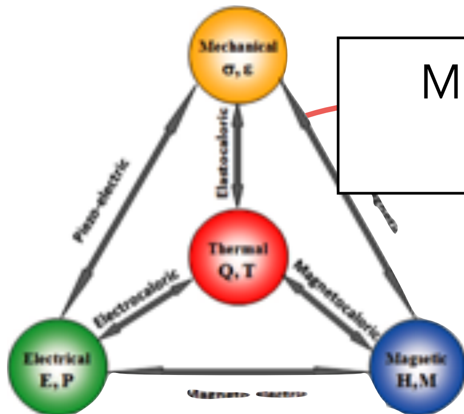
MAGiC: polarized single crystal diffractometer for magnetism

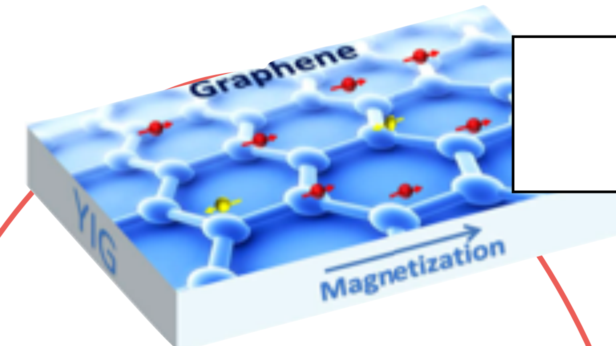
Lead scientist: X. Fabrèges
Lead engineer: S. Klimko

JCNS: W. Schweika, P. Harbott
PSI: U. Filges
LLB: A. Goukassov

The science behind MAGiC



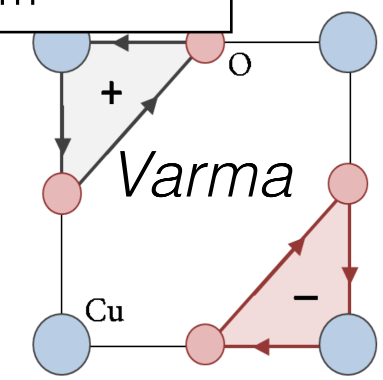
Multi-functional materials



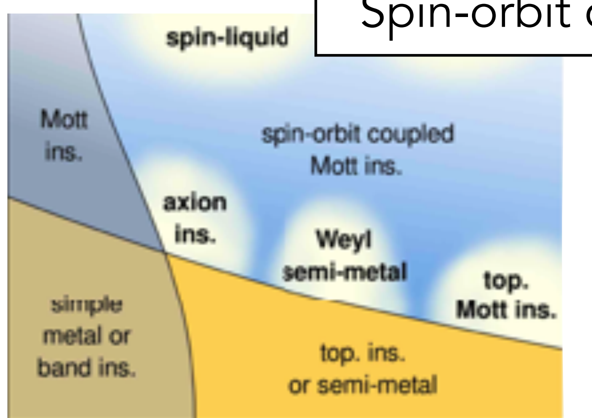
Magnetism at interfaces
Thin films

Phys. Rev. Lett. **114**, 016603

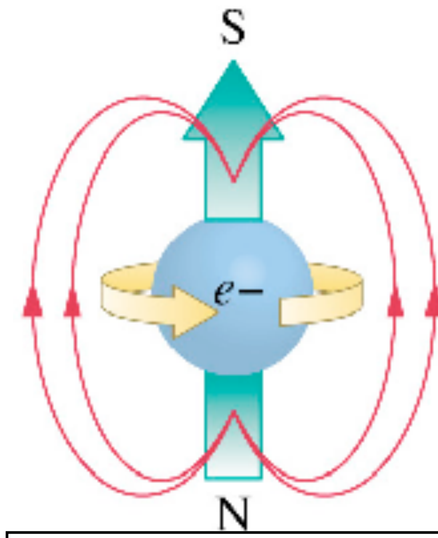
Superconductivity and magnetism



Spin-orbit coupling

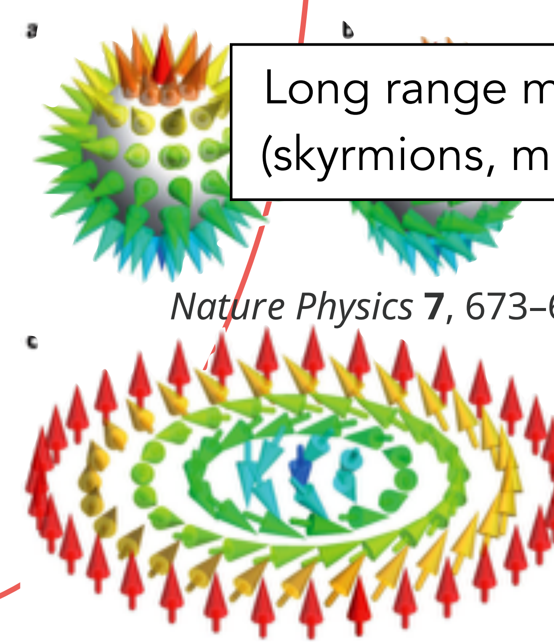


arXiv:1305.2193v2



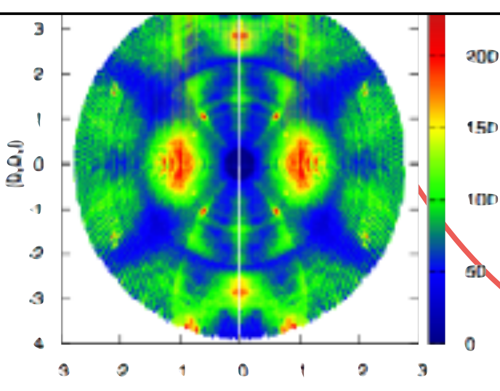
Molecular magnetism

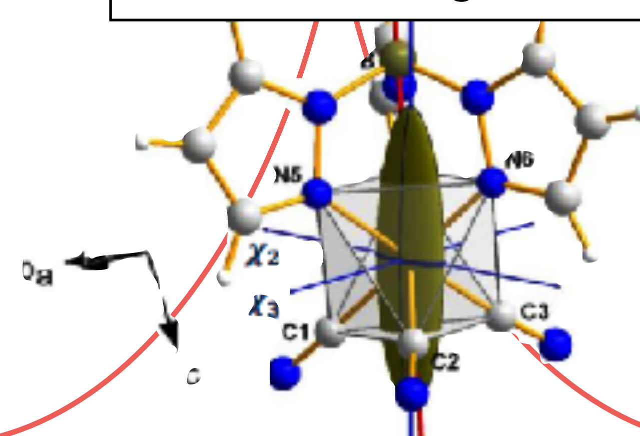
Long range magnetic states (skyrmions, multiferroics, …)



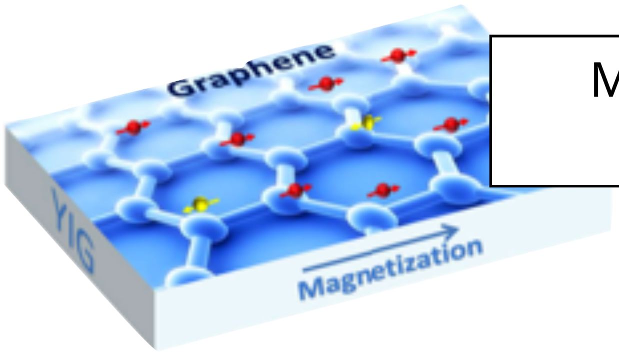
Nature Physics **7**, 673–674 (2011)

Fundamental magnetism and theory (Coulomb, Kitaev, …)





Epitaxial films



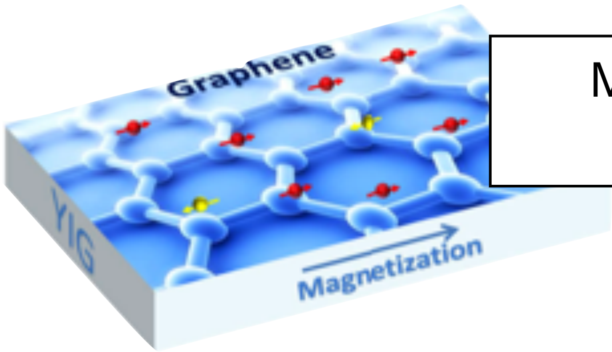
Magnetism at interfaces
Thin films

Phys. Rev. Lett. **114**, 016603

« A full magnetic structure refinement is not possible from the data »

- J.S. White *et al*, *PRL* (2013)

Epitaxial films

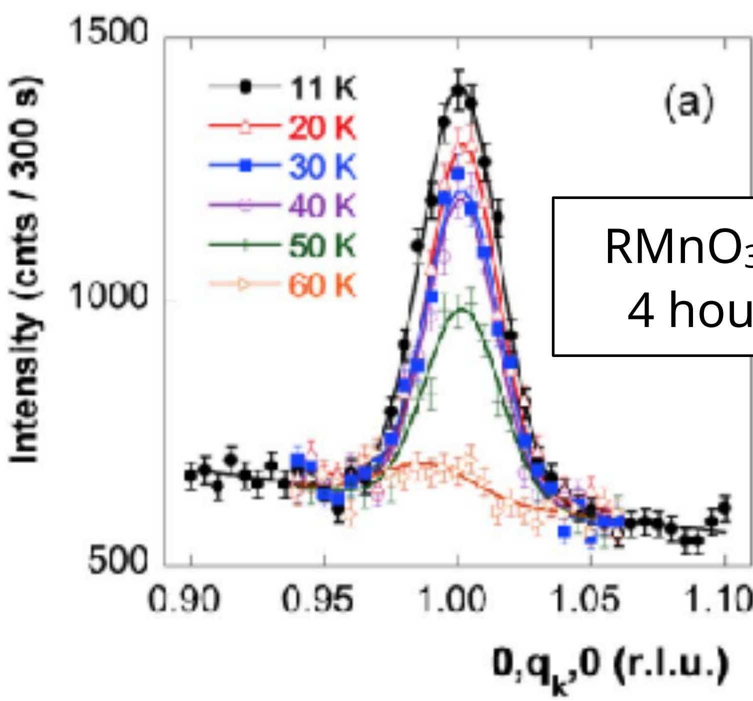


Magnetism at interfaces
Thin films

Phys. Rev. Lett. **114**, 016603

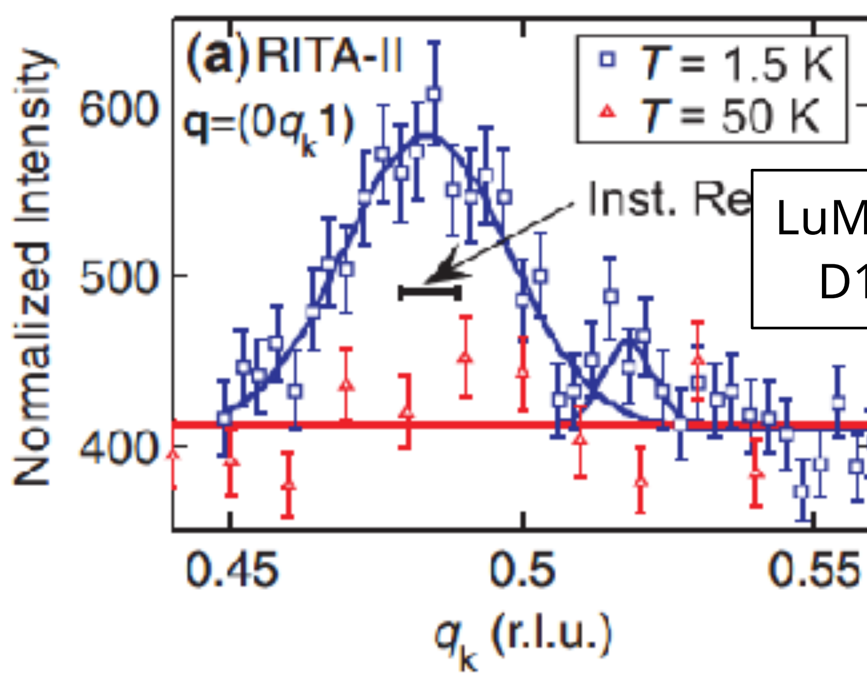
« A full magnetic structure refinement is not possible from the data »

I. Gelard *et al*, *Applied Phys. Lett.* **92**, 232506 (2008)



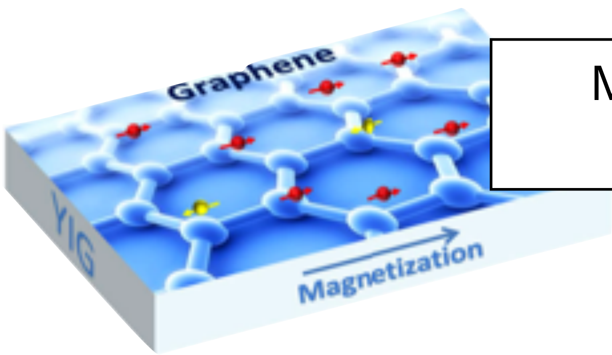
$RMnO_3$ / 400 nm
4 hours / peak

J.S. White *et al*, *Phys. Rev. Lett.* **111**, 037201 (2013)



$LuMnO_3$ / 80 nm
D10 / RITA-II

Epitaxial films

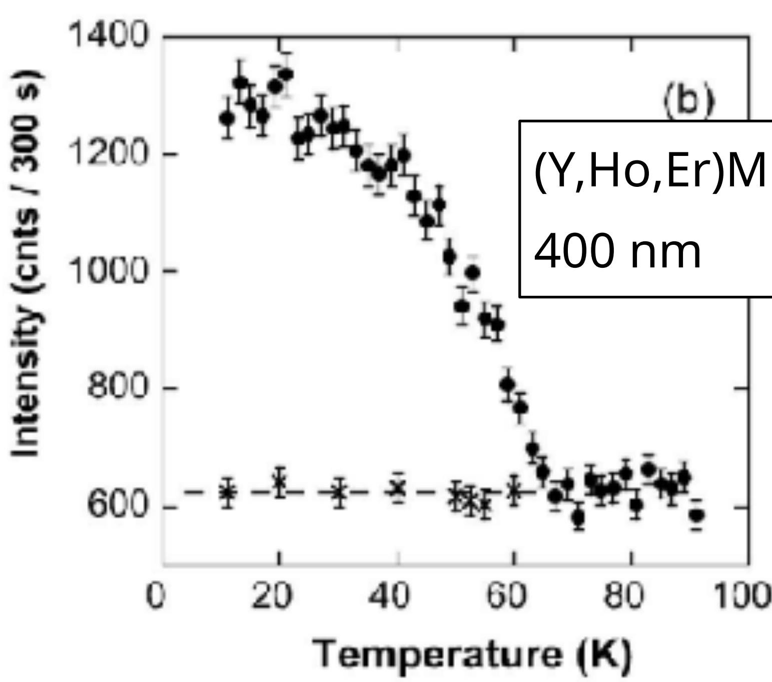


Magnetism at interfaces
Thin films

Phys. Rev. Lett. **114**, 016603

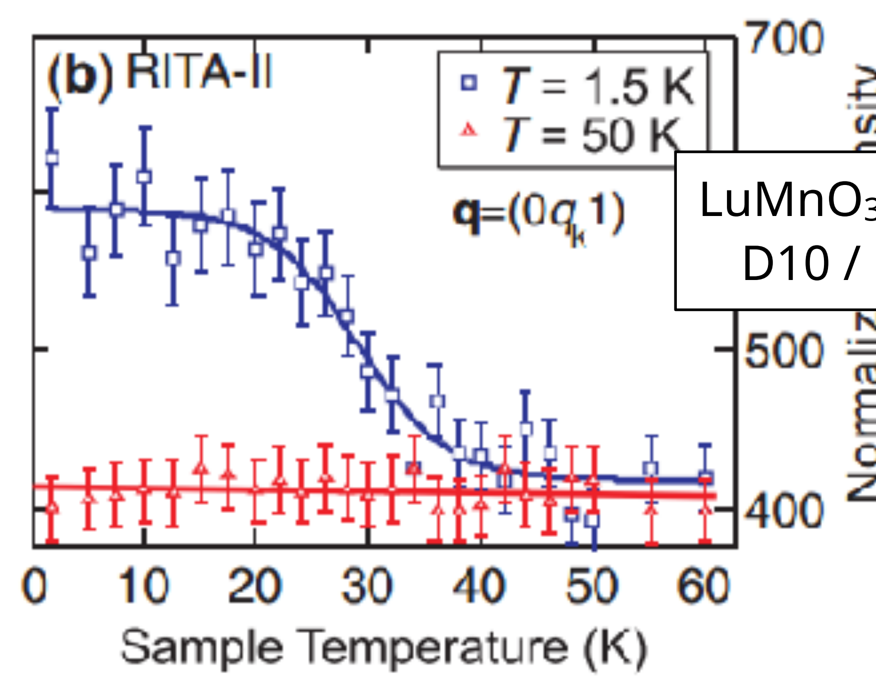
« A full magnetic structure refinement is not possible from the data »

I. Gelard *et al*, *Applied Phys. Lett.* **92**, 232506 (2008)



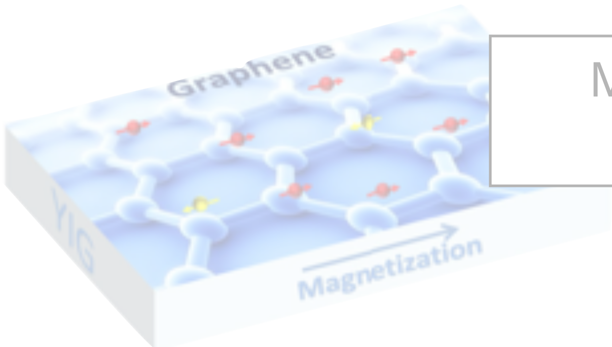
(Y,Ho,Er)MnO_3
400 nm

J.S. White *et al*, *Phys. Rev. Lett.* **111**, 037201 (2013)



$LuMnO_3$ / 80 nm
D10 / RITA-II

Epitaxial films



Magnetism at interfaces
Epitaxial films

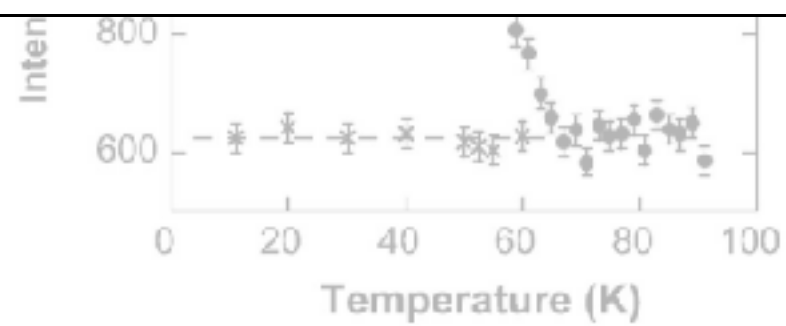
Phys. Rev. Lett. **114**, 016603

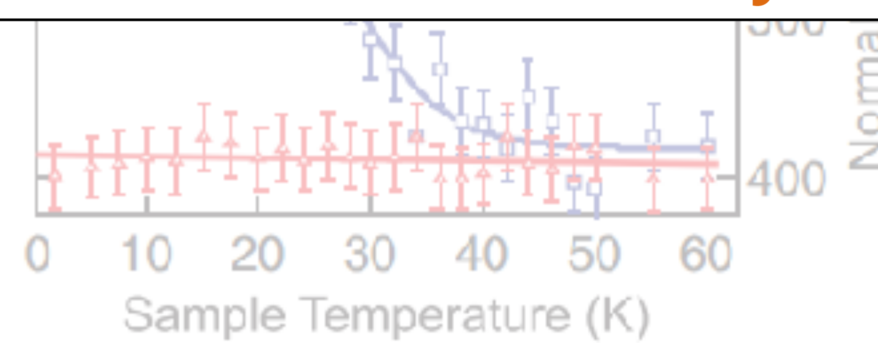
« A full magnetic structure refinement is not possible from the data »

50 - 100 nm thick films
Parametric studies only
Cold neutrons studies
Rare-earth and/or high-spin systems

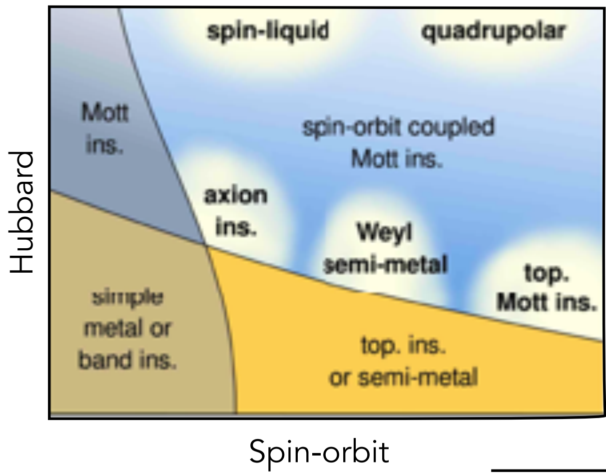
5 nm films in spintronics
Full magnetic structure refinement
Lower spin systems (S=1/2)

High flux
Thermal neutrons
Polarization analysis

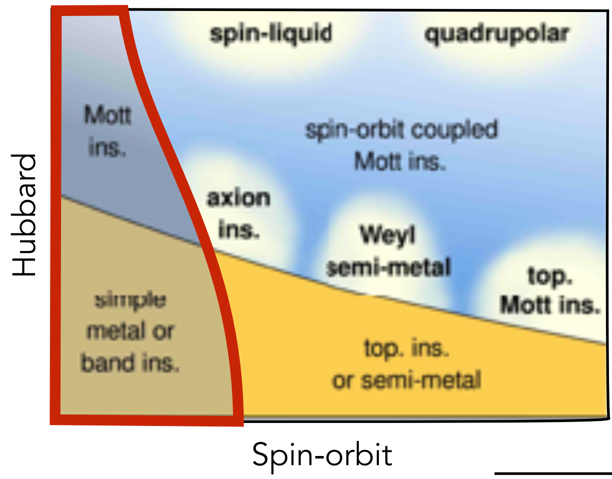


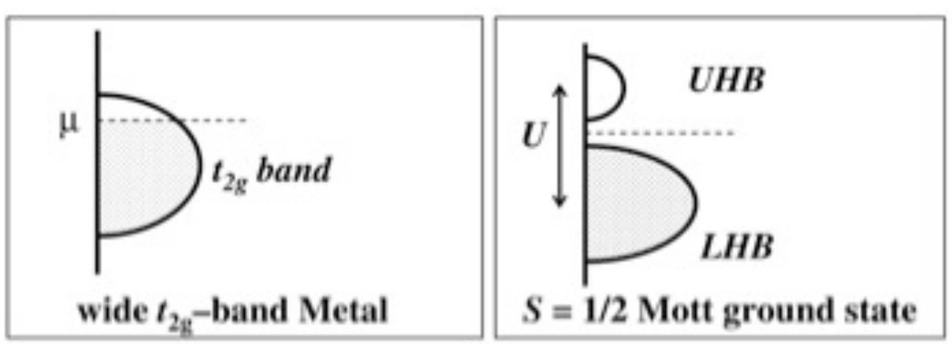


Spin-orbit coupling



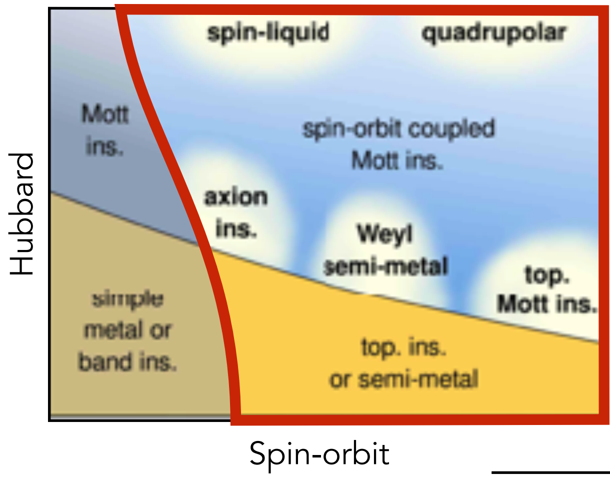
Spin-orbit coupling

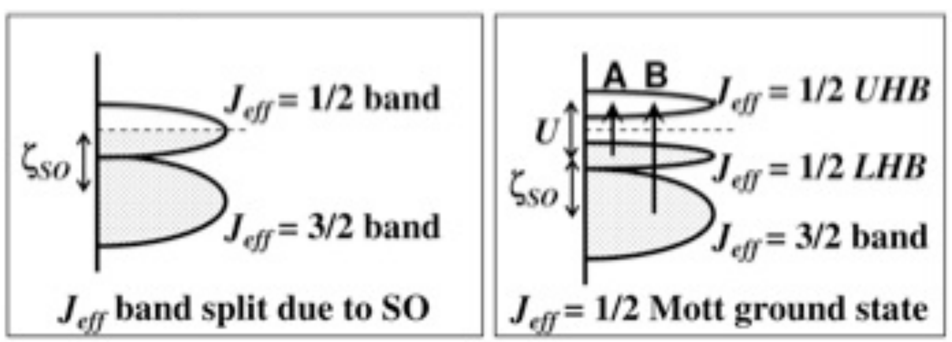




$$H = -t \sum_{\langle i,j \rangle,\sigma} (c^\dagger_{i,\sigma} c_{j,\sigma} + c^\dagger_{j,\sigma} c_{i,\sigma}) \qquad + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$

Spin-orbit coupling



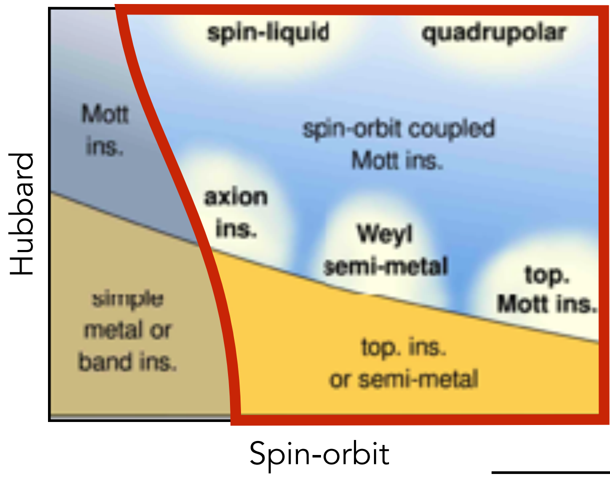


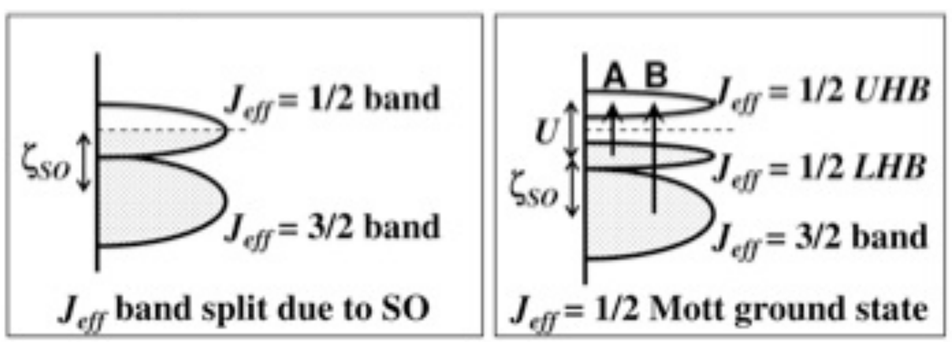
Kim *et al.* , *Physical Review Letters* **101**, 076402 (2008)

$$H = -t \sum_{\langle i,j\rangle,\sigma} (c^{\dagger}_{i,\sigma} c_{j,\sigma} + c^{\dagger}_{j,\sigma} c_{i,\sigma}) + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$

$+ \mathrm{S.}O\mathrm{.C}$

Spin-orbit coupling





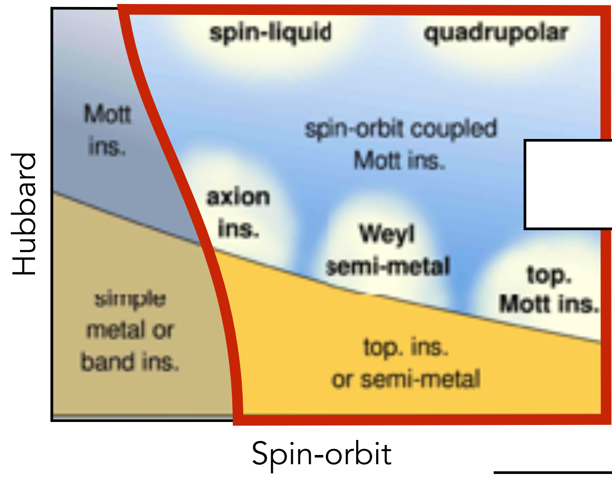
Kim *et al.* , *Physical Review Letters* **101**, 076402 (2008)

$$H = -t \sum_{\langle i,j\rangle,\sigma} (c^\dagger_{i,\sigma} c_{j,\sigma} + c^\dagger_{j,\sigma} c_{i,\sigma}) + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$

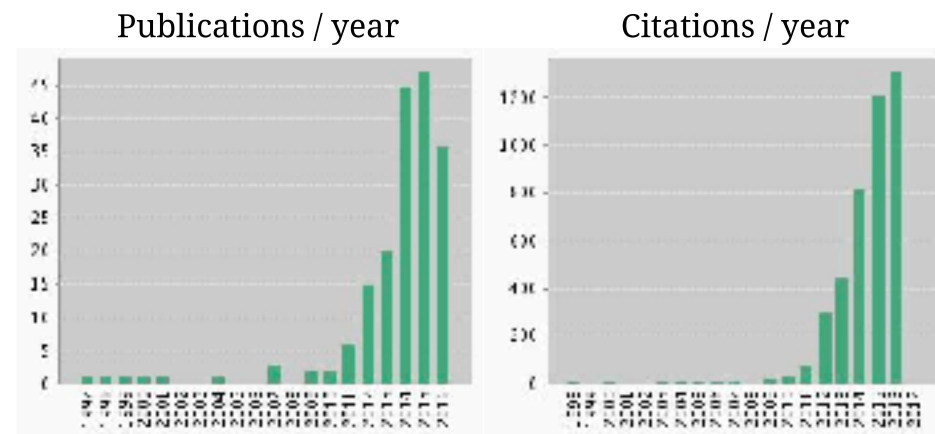
$+ \mathrm{S.O.C}$

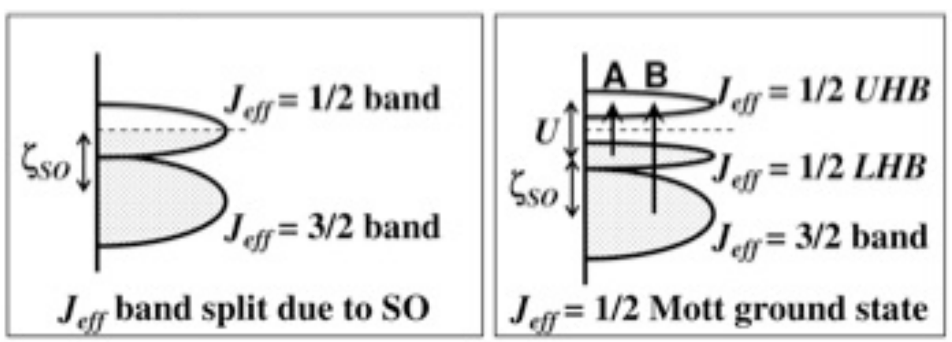
SOC = from classical to quantum !

Spin-orbit coupling



Iridates



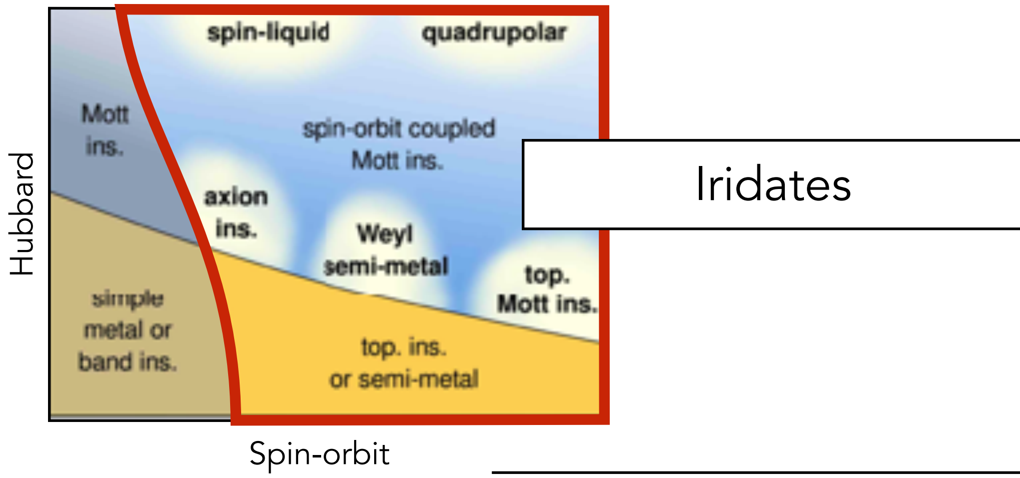


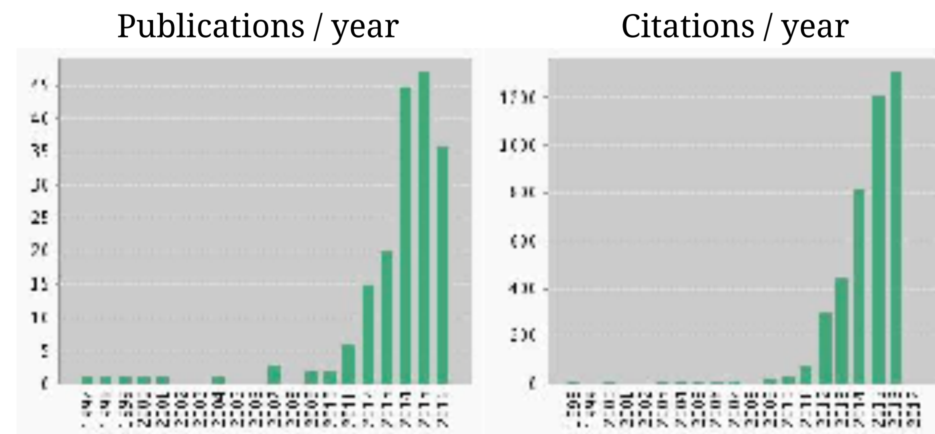
Kim *et al.* , *Physical Review Letters* **101**, 076402 (2008)

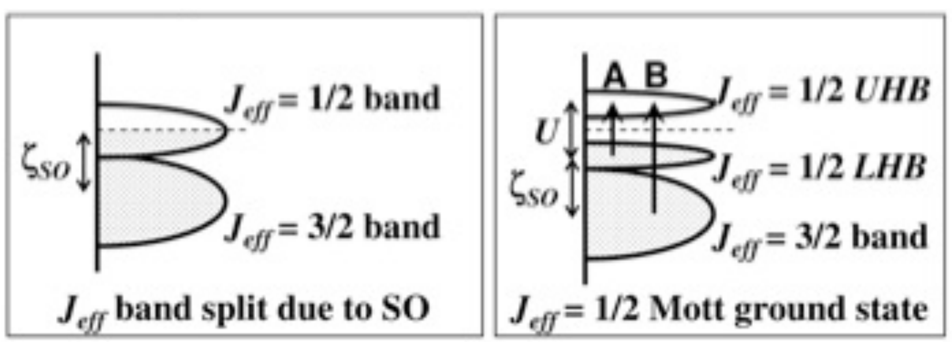
$$H = -t \sum_{\langle i,j\rangle,\sigma} (c^{\dagger}_{i,\sigma} c_{j,\sigma} + c^{\dagger}_{j,\sigma} c_{i,\sigma}) + \mathrm{S.O.C} + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$

SOC = from classical to quantum !

Spin-orbit coupling







Kim *et al.* , *Physical Review Letters* **101**, 076402 (2008)

$$H = -t \sum_{\langle i,j\rangle,\sigma} (c^\dagger_{i,\sigma} c_{j,\sigma} + c^\dagger_{j,\sigma} c_{i,\sigma}) + U \sum_{i=1}^{N} n_{i\uparrow} n_{i\downarrow}$$

$+ S.O.C$

SOC = from classical to quantum !

Metal-insulator transition
T. F. Qi *et* al, *Phys. Rev. B* **86**, 125105 (2012)

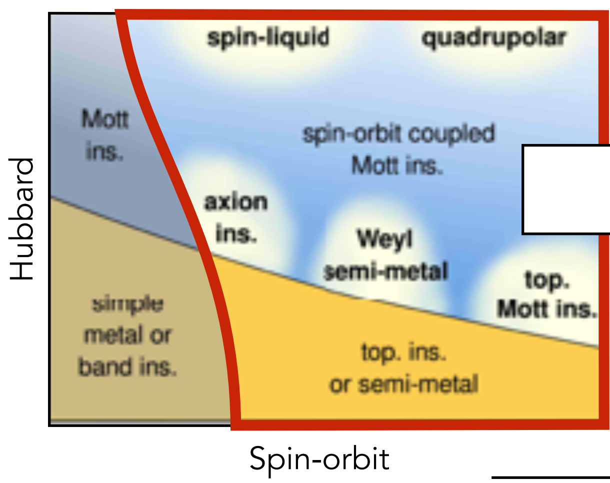
3D quantum spin liquids
Itamar Kimchi *et al*, *Phys. Rev. B* **90**, 205126 (2014)

Unconventional superconductivity (RVB model)
Y. J. Yan *et al*, *Phys. Rev. X* **5**, 041018 (2015)

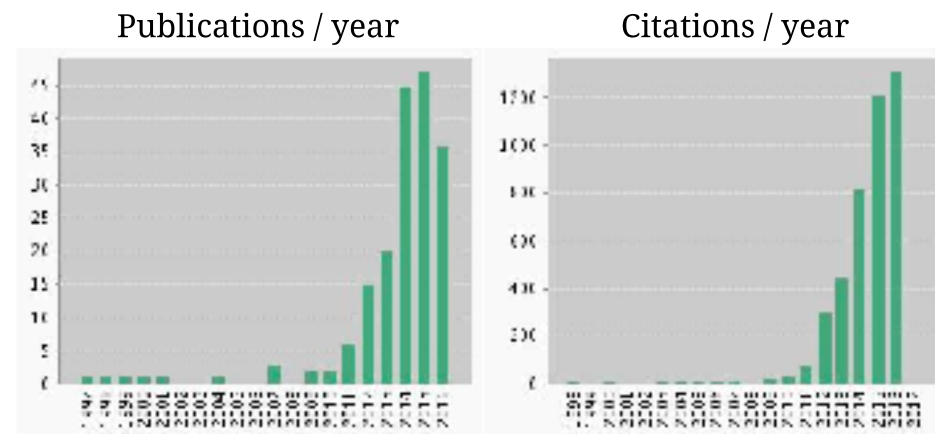
Topological Mott insulator
W. Witczak-Krempa *et al*, *Ann. Rev. of Cond. Mat. Phys.* (2014)

Bond directional interactions
Saeed S. Jahromi *et al*, *Phys. Rev. B* **94**, 125145 (2016)

Spin-orbit coupling



Iridates

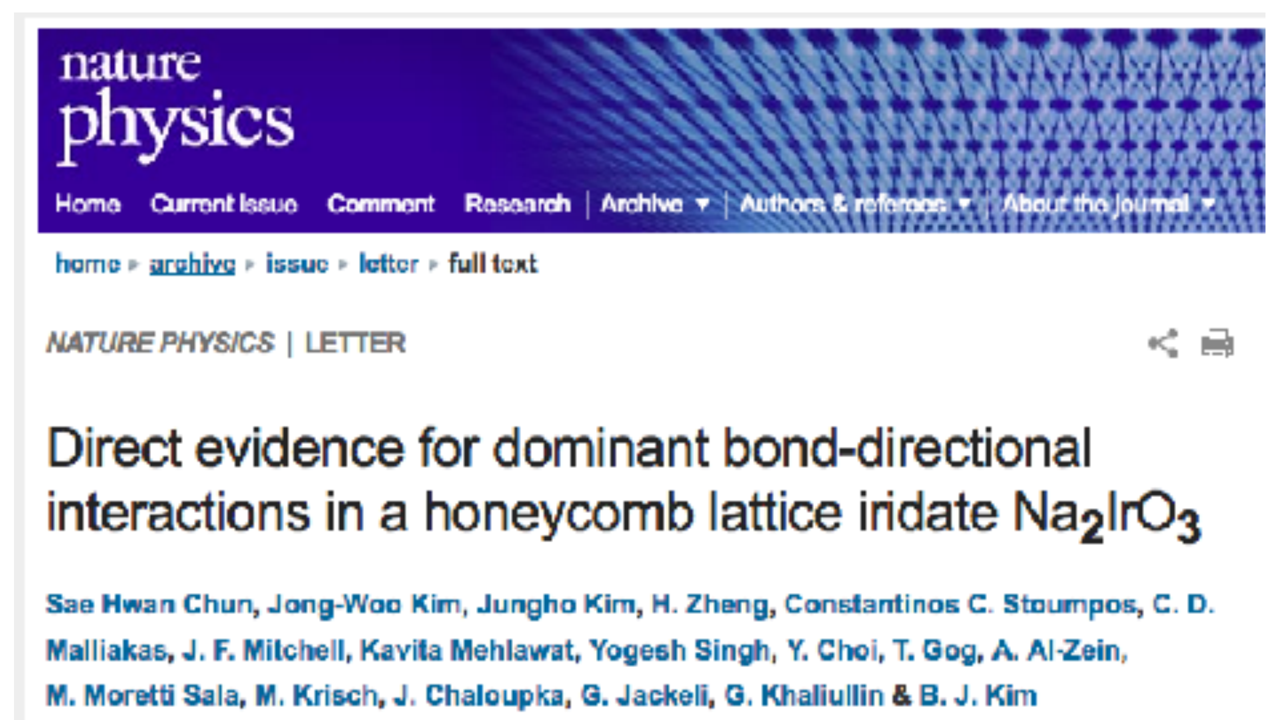


The road to Quantum Spin Liquid: Kitaev

$$\hat{H} = -J_x \sum_{x-\text{links}} \hat{\sigma}_i^x \hat{\sigma}_j^x - J_y \sum_{y-\text{links}} \hat{\sigma}_i^y \hat{\sigma}_j^y - J_z \sum_{z-\text{links}} \hat{\sigma}_i^z \hat{\sigma}_j^z$$

Honeycomb and hyper-honeycomb lattices
Triggered by spin-orbit coupling

Stabilizes a quantum spin liquid state !


nature physics

Home | Current issue | Comment | Research | Archive | Authors & referees | About the journal

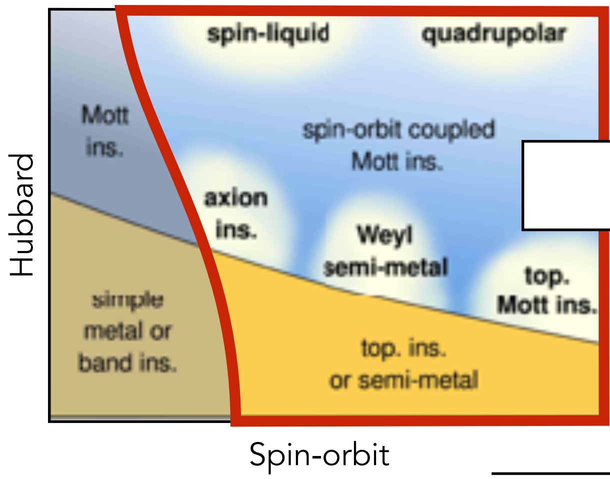
home ▸ archive ▸ issue ▸ letter ▸ full text

NATURE PHYSICS | LETTER

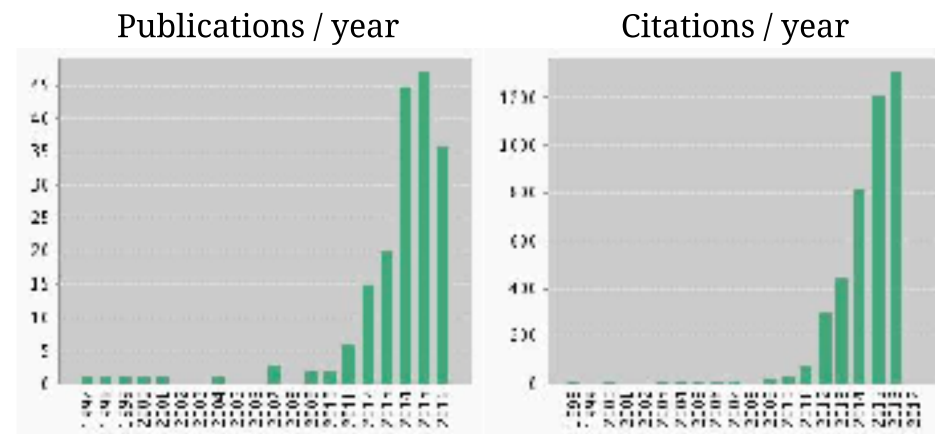
Direct evidence for dominant bond-directional interactions in a honeycomb lattice iridate Na_2IrO_3

Sae Hwan Chun, Jong-Woo Kim, Jungho Kim, H. Zheng, Constantinos C. Stoumpos, C. D. Malliakas, J. F. Mitchell, Kavita Mehlawat, Yogesh Singh, Y. Choi, T. Gog, A. Al-Zein, M. Moretti Sala, M. Krisch, J. Chaloupka, G. Jackeli, G. Khaliullin & B. J. Kim

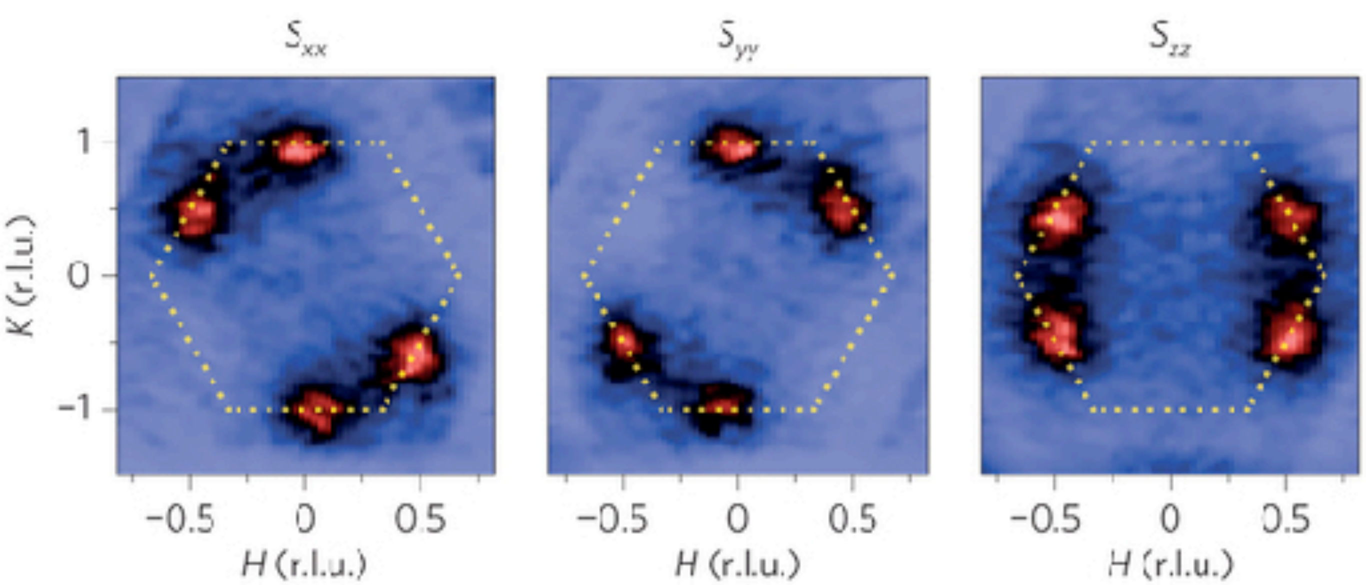
Spin-orbit coupling

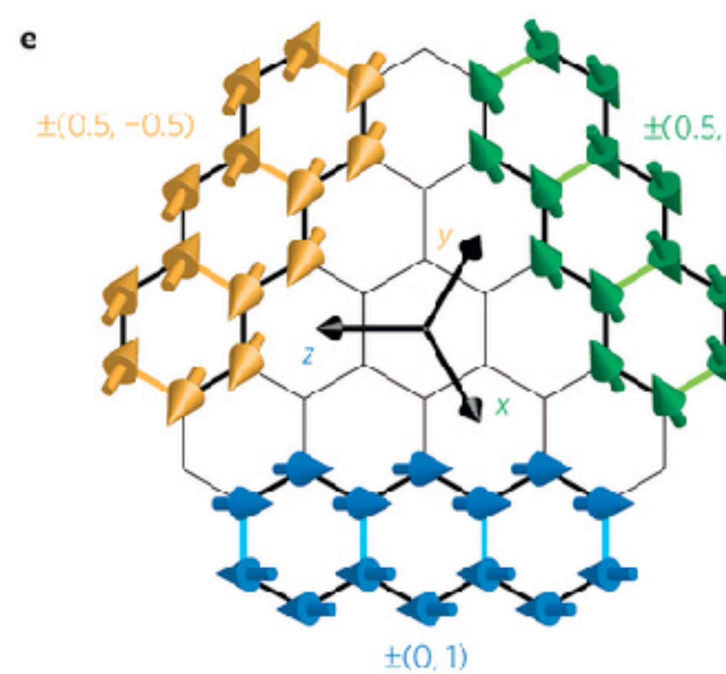


Iridates



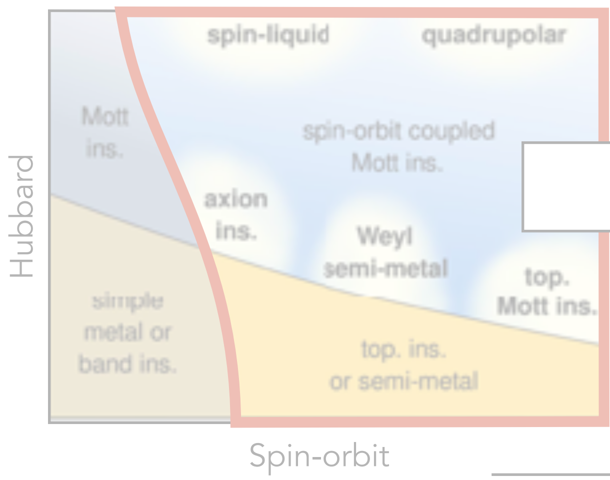
Anisotropic Hamiltonian: Kitaev



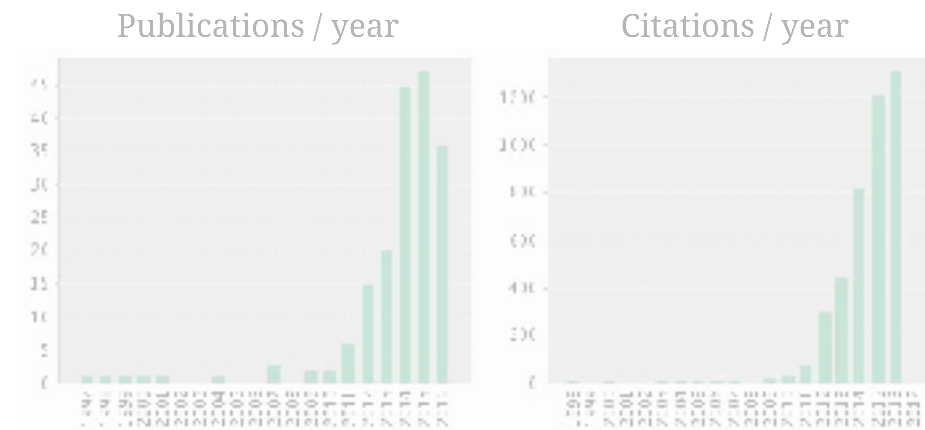


Small single crystals !
Pseudo-spin 1/2

Spin-orbit coupling

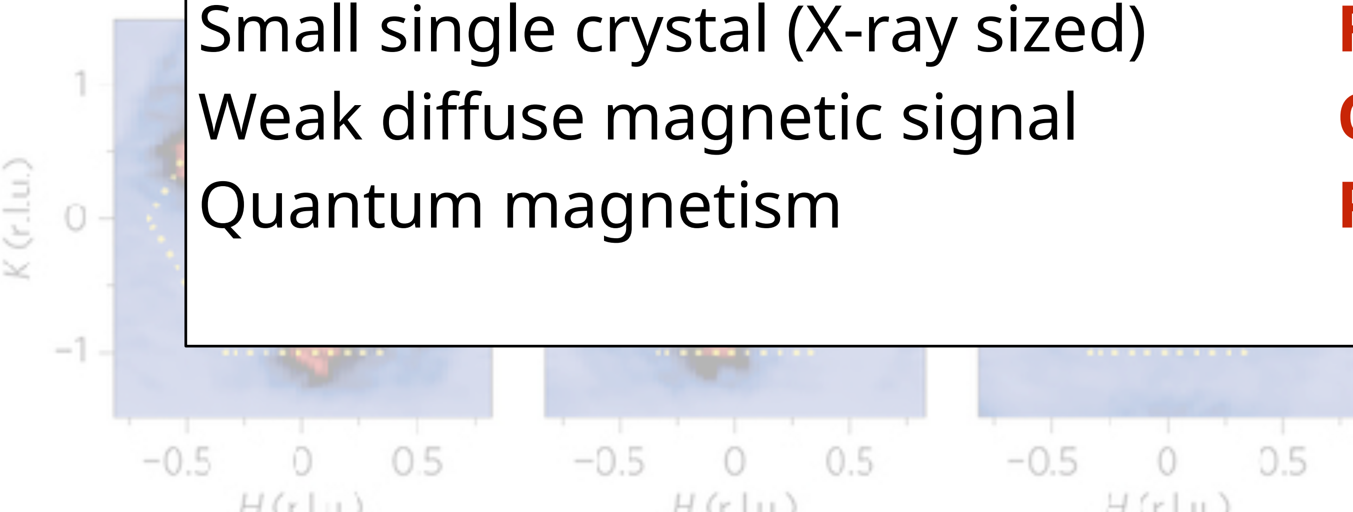


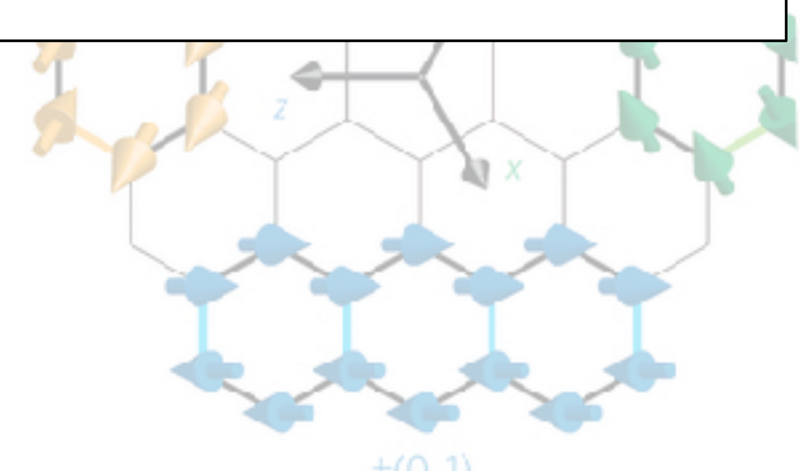
Iridates



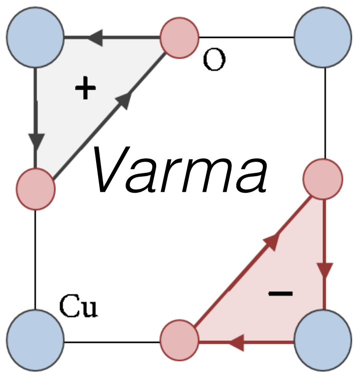
Anisotropic Hamiltonian: Kitaev

Small single crystal (X-ray sized)	**Focusing < $1mm^2$**
Weak diffuse magnetic signal	**Collimation of scattered beam**
Quantum magnetism	**Polarization analysis**

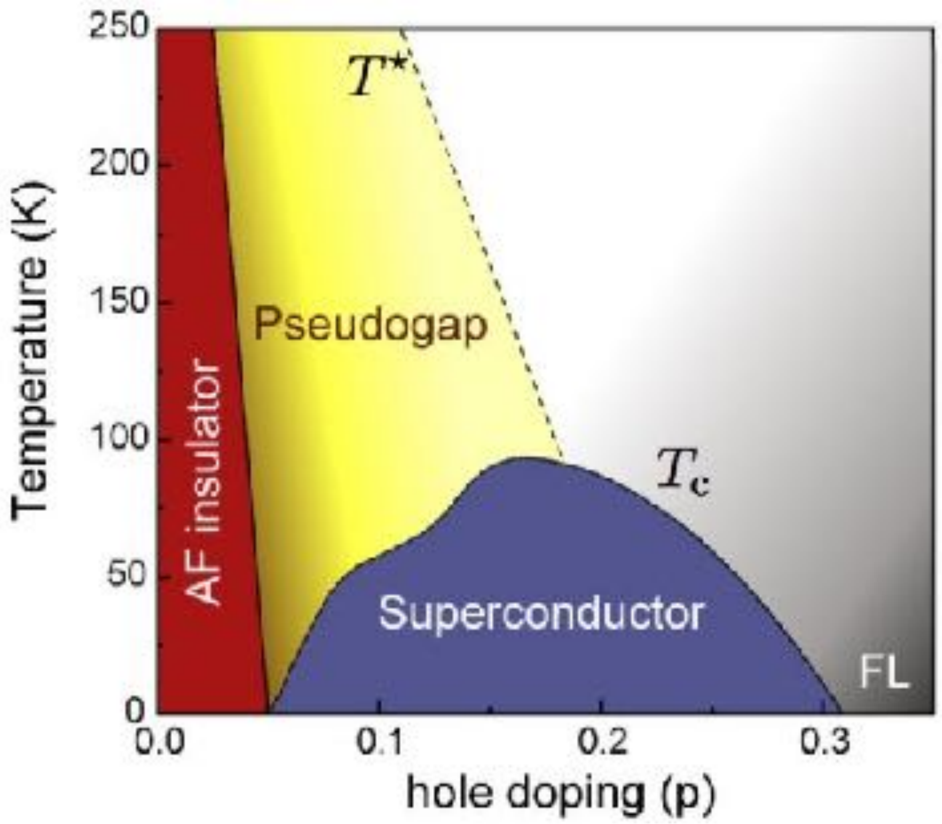




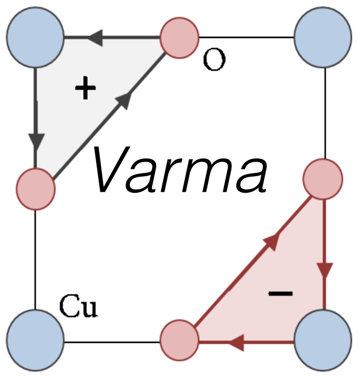
HT$_c$ superconductivity



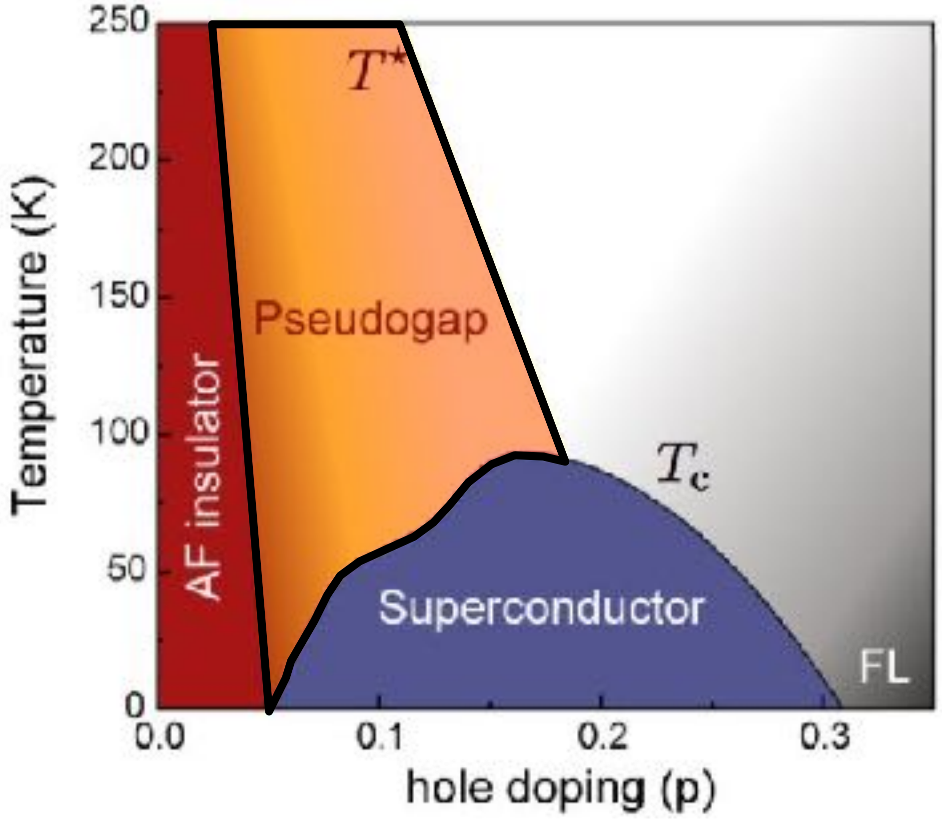
Origin of the pseudo-gap phase



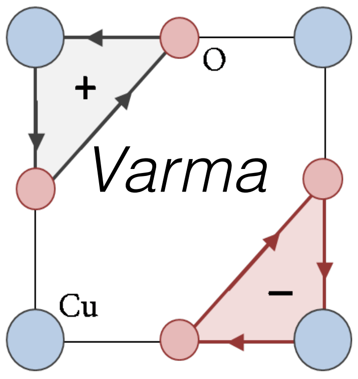
HT_c superconductivity



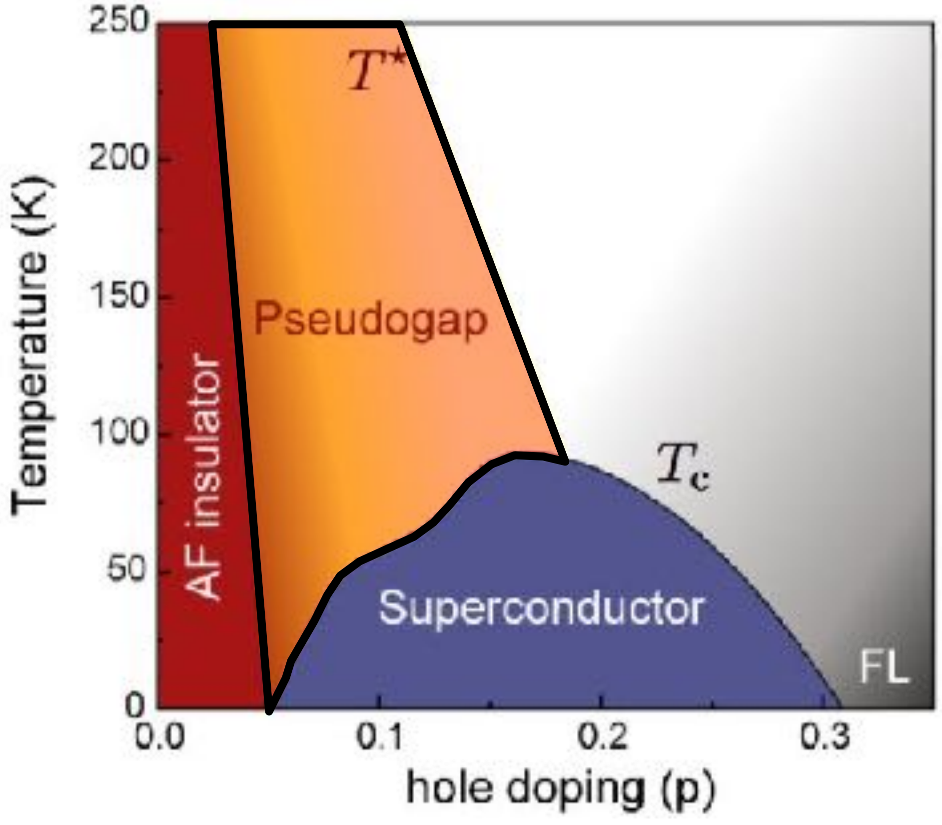
Origin of the pseudo-gap phase

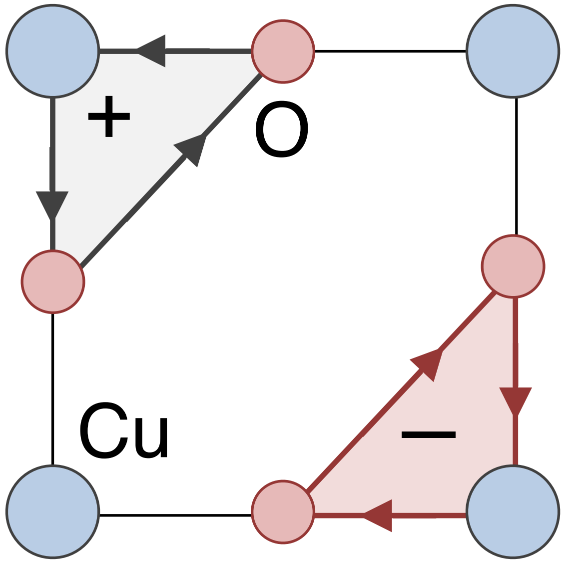


HT$_c$ superconductivity



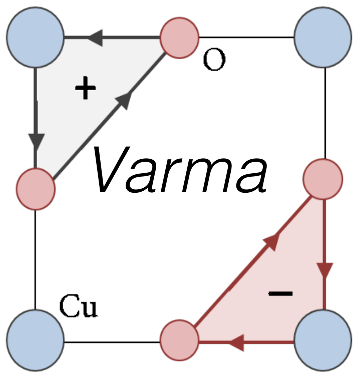
Origin of the pseudo-gap phase



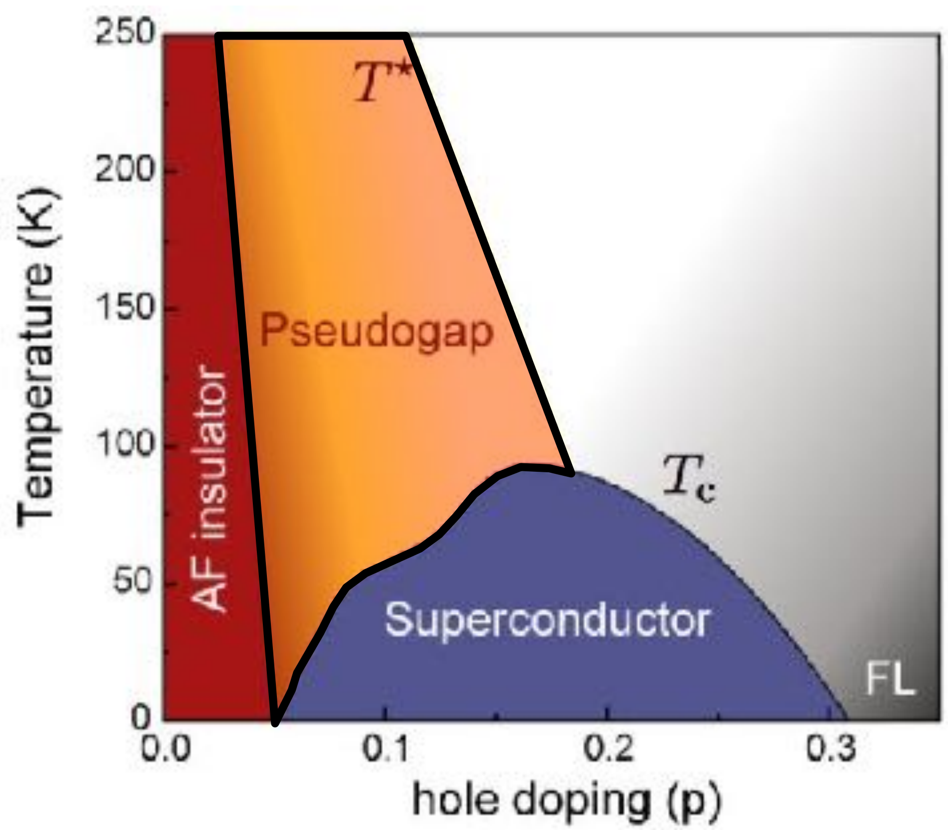


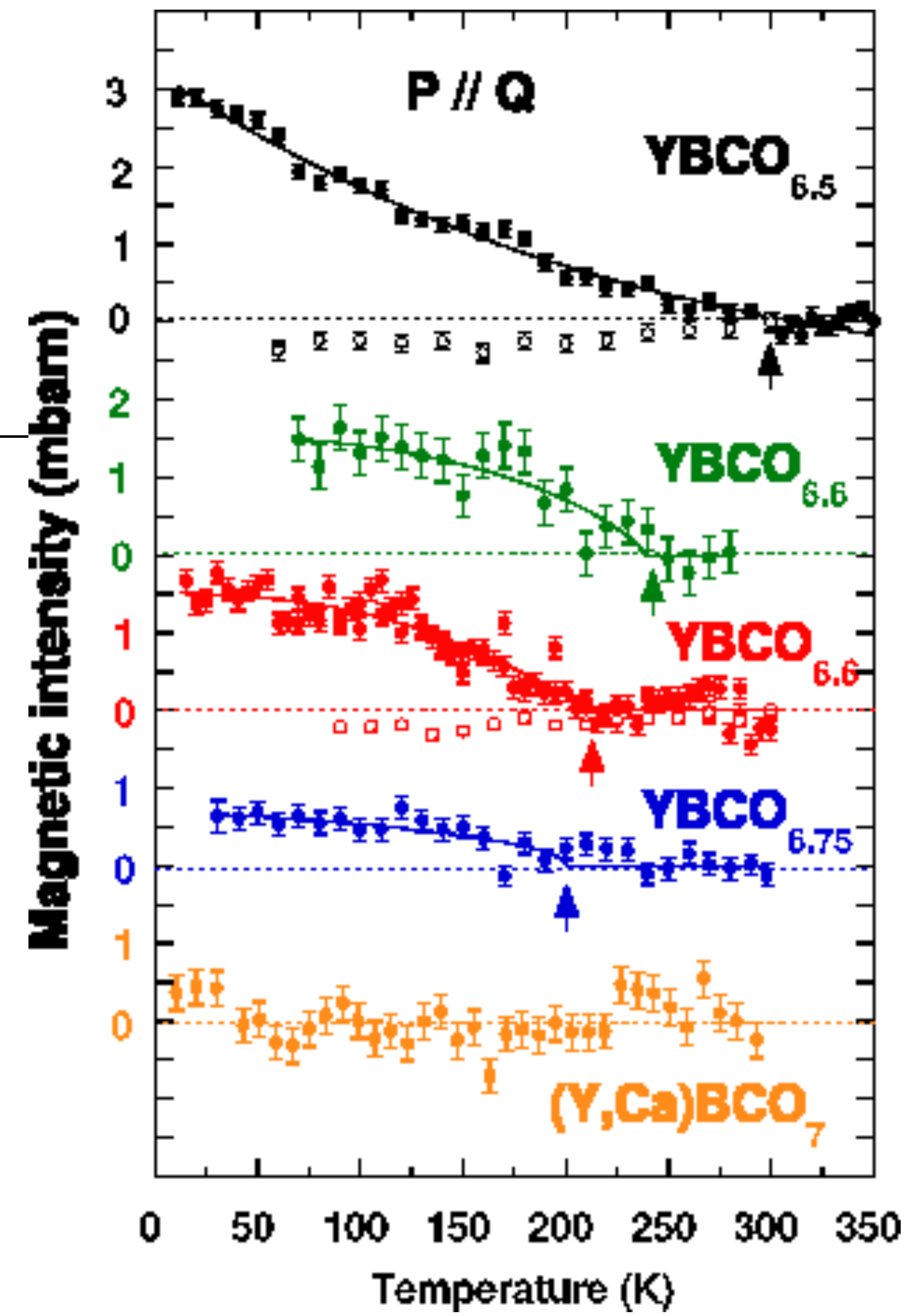
Varma, *Phys. Rev. B* **73**, 155113 (2006)

HT_c superconductivity



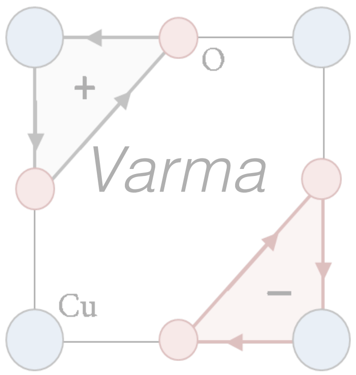
Origin of the pseudo-gap phase



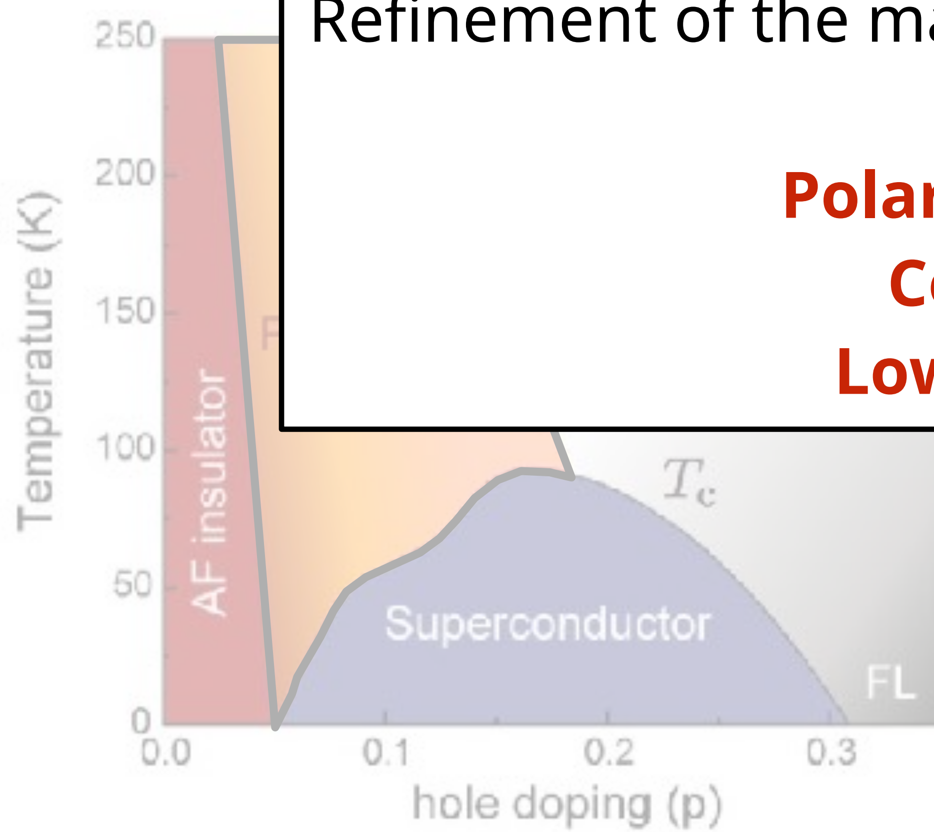


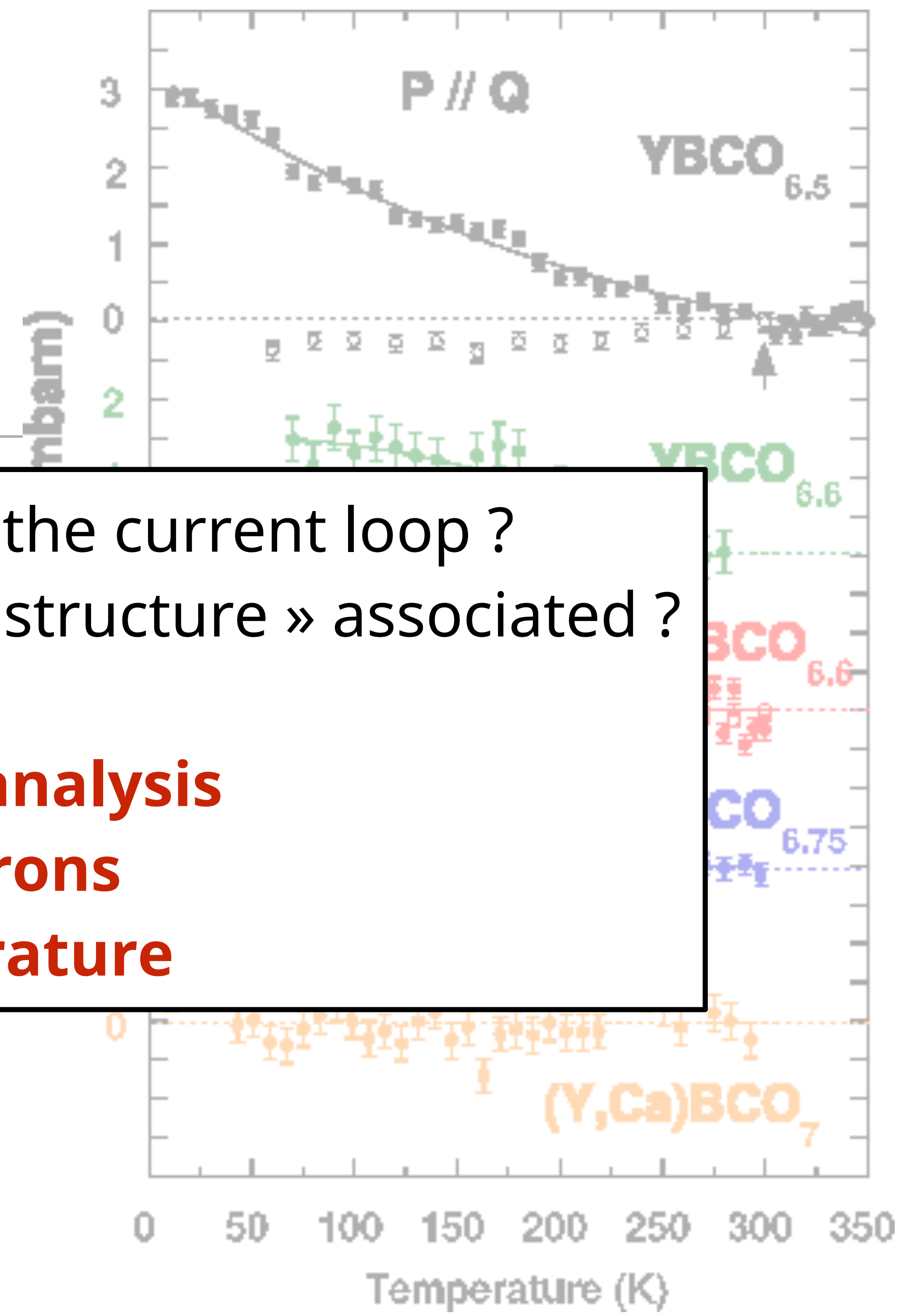
B. Fauqué *et al.*, *PRL* **96,** 197001 (2006)

HT_c superconductivity



Origin of the pseudo-gap phase





Magnetic form factor of the current loop ?

Refinement of the magnetic « structure » associated ?

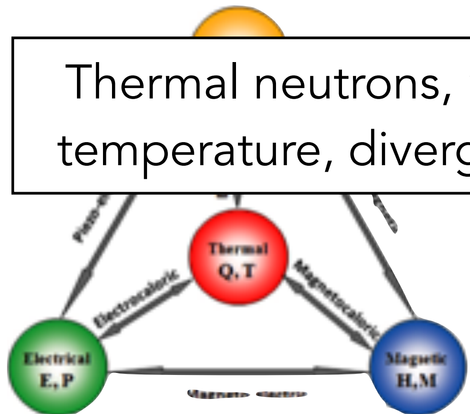
Polarization analysis

Cold neutrons

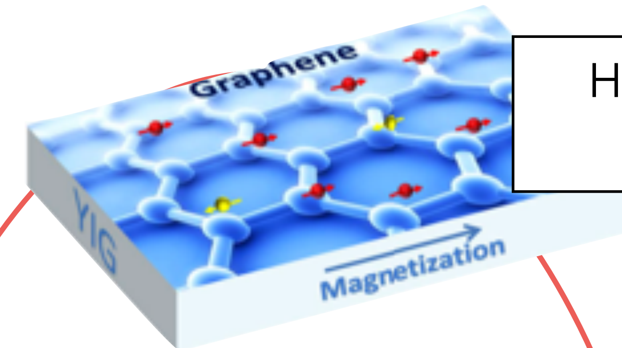
Low temperature

B. Fauqué *et al.*, *PRL* **96,** 197001 (2006)

The science behind MAGiC

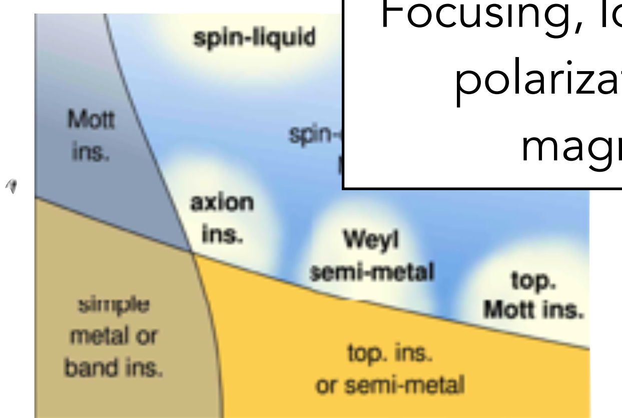


Thermal neutrons, magnetic field, temperature, divergence, focusing



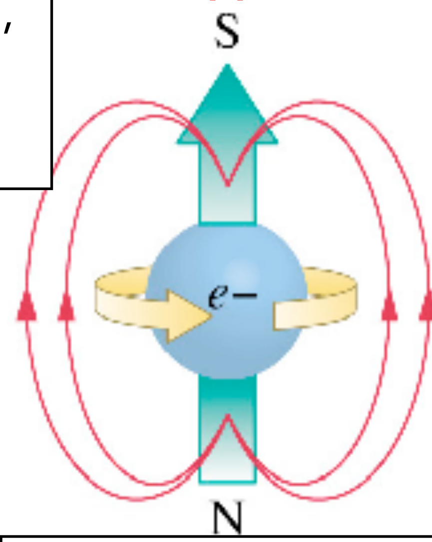
High flux, thermal neutrons, polarization analysis

Phys. Rev. Lett. **114**, 016603

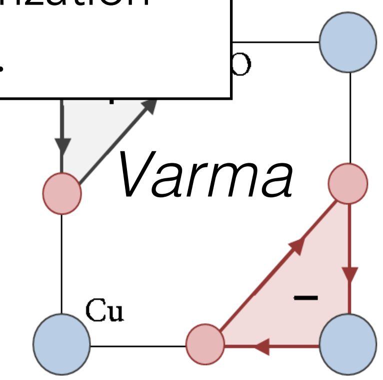


Focusing, low temperature, polarization analysis, magnetic field

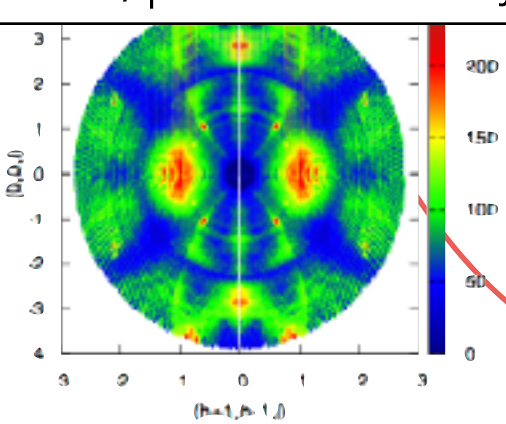
arXiv:1305.2193v2



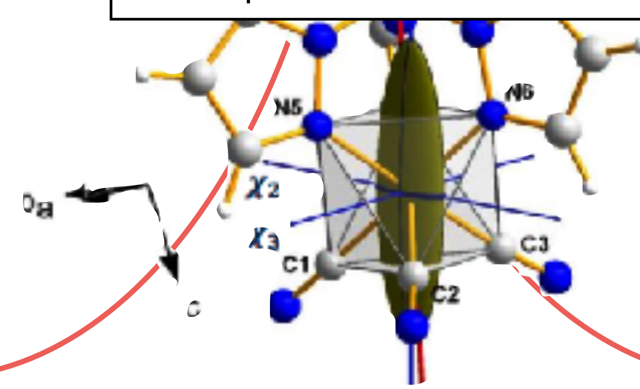
Low temperature, cold neutrons, polarization analysis.



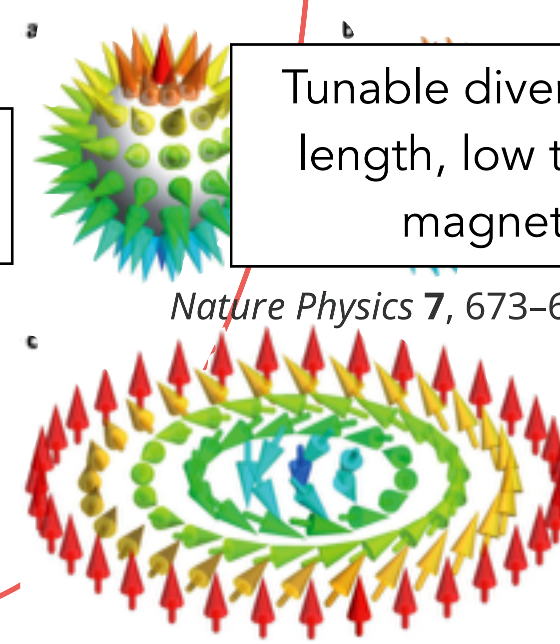
Sub-K, magnetic field, cold neutrons, polarization analysis



Magnetic field, half-polarized, low temperature, thermal neutrons



Tunable divergence, pulse length, low temperature, magnetic field.



Nature Physics **7**, 673–674 (2011)

Building for tomorrow

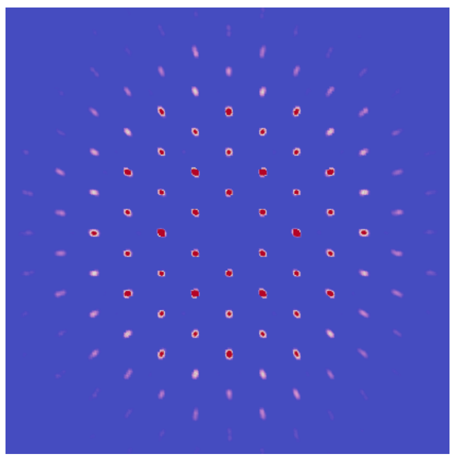
- New scientific trends will emerge in the next decades

- Open land: difficult to predict
- 20 years ago: no spin-liquids, multiferroics, spintronic …

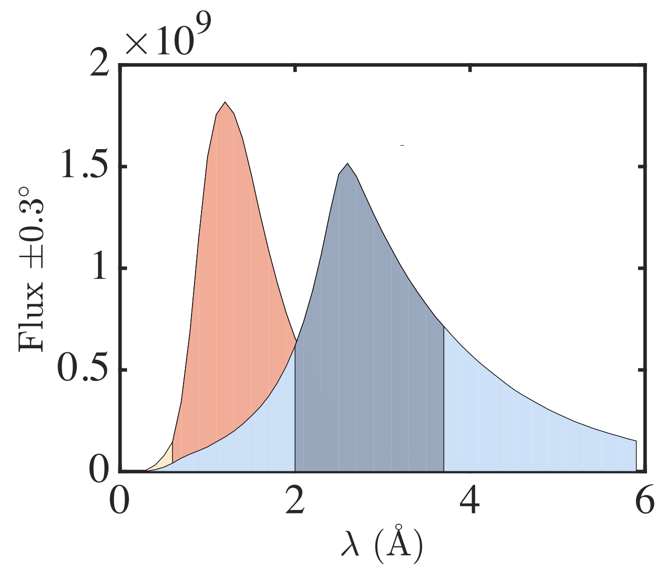
- Instrument needs flexibility/adaptability

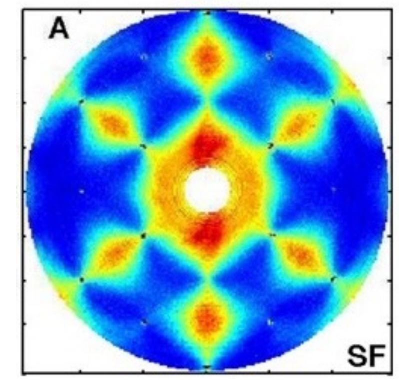
Functional requirements

Spectrum: thermal & cold



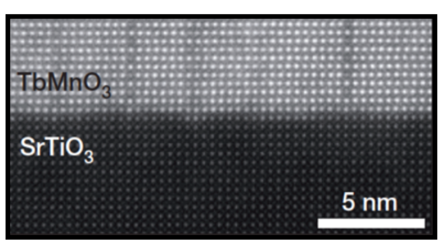
Crystal & magnetic structures
Spin-lattice coupling

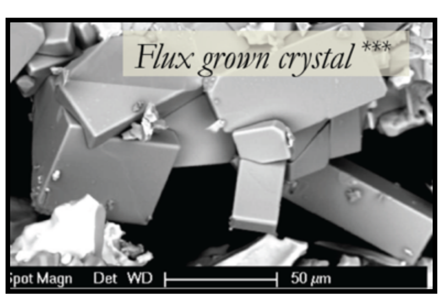




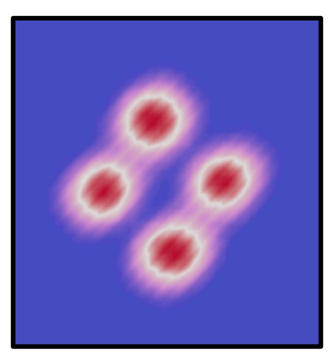
Fundamental magnetism
Diffuse scattering

Focusing



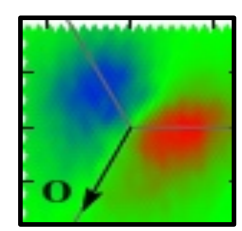


Flexible Q-resolution

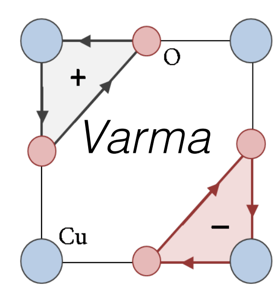


$\Delta Q \sim 10^{-2} \ldots 10^{-3} \text{Å}^{-1}$

Polarised

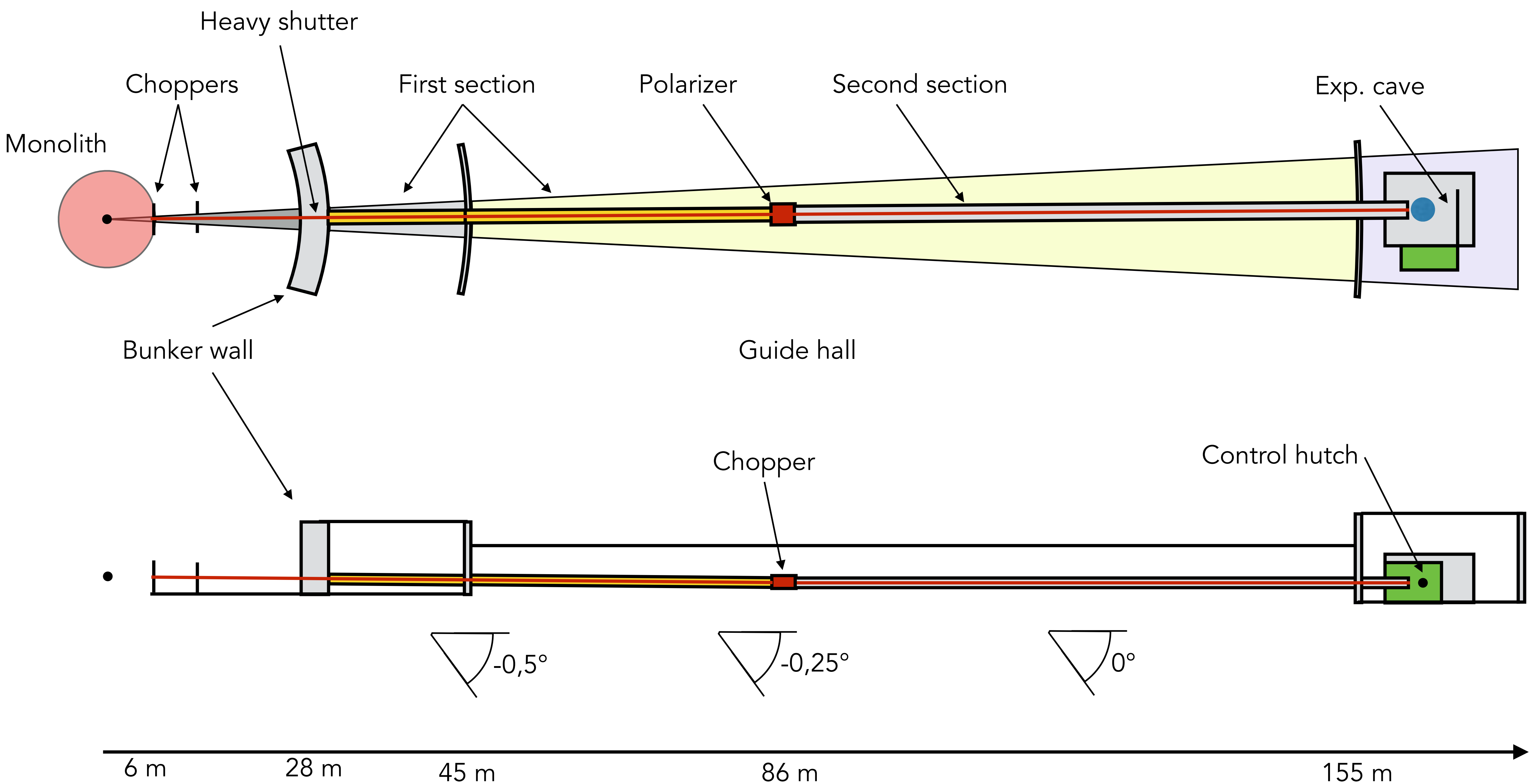


Vector properties
Chirality

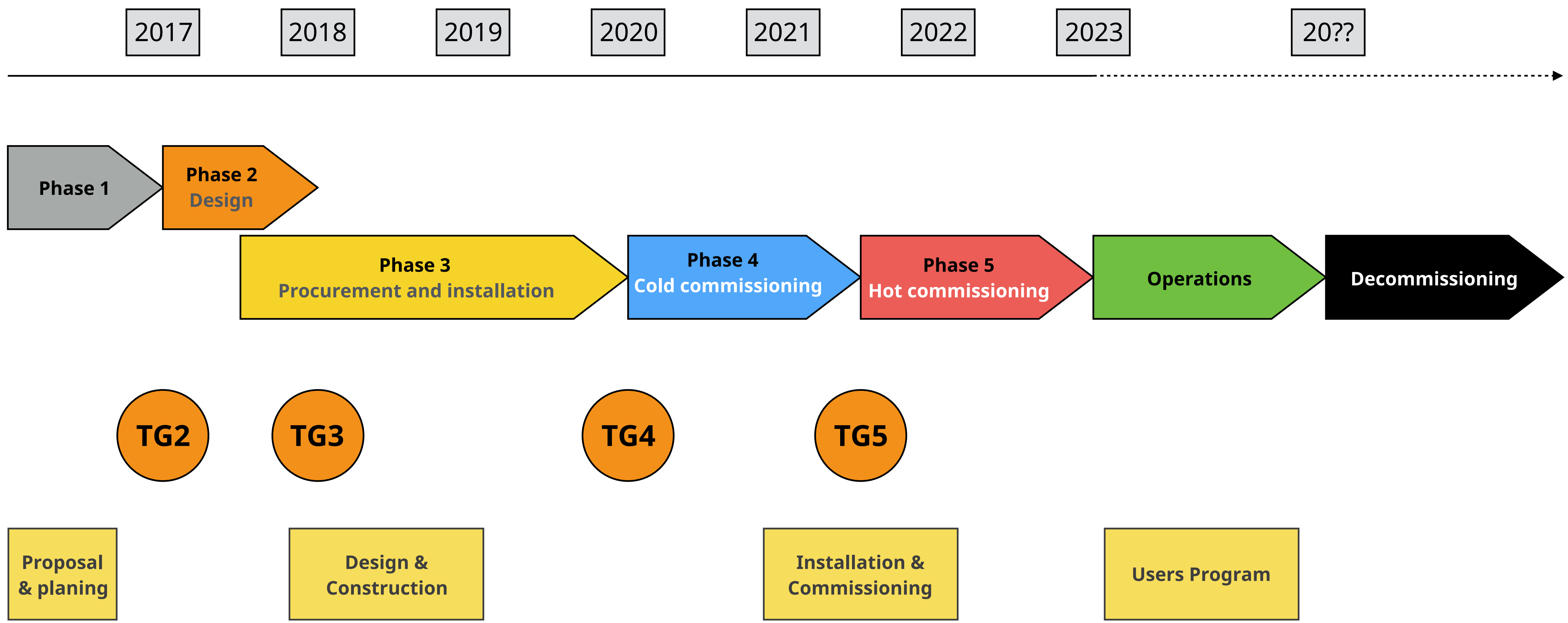


Separation of weak
Magnetic from nuclear
contributions

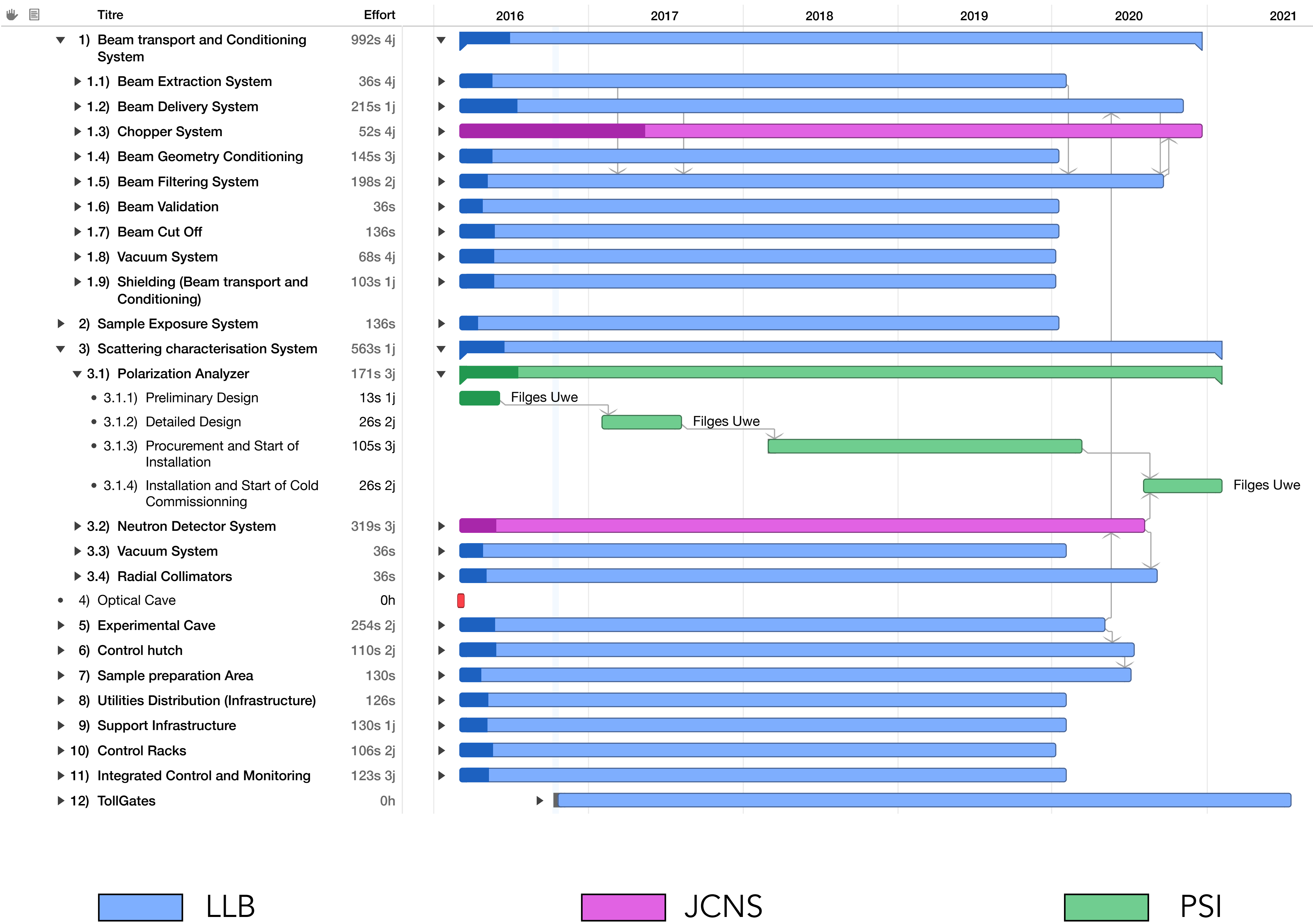
MAGiC layout



Instrument lifecycle



Detailed schedule



Critical Path: polarization analyzer

- 01/06/2016: preliminary design (3 months)
- 01/12/2017: detailed design (7 months)
- 01/03/2018: start of construction (>=24 months)
- 01/06/2020: delivery on site
- 01/06/2020: detectors installation & commissioning
- 01/01/2021: installation & commissioning (6 months)

- Important schedule risk:
  - Detector: CDT is working on DREAM's one
  - Neutron guide: huge load in the next years
  - Choppers

Critical Path: polarization analyzer

- 01/06/2016: preliminary design (3 months)
- 01/12/2017: detailed design (7 months)
- 01/03/2018: start of construction (>=24 months)
- 01/06/2020: delivery on site
- 01/06/2020: detectors installation & commissioning
- 01/01/2021: installation & commissioning (6 months)

- Important schedule risk:
    - Detector: CDT is working on DREAM's one
    - Neutron guide: huge load in the next years
    - Choppers

Early procurement !