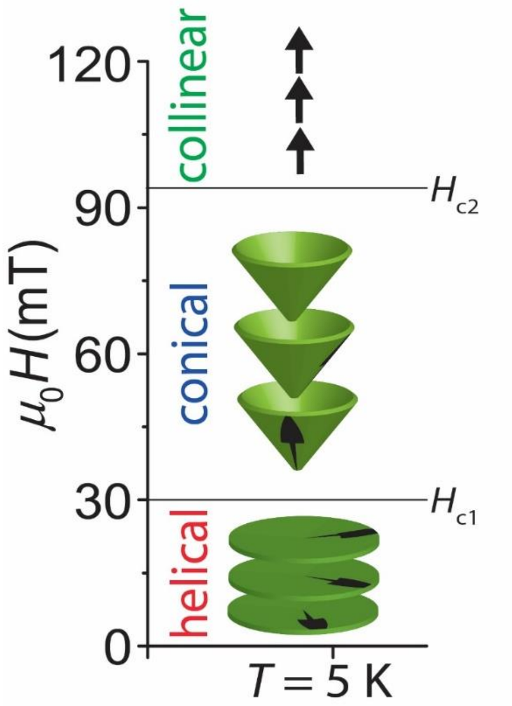


Cu_2OSeO_3







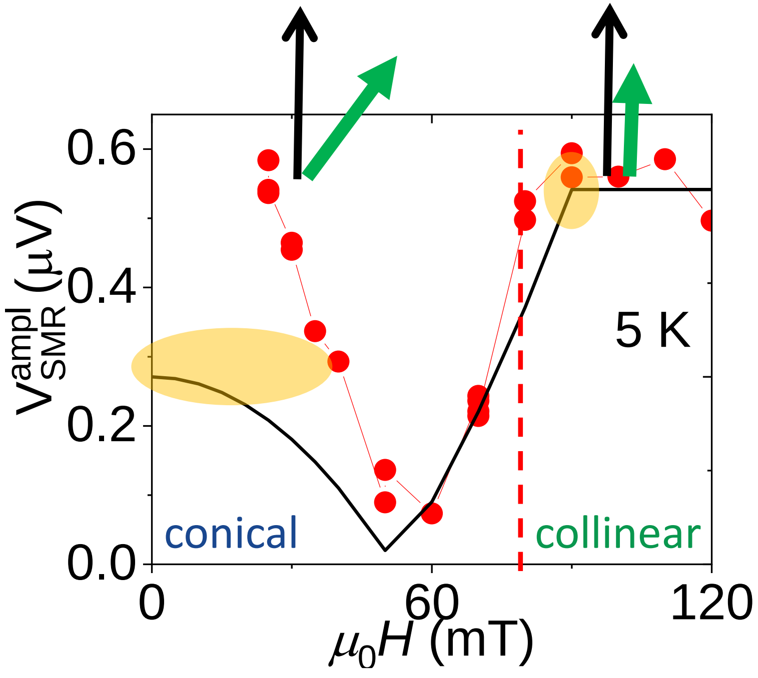


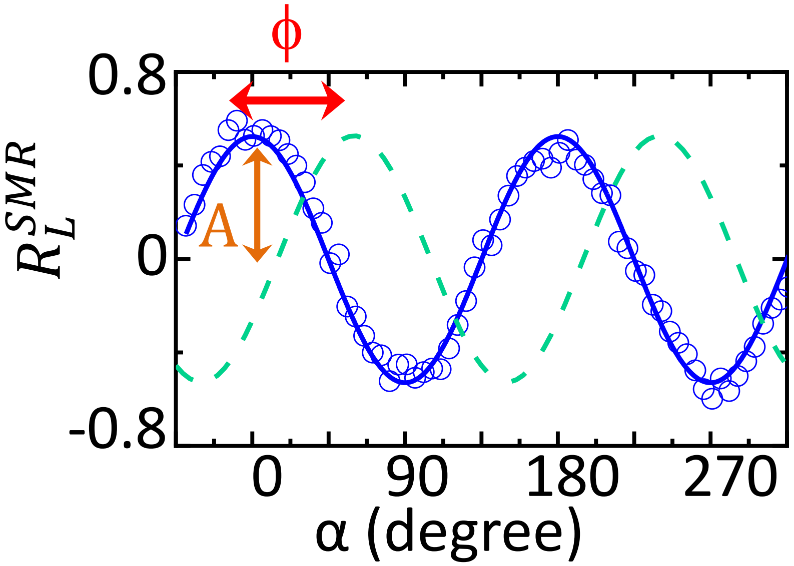
Aqeel, et al., Phys. Rev. B, 94, 134418 (2016); Aqeel, *et al.*, J. Phys. D Appl. Phys. 50, 174006 (2017)

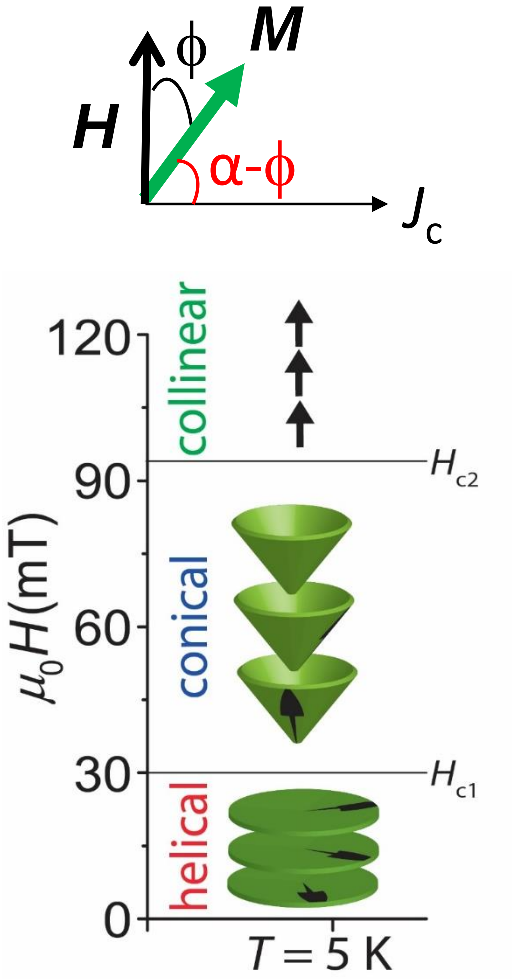
SMR in non-collinear magnets

$$R_T^{SMR} \propto < m_x m_y >= A \sin(2(\alpha - \phi))$$

$$A = R_0 \frac{|3(H/H_{c2})^2 - 1|}{2}$$







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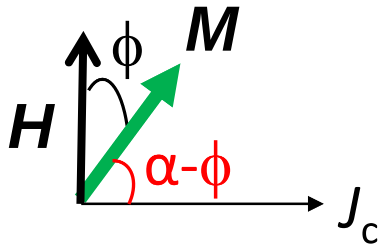

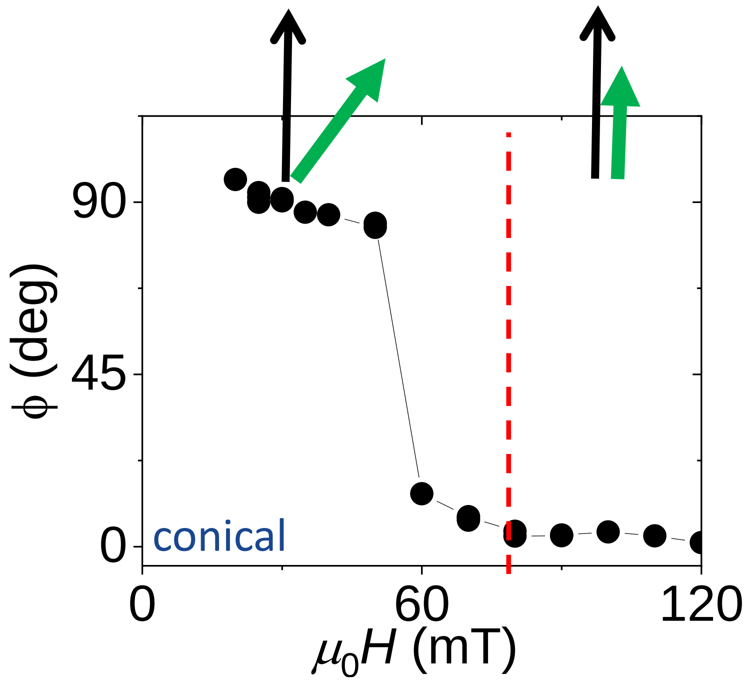

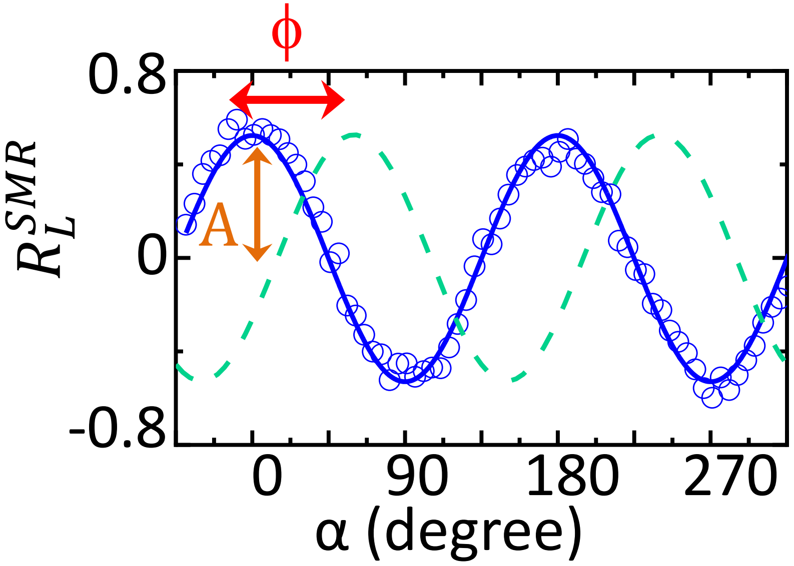

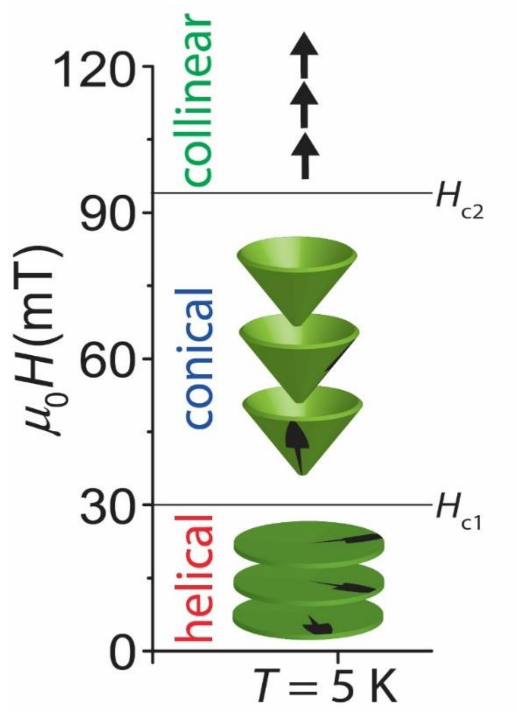

Aqeel, et al., Phys. Rev. B, 94, 134418 (2016); Aqeel, *et al.*, J. Phys. D Appl. Phys. 50, 174006 (2017)

T dependence of SMR

$$R_T^{SMR} \propto \langle m_x m_y \rangle = \mathrm{A}\sin(2(\alpha - \phi))$$

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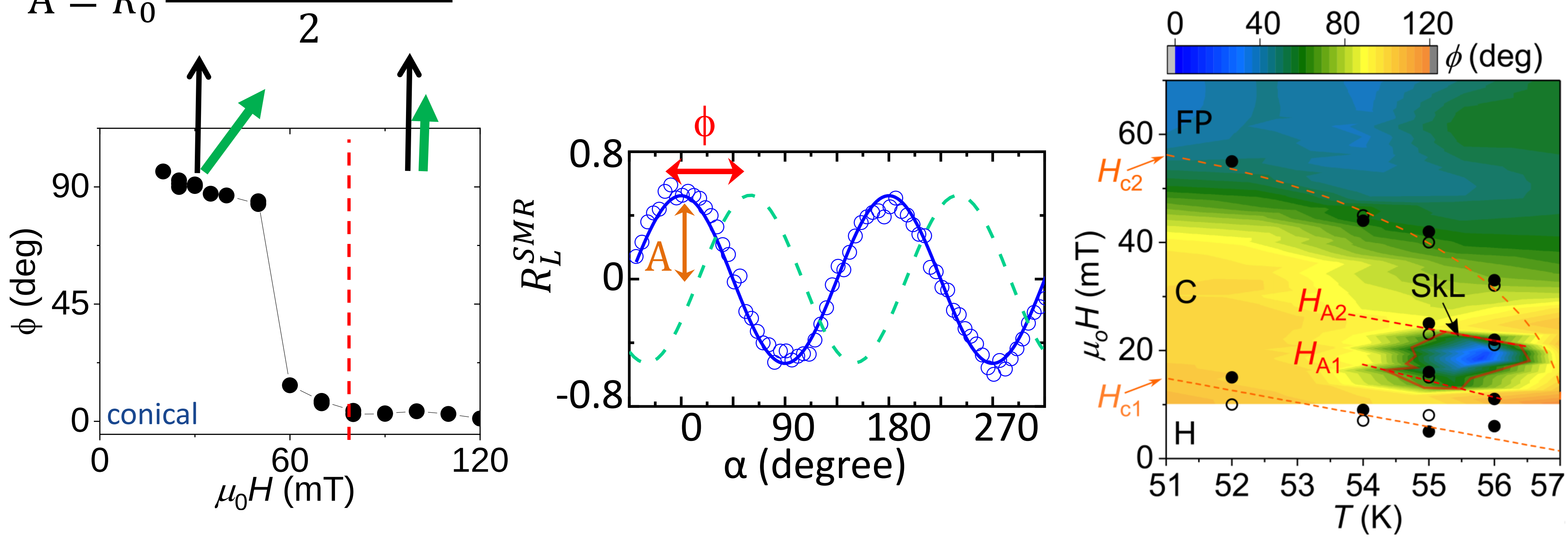

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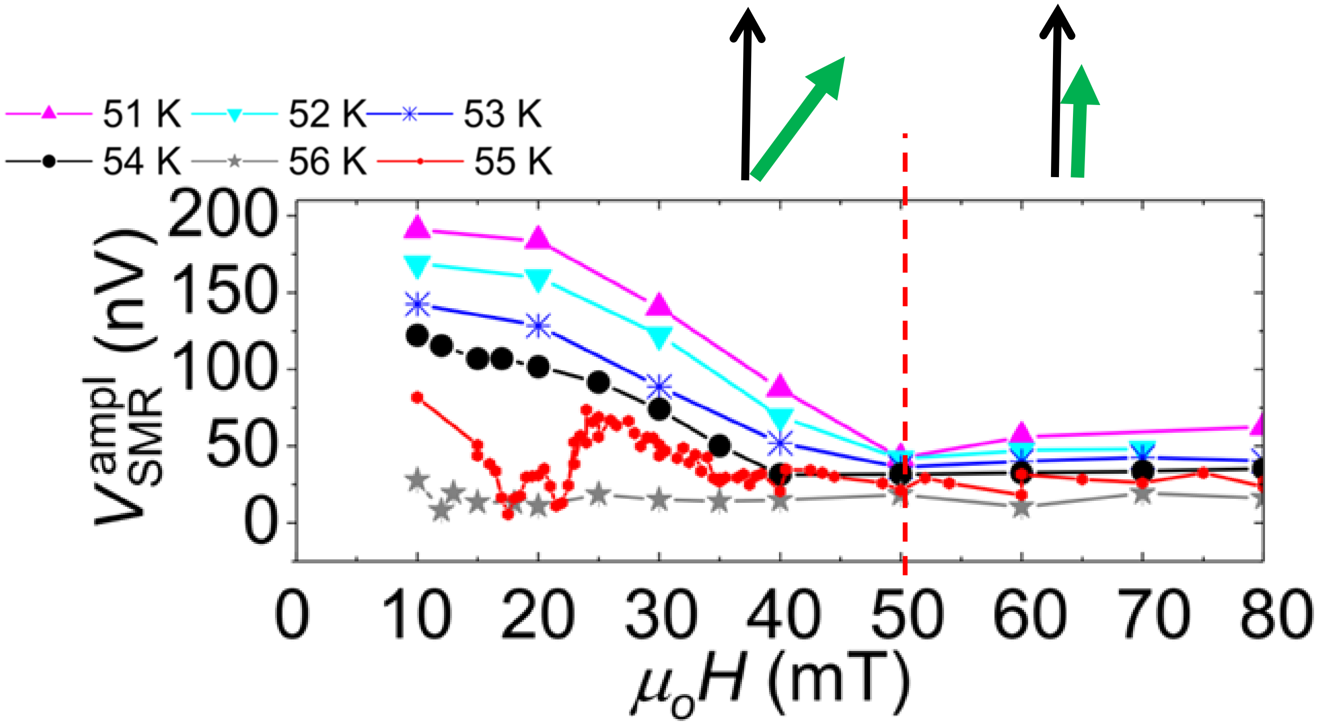

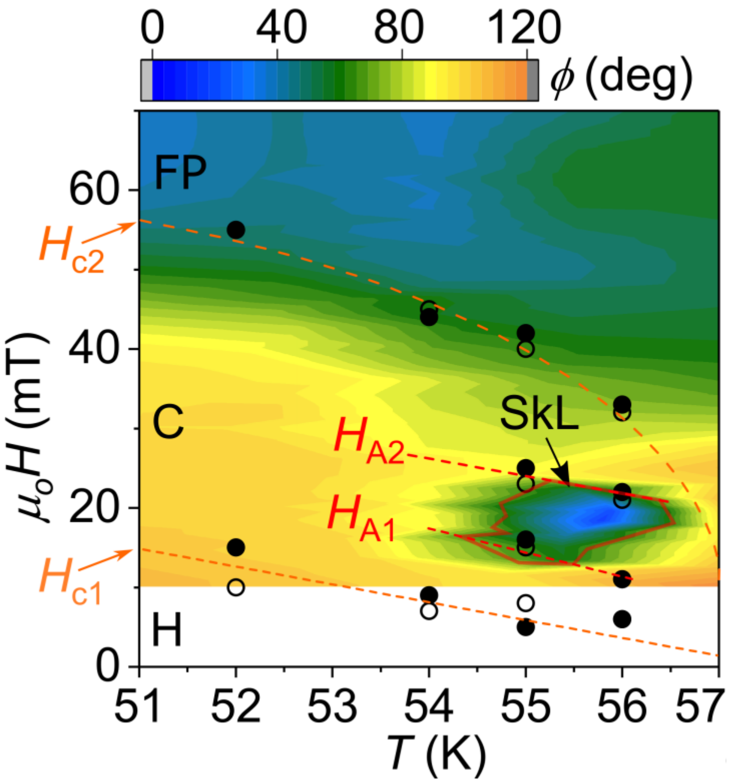

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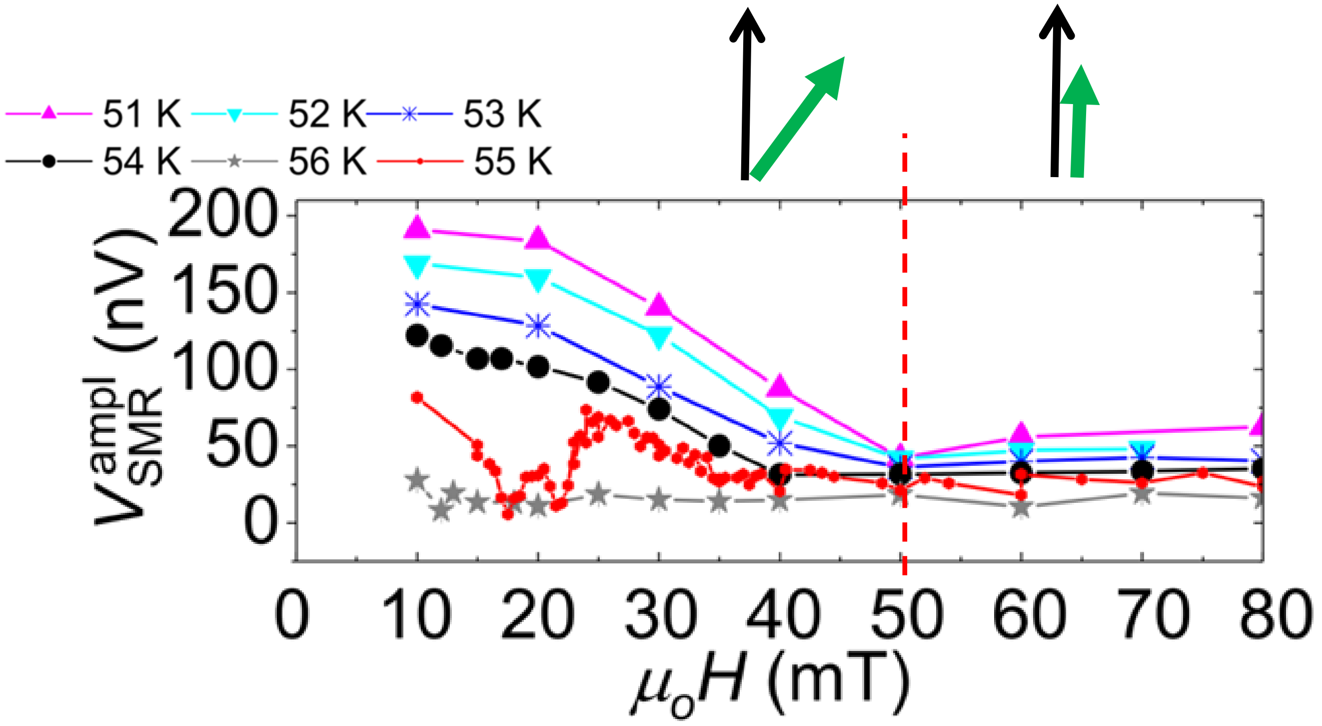
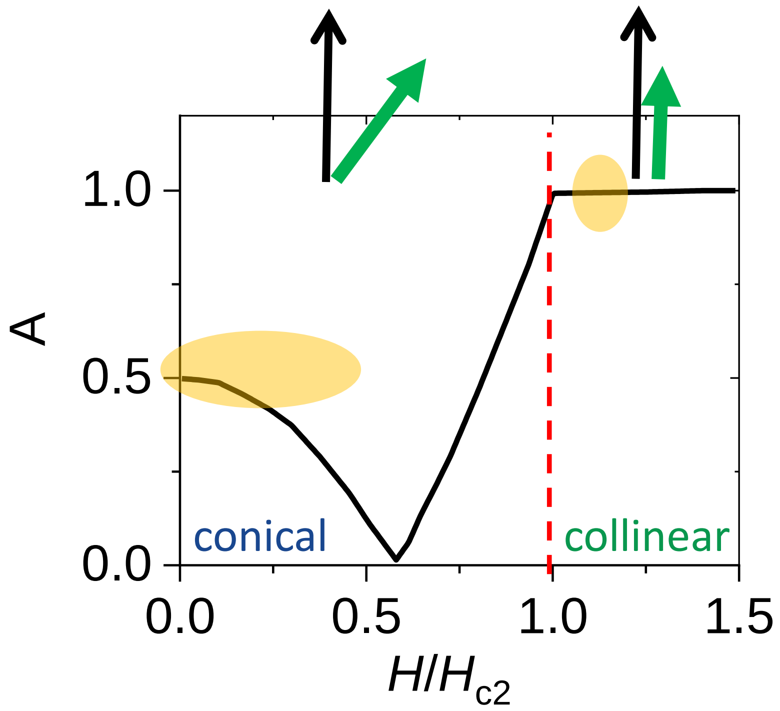
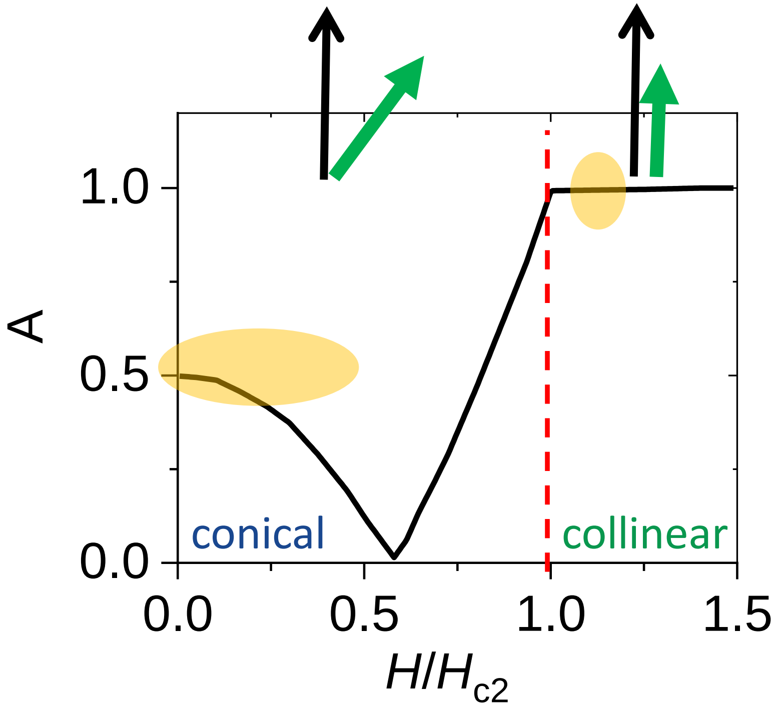




Can there be a second term?

$$R_T^{SMR} \propto < m_x m_y >= \mathrm{A} \sin(2(\alpha - \phi))$$

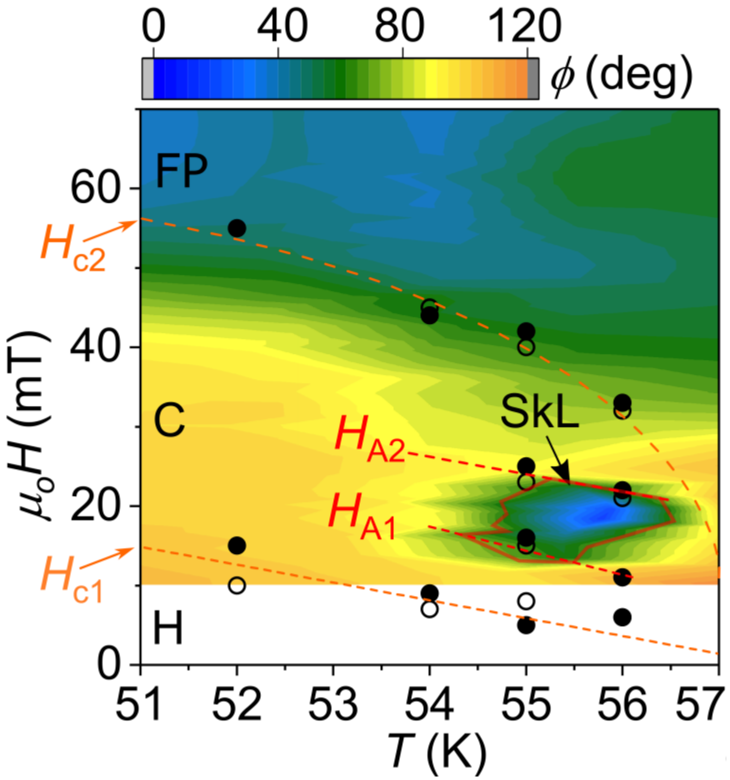


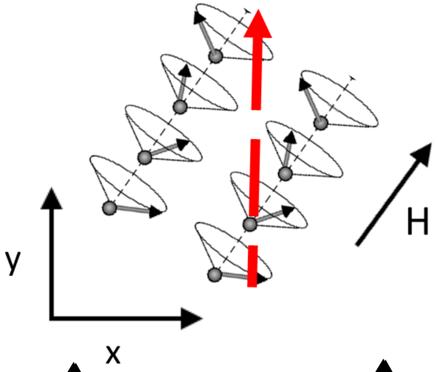
SMR theory

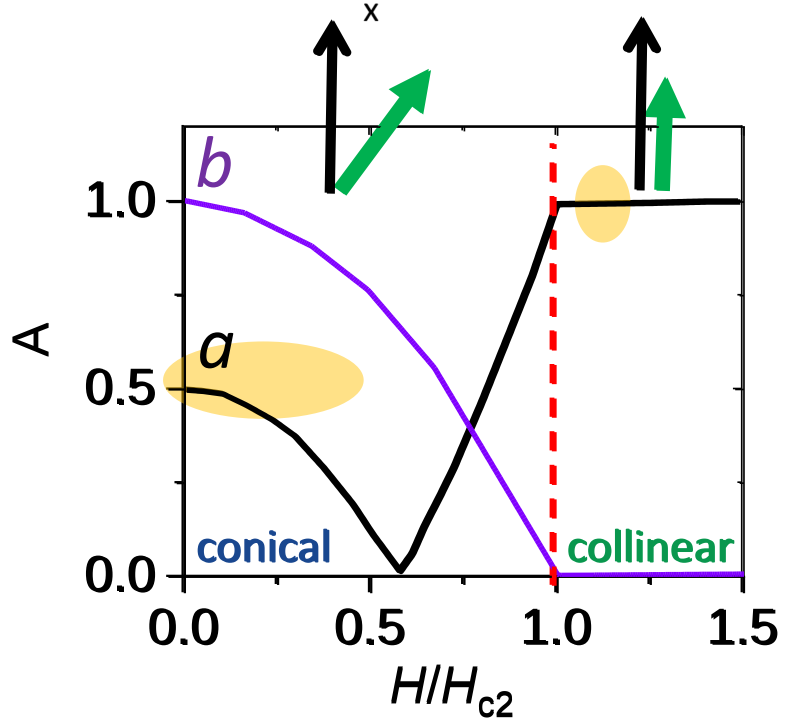
$$R_T^{SMR} \propto \langle m_x m_y \rangle = A\sin(2(\alpha - \phi))$$

↓ In-plane

$$+b \left\langle m_z \frac{\partial m_x}{\partial y} - \frac{\partial m_z}{\partial y} m_x \right\rangle$$

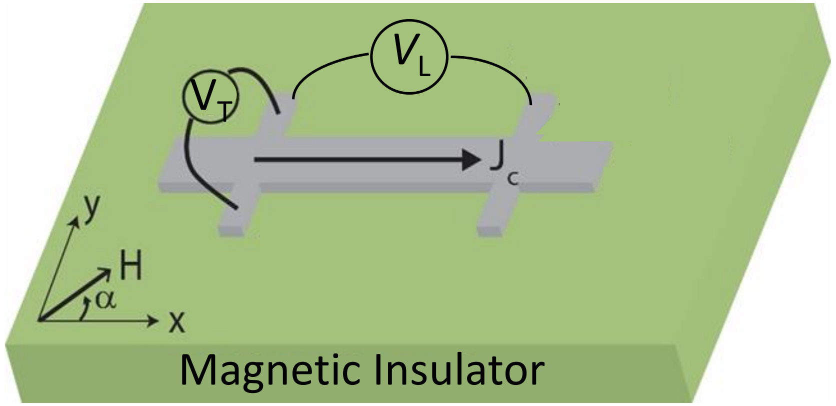




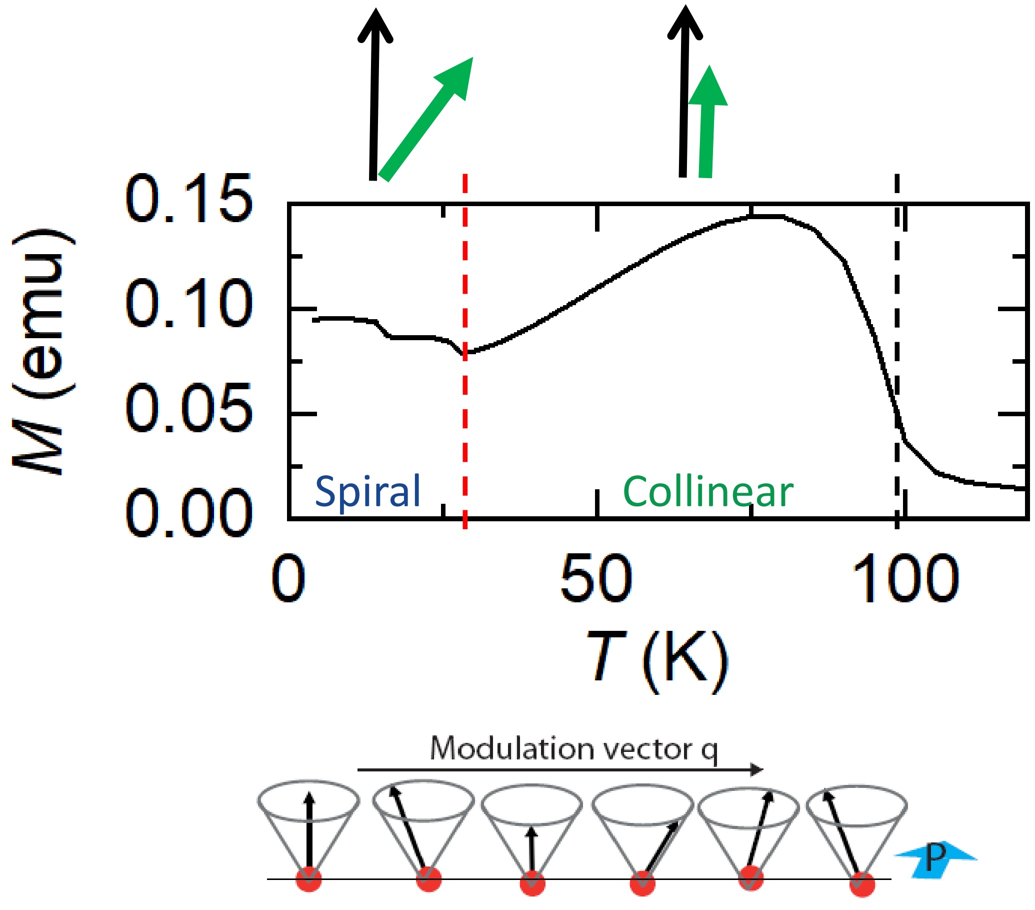


Aqeel, et al., Phys. Rev. B, **103**, *L100410.* (2021)

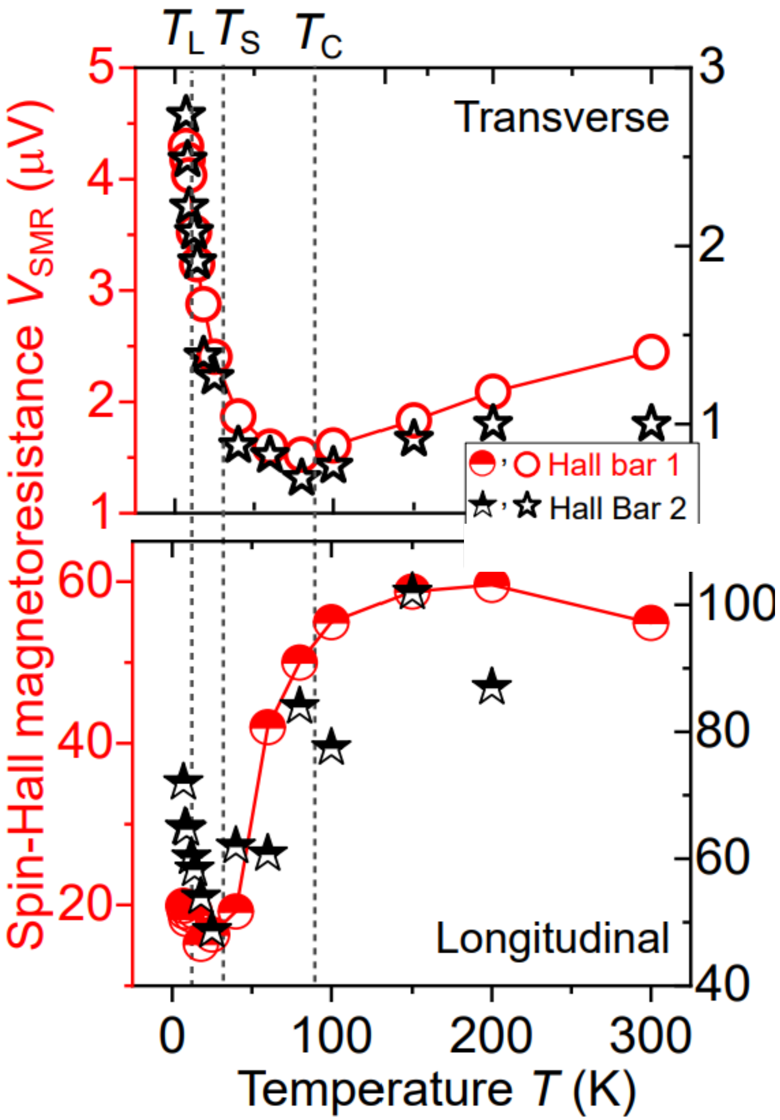
SMR in Pt/$CoCr_2O_4$

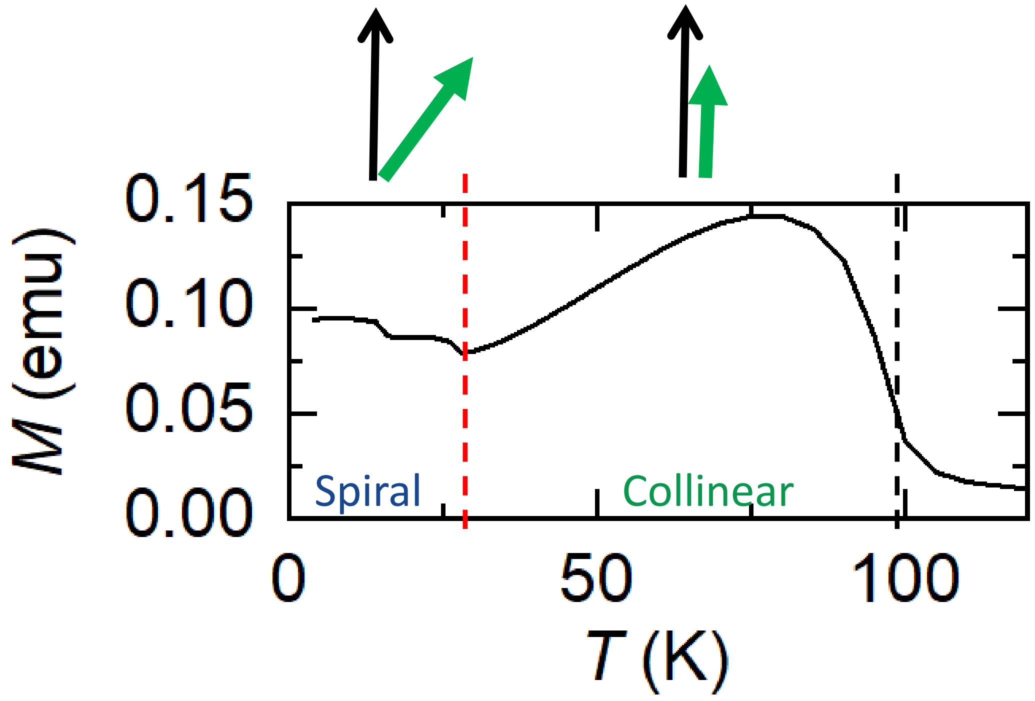


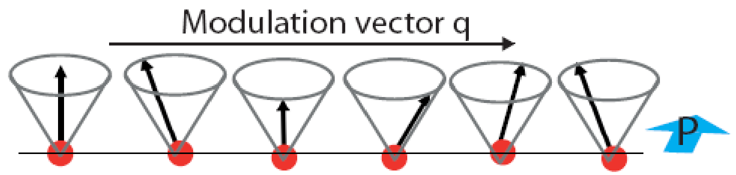
(35nm) $CoCr_2O_4/MgAl_2O_4$



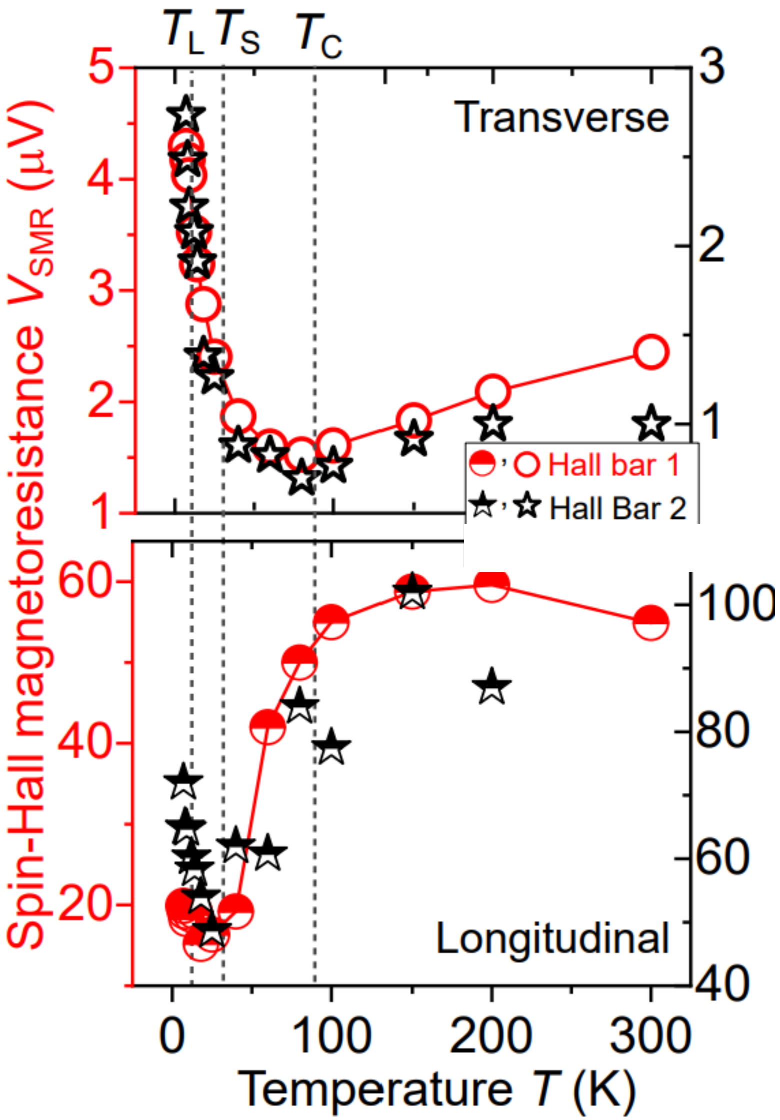
SMR in $Pt/CoCr_2O_4$

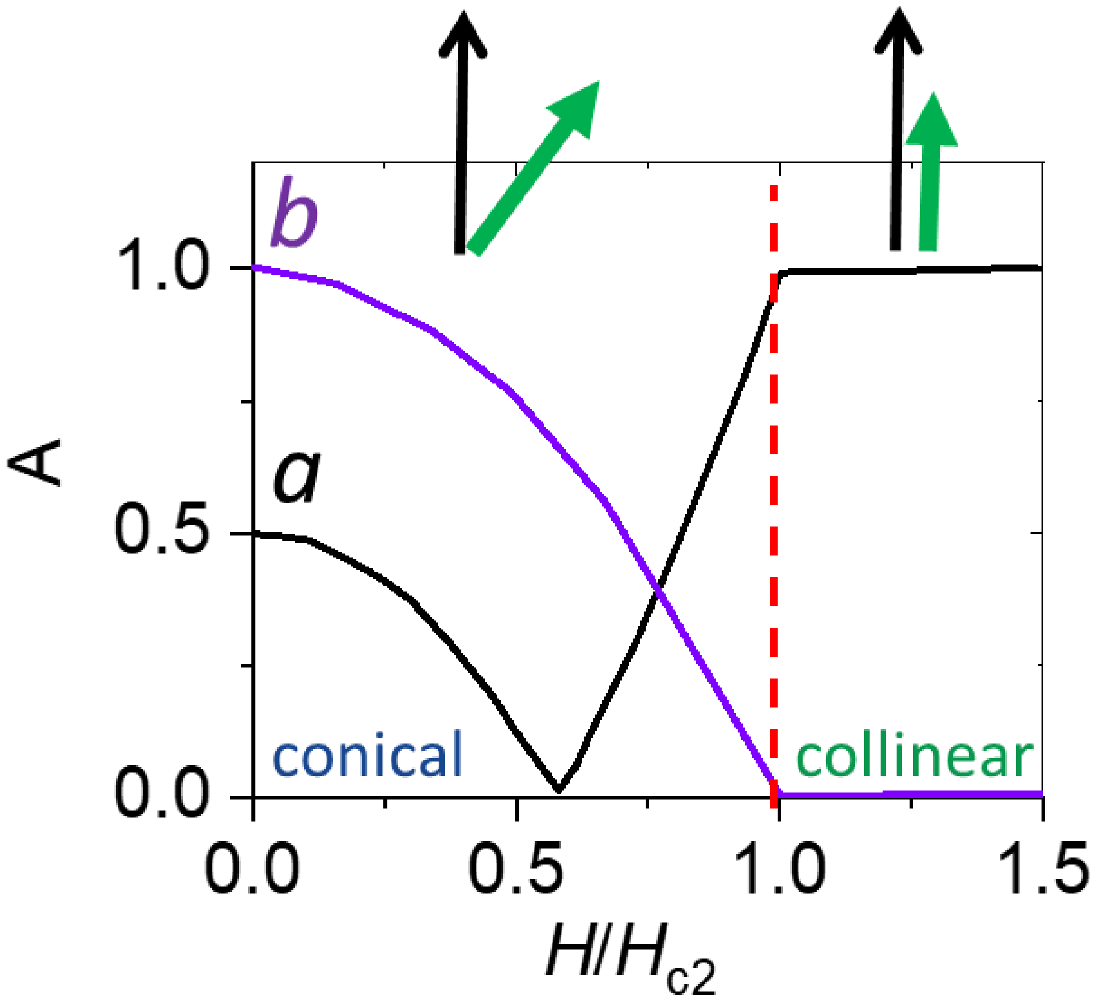




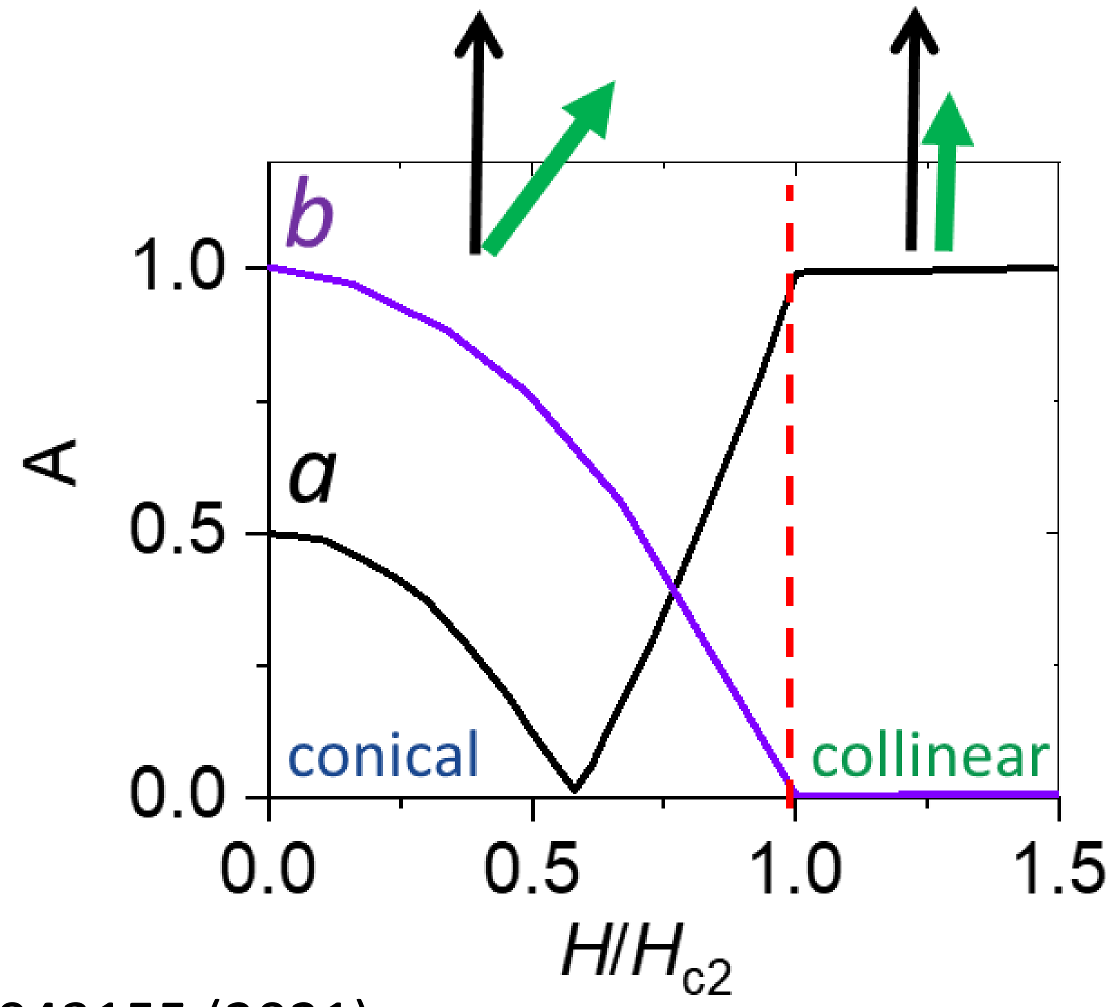


SMR in Pt/$CoCr_2O_4$





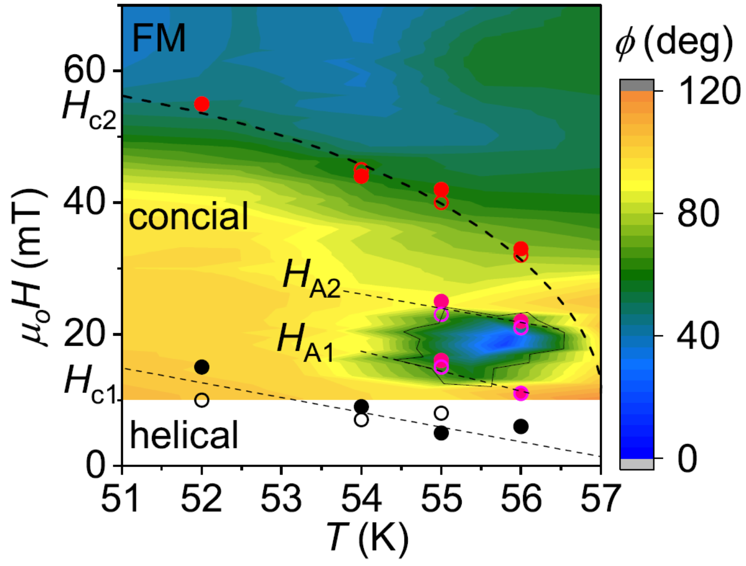
Is second term chiral/orientation dependent?



Kipp, Lux, Mokrousov, Phys. Rev. R 3, 043155 (2021)

Summary

- SMR for electric detection of spirals and skyrmions.



- Can there be chiral/directional contributions?