UTRGV

Mid-/far infrared anomalous Hall effect

Myoung-Hwan Kim

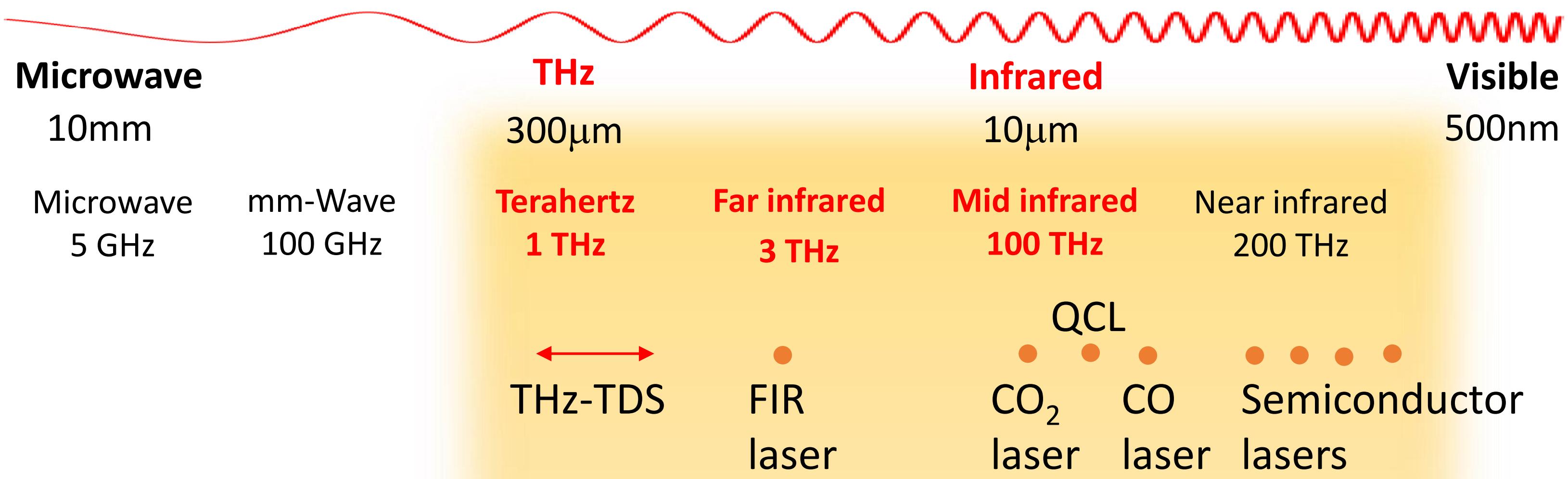
Department of Physics and Astronomy

The University of Texas Rio Grande Valley

Joint KPS-AKPA Symposium on New Frontiers in Physics

March 4th, 2018

Mid-/far infrared spectrum



Applied physics research

Microwave
10mm

THz
300μm

Infrared
10μm

Visible
500nm

Microwave
5 GHz

mm-Wave
100 GHz

Terahertz
1 THz

Far infrared
3 THz

Mid infrared
100 THz

Near infrared
200 THz

QCL

THz-TDS

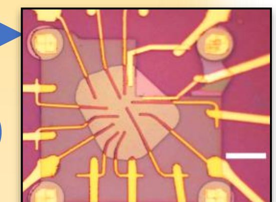
FIR laser

CO_2 laser

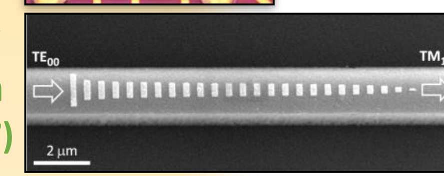
CO laser

Semiconductor lasers

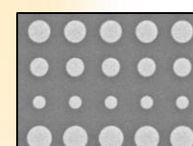
Graphene hot electron bolometer
(Nat. Nano. 2012)

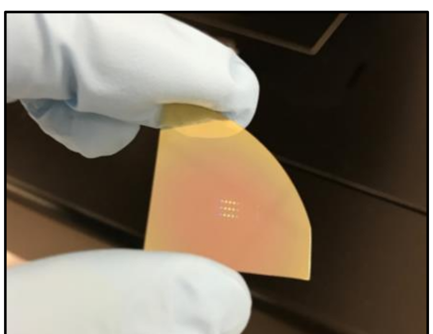


Metasurface - photonic integration
(Nat. Nano./Nat. Comm. 2017)



Metalens **(Opt. Ex. 2016)**





Surface polaritonic metasurfaces (current project)

Under-explored infrared Hall spectrum

Microwave 10mm | **THz** 300μm | **Infrared** 10μm | **Visible** 500nm

Microwave 5 GHz

mm-Wave 100 GHz

Terahertz 1 THz

Far infrared 3 THz

Mid infrared 100 THz

Near infrared 200 THz

QCL

THz-TDS

FIR laser

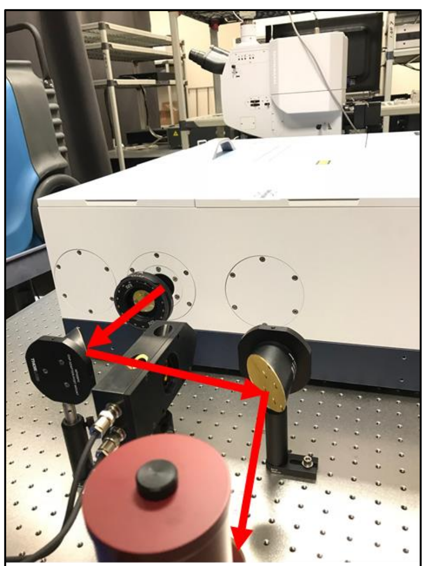
CO_2 laser

CO laser

Semiconductor lasers

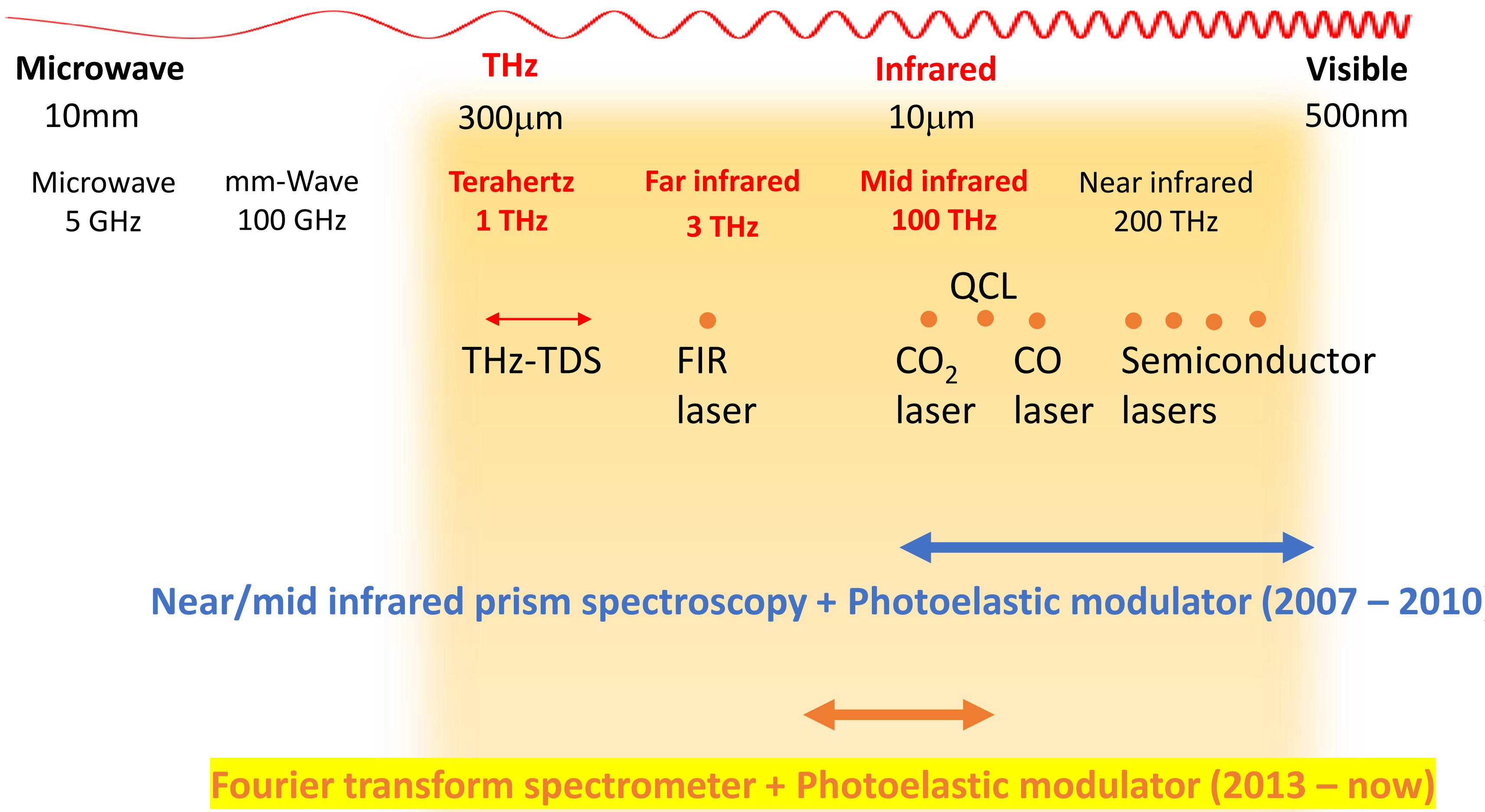
Ferromagnetic semiconductor (PRL 2009)
Itinerant ferromagnetic oxide (PRB 2010, 2013)
Graphene (Sci. Rep. 2013)
High-Tc superconductivity (PRB 2007)
Semiconductors and insulators (JOSAB 2011)

Topological insulator (PRB 2012)
Quantum well system (unpublished 2013)

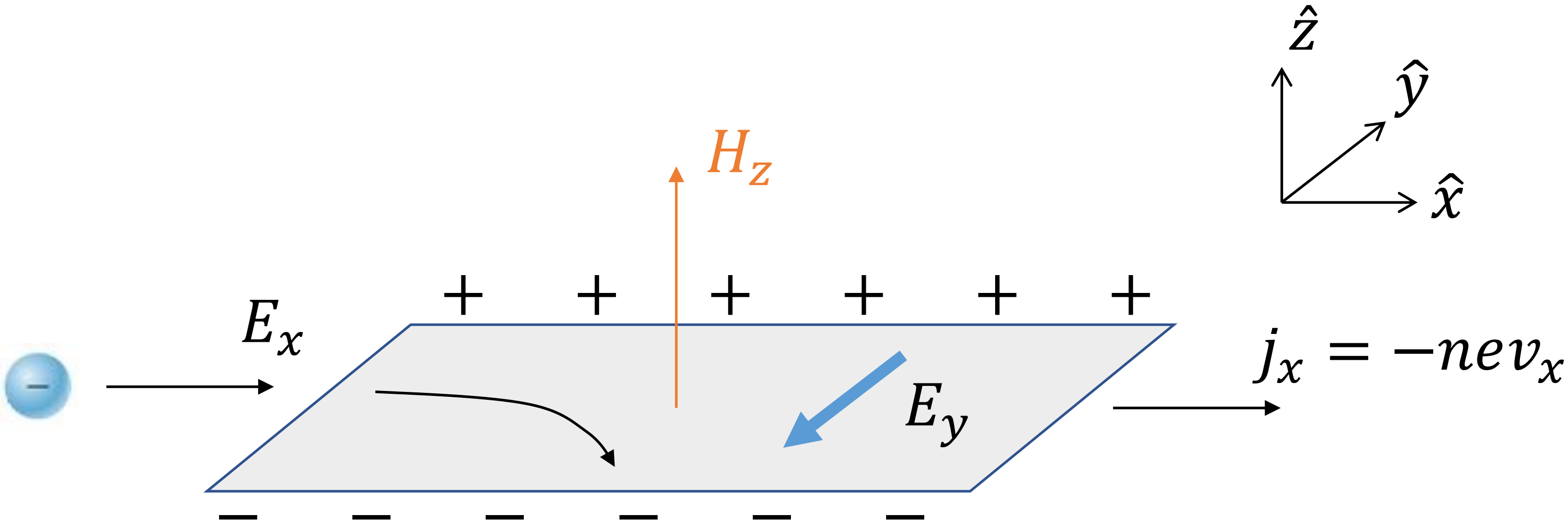


Under-explored infrared Hall spectrum (current project)

Magneto-polarimetry tool development



Ordinary Hall effect

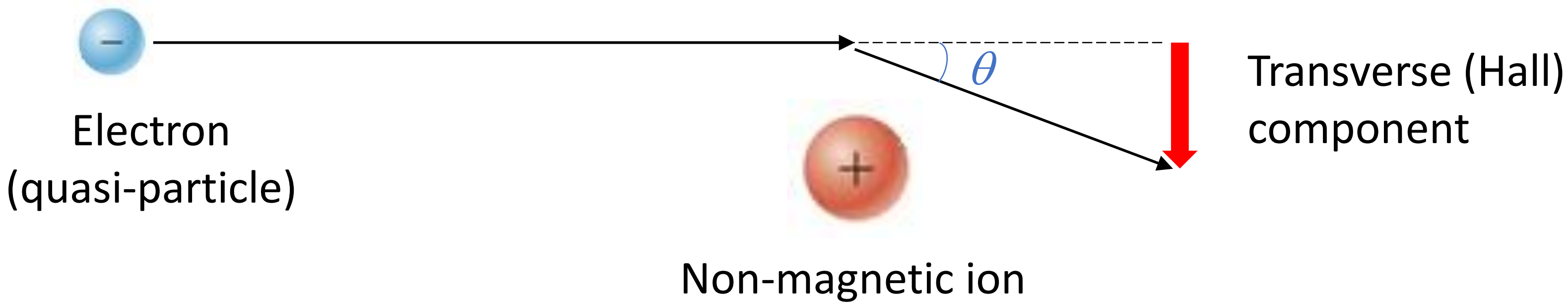


$$\rho_H = R_0 B = \left(\frac{1}{nq}\right) B$$

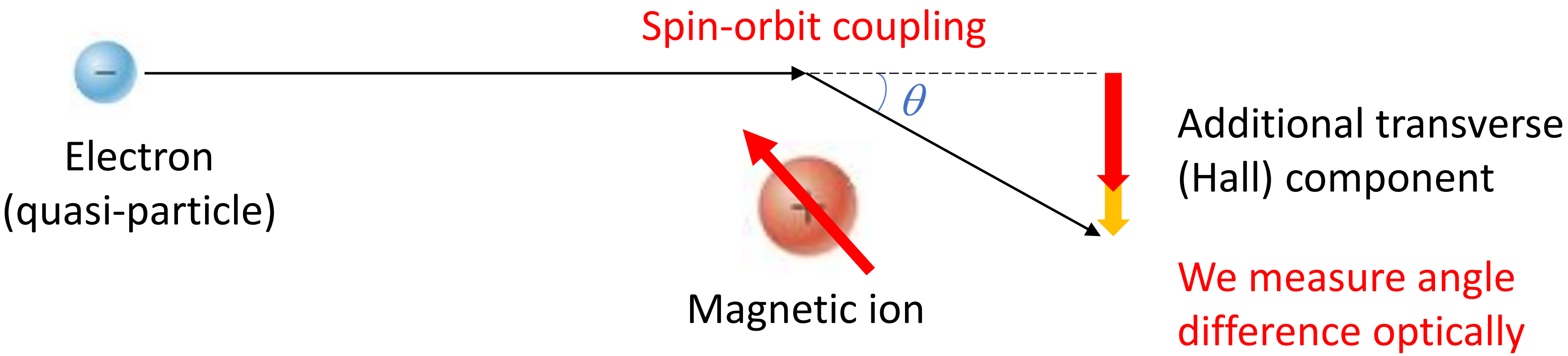
Independent of scattering rate, $\dfrac{1}{\tau}$

Anomalous Hall effect (AHE)

Classical scattering



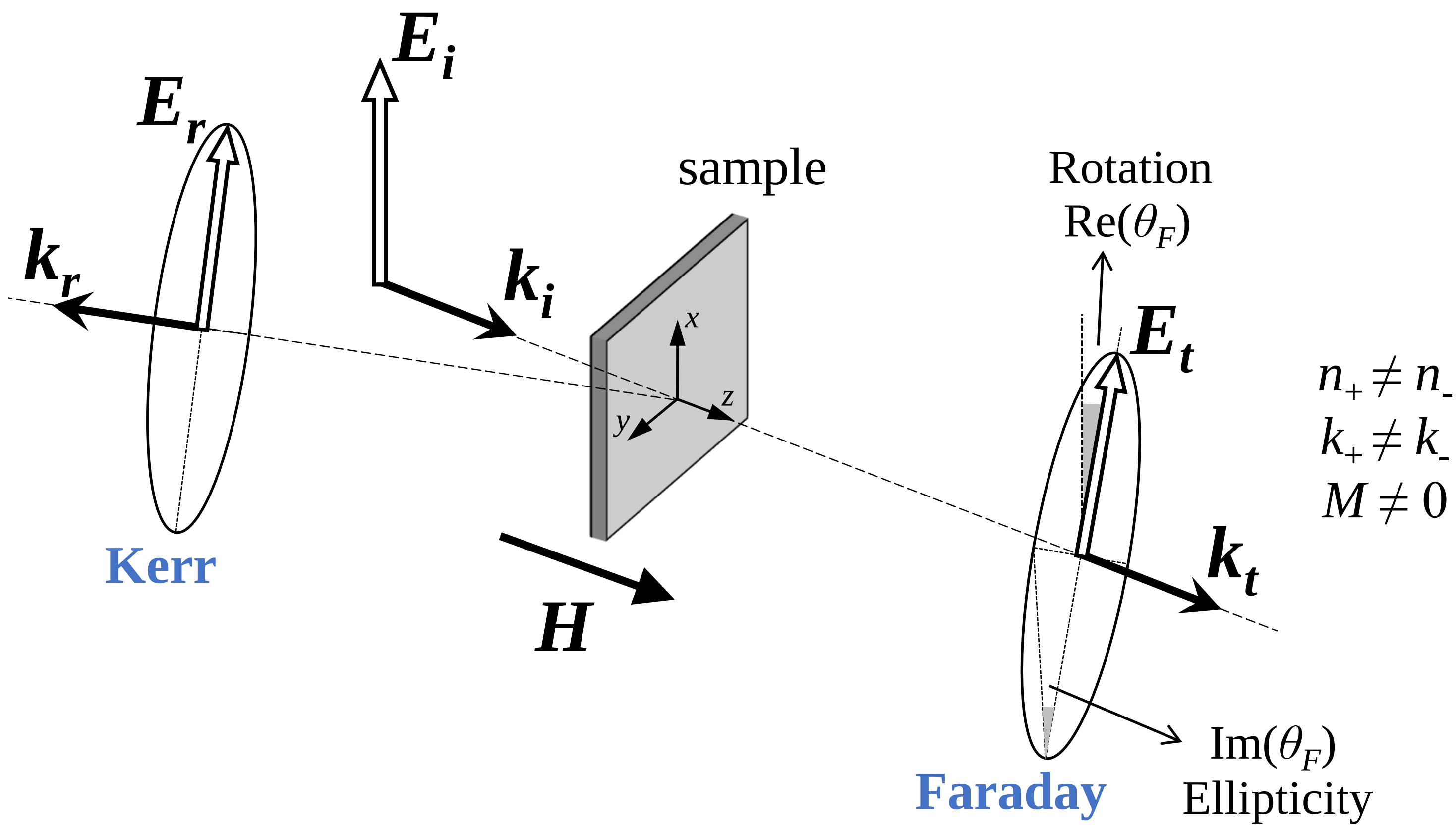
Quantum scattering



$$\rho_H^{AHE}(M, \rho_{xx}) = \rho_H^{AHE}\left(M, \frac{1}{\tau}\right)$$

Goal: deep understanding of abnormal quasi-particle scattering in time-reversal symmetry broken system using low optical excitation energy.

Angle measurement



$$\left.\begin{array}{l}\theta_F(x,\omega,T)\\ \theta_K(x,\omega,T)\end{array}\right\} \Rightarrow \left\{\begin{array}{l}\sigma_{xx}(x,\omega,T)\\ \sigma_{xy}(x,\omega,T)\end{array}\right.$$

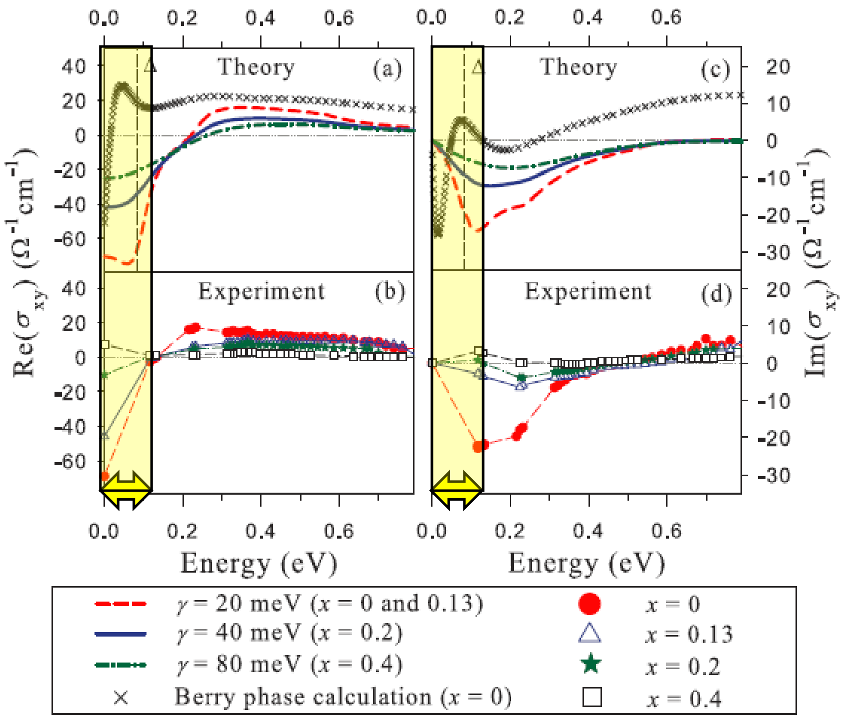
Complex Faraday and Kerr angle → Complex longitudinal and Hall conductivities

M.-H. Kim et. al. PRB 2007

Limitation

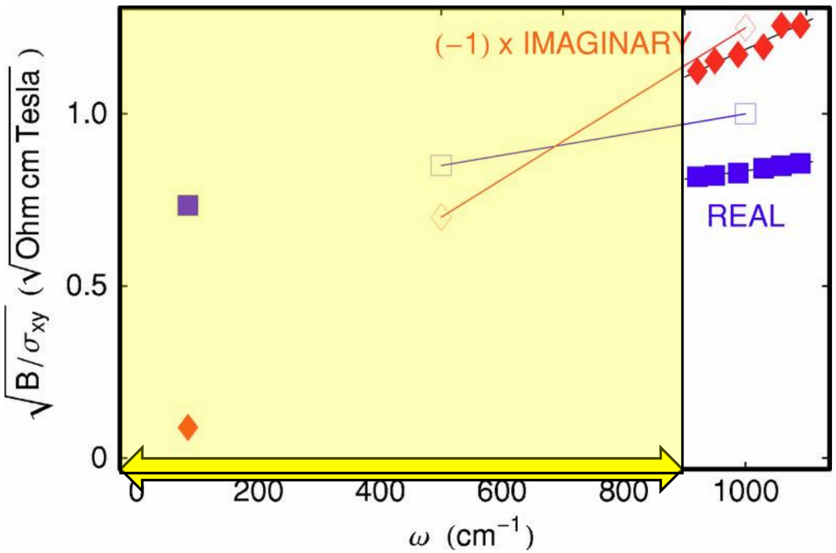
No deep mid and far infrared polarimetry (Hall angle measurement)

Itinerant ferromagnet



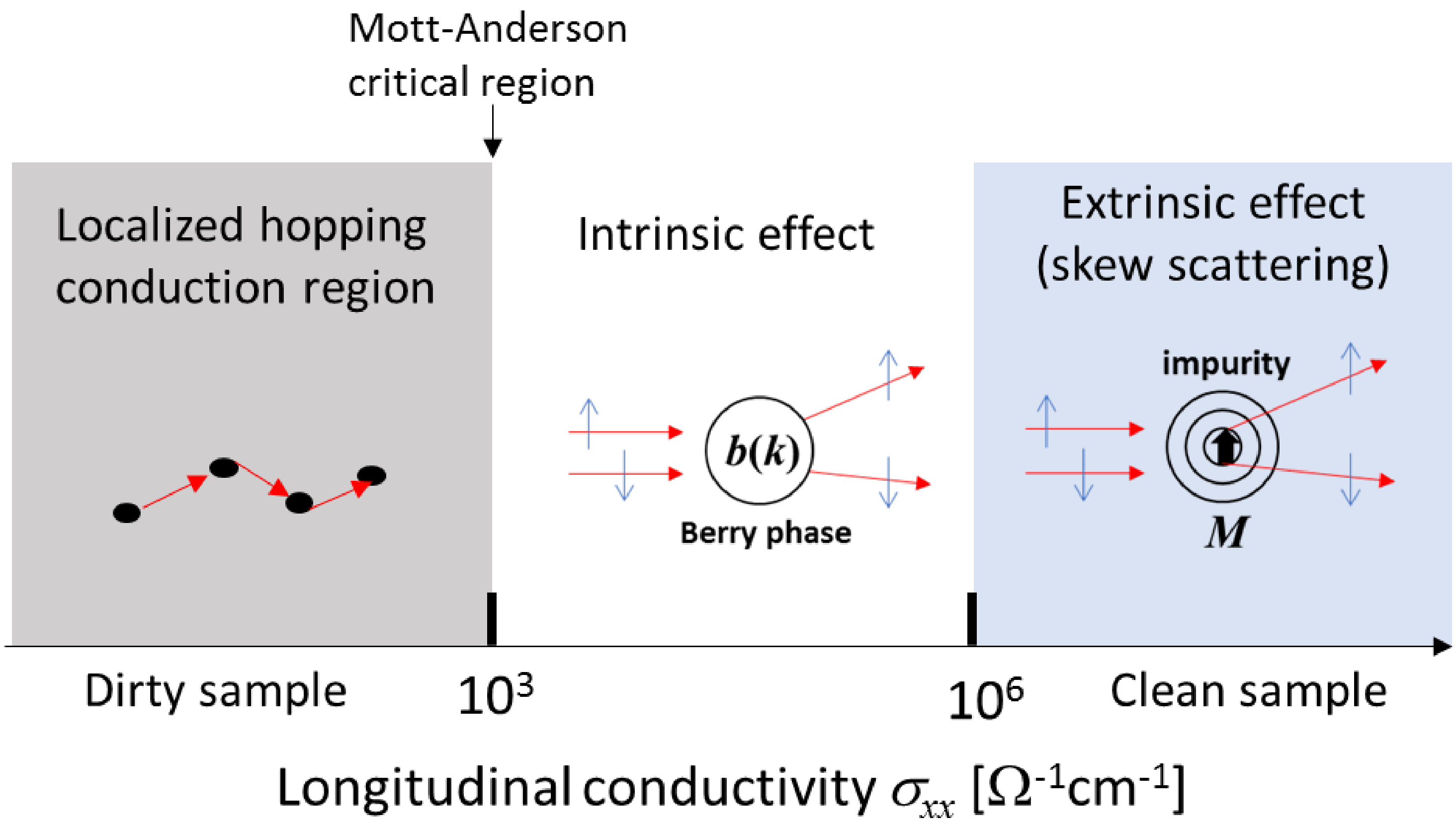
M.-H. Kim et. al. PRB 2013

Superconductivity



D. C. Schmadel et. al. PRB(R) 2007

AHE mechanisms



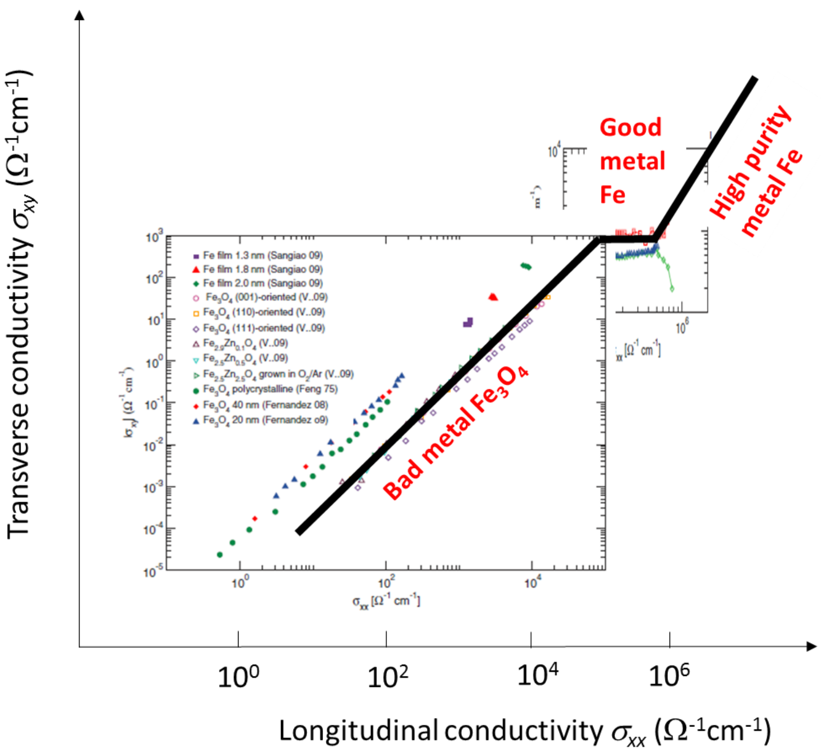
Ref) N. Nagaosa et. al. Rev. Mod. Phys. 82, 1539 (2010)

AHE in transition metal films

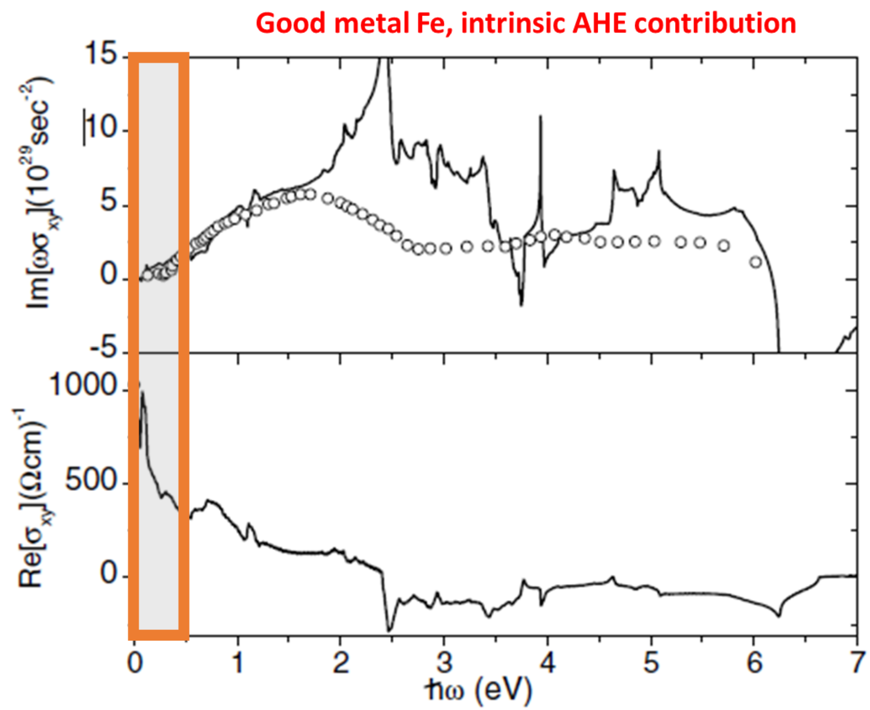
At DC

At optical frequency

(a)



(b)



Ref) N. Nagaosa et. al. Rev. Mod. Phys. 82, 1539 (2010)

Summary

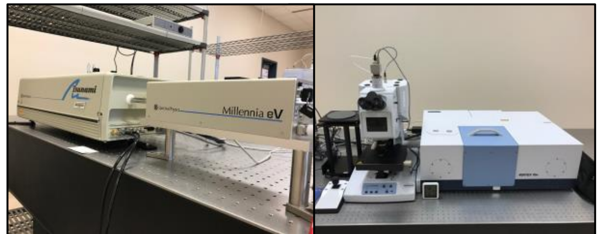
- **The infrared Hall angle measurement** is one of the most powerful ways to disclose Fermi surface information from simple ferromagnetic metal systems to highly correlated electron systems including normal state superconductivity.

- **The Hall results are comparable with** the results acquired from angular-resolved photoemission spectroscopy (ARPES) and de Hass-van Alphen oscillations at dc.

- The objective of this project is to address the fundamental question of how dc anomalous Hall effect evolves at underexplored finite frequencies to provide insight into new developing ideas about how to resolve quasiparticle scatterings in the time-reversal symmetry broken system.

Acknowledgement

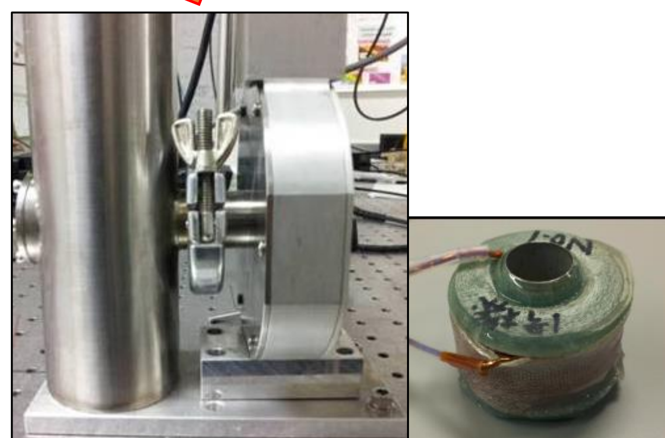
DC Hall measurements
Dr. Martirosyan,
Physics, UTRGV



Polarimetric Spectroscopy
THz-FIR-NIR
Dr. Kim, Physics, UTRGV

Theory
Dr. Qian Niu, UT Austin

Transition metal film growth
Dr. Huq, EE, UTRGV
Univ. of Houston, Nanofab.



Magnet with optical access
Dr. Kono, ECE & Physics, Rice U.