Dirac Fermions in Newly Discovered Iron-Based Superconductors

The fourth Dirac Fermion in condensed matters

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in collaboration with
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T. Morinari, E. Kaneshita, T.T.,
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The first Dirac fermions: GRAPHENE

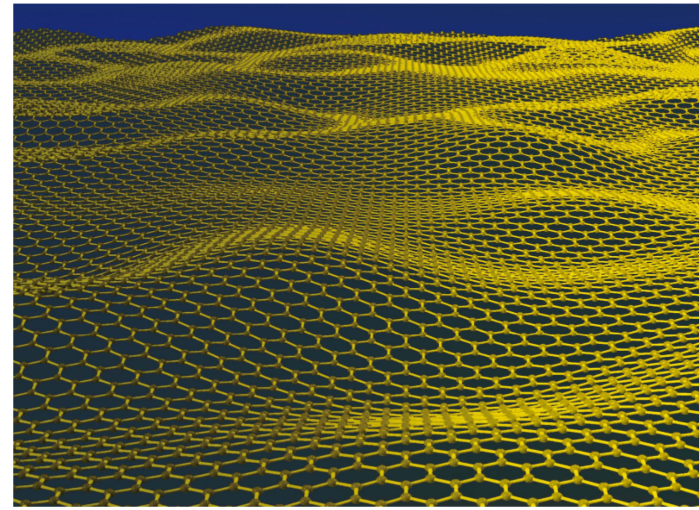
Nobel Prize in Physics 2010

Konstantin Novoselov

Andre Geim

- Ig nobel prize in 2000 "to make a frog levitate in a magnetic field"
- Invited speaker of YKIS2007

"for groundbreaking experiments regarding the two-dimensional material graphene"



Single layer Carbon:

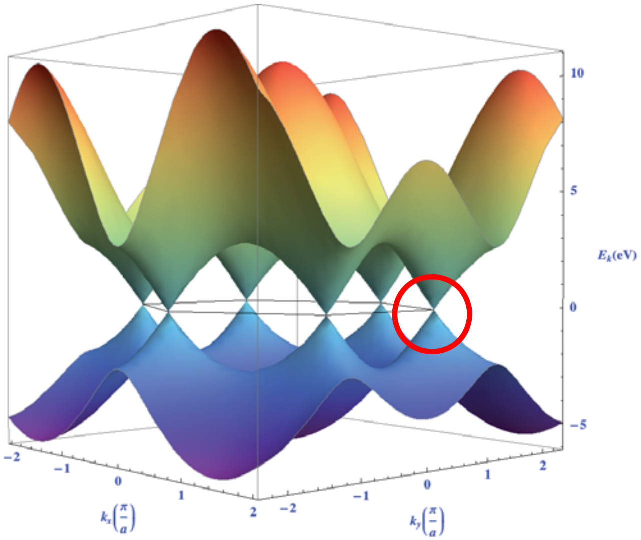
Science **306**, 666 (2004)

– the perfect atomic lattice

A thin flake of ordinary carbon, just one atom thick, lies behind this year's Nobel Prize in Physics. Andre Geim and Konstantin Novoselov have shown that carbon in such a flat form has exceptional properties that originate from the remarkable world of quantum physics.

Dirac fermions

The first Dirac fermions: graphene



linear dispersion $$E_{\pm}(\mathbf{p}) = \pm\hbar v_F\, p, \quad p = \sqrt{p_x^2 + p_y^2}$$

$$H_{\mathbf{p}} = \hbar v_F \left(p_x \sigma_x + p_y \sigma_y \right) = \hbar v_F \begin{pmatrix} 0 & p_x - i p_y \\ p_x + i p_y & 0 \end{pmatrix}$$

wavefunction

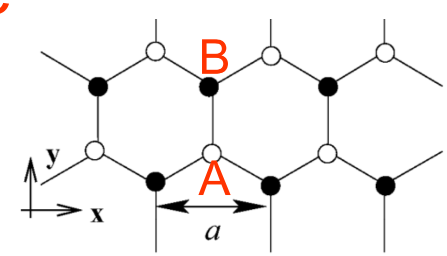
$$\Psi_{\mathbf{p}}^{(\mathrm{e})} = \frac{1}{\sqrt{2}} \begin{pmatrix} +e^{-i\theta/2} \\ e^{i\theta/2} \end{pmatrix}, \quad \Psi_{\mathbf{p}}^{(\mathrm{h})} = \frac{1}{\sqrt{2}} \begin{pmatrix} -e^{-i\theta/2} \\ e^{i\theta/2} \end{pmatrix} \qquad \left(\tan\theta = \frac{p_y}{p_x} \right)$$

chirality helicity operator: $$\hat{h} = \frac{\mathbf{p}\cdot\boldsymbol{\sigma}}{p}$$

$$\hat{h}\Psi_{\mathbf{p}}^{(\mathrm{e})} = +\Psi_{\mathbf{p}}^{(\mathrm{e})}, \quad \hat{h}\Psi_{\mathbf{p}}^{(\mathrm{h})} = -\Psi_{\mathbf{p}}^{(\mathrm{h})}$$

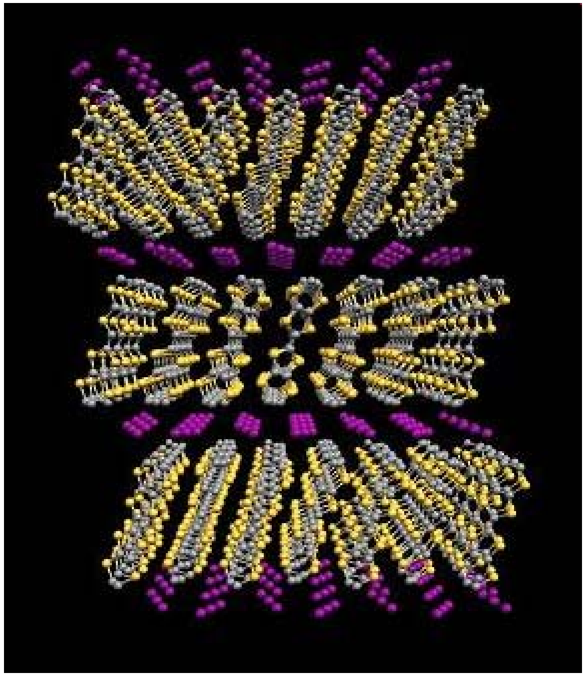
Pseudo-spins

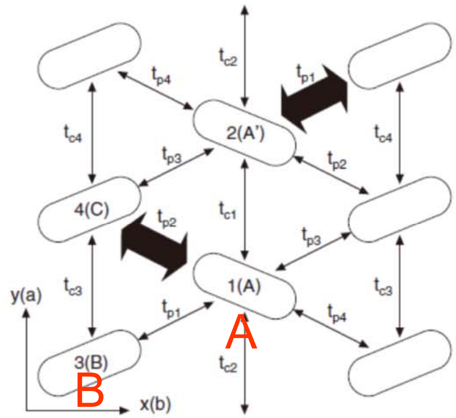
A, B sublattices in honeycomb structure

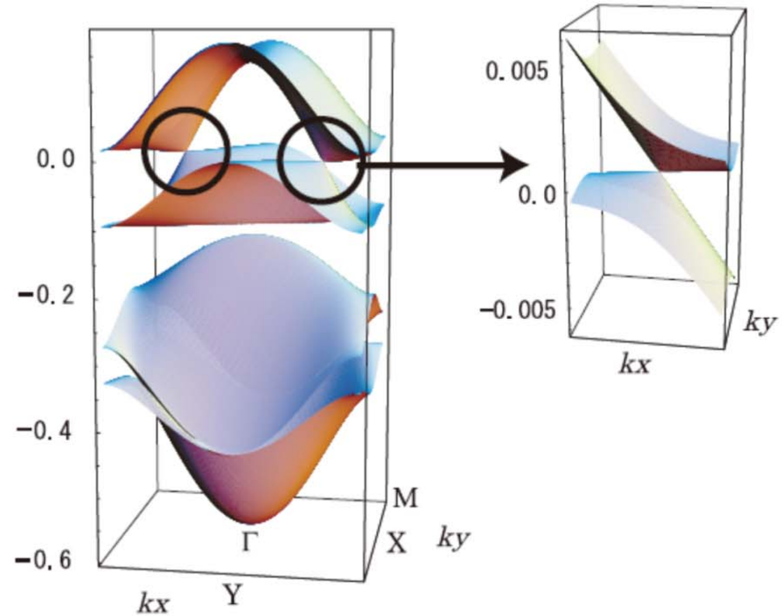


Dirac point = Fermi level

The second Dirac fermions: α-(BEDT-TTF)$_2$I$_3$







Tilted Dirac dispersions

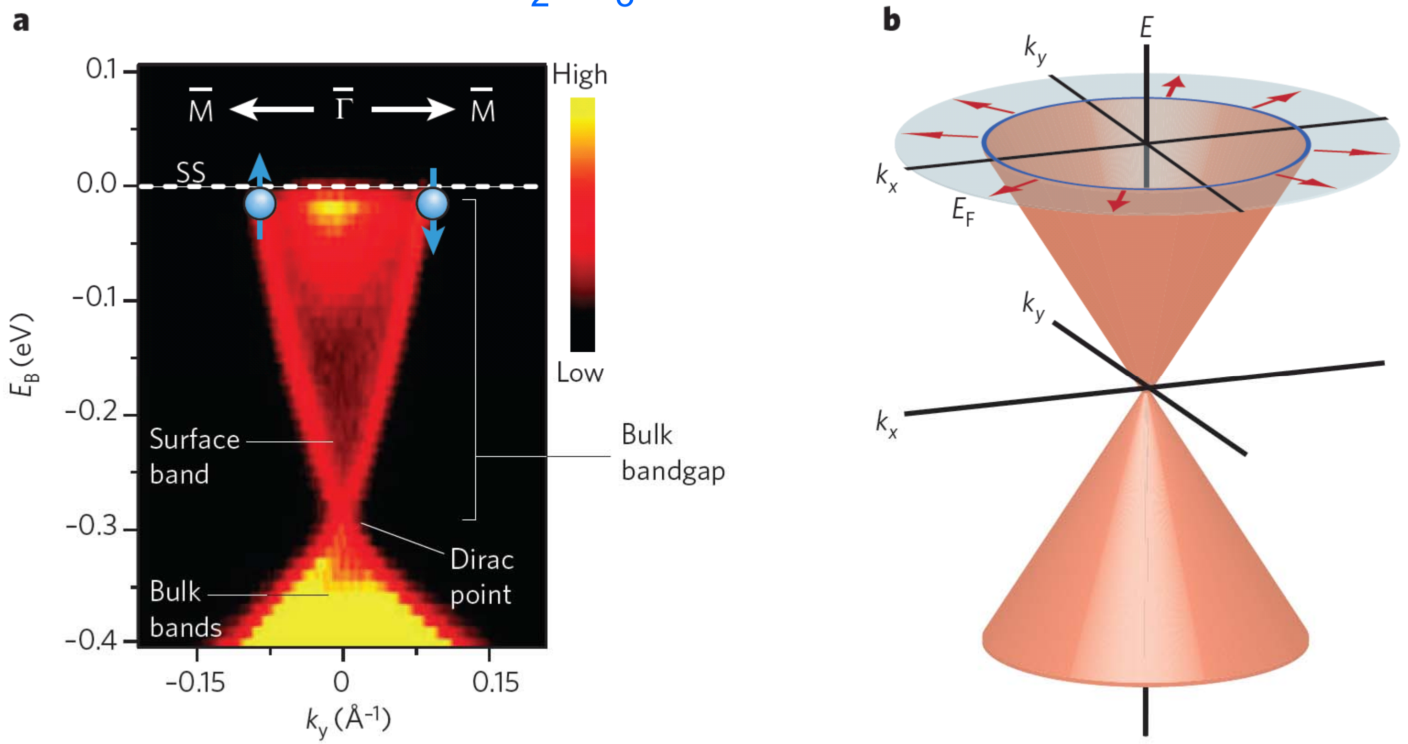
Pseudo-spins

A, B sublattices in BEDT-TTF layer

Dirac point = Fermi level

The third Dirac fermions: topological insulator

On the surface of Bi_2Se_3



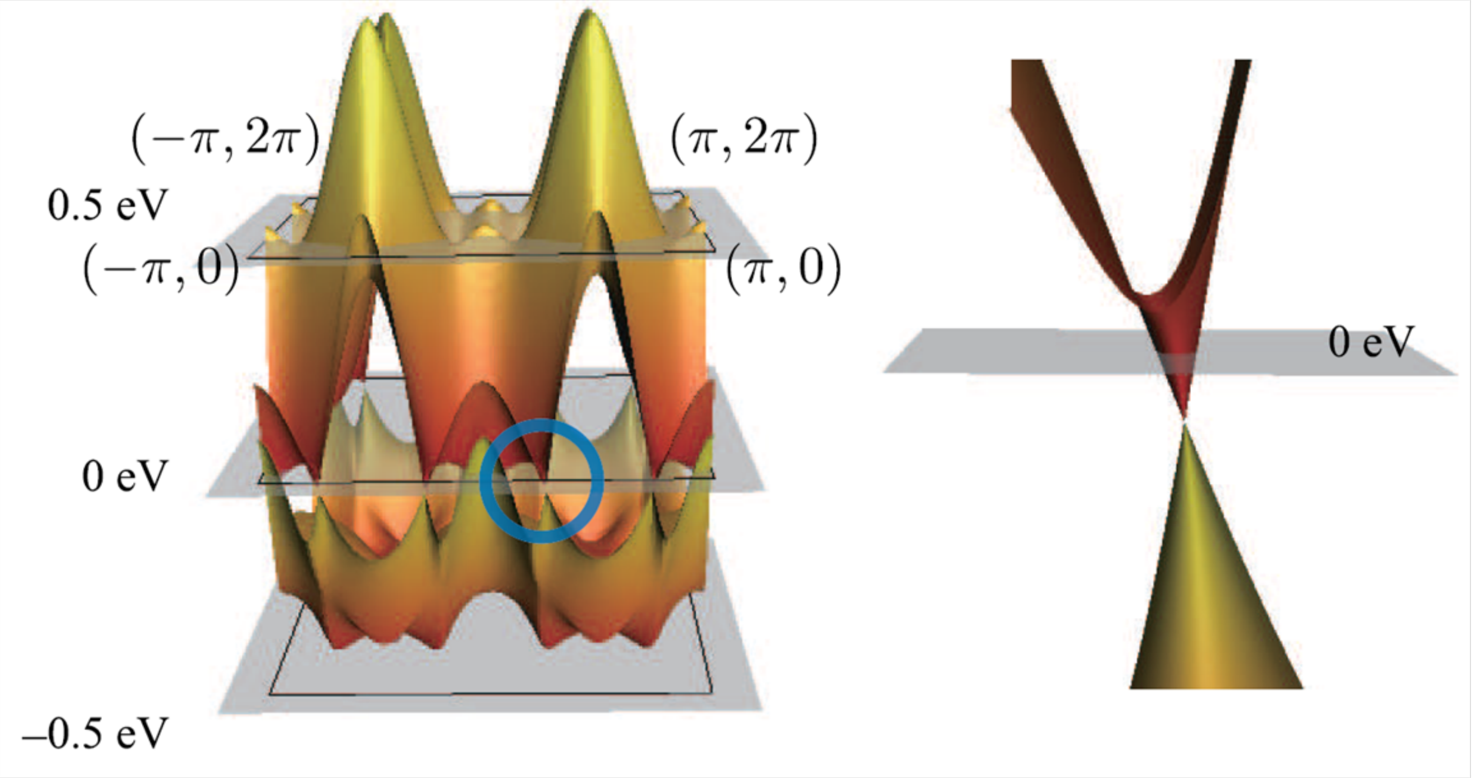
Pseudo-spins

Real spins of electrons in surface layer

Dirac point ≠ Fermi level

The fourth Dirac fermions

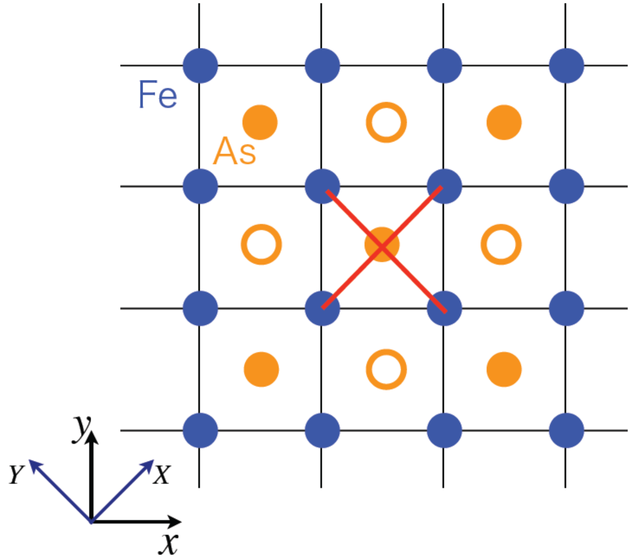
Antiferromagnetic metallic phase of iron-based high-temperature superconductors



Pseudo-spins

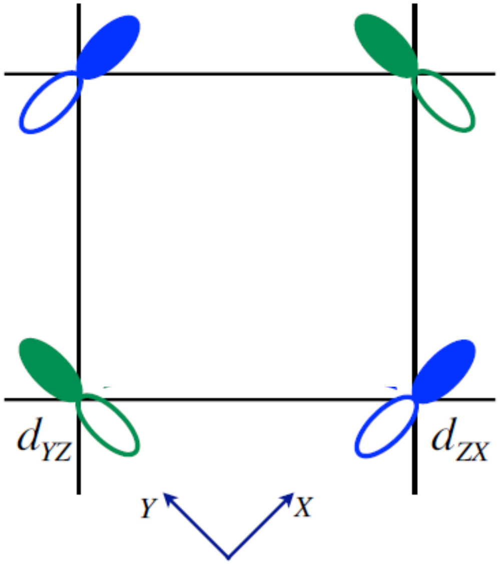
Two orbitals (zx and yz) on Fe

Dirac point ≠ Fermi level



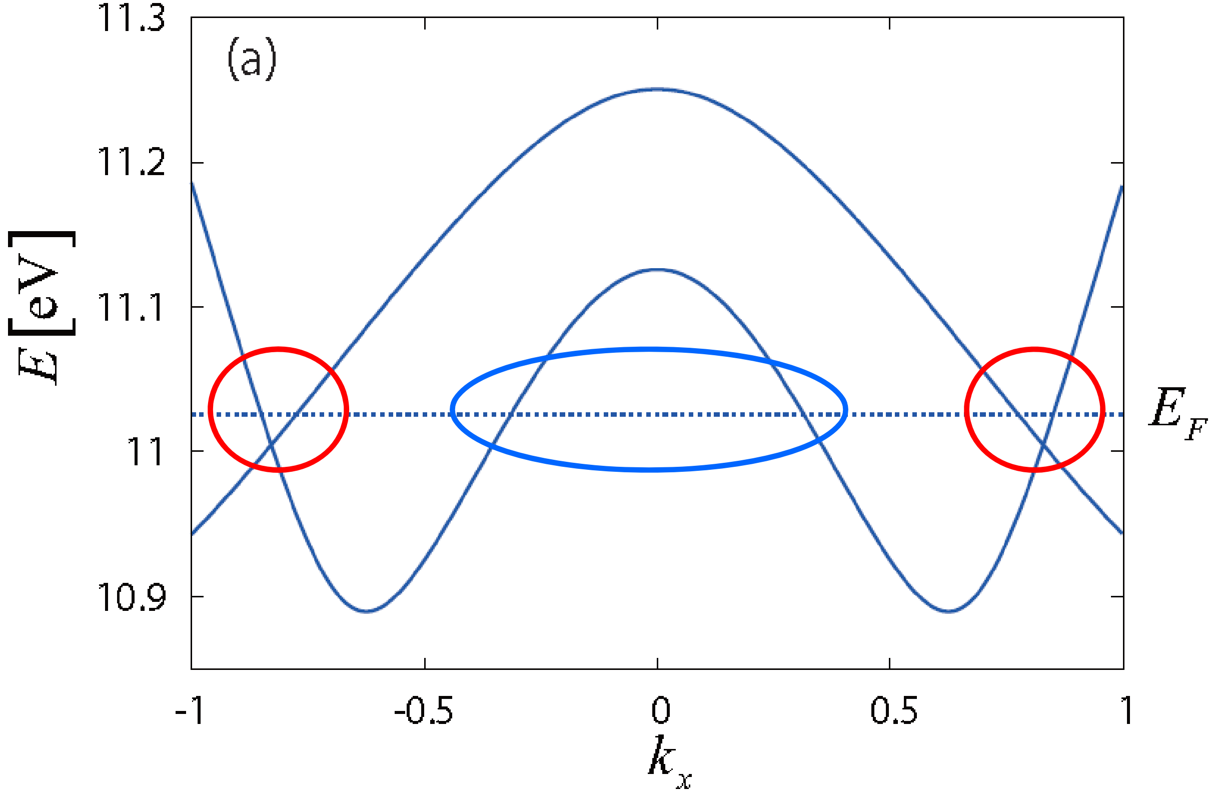
Along a symmetric direction in the momentum space, the degeneracy of the two atomic orbitals zx and yz on Fe are lifted.

Y. Ran *et al*., PRB **79**, 014505 (2009)



Complication

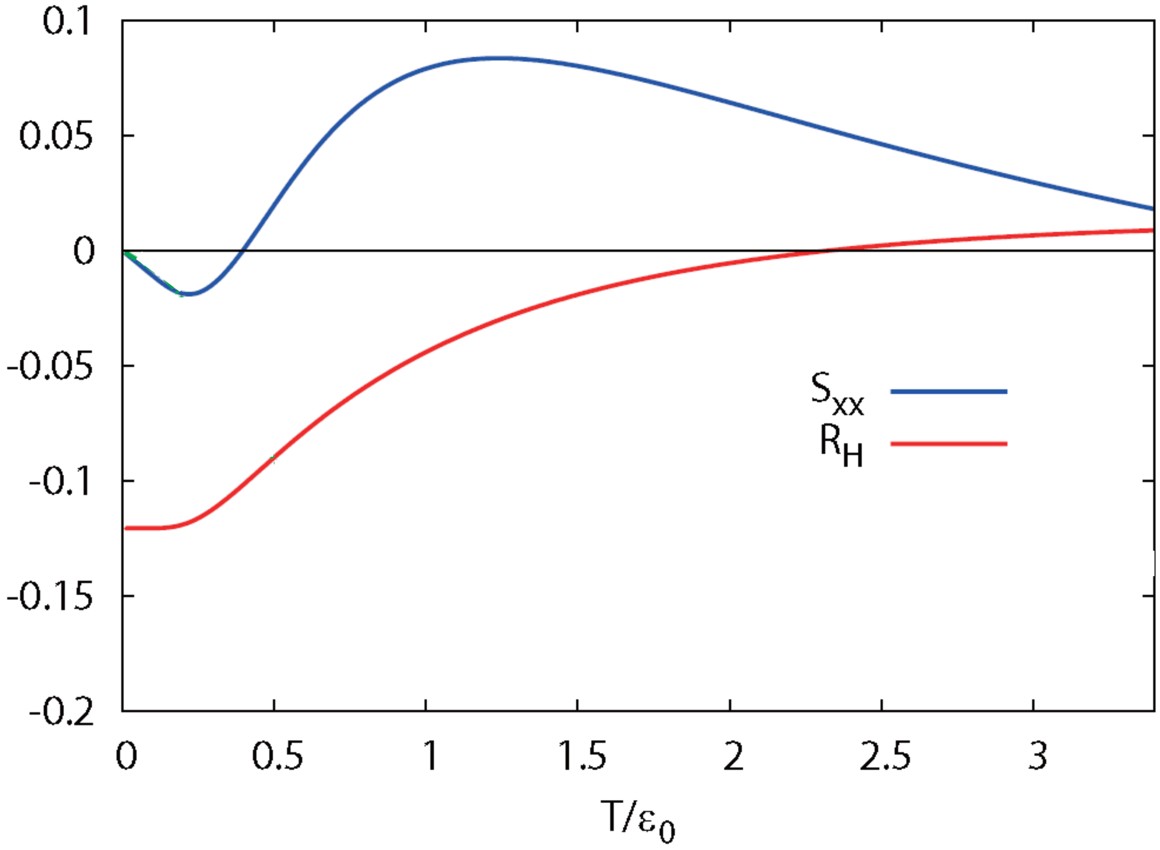
Not only Dirac electrons but also standard hole carriers

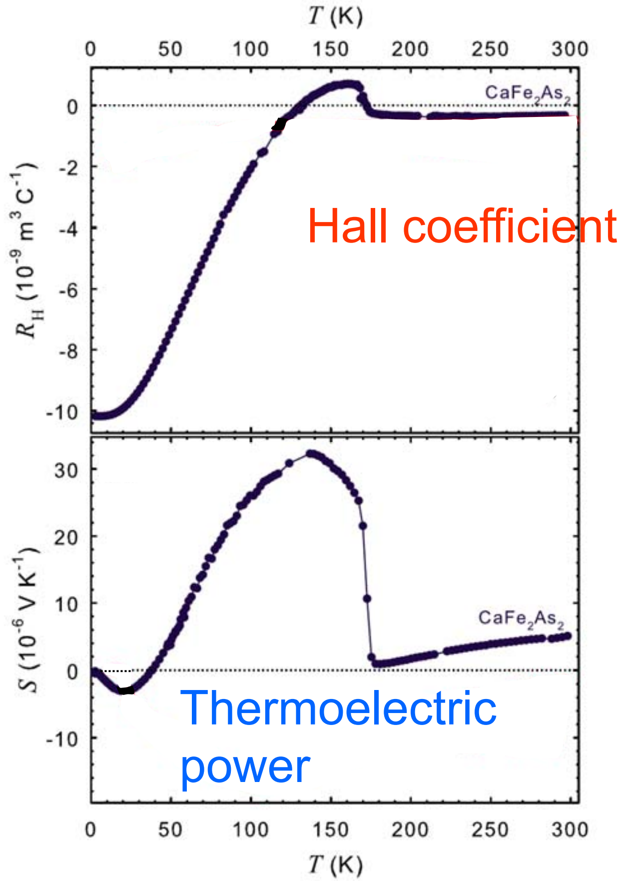


New possibility of Dirac physics

Hall Coefficient R_H, Thermoelectric Power S

Small number of electron carriers but small scattering rate due to Dirac electrons





T. Morinari, E. Kaneshita, T.T.,Phys. Rev. Lett. **105**, 037203 (2010)