Analytis Lab

Analytis Lab

Problems at the frontier of condensed matter physics

- Part I : Introduction.
- Part II : Some current projects.
- Part III : How the Analytis Lab functions.

What do we do?

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Mission Statement:

1. To investigate some of the most difficult problems in condensed matter physics.

What do we do?

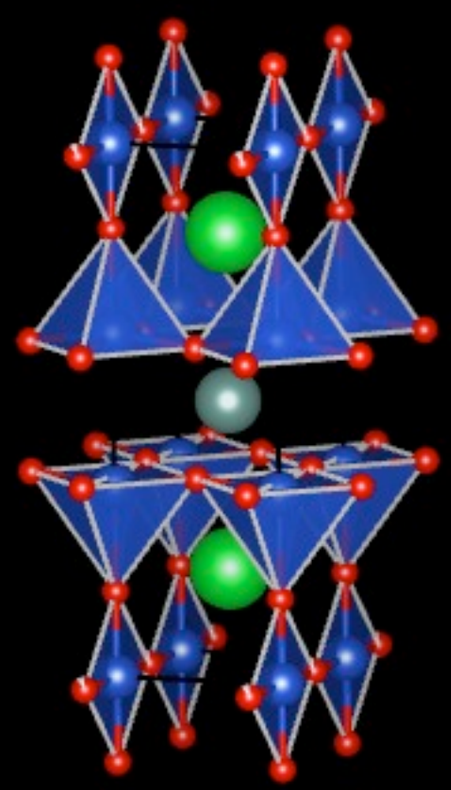
Mission Statement:

1. To investigate some of the most difficult problems in condensed matter physics.

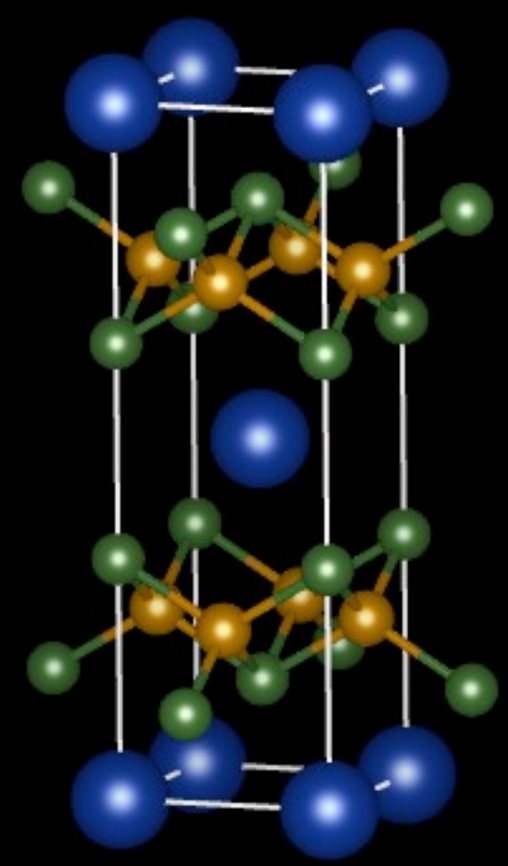
2. To create entirely new problems.

What are the most difficult problems?

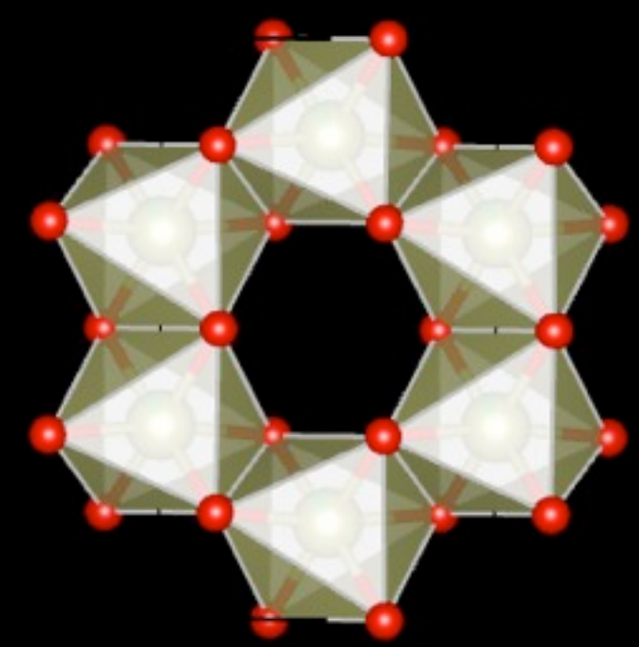
High Temperature superconductivity

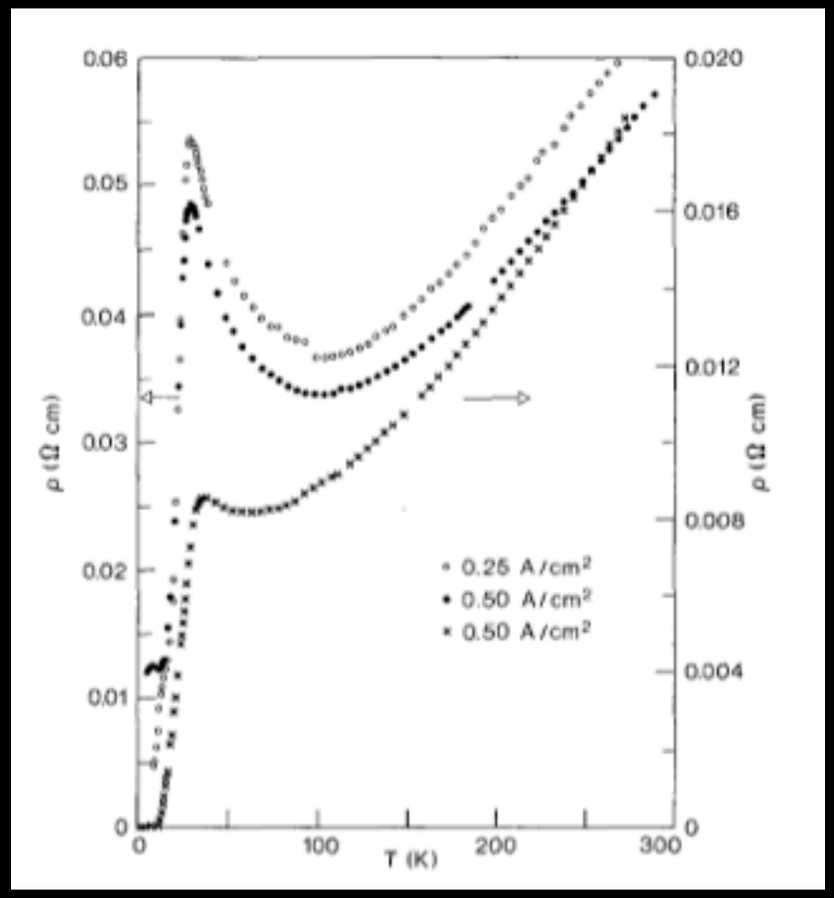


Quantum critical metals

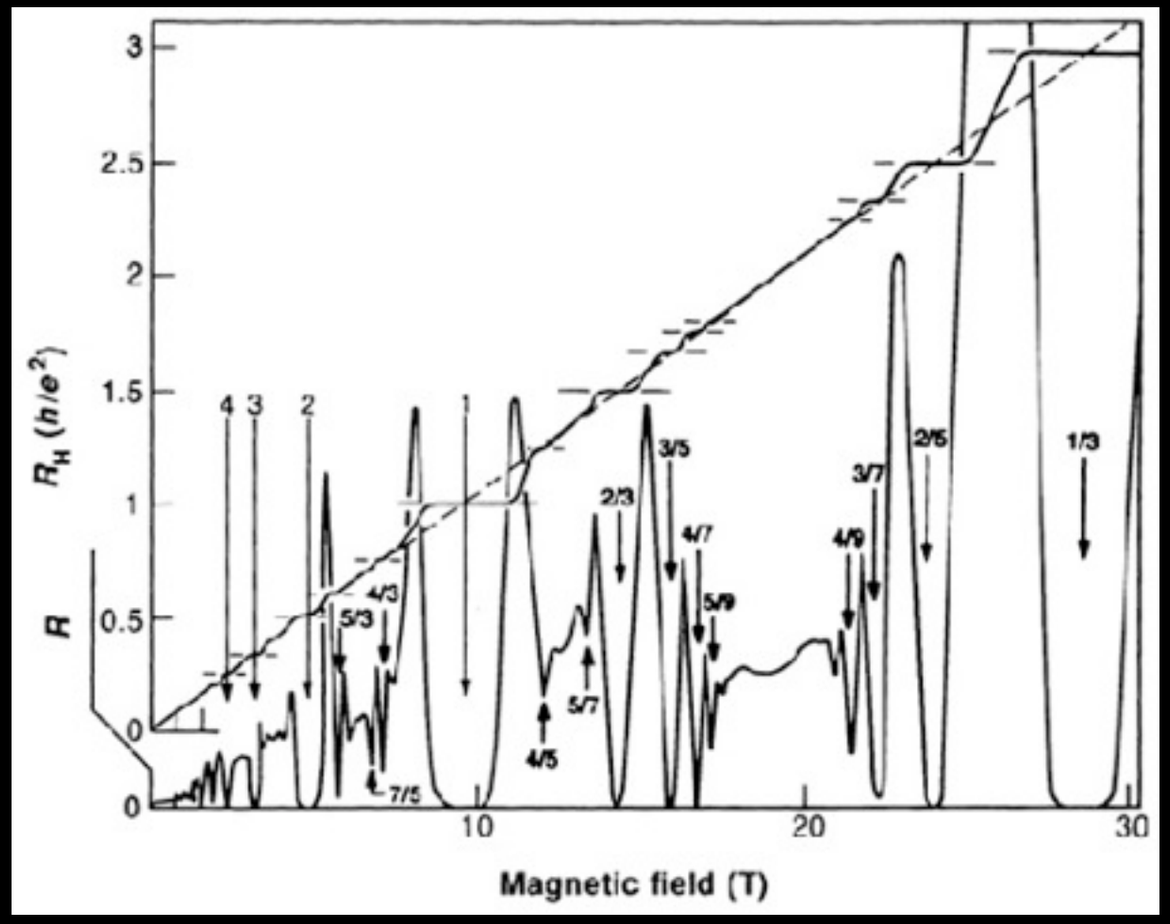


Topology and correlations





Cuprates
Bednorz & Muller 1986



Fractional Quantum Hall
Tsui & Stormer 1982

How do we create new fields?

Quantum foundations of Condensed Matter Physics

Quantum foundations of Condensed Matter Physics

- Heat Capacity

Quantum foundations of Condensed Matter Physics

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- Magnetization

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Quantum foundations of Condensed Matter Physics

- Heat Capacity
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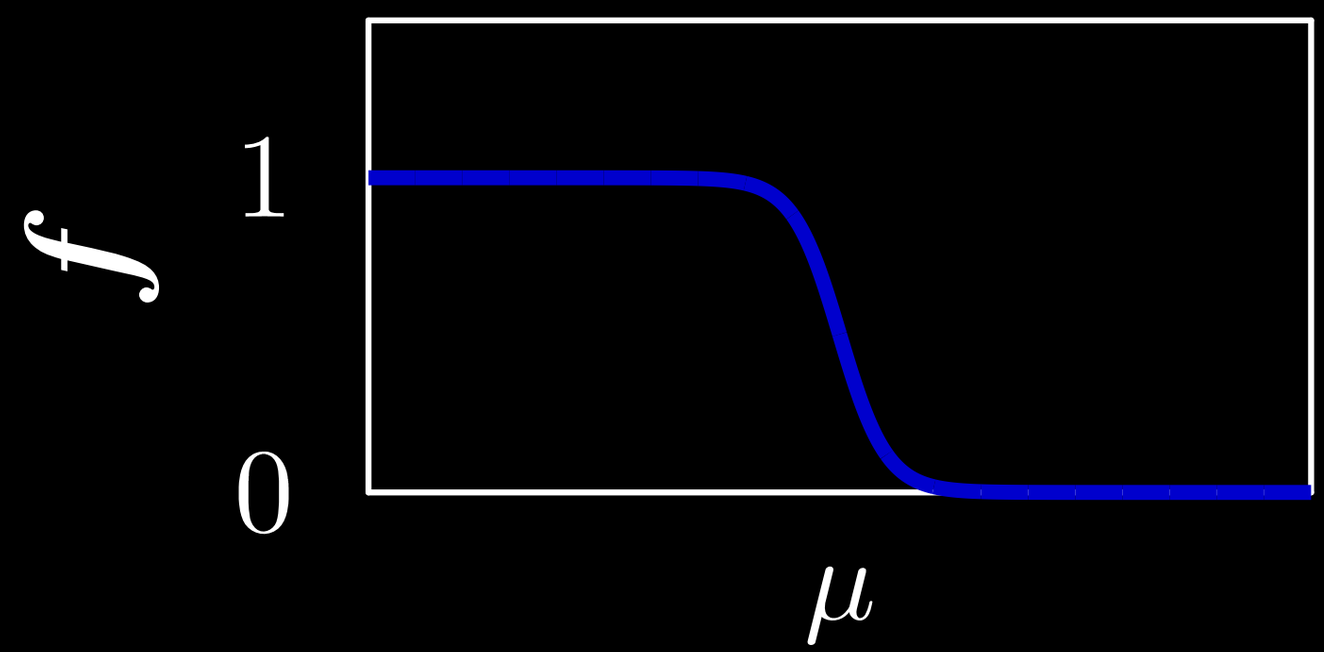
- Resistivity

Answer : Fermi liquid theory

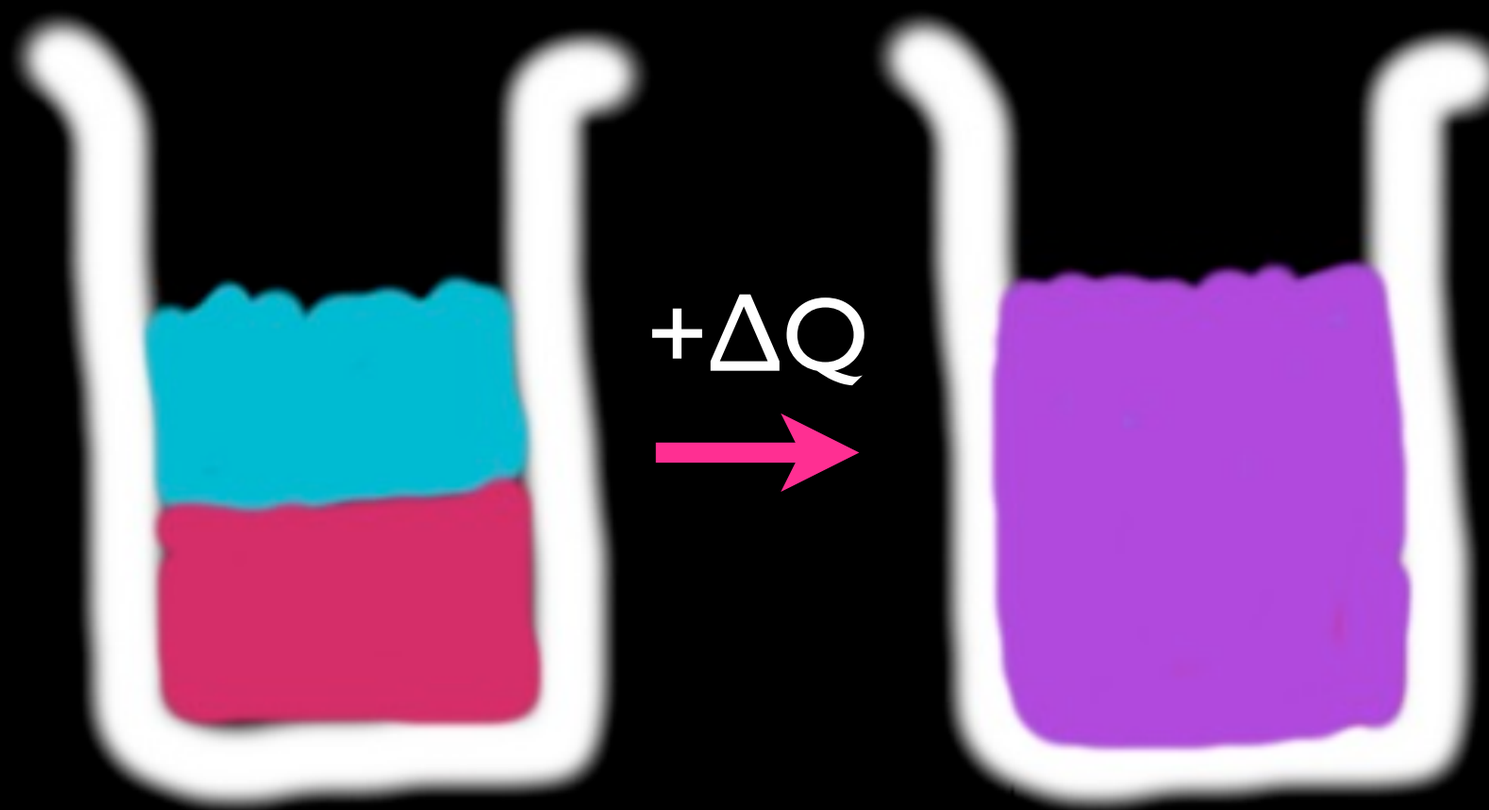


Assume adiabatic continuity

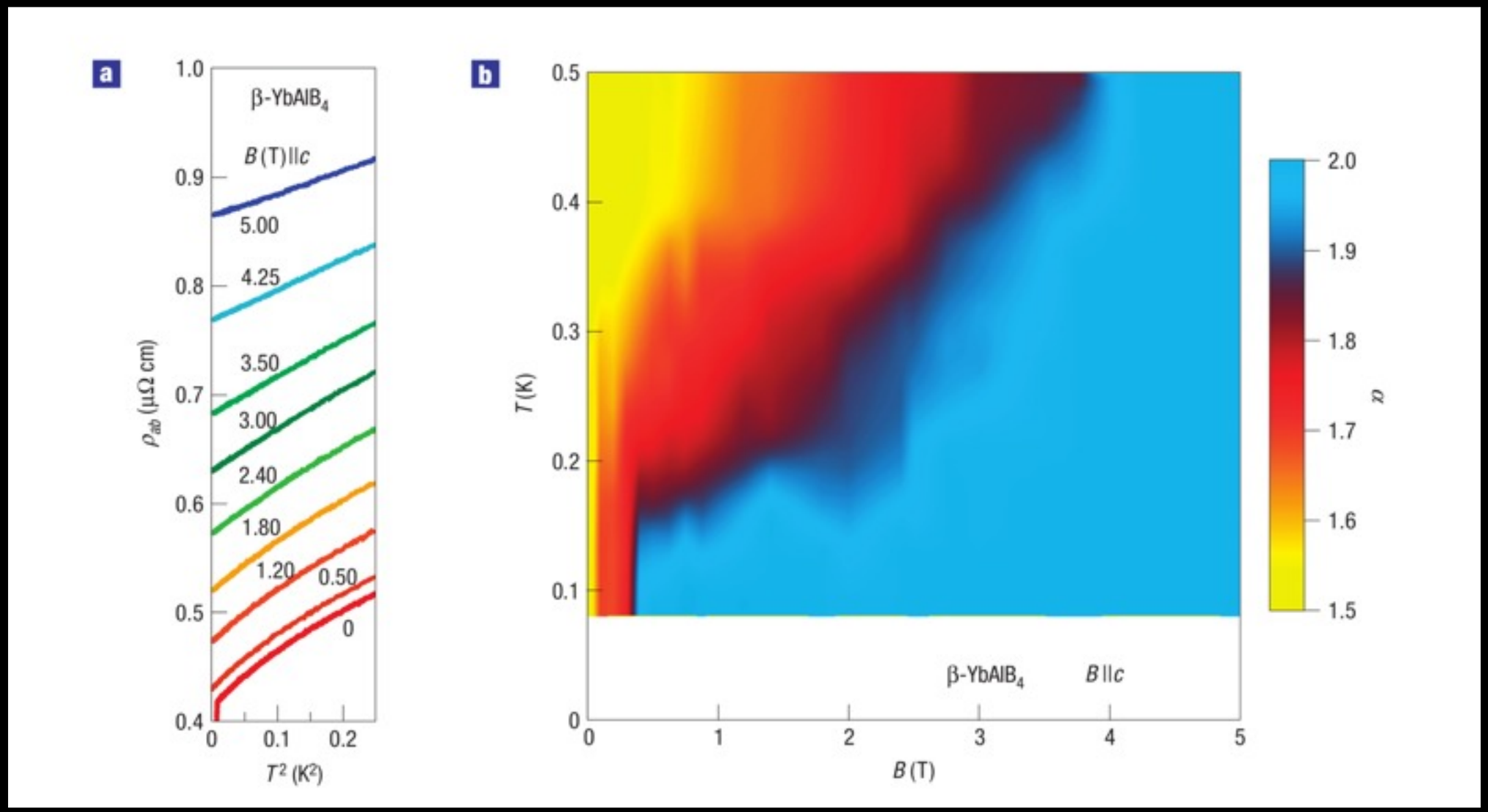
Why are these problems so difficult?

Consider quantum criticality.....

Methanol + Hexane

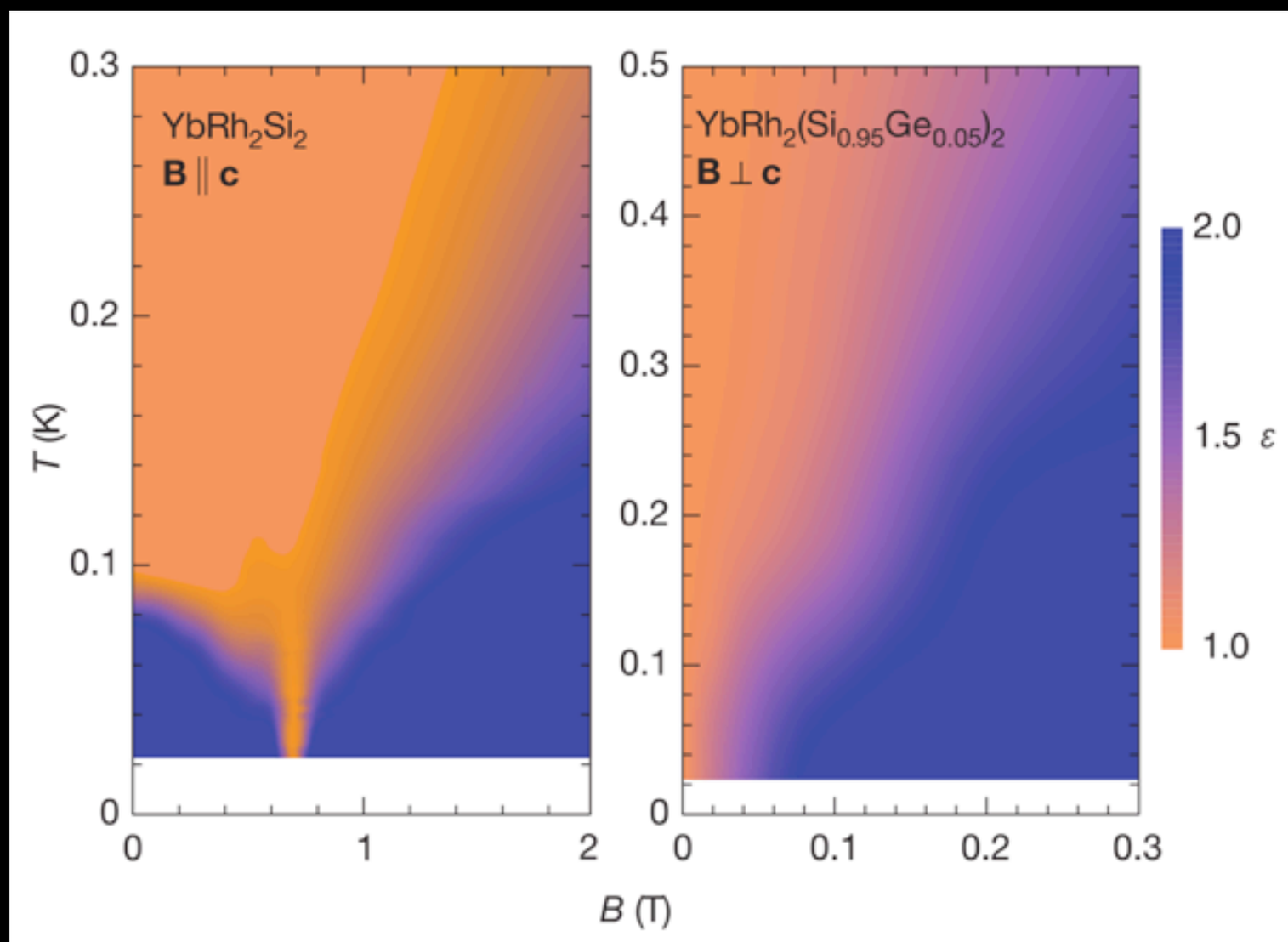


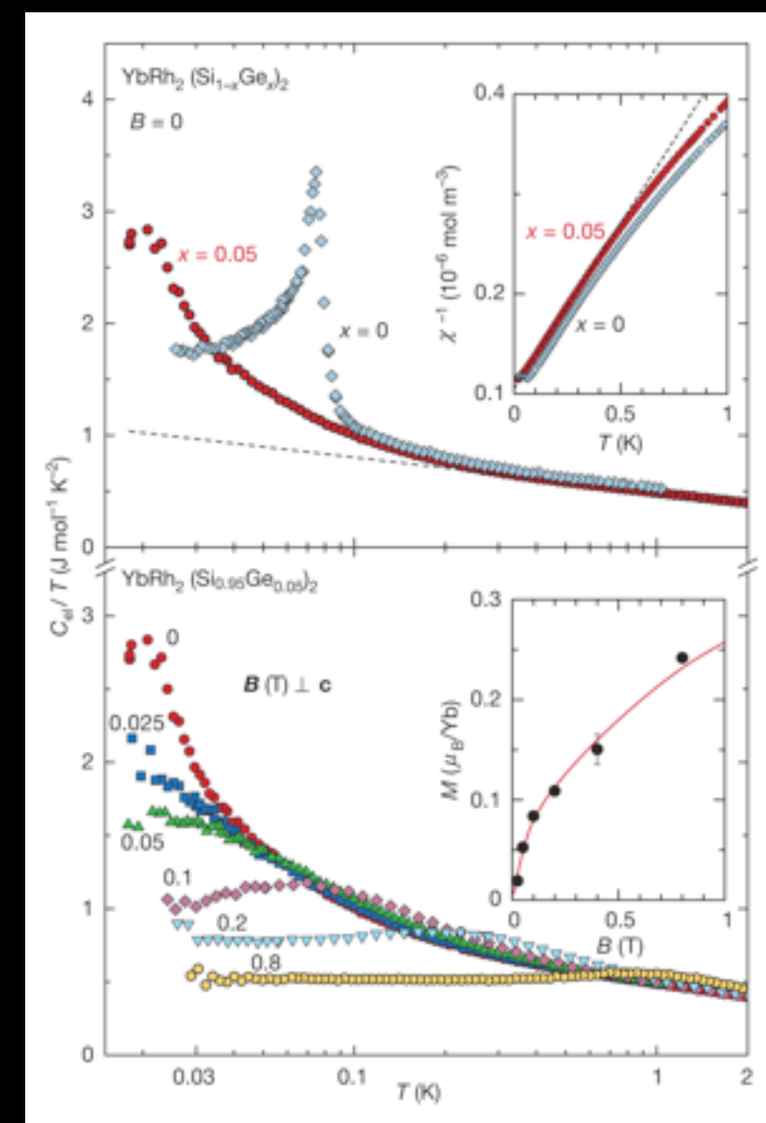
Properties of quantum critical materials : $YbAlB_4$



Nakatsuji et al. Nature Physics 2008

Properties of quantum critical materials :$YbRh_2Si_2$

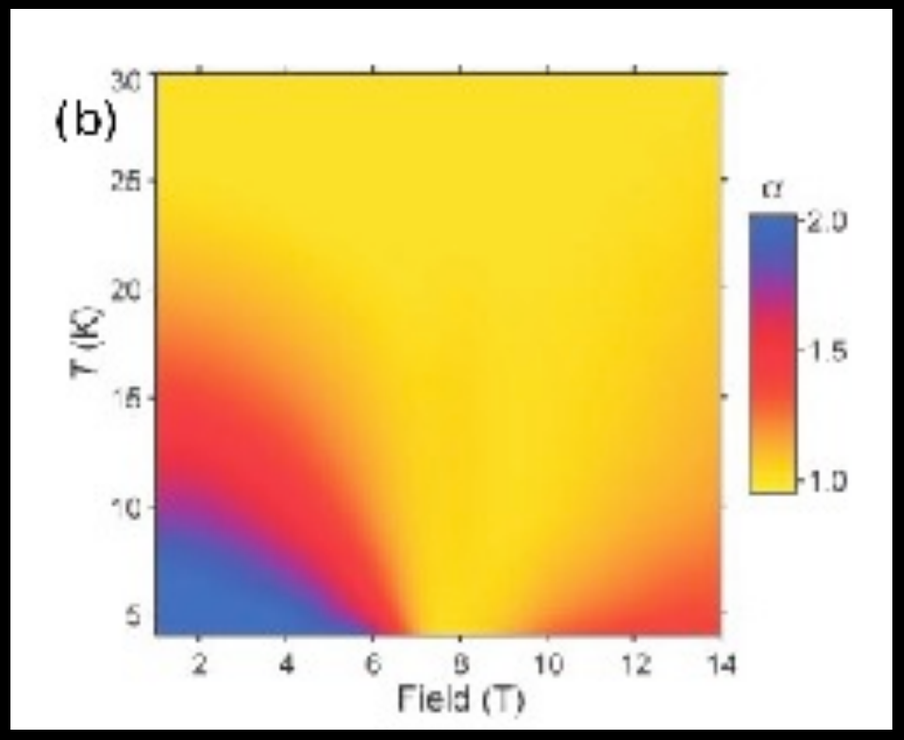




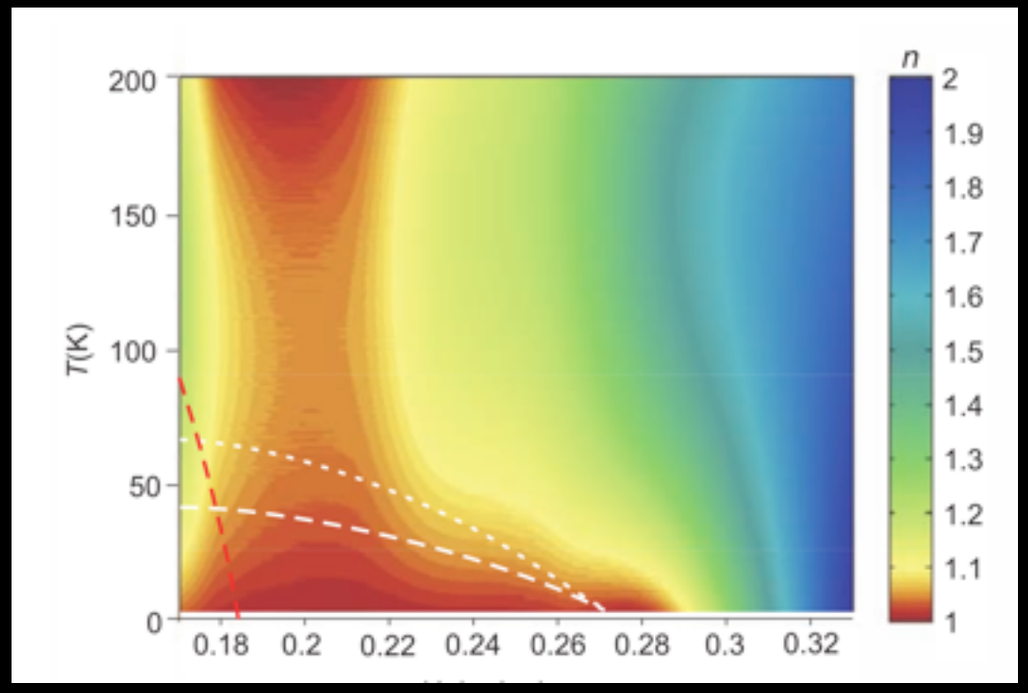
Custers et al. Science 2003

Universality of quantum critical properties

$Sr_3Ru_2O_7$



$La_{2-x}Sr_xCuO_4$



It's not just that we cannot calculate their properties, we don't even have a basic phenomenology.

How do we create new fields?

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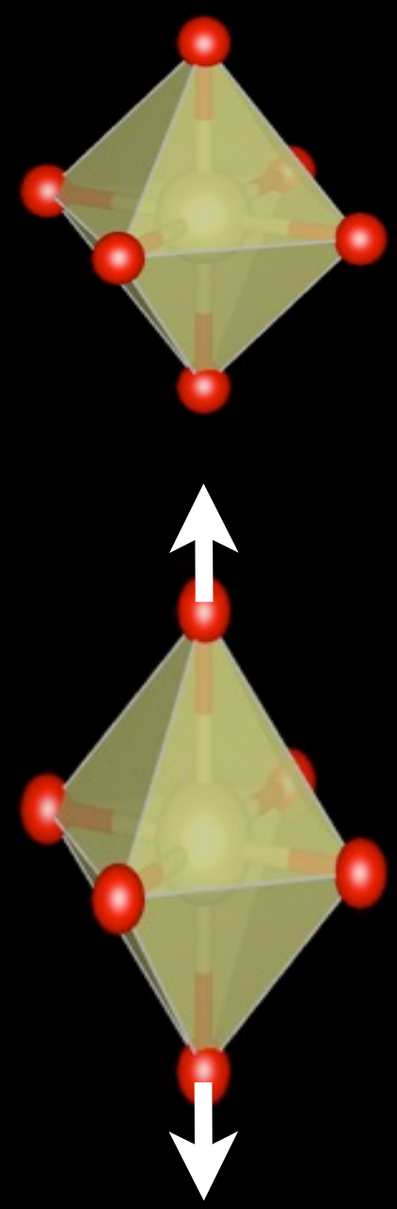
Crystal Field



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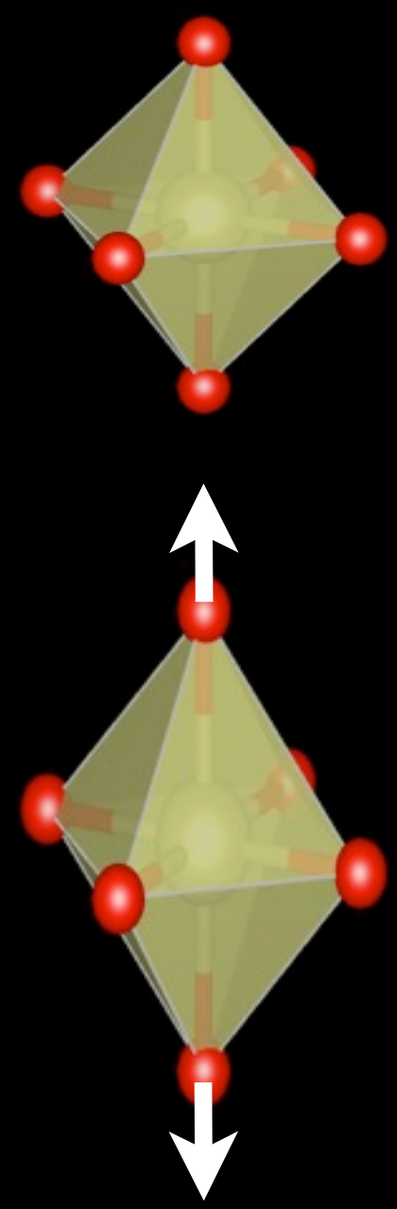
Crystal Field

Spin-orbit



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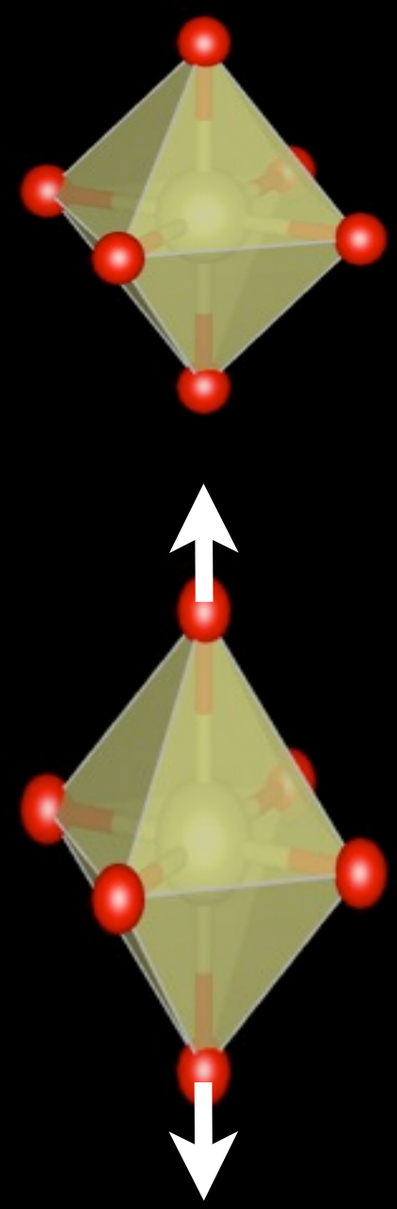
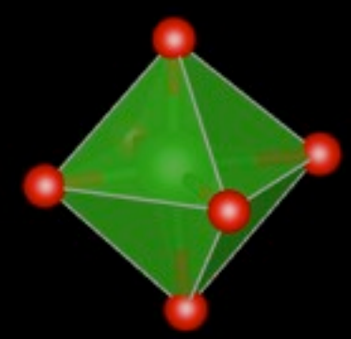


Co



3d

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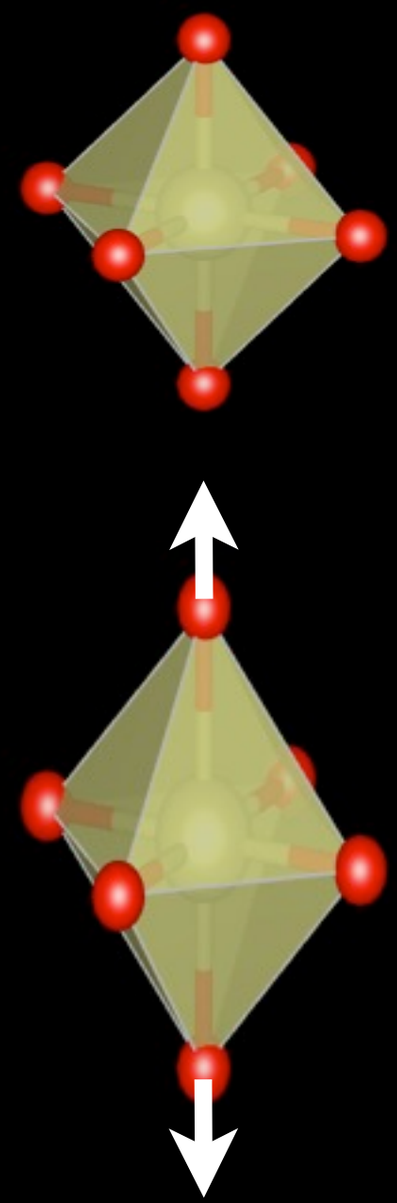

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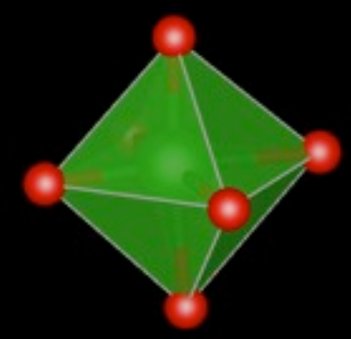
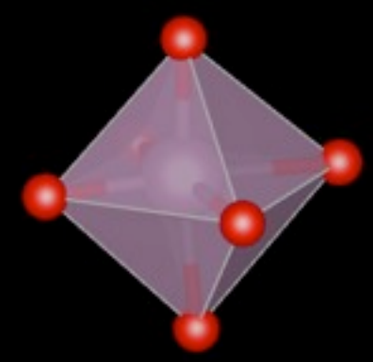


3d

Rh



4d

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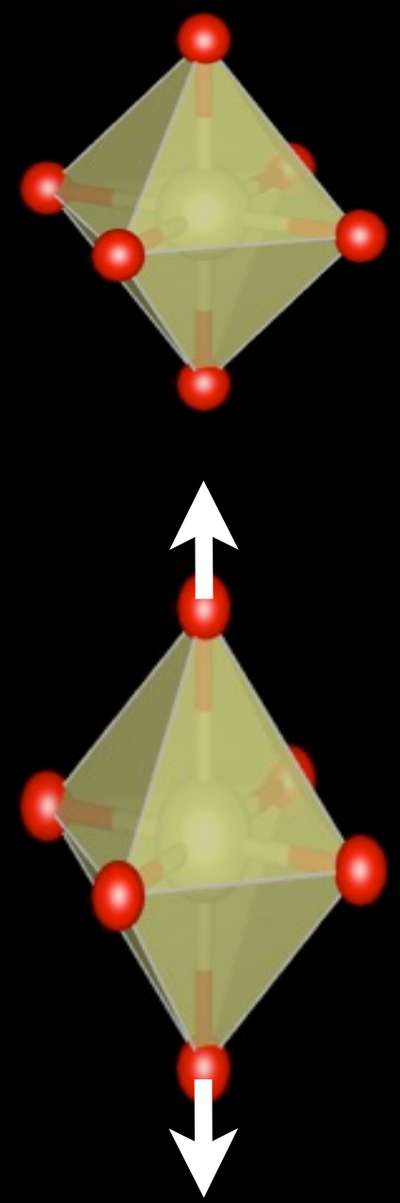
Crystal Field

Spin-orbit



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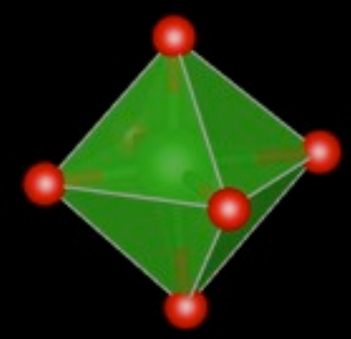

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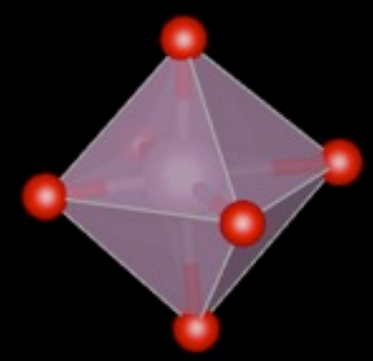
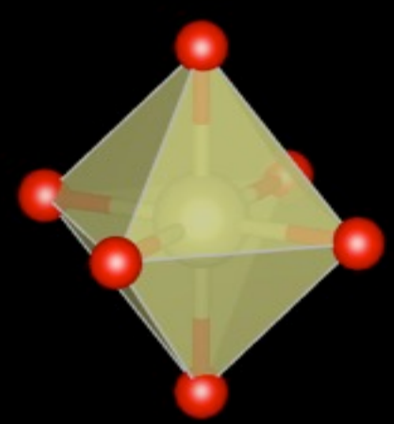
Rh



4d

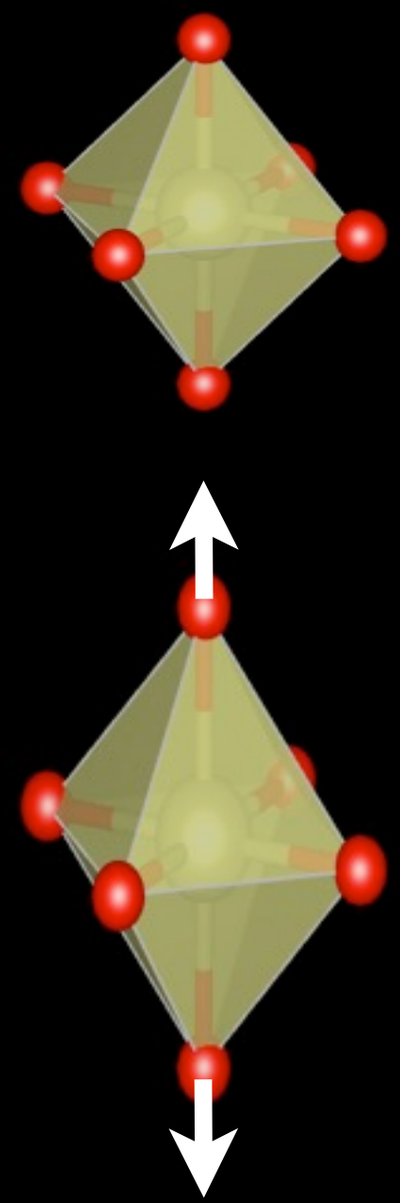
Ir



5d

How do we create new fields?

Crystal Field Spin-orbit Symmetry



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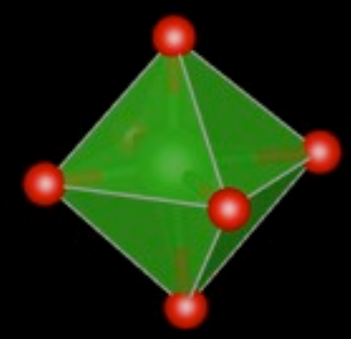

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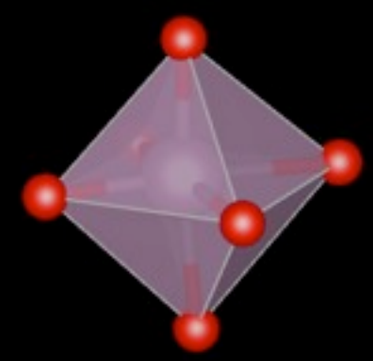
Rh



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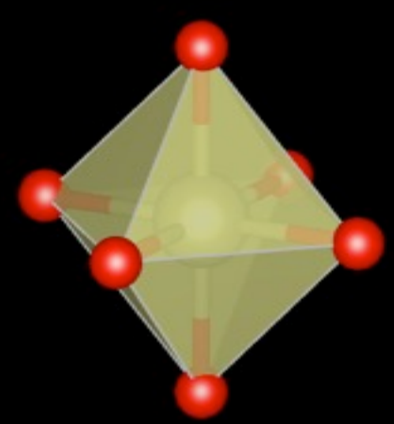

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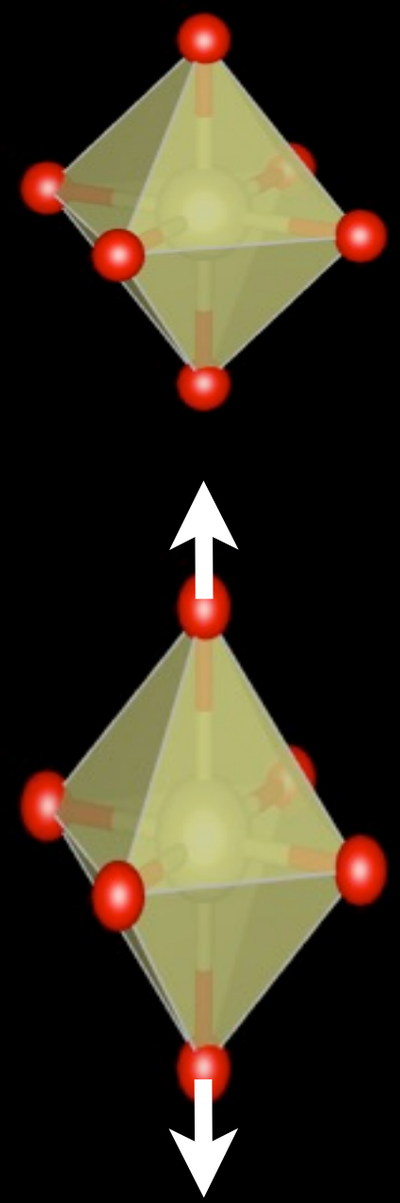
How do we create new fields?

Crystal Field

Spin-orbit

Symmetry



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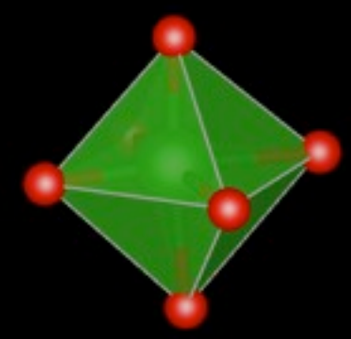

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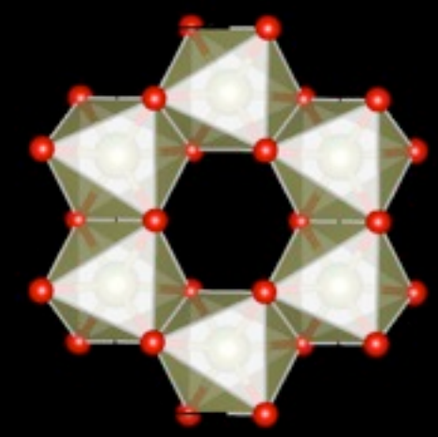

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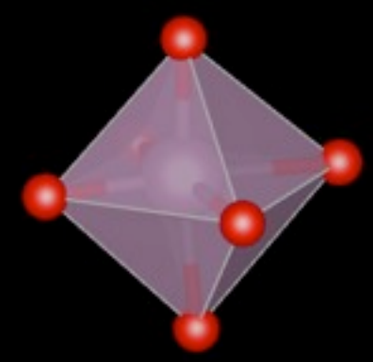

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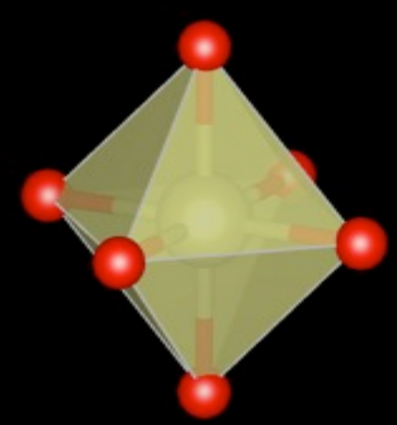

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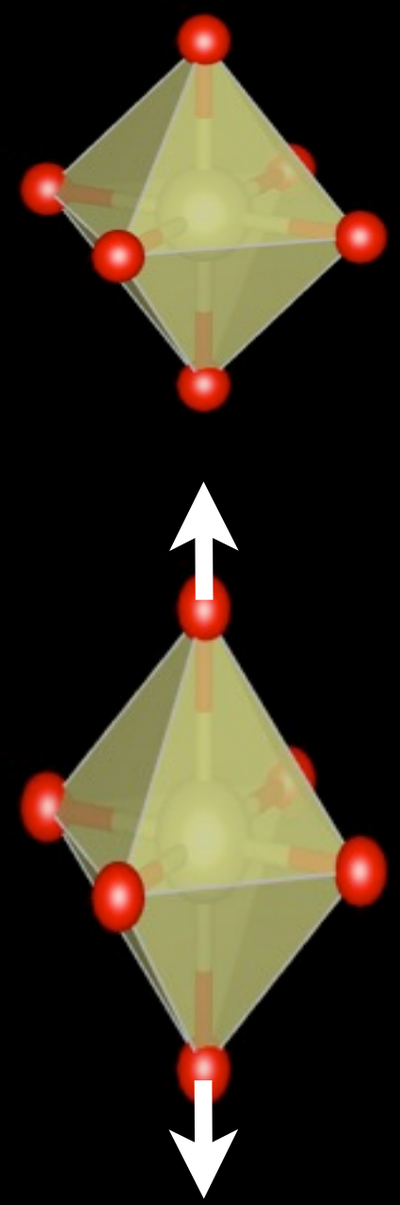
How do we create new fields?

Crystal Field | Spin-orbit | Symmetry



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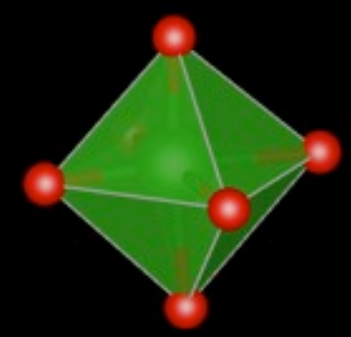

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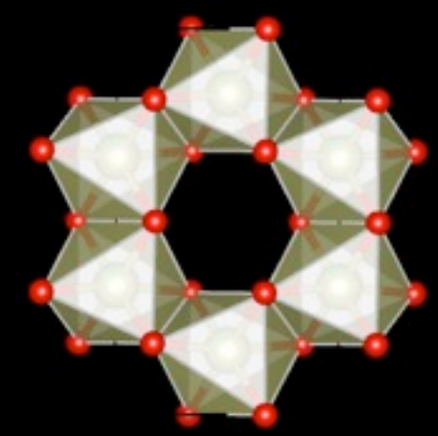

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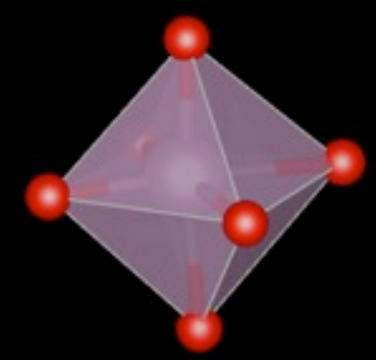

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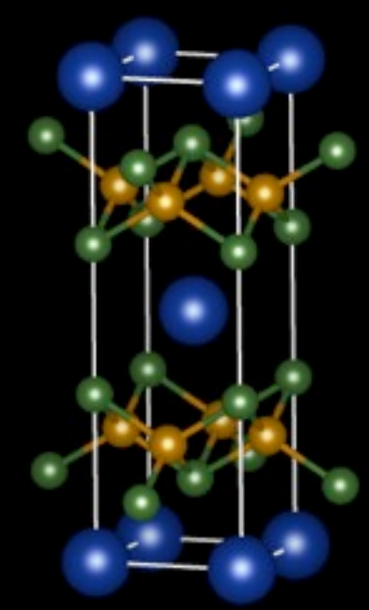

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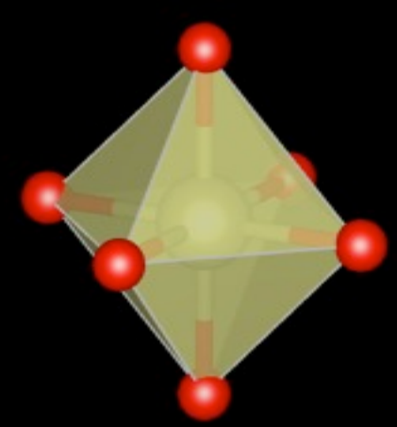

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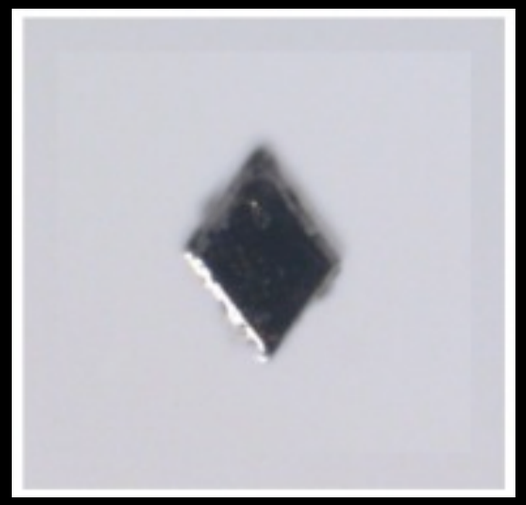
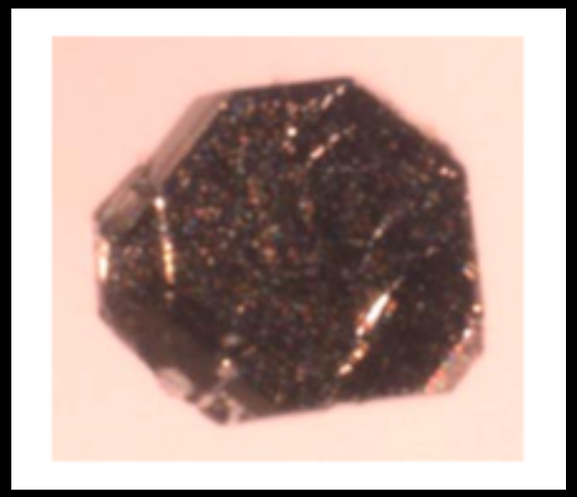
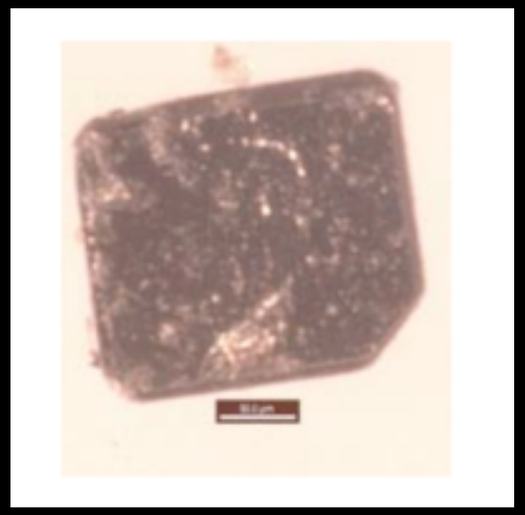


Li_2IrO_3

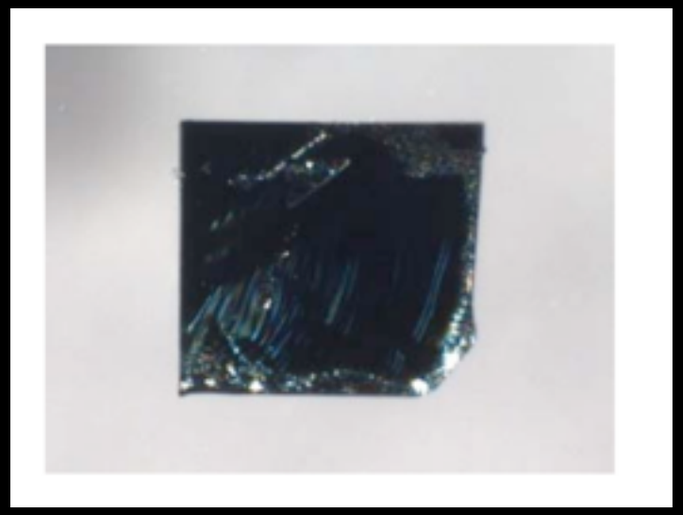


$SrFe_2P_2$

Bi_2Te_3



LaFePO



$BaFe_2As_2$

Techniques - thermodynamic

- Heat Capacity
- Magnetization
- Elastic constants (resonant ultrasound)

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} Measurements of the free energy

Techniques - transport

- Electrical resistivity
- Thermal conductivity
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} Two-particle correlation functions

Measuring the Fermi surface : de Haas-van Alphen effect

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$$\oint p dq = \left(n + \frac{1}{2}\right) h$$

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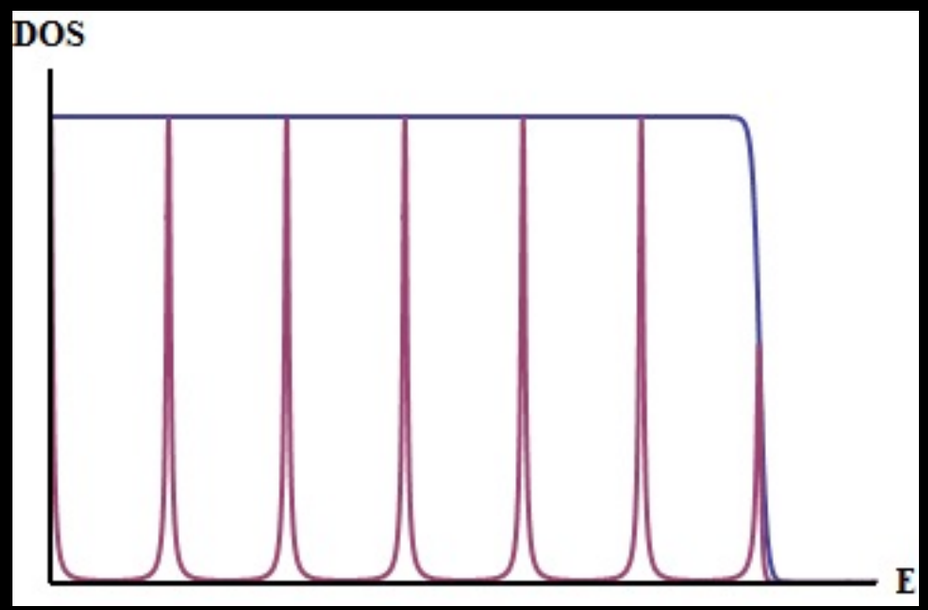
Onsager Phil. Mag. 1952, also independently I. M. Lifshitz

The effect of finite scattering



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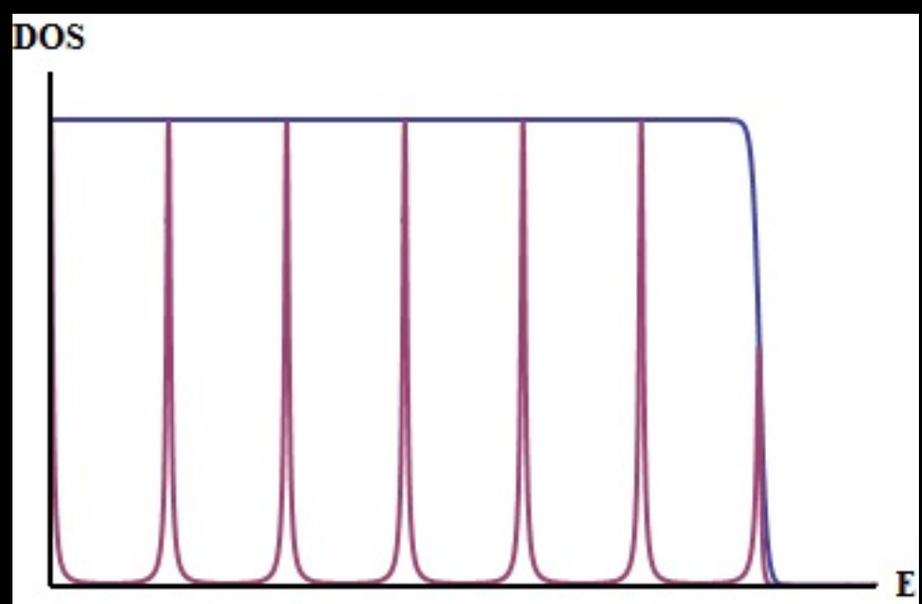

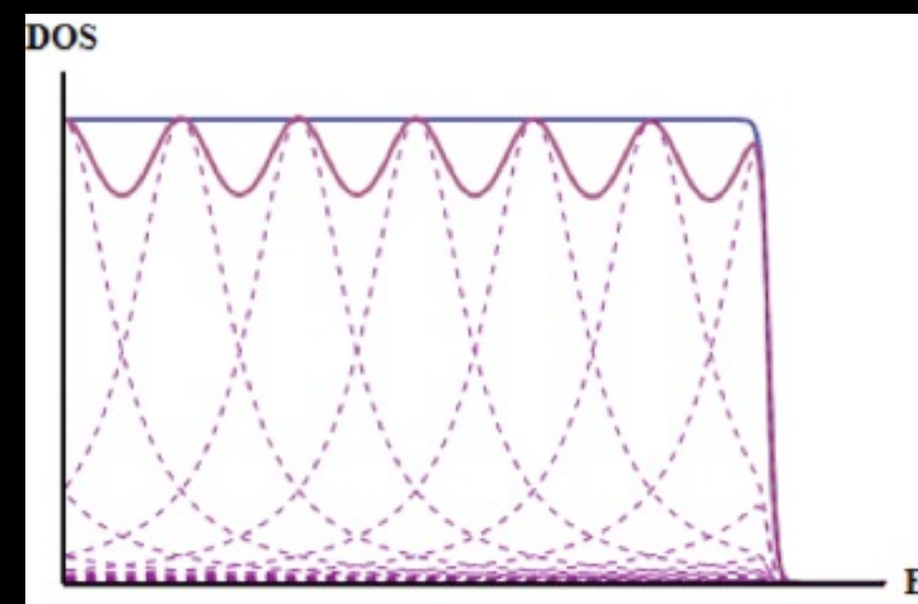

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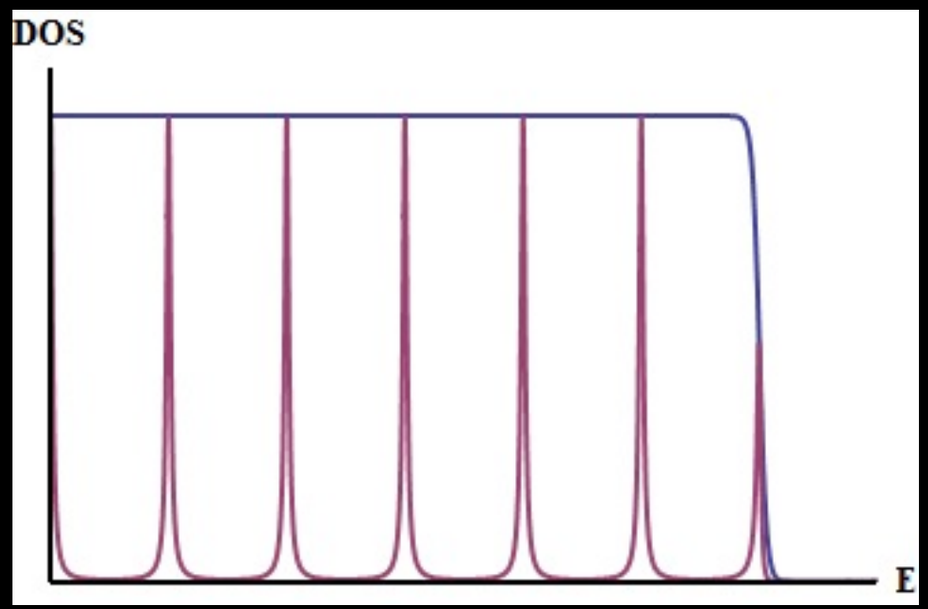

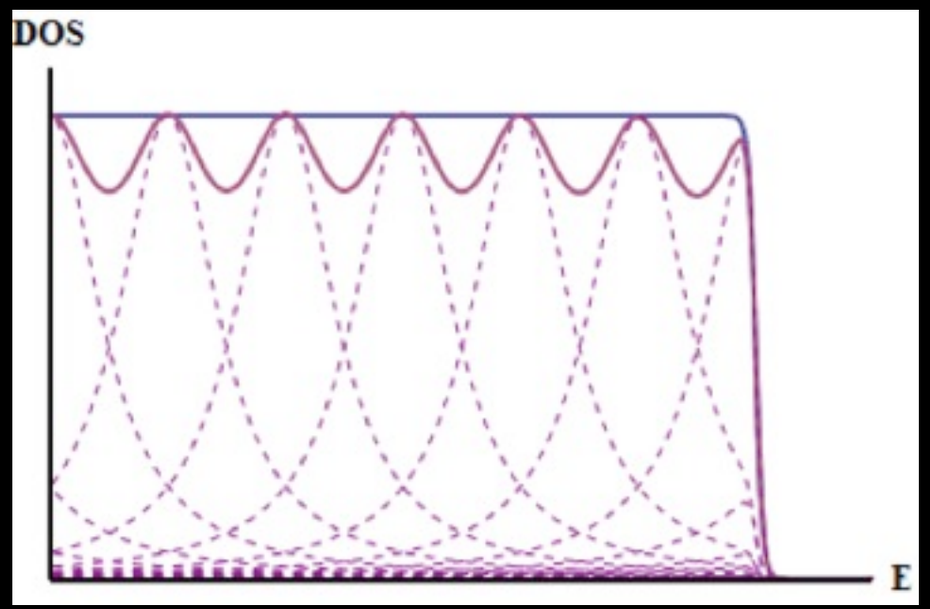

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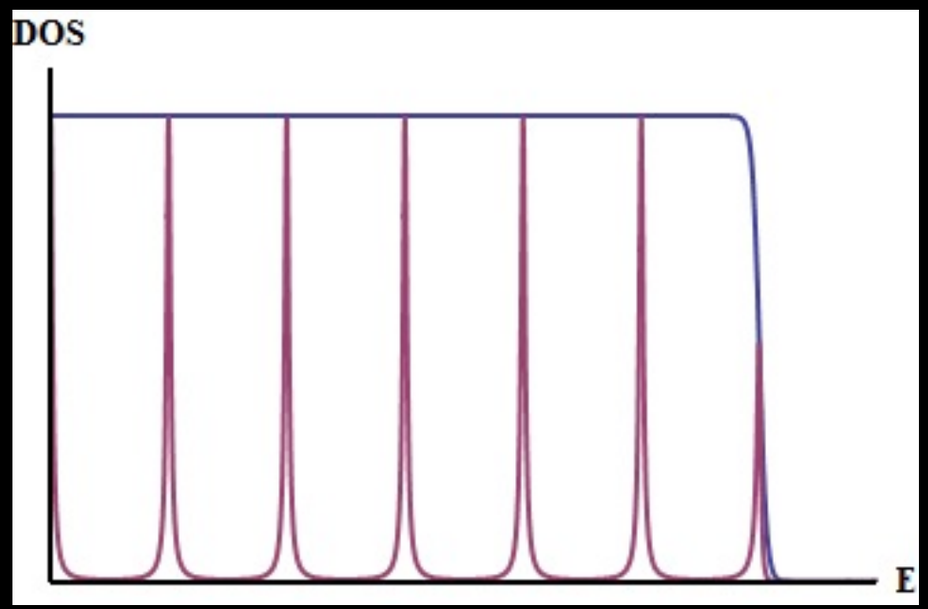

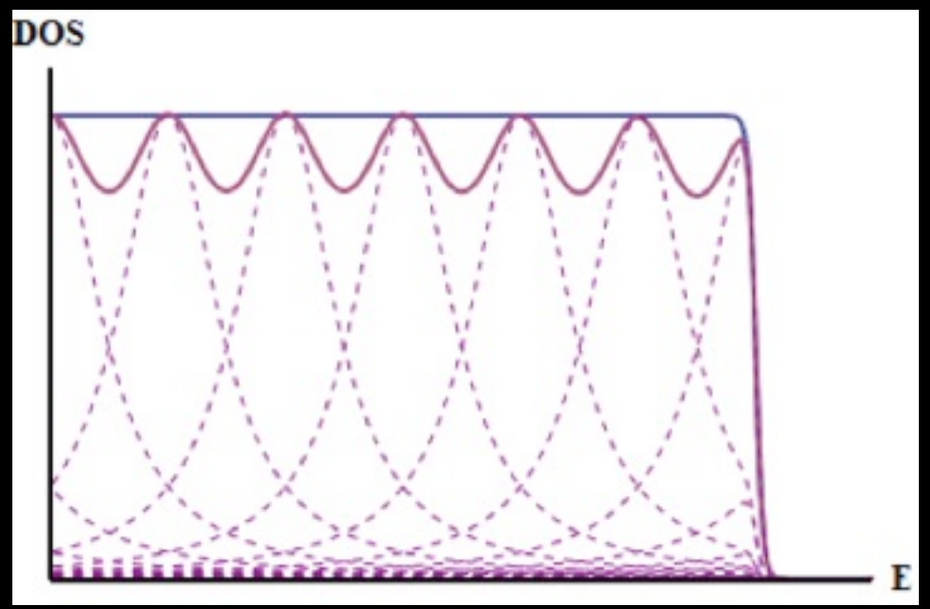

The affect of finite scattering, is to rapidly broaden these levels

Consider a typical metal with k_F=0.5Å in a field of 16T

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A very clean metal

- l=1000Å
- I_{meas}/I_0=0.006

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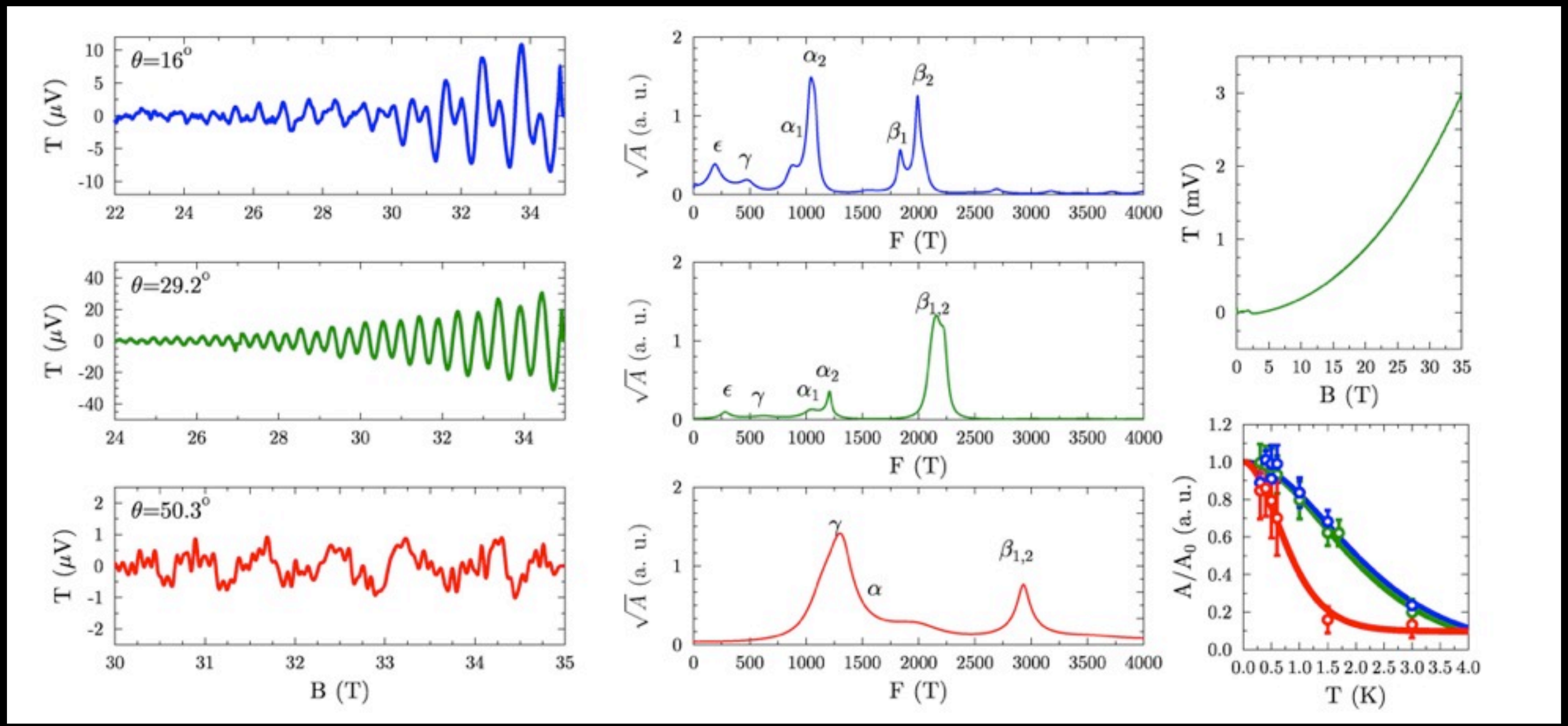
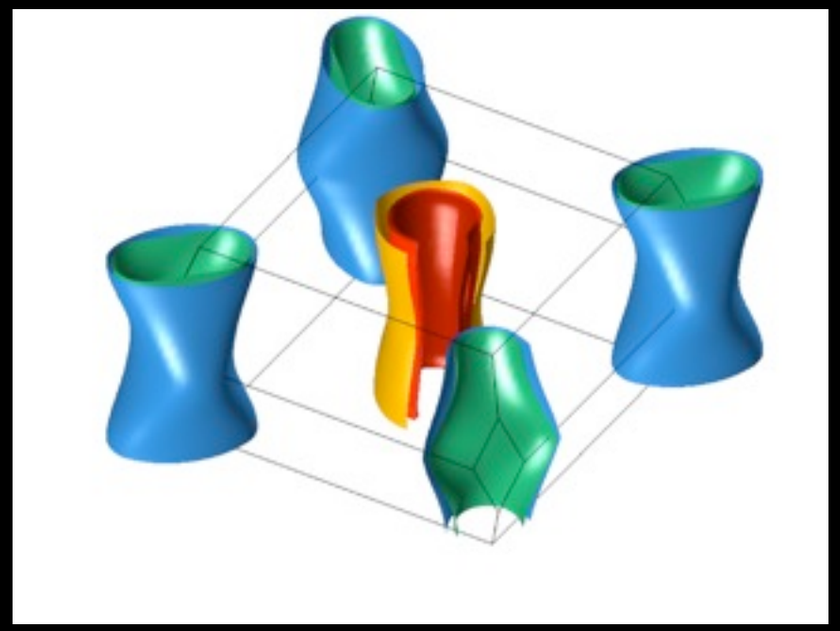
We either need HUGE magnetic fields or FANTASTIC materials

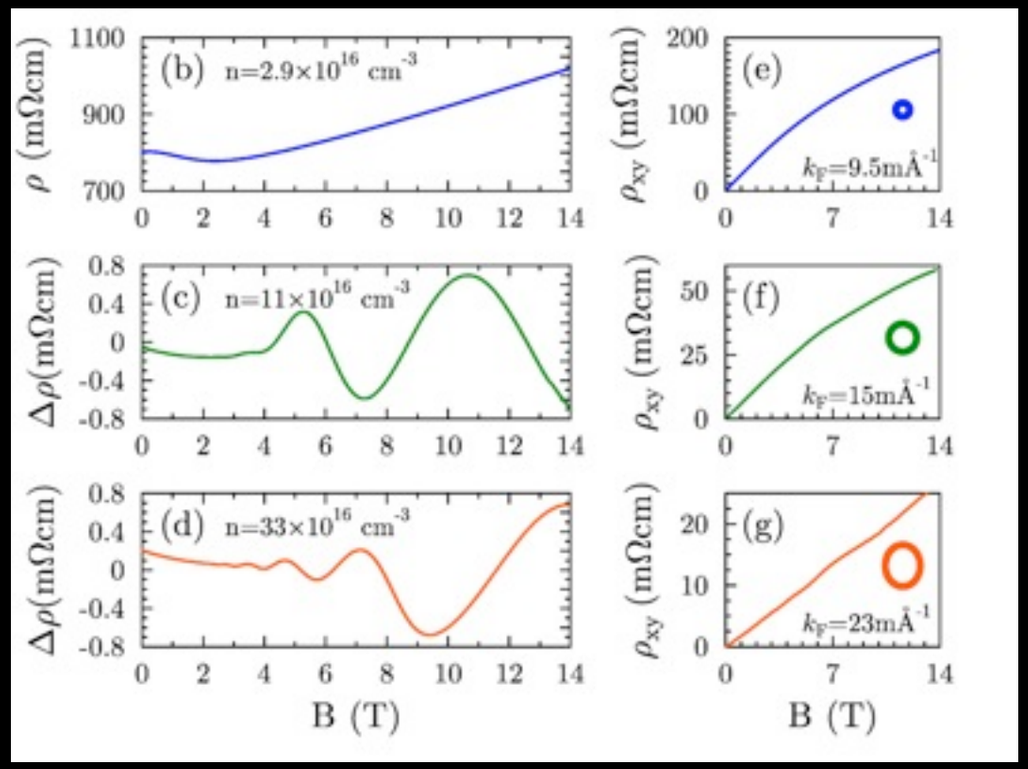
Doped $BaFe_2(As_{1-x}P_x)_2$



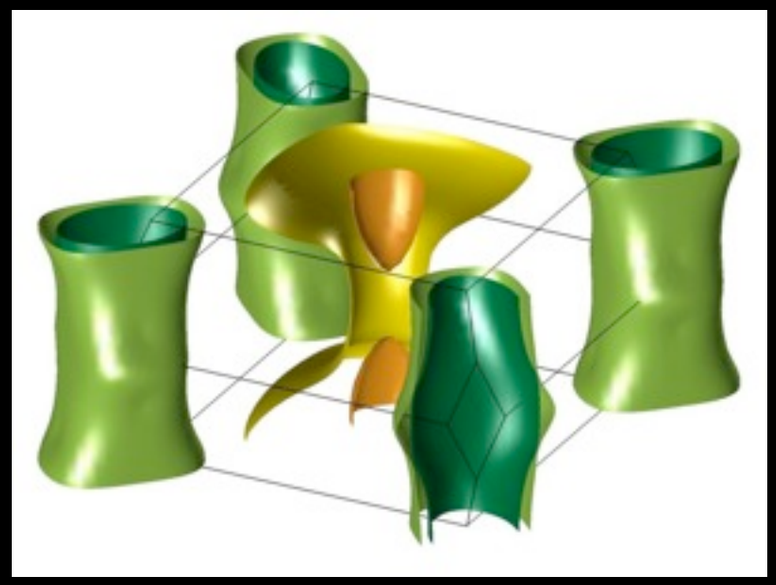
Analytis et al. *PRL* 2010



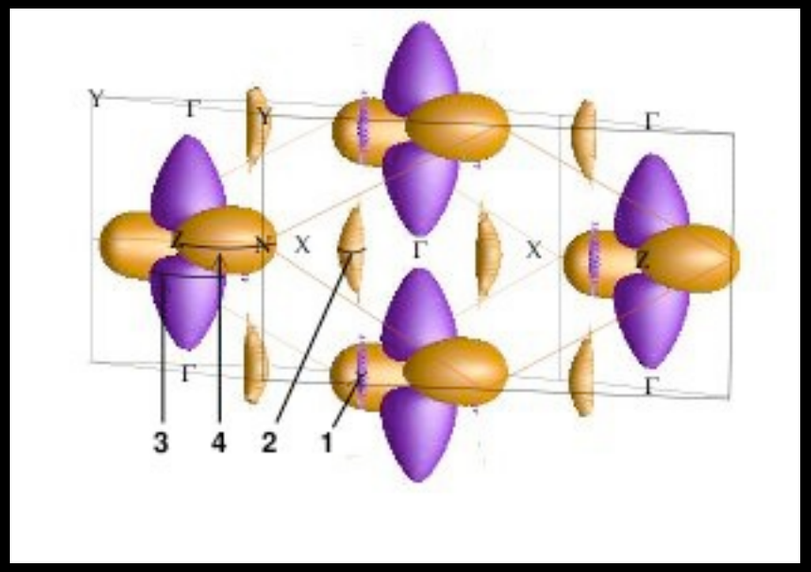
Analytis et al. PRL 2010



Analytis et al. Nature Physics 2010



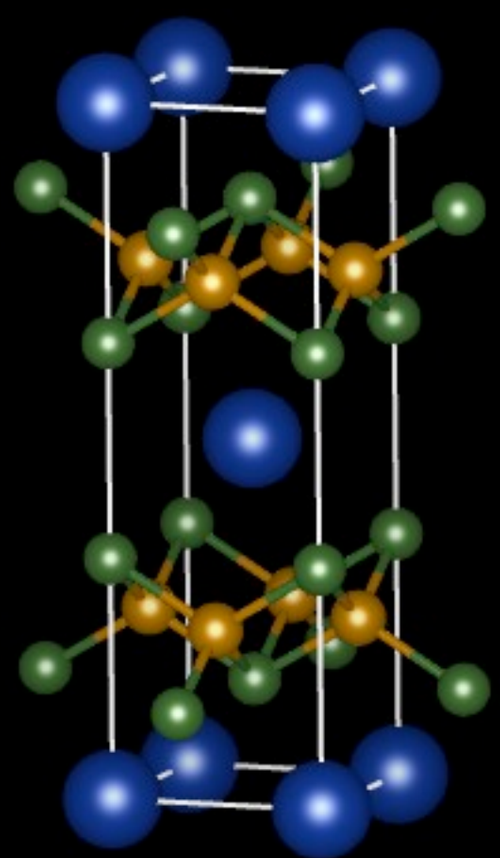
Analytis et al. PRL 2009



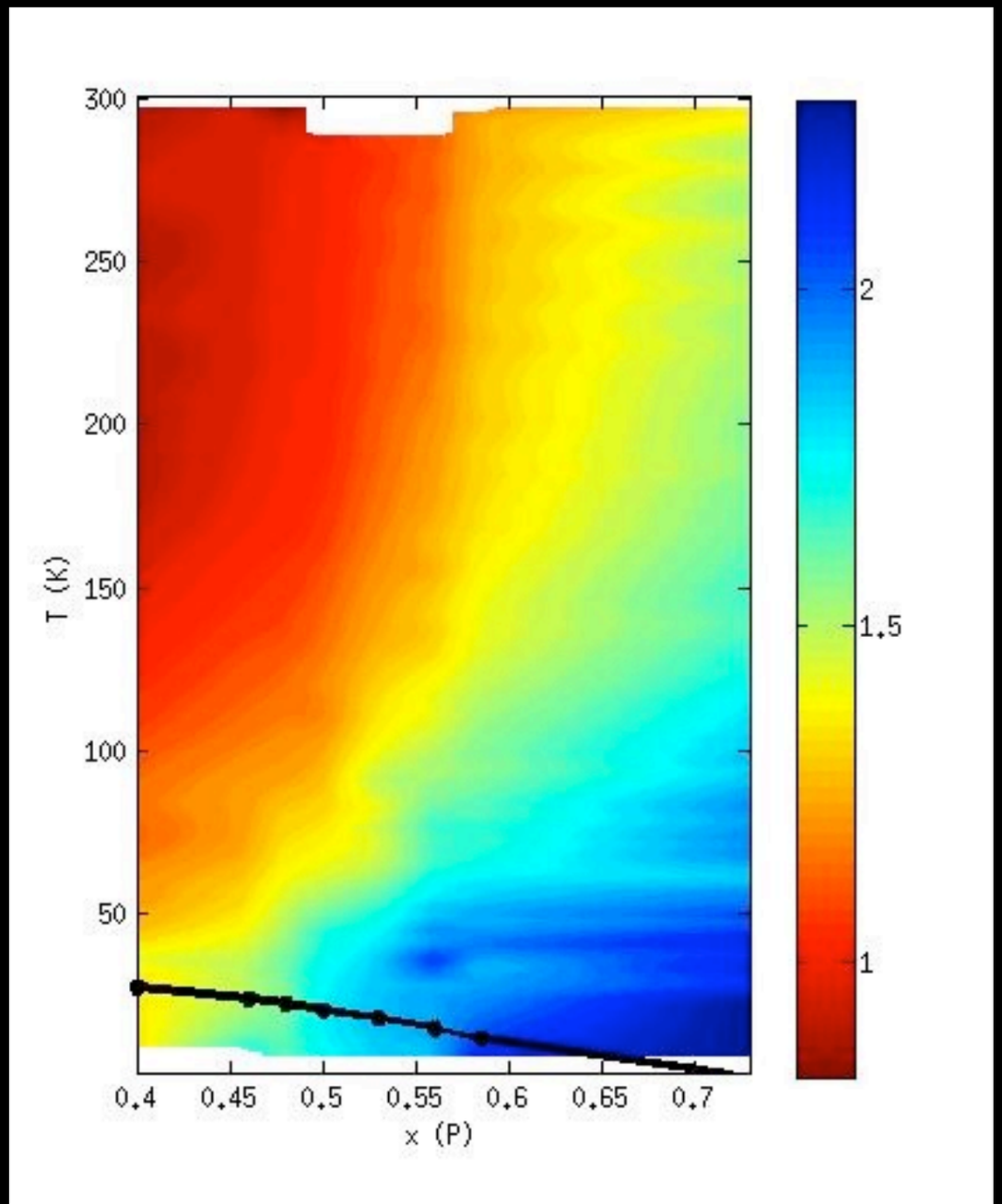
Analytis et al. PRL 2009

Part II : Some current projects

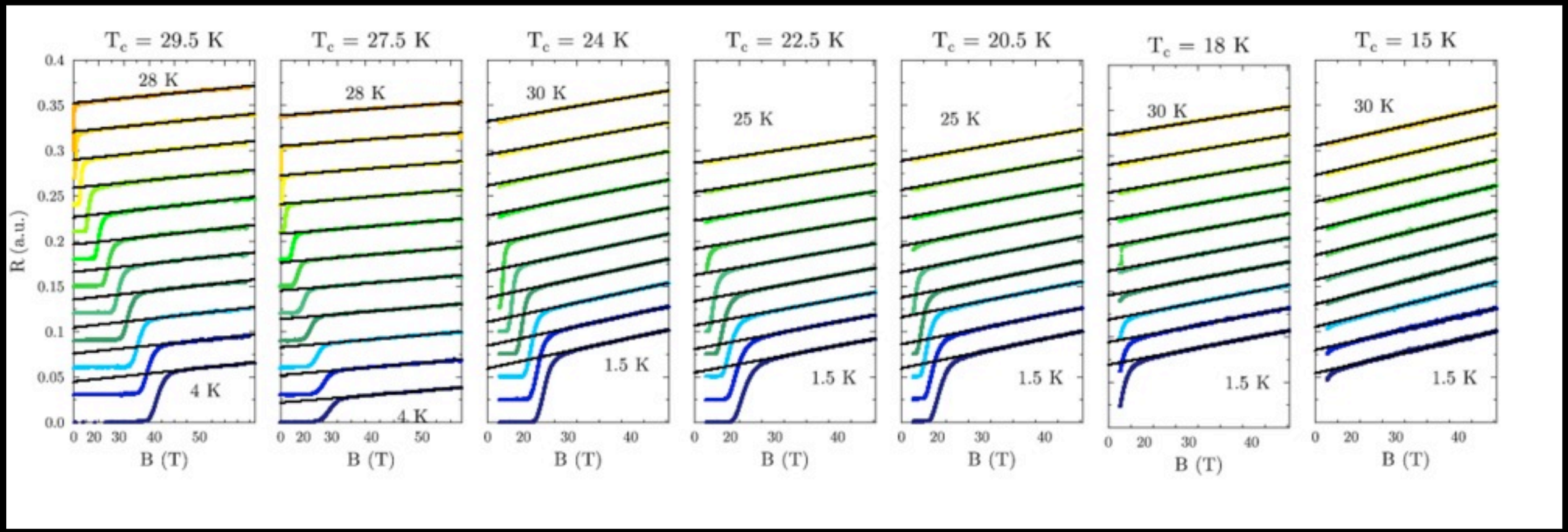
Unification of energy scales in quantum critical systems

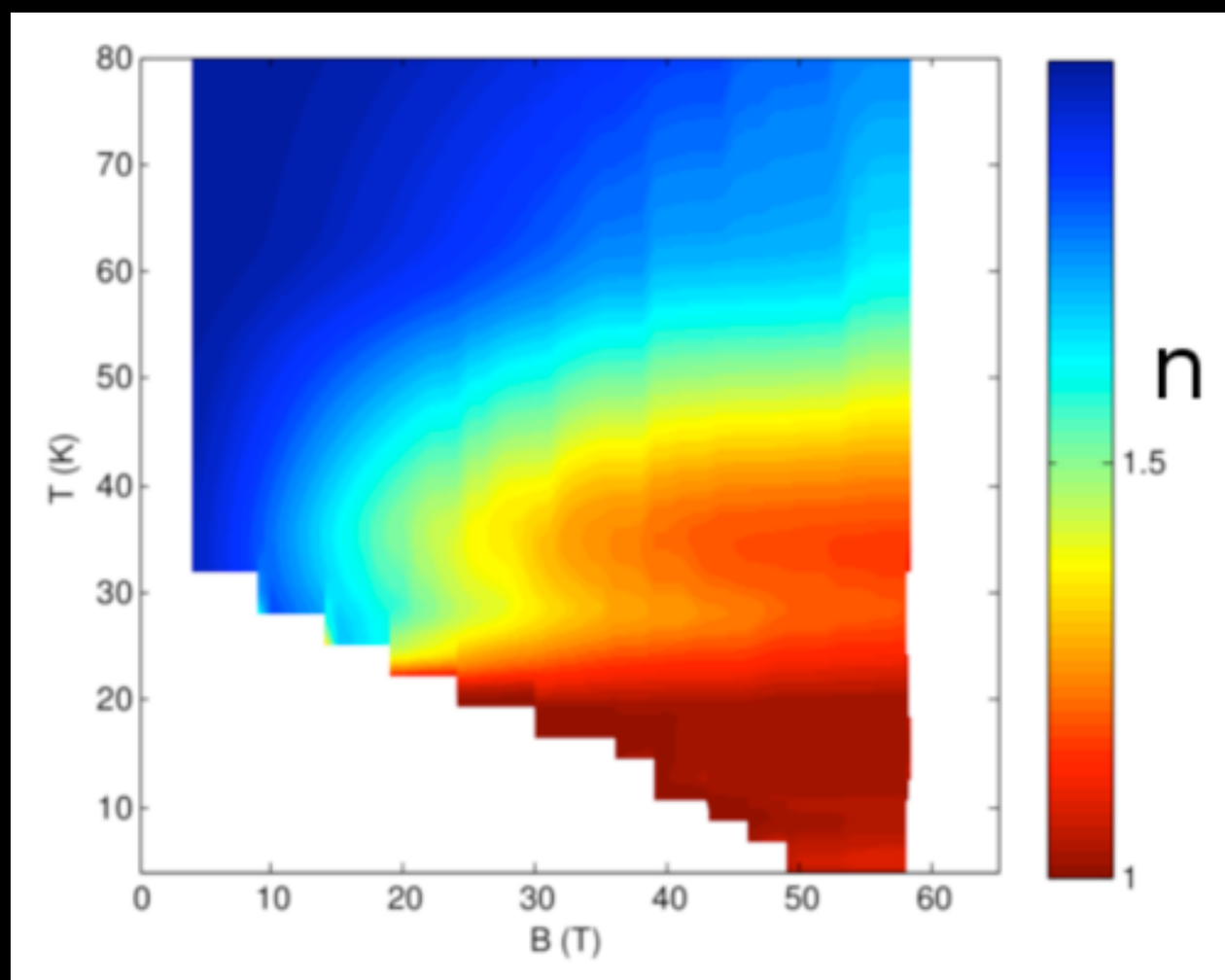


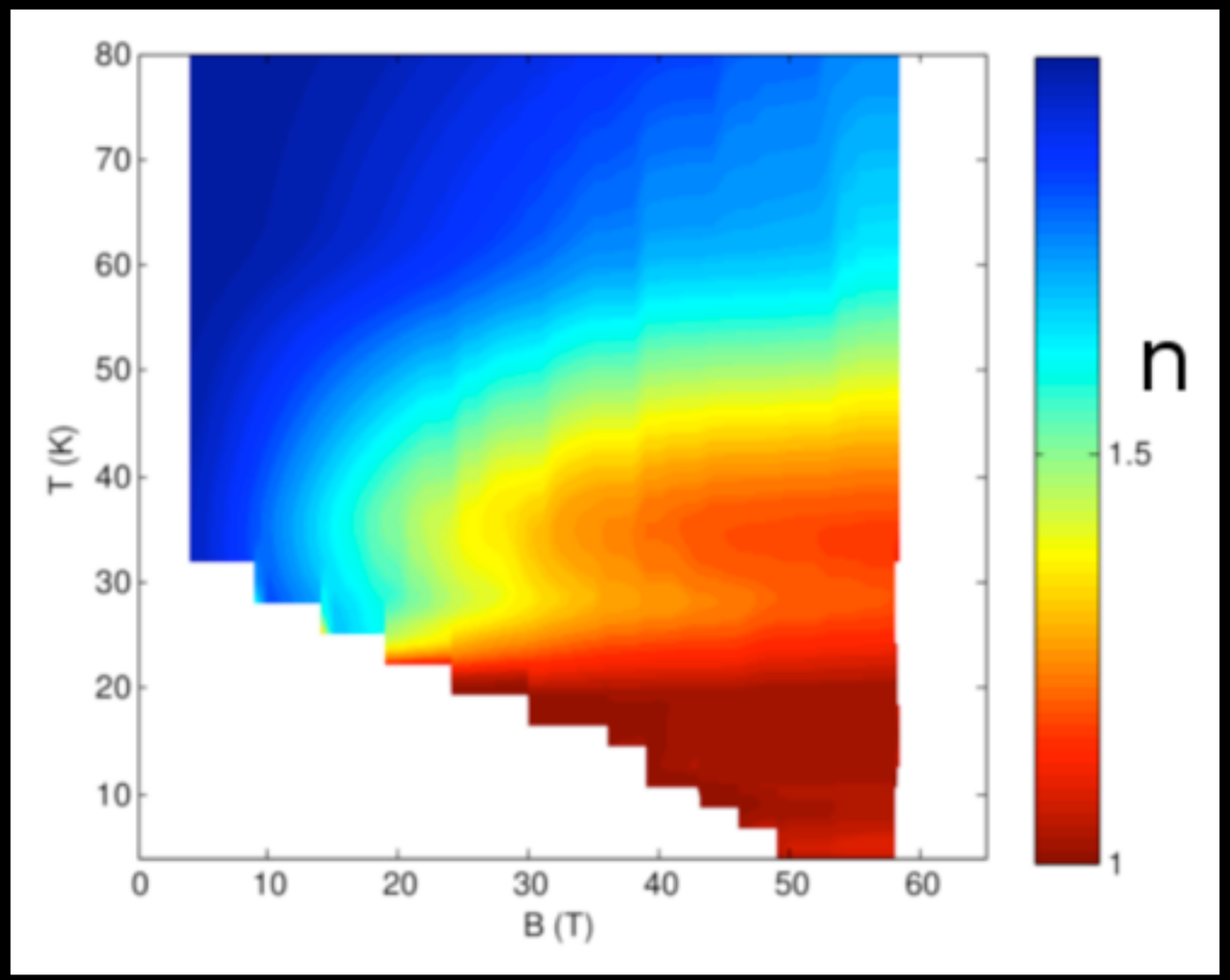
$BaFe_2(As_{1-x}P_x)_2$

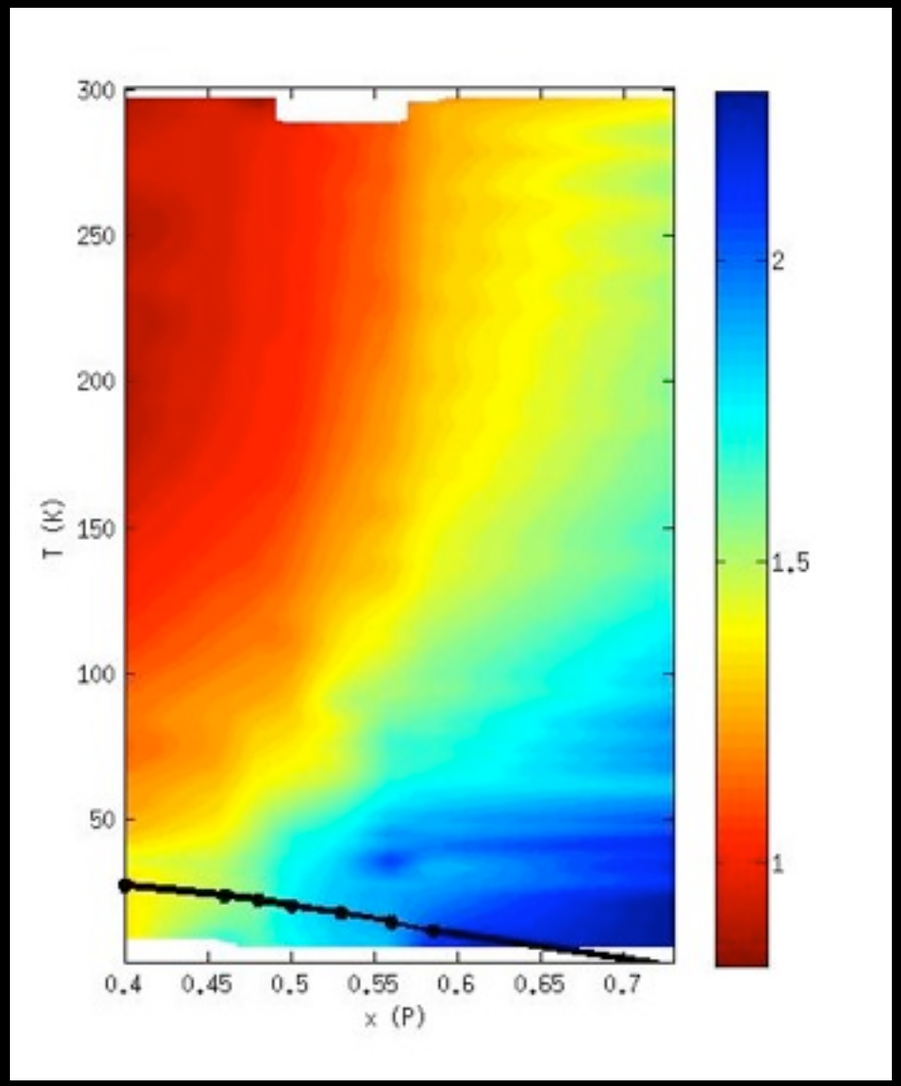


High-Field magnetoresistance $BaFe_2(As_{1-x}P_x)_2$

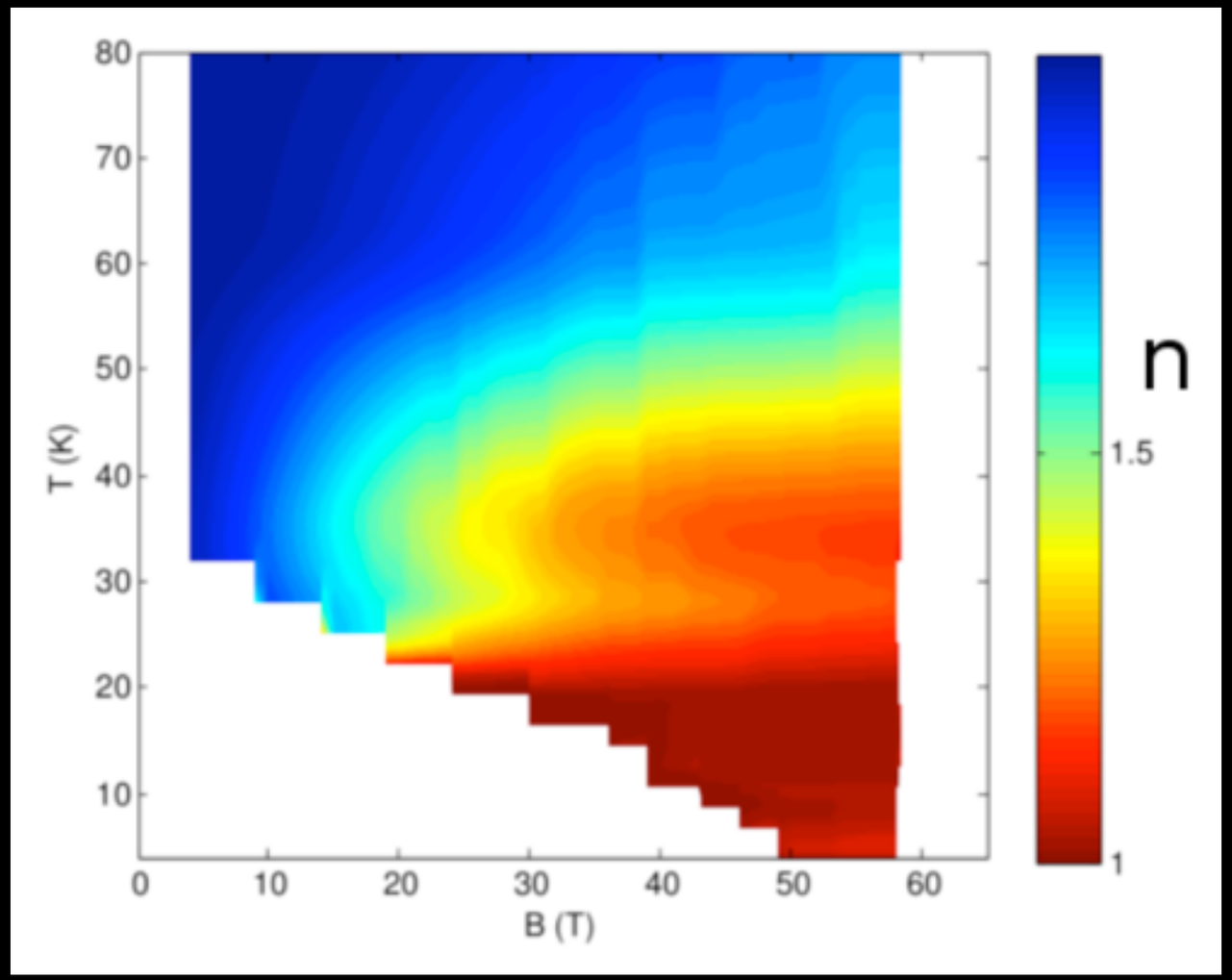


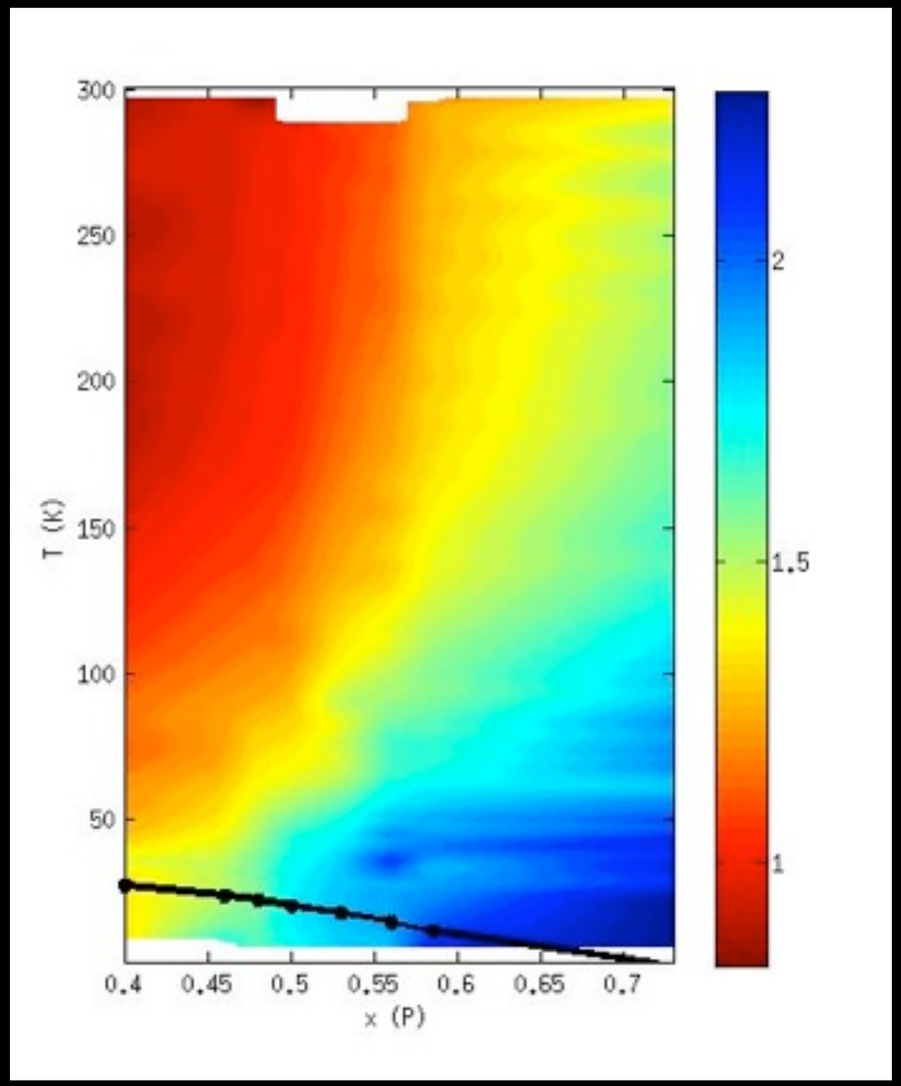

80
70
60
50
40
30
20
10
T (K)
0
10
20
30
40
50
60
B (T)
n
1.5
1


n
T (K)
B (T)
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
1.5
1

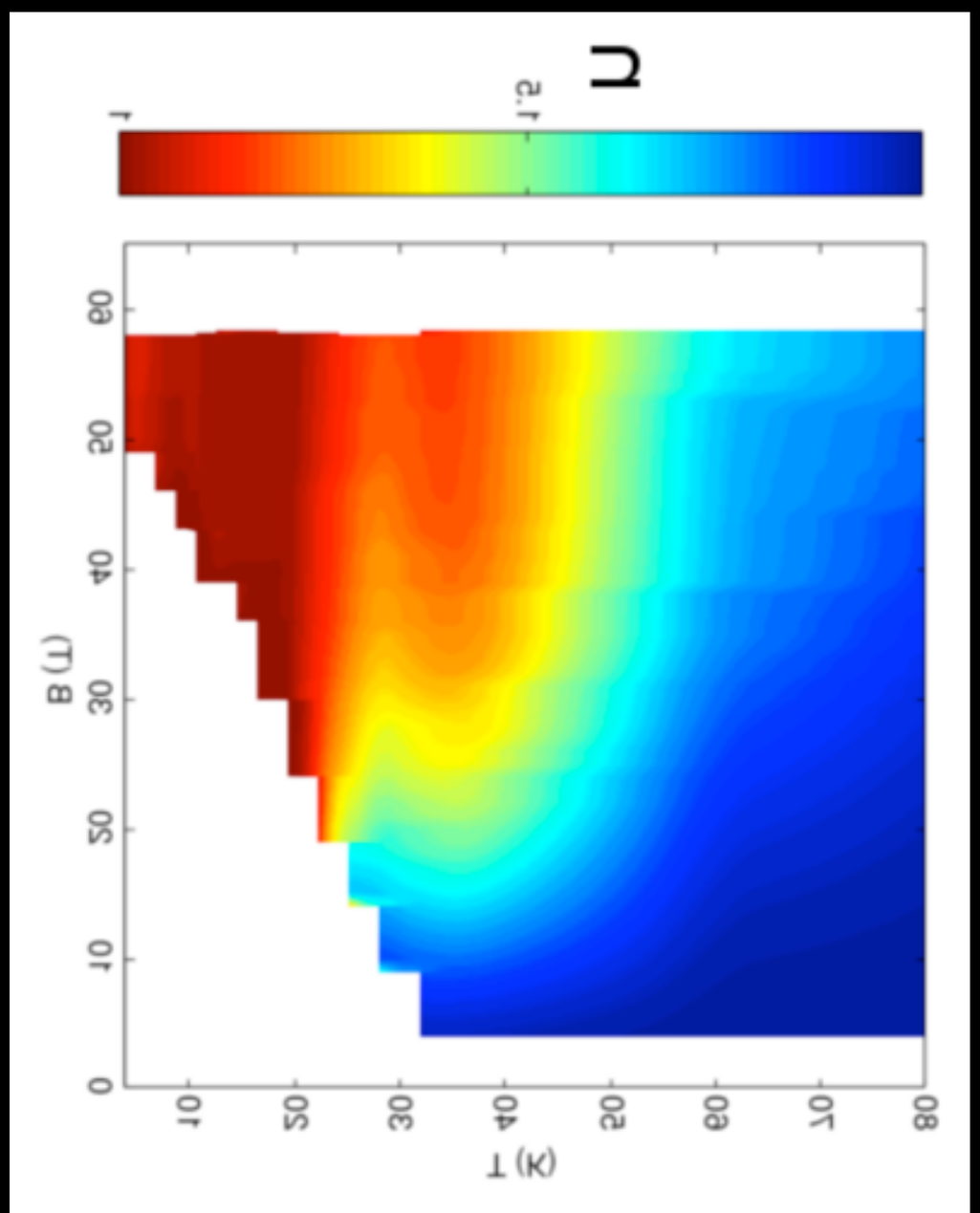

T (K)
x (P)
300
250
200
150
100
50
0.4
0.45
0.5
0.55
0.6
0.65
0.7
2
1.5
1

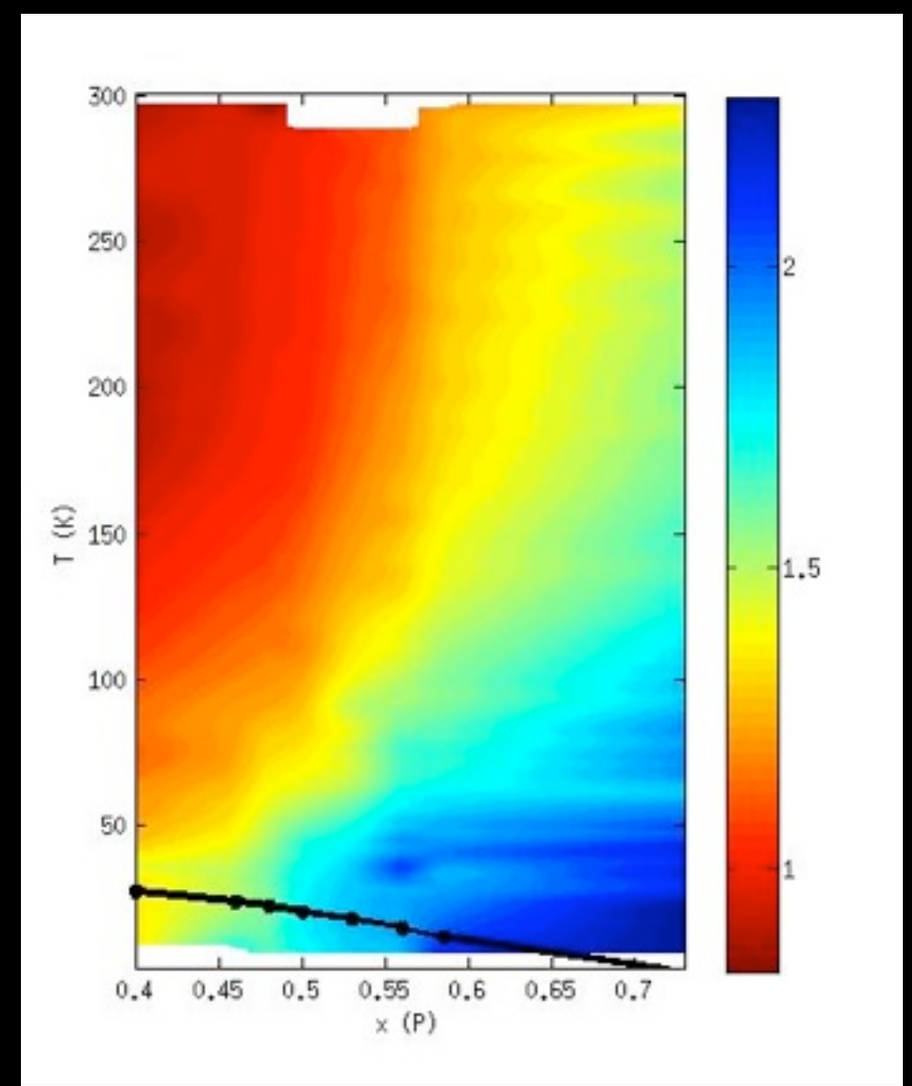
Field-Temperature equivalence





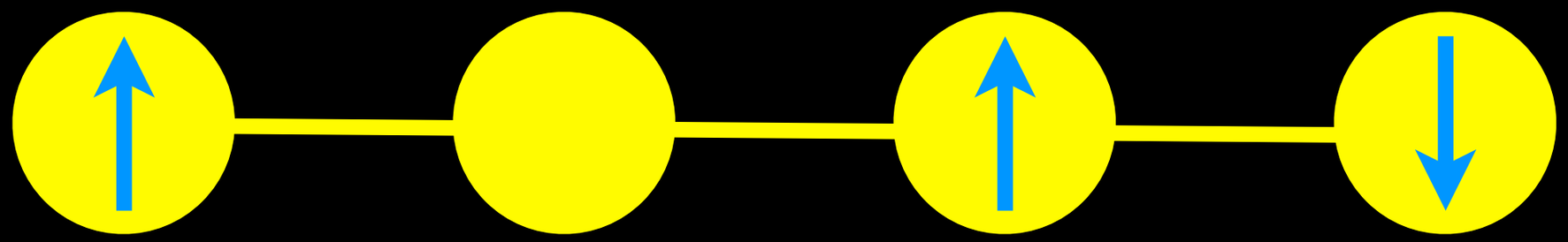
Field-Temperature equivalence



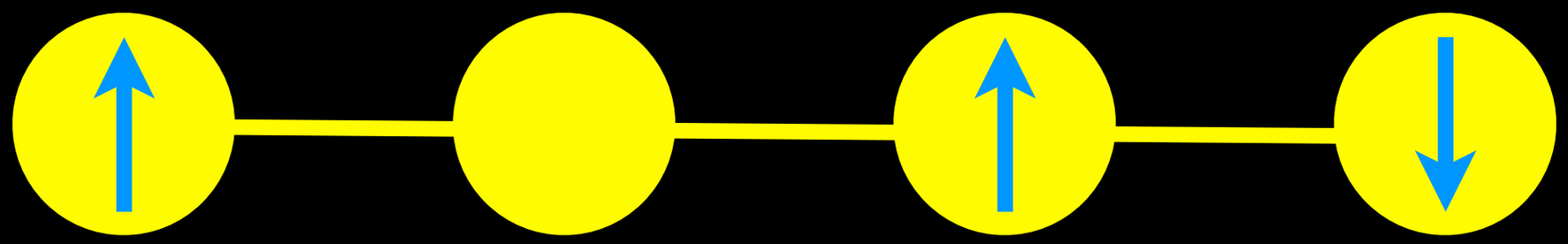


Tunable Luttinger liquid

Tunable Luttinger liquid

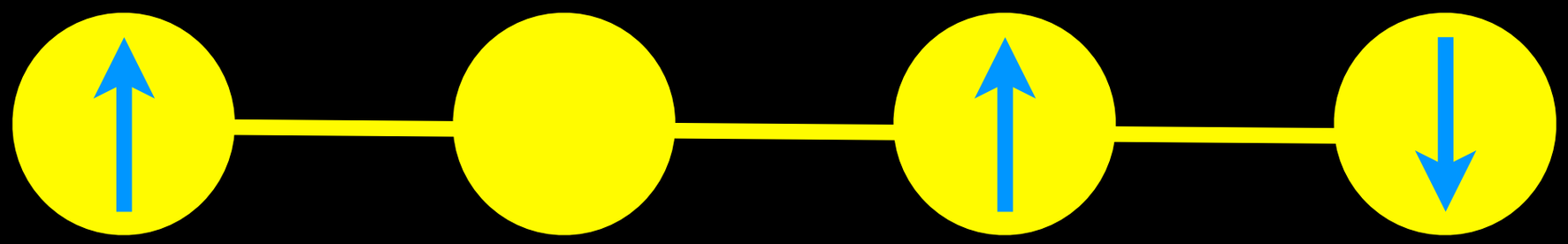


Tunable Luttinger liquid

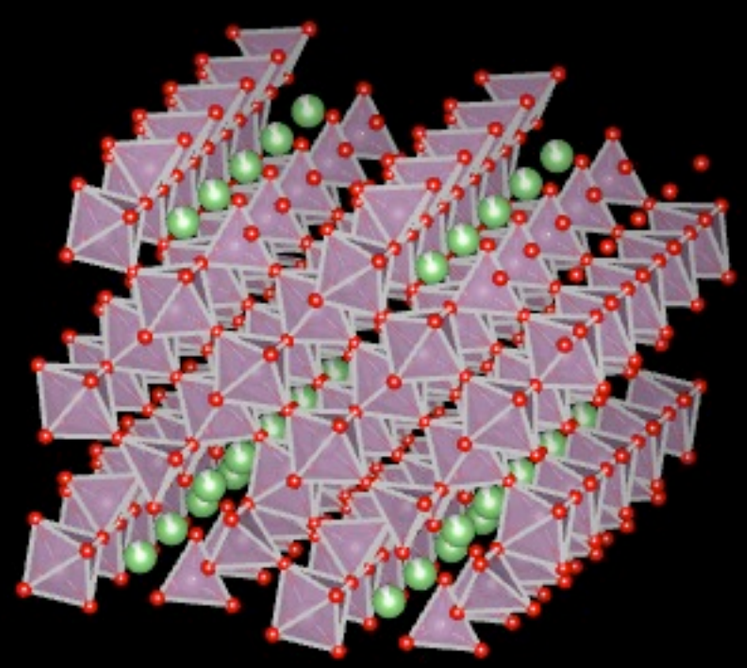


Spin-charge separation?

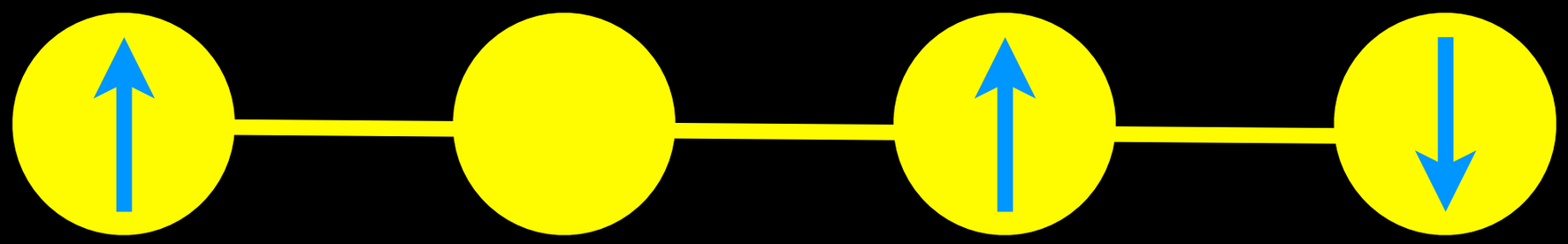
Tunable Luttinger liquid



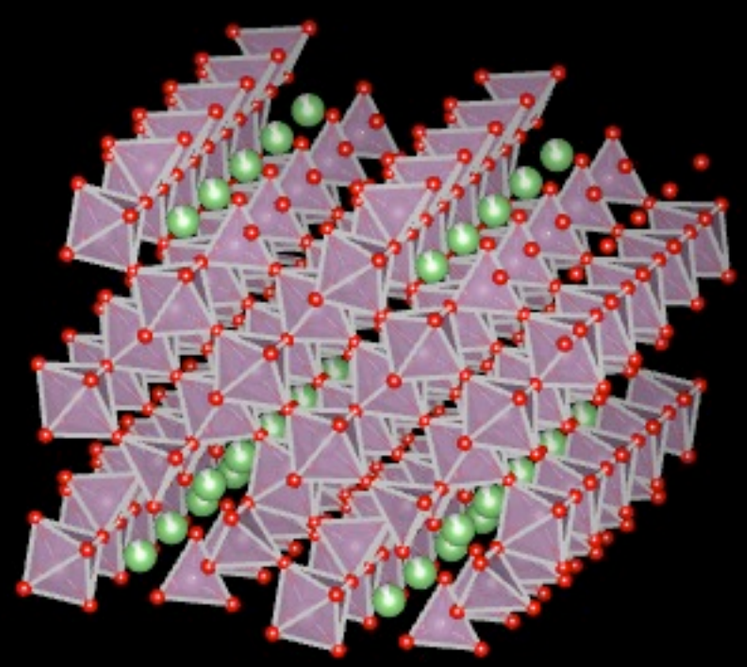
Spin-charge separation?



Tunable Luttinger liquid

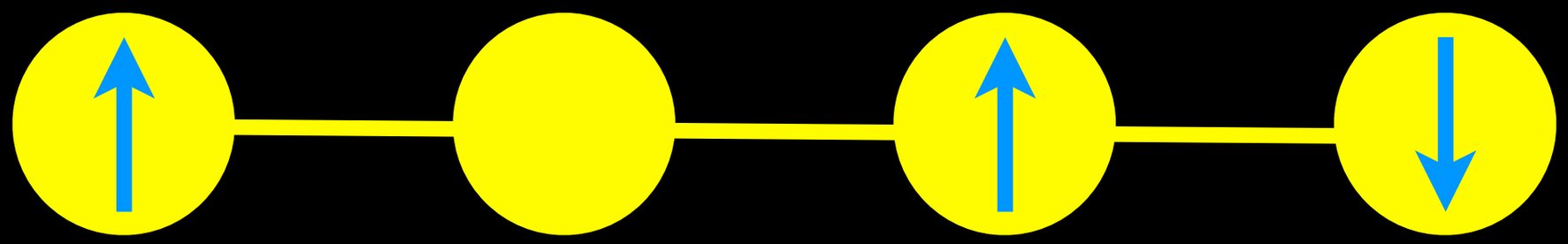


Spin-charge separation?

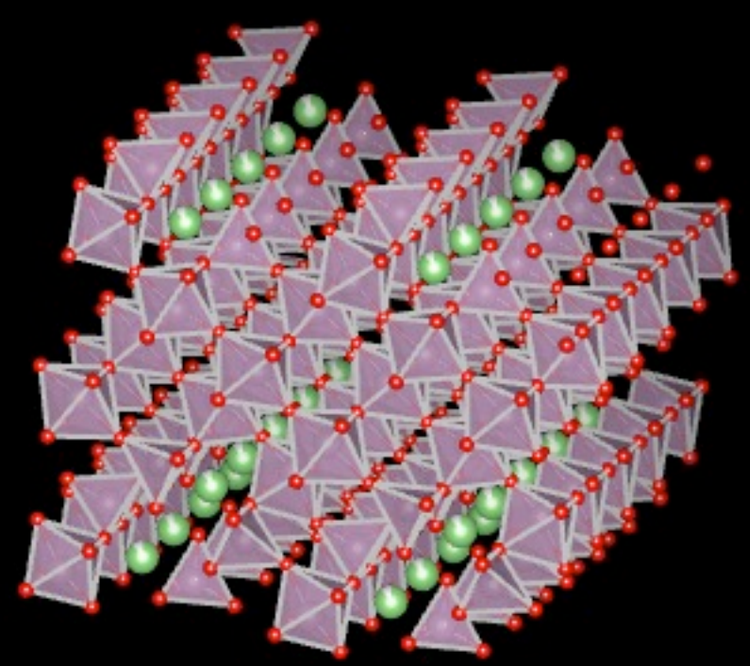


$LiMo_6O_{17}$

Wiedemann-Franz Law as a function of dimensionality



Entropy carried in a very different way to electricity

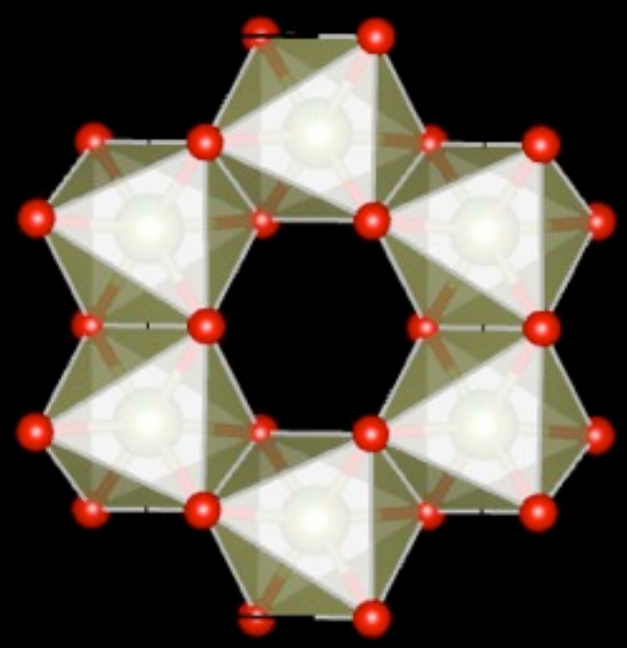


$LiMo_6O_{17}$

Topological Mott Insulators : Li_2IrO_3

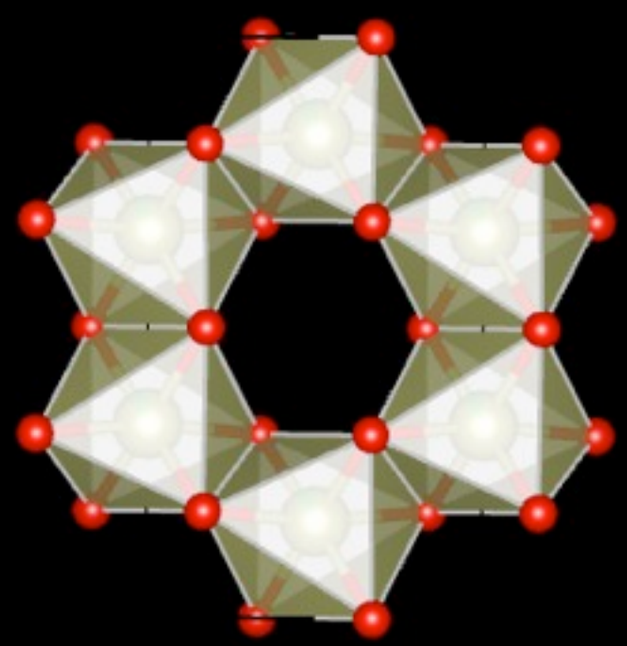
Crystal Field + Spin-orbit + electron-electron correlations

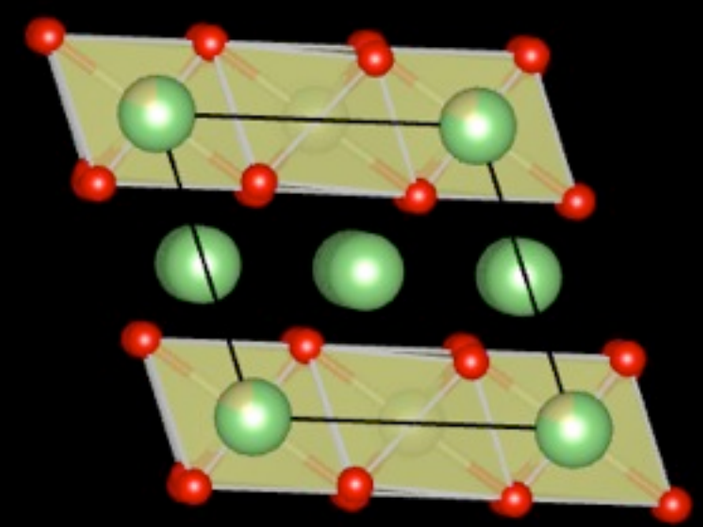
Topological Mott Insulators : Li_2IrO_3



Crystal Field + Spin-orbit + electron-electron correlations

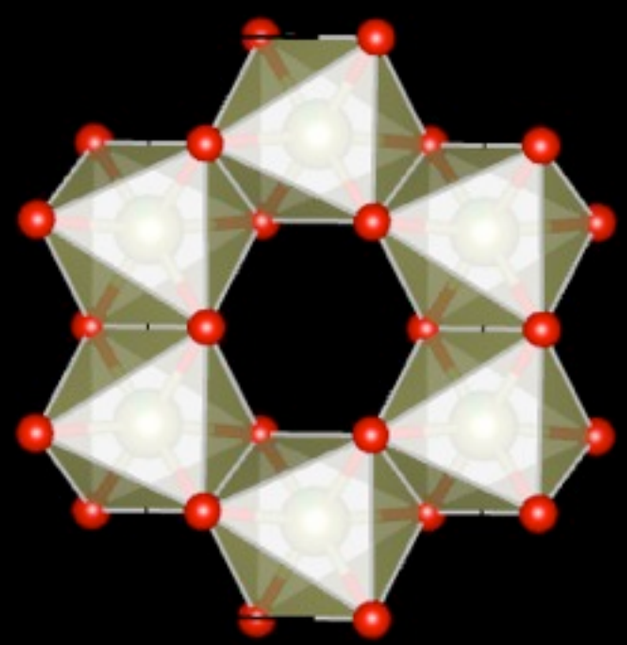
Topological Mott Insulators : Li_2IrO_3

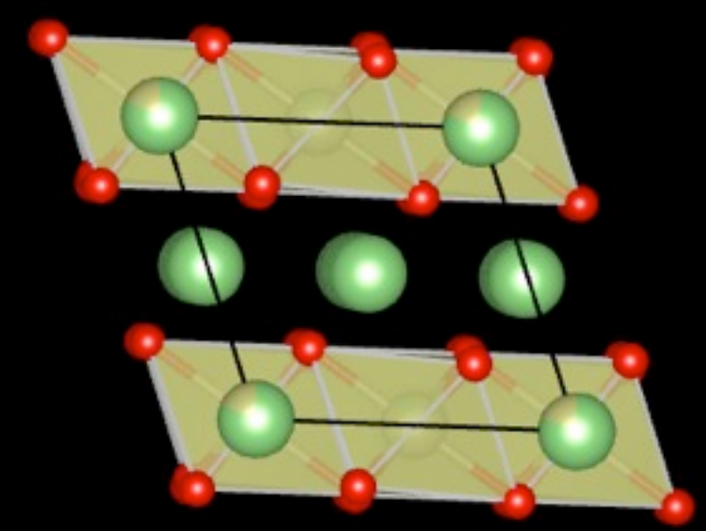


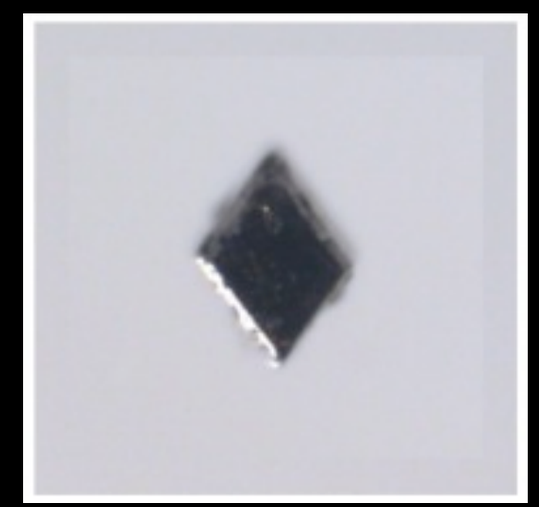


Crystal Field + Spin-orbit + electron-electron correlations

Topological Mott Insulators : Li_2IrO_3



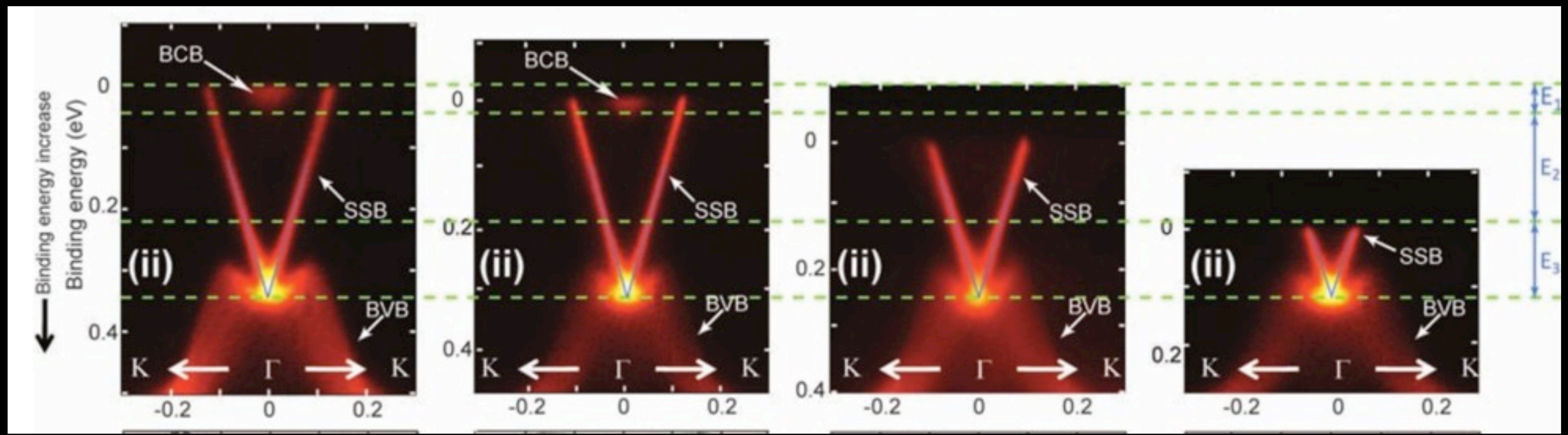




Crystal Field + Spin-orbit + electron-electron correlations

Example : Sn-doped Bi_2Te_3

Chen/Analytis et al. Science 2009



Sn-doping

$Li_{2-x}Na_xIrO_3$ Chemical Pressure

$Li_{2-x}Na_xIrO_3$ Chemical Pressure

Doping electrons $Li_2Ir_{1-x}Pt_xO_3$

$Li_{2-x}Na_xIrO_3$ Chemical Pressure

Doping electrons $Li_2Ir_{1-x}Pt_xO_3$

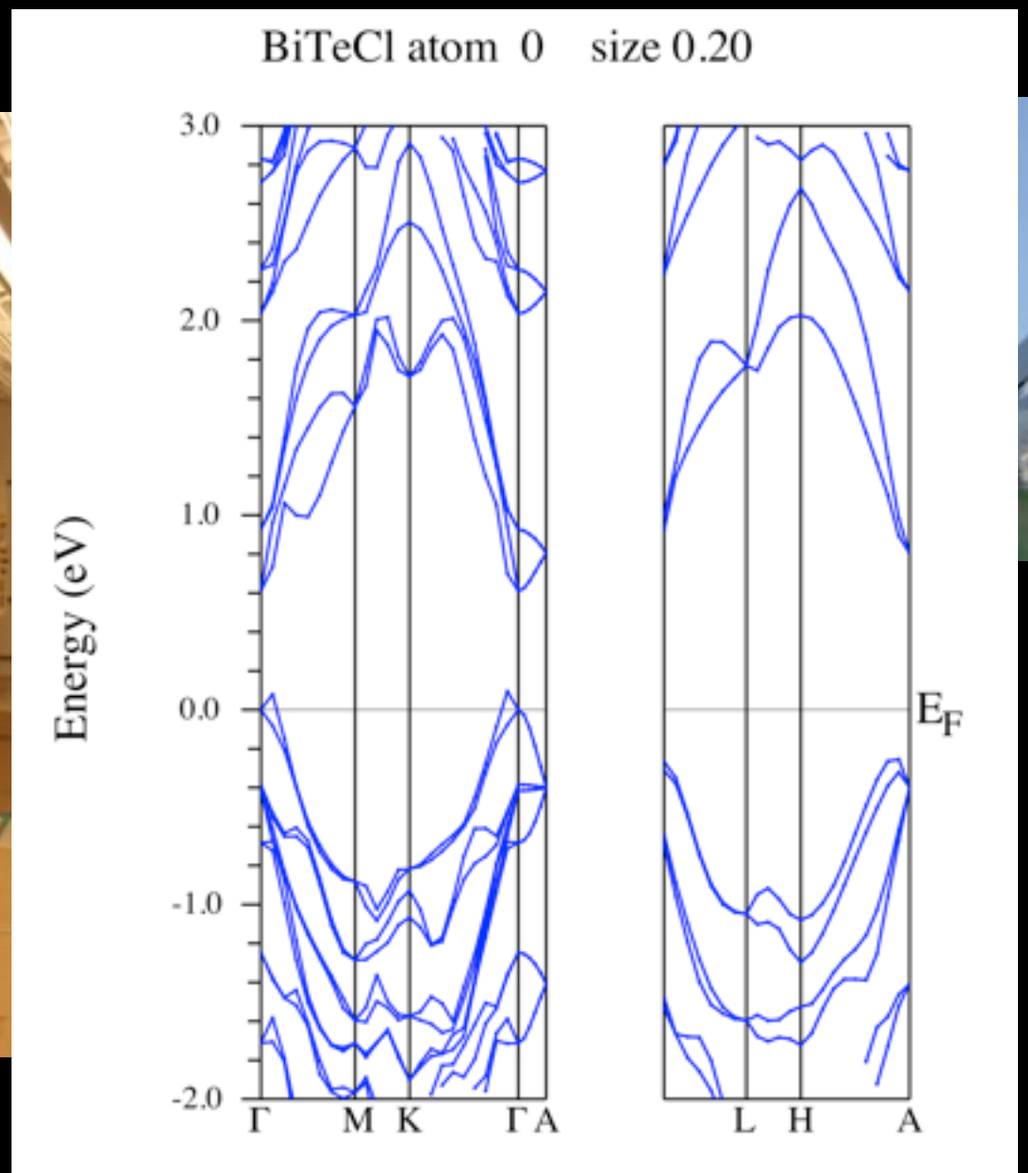
$Li_2Ir_{1-x}Rh_xO_3$ Spin-orbit coupling

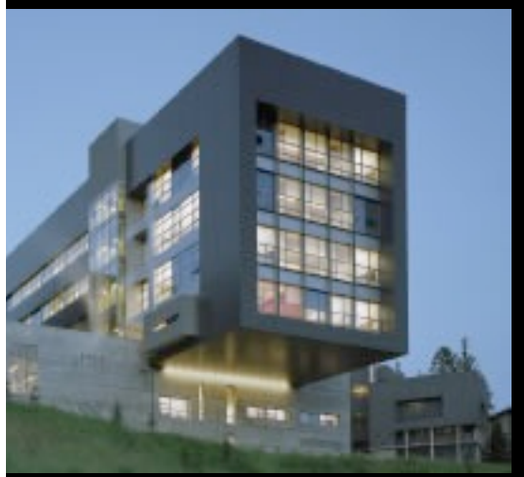
Part III : How the Analytis Lab functions

SYNTHESIS

SYNTHESIS

Density Functional Theory





PROBE DESIGN

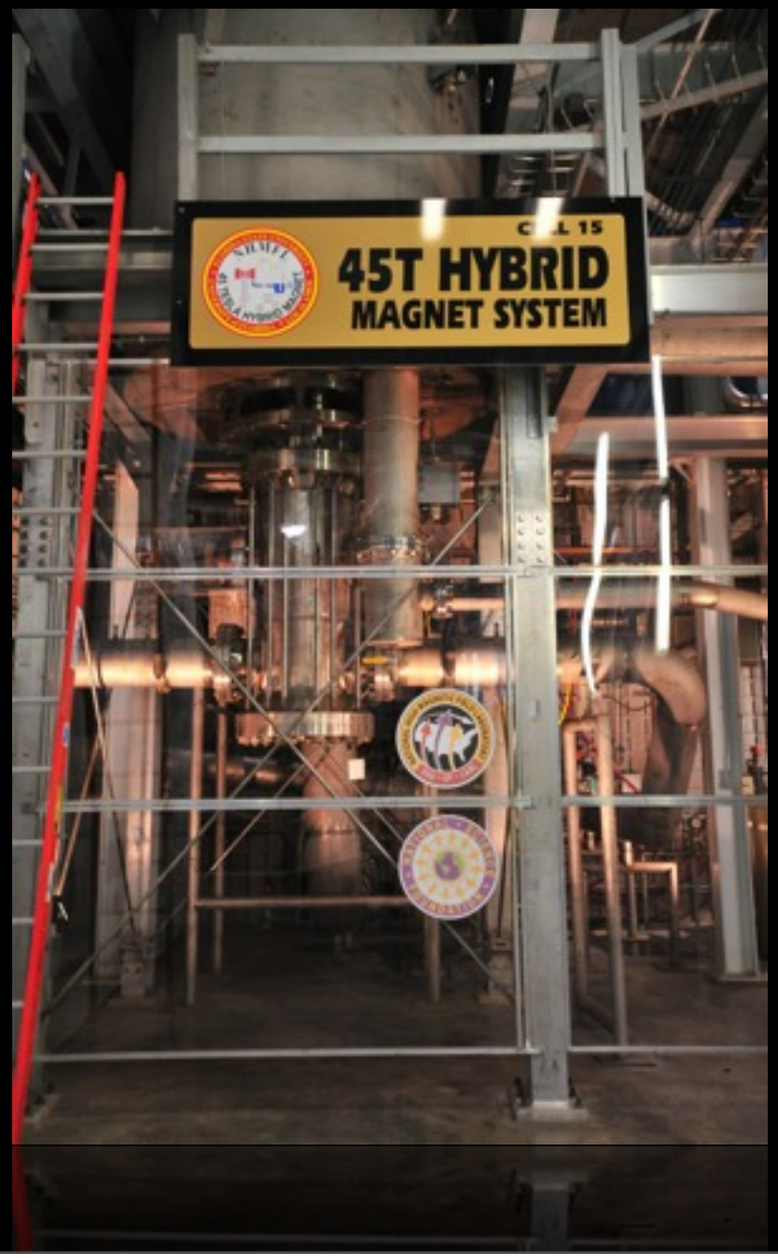
MEASUREMENT & ANALYSIS : LOCAL

16T Cryogen Free

7T SQUID

MEASUREMENT :
NON-LOCAL

45T HYBRID NHMFL, FL



MEASUREMENT :
NON-LOCAL

45T HYBRID NHMFL, FL

MEASUREMENT :

NON-LOCAL

45T HYBRID NHMFL, FL

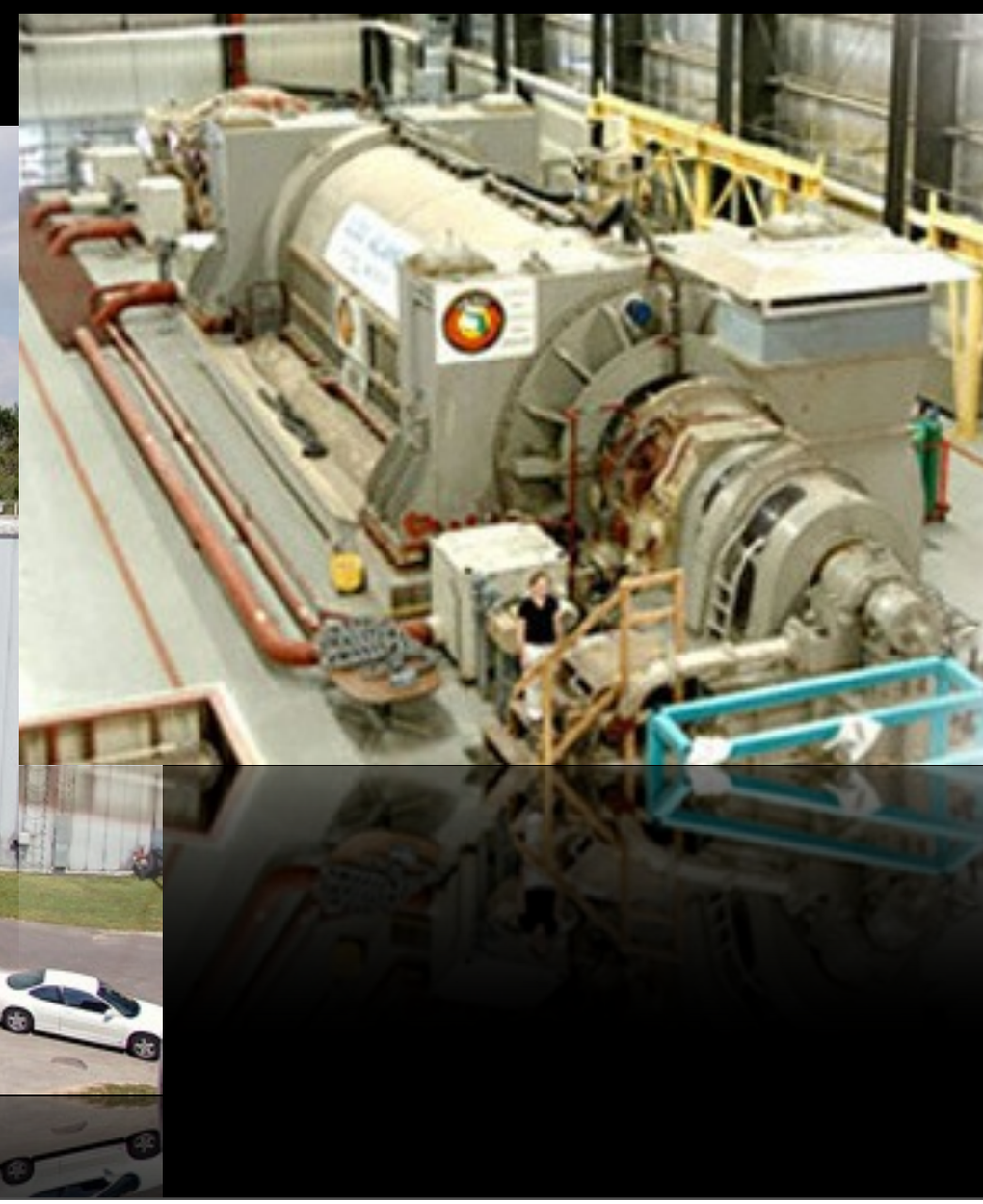
100T PULSED LANL, NM

MEASUREMENT :

NON-LOCAL

45T HYBRID NHMFL, FL

100T PULSED LANL, NM



MEASUREMENT :
NON-LOCAL

35T HFML, Neijmegen, NL

75T PULSED Toulouse, FR

ANALYTIS LAB

ARPES

Lanzara

ANALYTIS LAB

ARPES
Lanzara

STM
Crommie

ANALYTIS LAB

ARPES
Lanzara

STM
Crommie

ANALYTIS LAB

NEUTRON SCATERRING
Birgeneau

ARPES
Lanzara

STM
Crommie

ANALYTIS LAB

NEUTRON SCATERRING
Birgeneau

DEVICES
Siddiqi

ARPES
Lanzara

STM
Crommie

OPTICS
Orenstein

ANALYTIS LAB

NEUTRON SCATERRING
Birgeneau

DEVICES
Siddiqi

ARPES
Lanzara

STM
Crommie

OPTICS
Orenstein

ANALYTIS LAB

THEORY
Vishwanath
Moore
DH Lee
S. Louie

NEUTRON SCATERRING
Birgeneau

DEVICES
Siddiqi

ARPES
Lanzara

STM
Crommie

OPTICS
Orenstein

MSD
Neaton

ANALYTIS LAB

THEORY
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Moore
DH Lee
S. Louie

NEUTRON SCATERRING
Birgeneau

DEVICES
Siddiqi

ARPES
Lanzara

STM
Crommie

OPTICS
Orenstein

MSD
Neaton

Molecular Foundry
Yaghi

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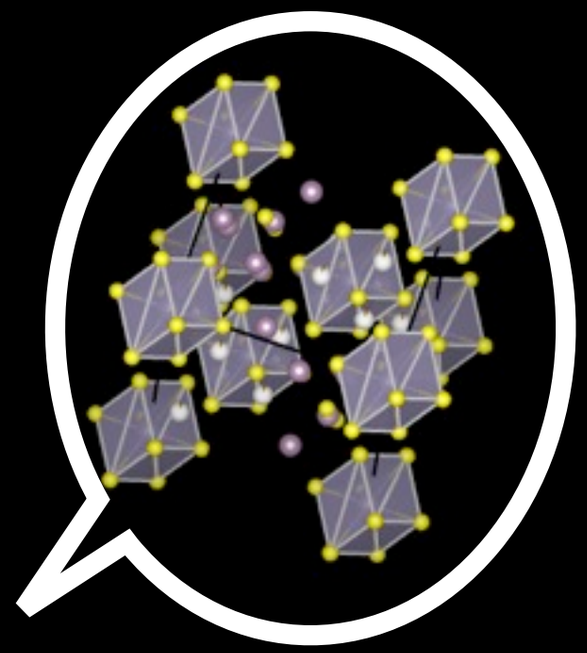
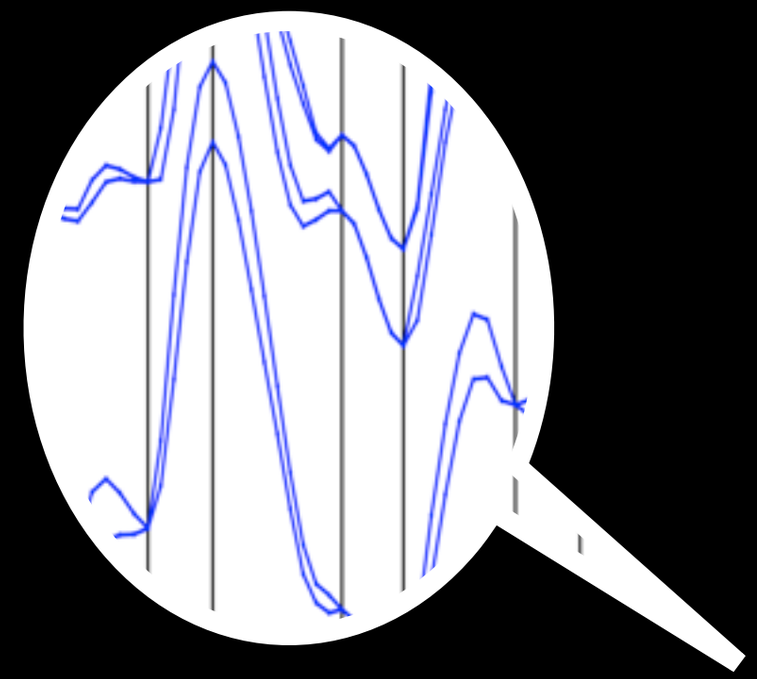
THEORY
Vishwanath
Moore
DH Lee
S. Louie

NEUTRON SCATERRING
Birgeneau

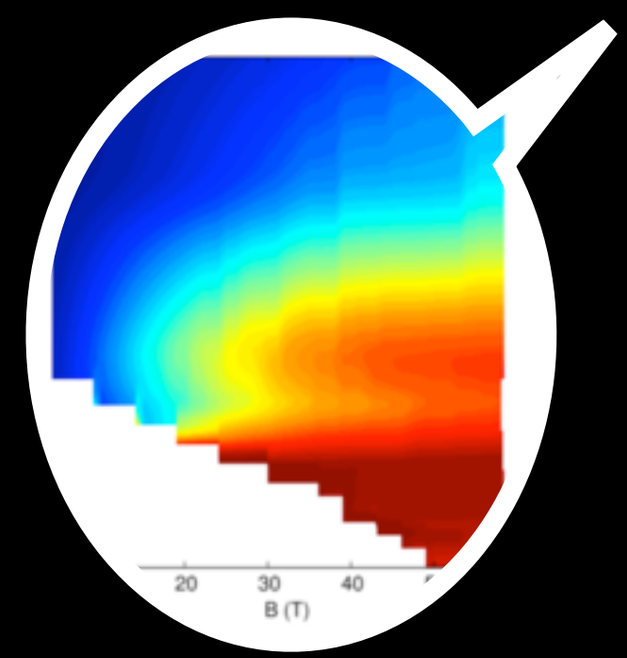
DEVICES
Siddiqi





Material "design"

Calculation

Synthesis

Experiment