INSTITUTE FOR QUANTUM MATTER

A collaboration between
JOHNS HOPKINS UNIVERSITY
and PRINCETON UNIVERSITY

Impacts of Neutron Scattering on Hard Condensed Matter Physics

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Materials Sciences & Engineering
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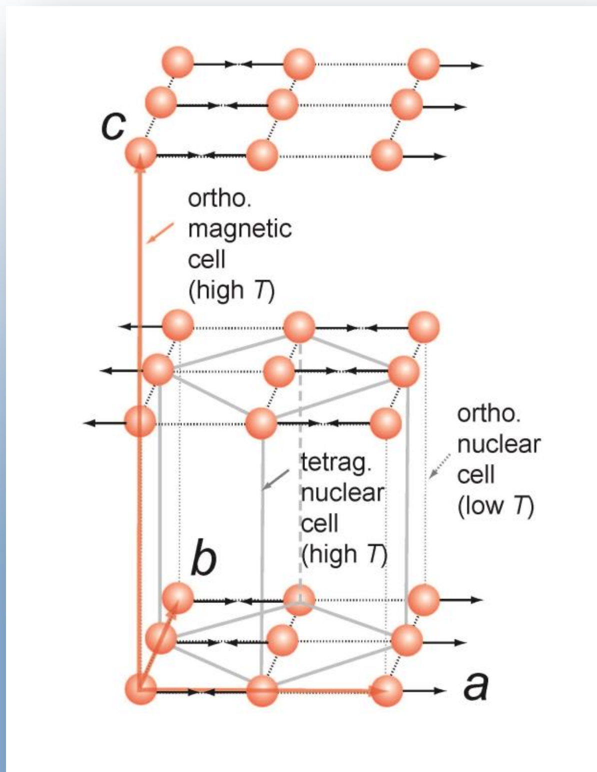
Outline

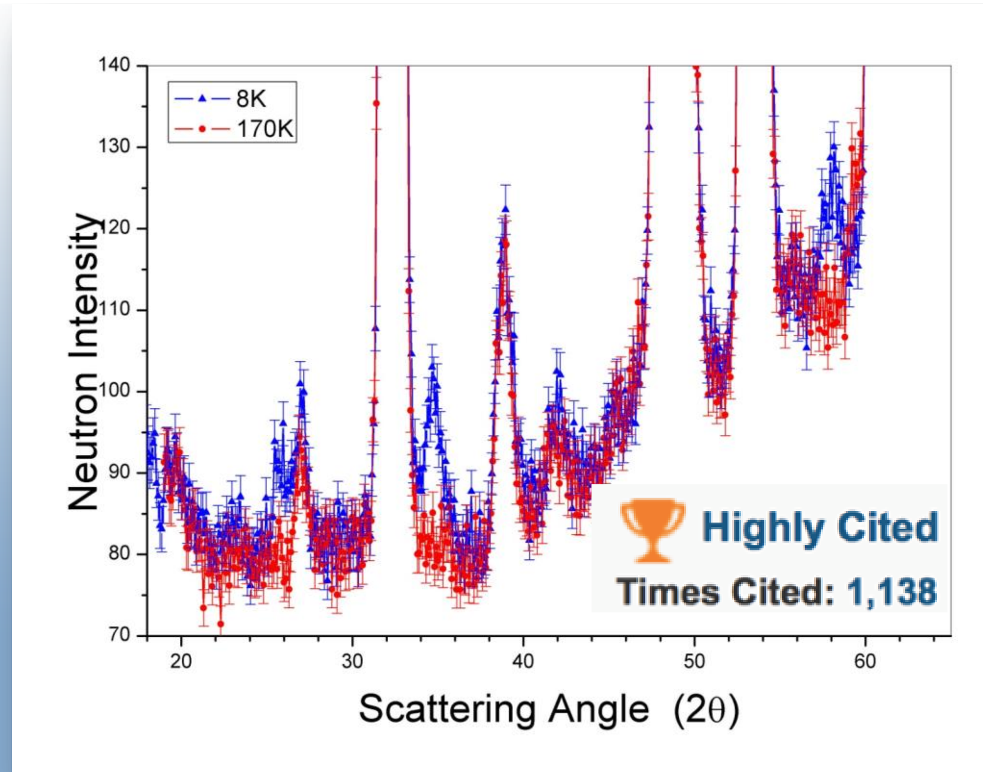
- **The past:**
  - Hard CMP & Neutrons (lessons from the millennium)
- **The future:**
  - Emerging areas of Hard CMP
  - Instrumentation needs and opportunities

Vol 453|12 June 2008|doi:10.1038/nature07057 nature

Magnetic order close to superconductivity in the iron-based layered $LaO_{1-x}F_xFeAs$ systems

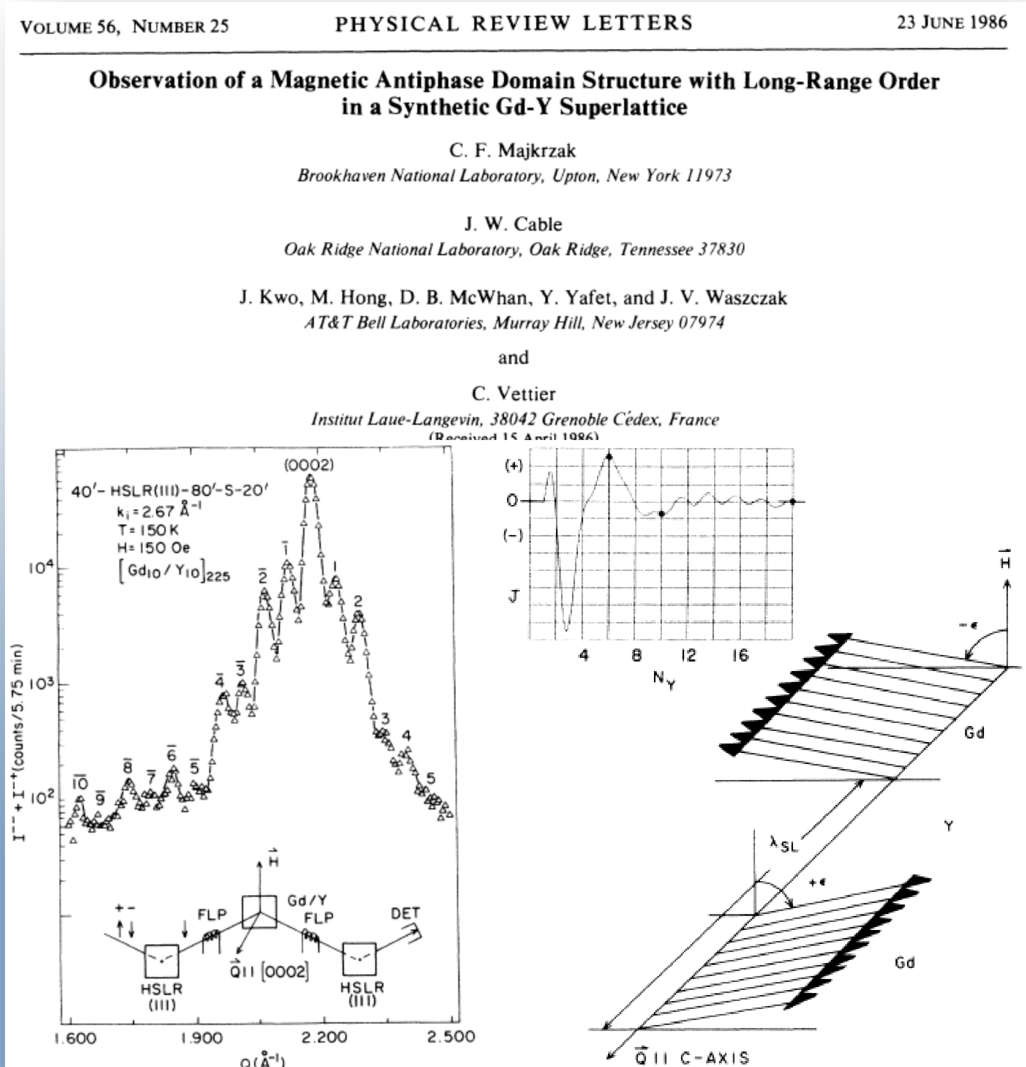
Clarina de la Cruz[1,2], Q. Huang[3], J. W. Lynn[3], Jiying Li[3,4], W. Ratcliff II[3], J. L. Zarestky[5], H. A. Mook[2], G. F. Chen[6], J. L. Luo[6], N. L. Wang[6] & Pengcheng Dai[1,2]





- High Intensity powder diffraction
- Engaged with forefront materials synthesis
- Hustle to be first and to be right

Giant Magneto Resistance


VOLUME 56, NUMBER 25 PHYSICAL REVIEW LETTERS 23 JUNE 1986

Observation of a Magnetic Antiphase Domain Structure with Long-Range Order in a Synthetic Gd-Y Superlattice

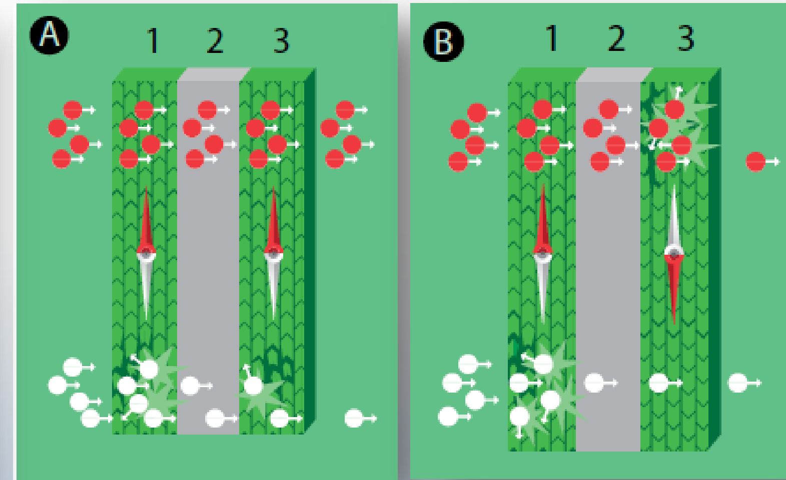
C. F. Majkrzak
Brookhaven National Laboratory, Upton, New York 11973

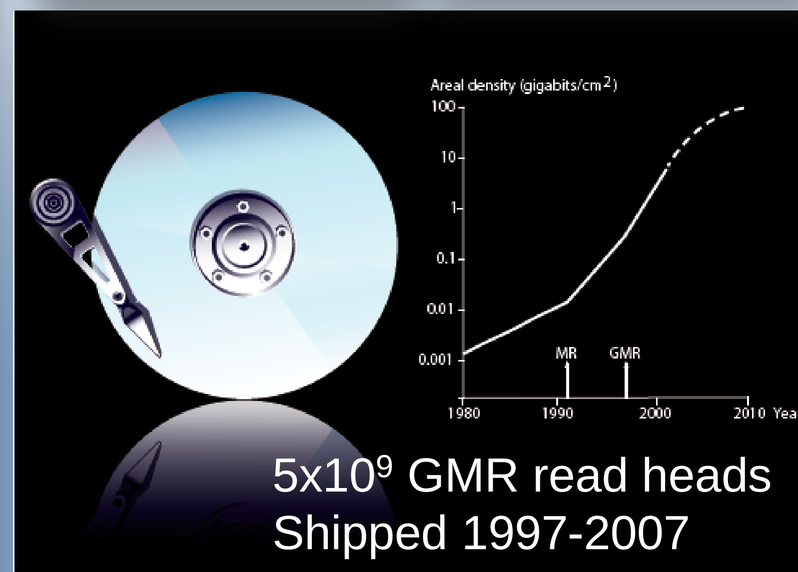
J. W. Cable
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

J. Kwo, M. Hong, D. B. McWhan, Y. Yafet, and J. V. Waszczak
AT&T Bell Laboratories, Murray Hill, New Jersey 07974

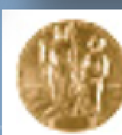
and

C. Vettier
Institut Laue-Langevin, 38042 Grenoble Cédex, France





Grünberg: The underlying mechanism was known before GMR was discovered



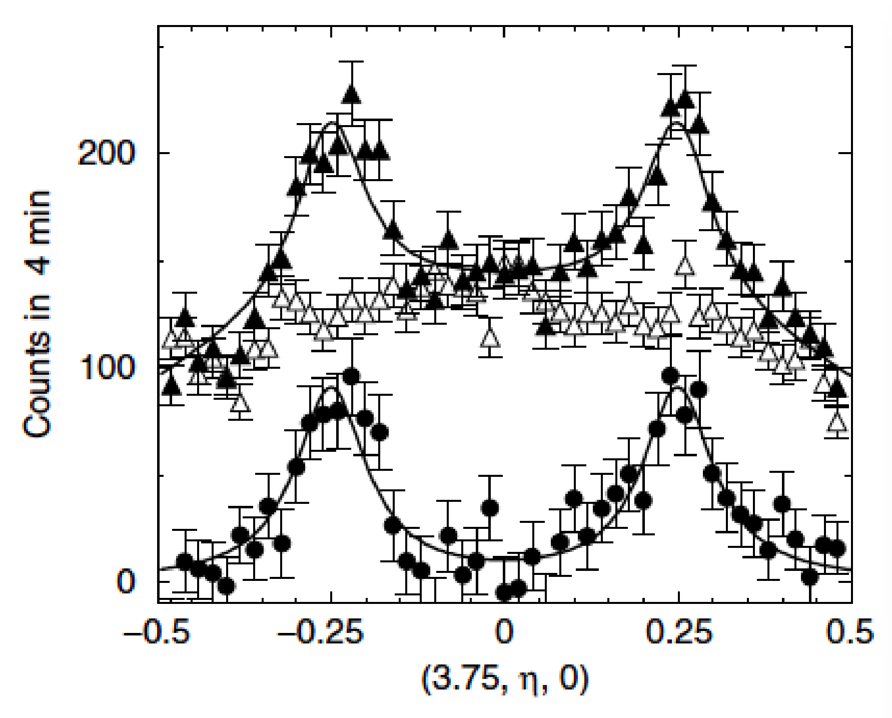
The Nobel Prize in Physics 2007

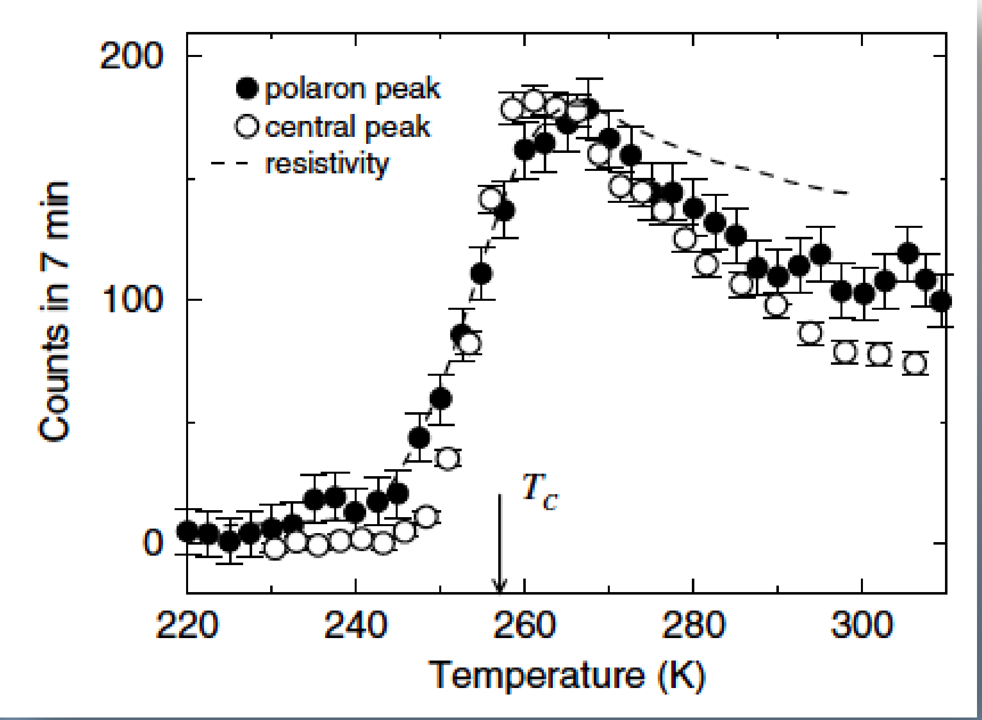
Albert Fert, Peter Grünberg

VOLUME 85, NUMBER 18 PHYSICAL REVIEW LETTERS 30 OCTOBER 2000

Charge Ordering and Polaron Formation in the Magnetoresistive Oxide $La_{0.7}Ca_{0.3}MnO_3$

C. P. Adams,[1,2] J. W. Lynn,[1,2] Y. M. Mukovskii,[3] A. A. Arsenov,[3] and D. A. Shulyatev[3]

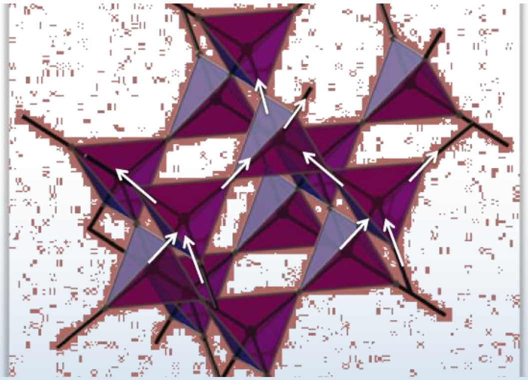


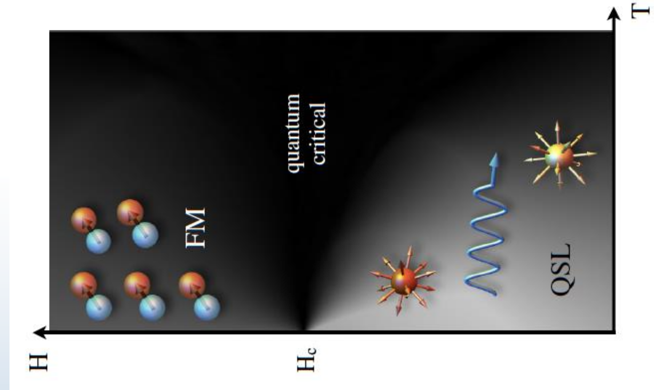


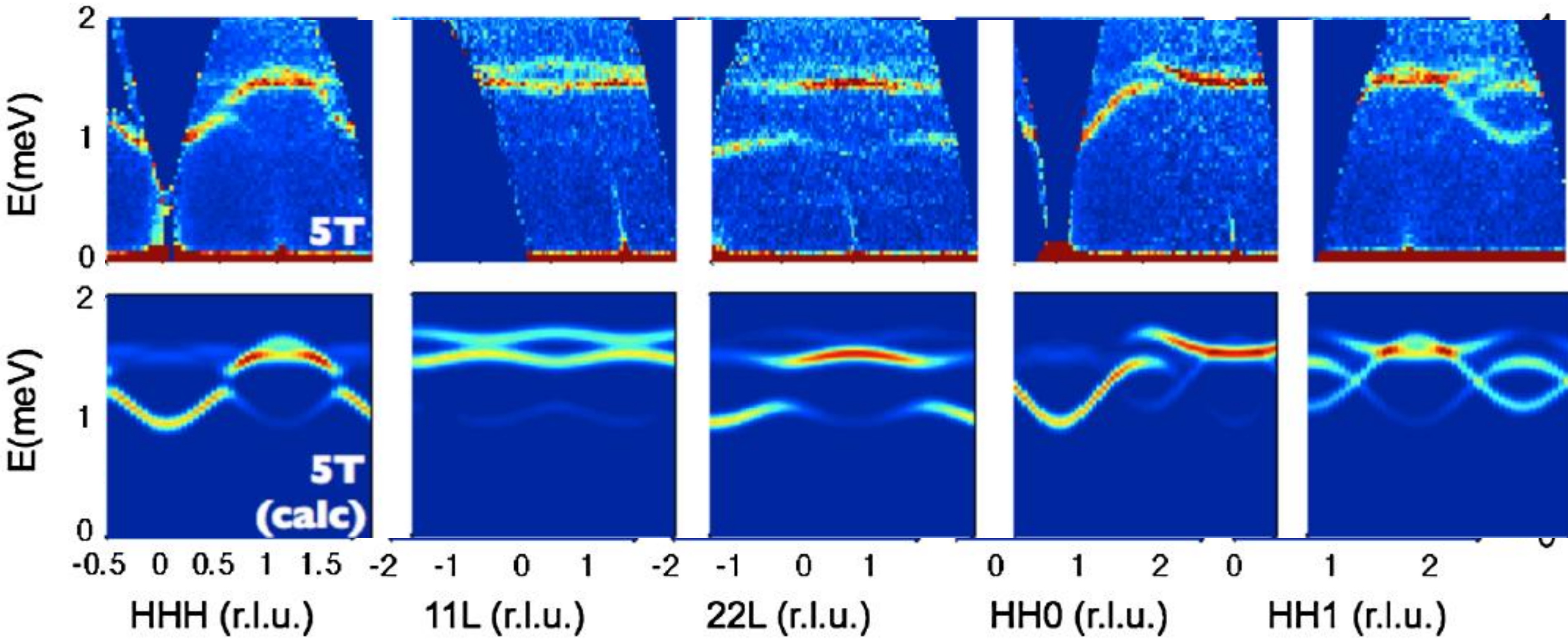
- Neutrons provide explanation for Colossal magneto-resistance
- Thermal TAS: Still versatile & effective but can it survive TOF?

Quantum Excitations in Quantum Spin Ice

Kate A. Ross,[1] Lucile Savary,[2] Bruce D. Gaulin,[1,3,4] and Leon Balents[5,*]

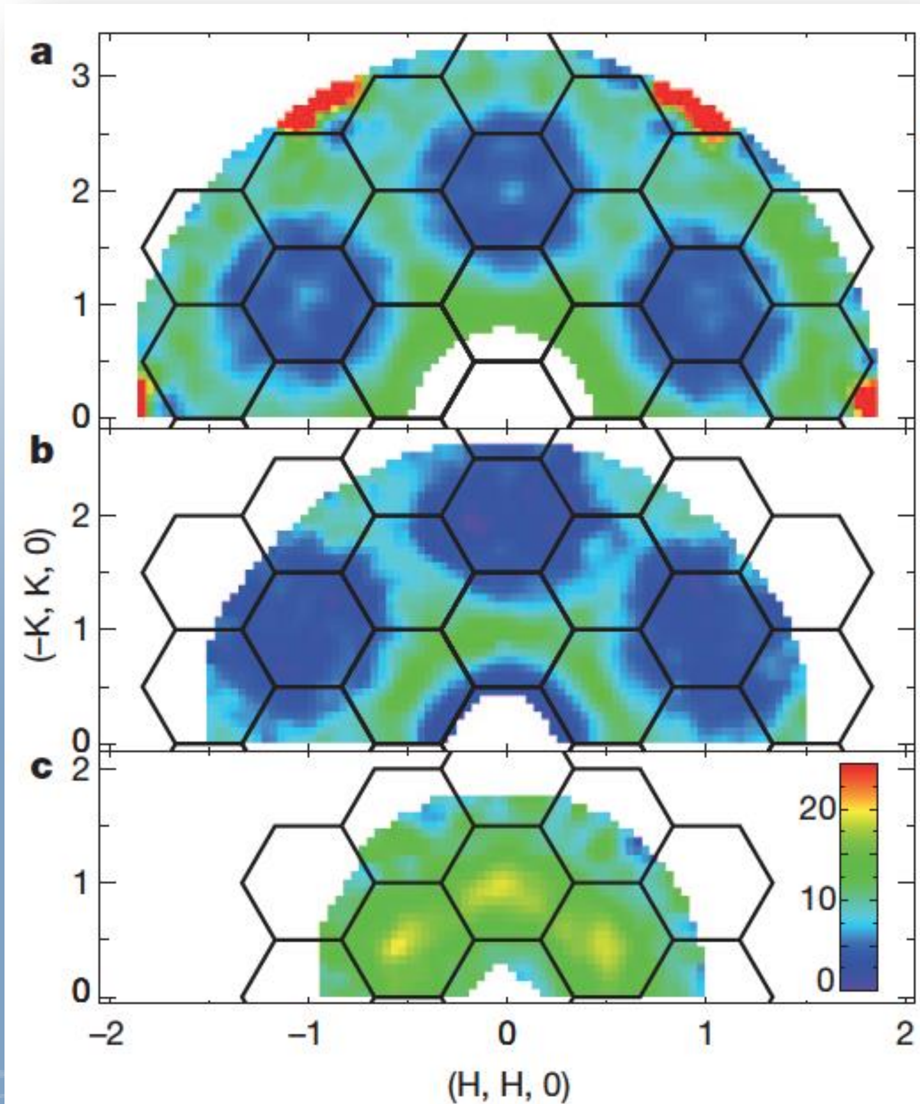


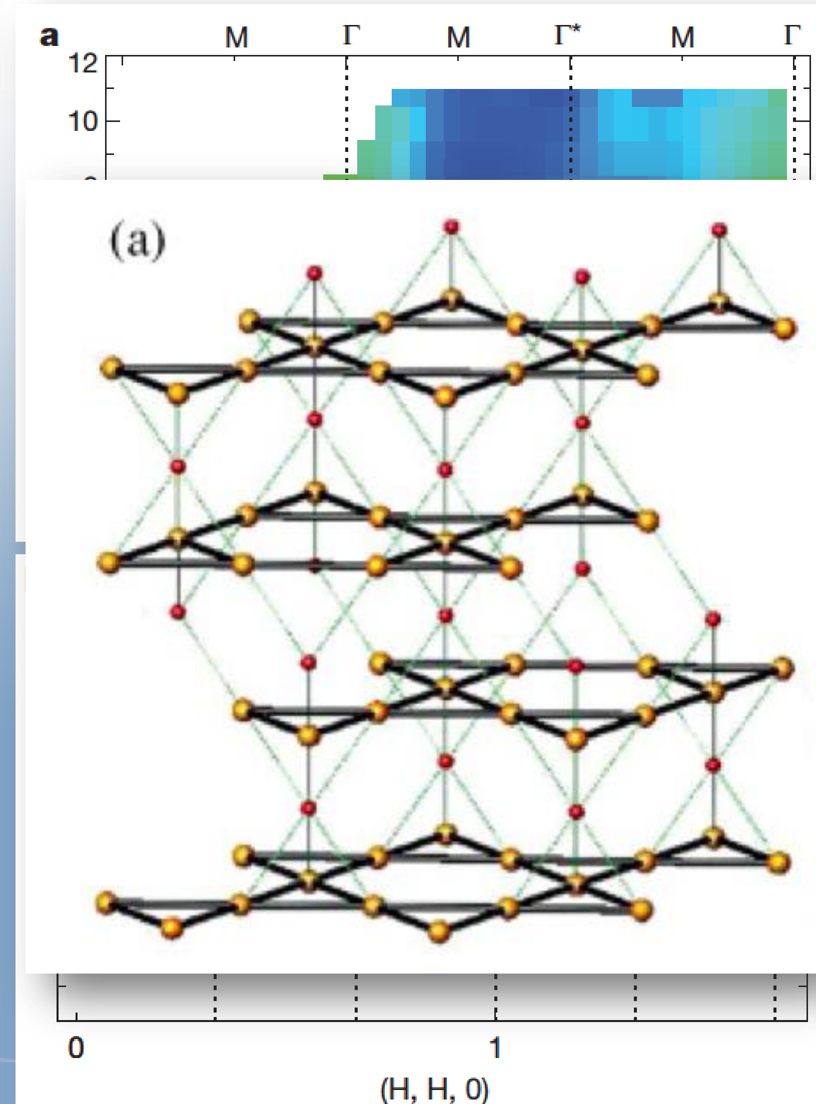




Fractionalized excitations in the spin-liquid state of a kagome-lattice antiferromagnet

Tian-Heng Han[1], Joel S. Helton[2], Shaoyan Chu[3], Daniel G. Nocera[4], Jose A. Rodriguez-Rivera[2,5], Collin Broholm[2,6] & Young S. Lee[1]





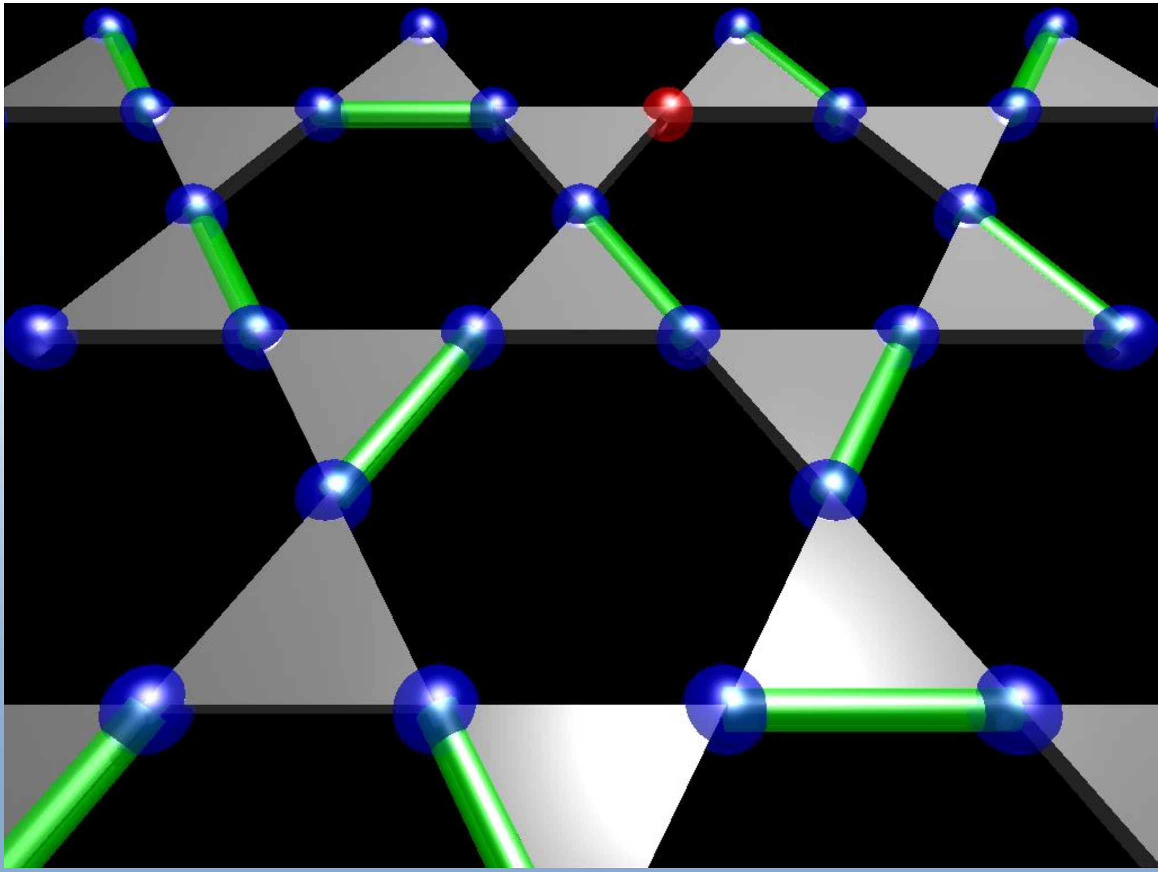
Spinons on kagome

S = ½ kagome AFM has a finite concentration of **spinons** in its ground state.

Spinons are solitons with spin *S* = ½ and fermionic statistics.

Spinons cannot be created/anihilated individually

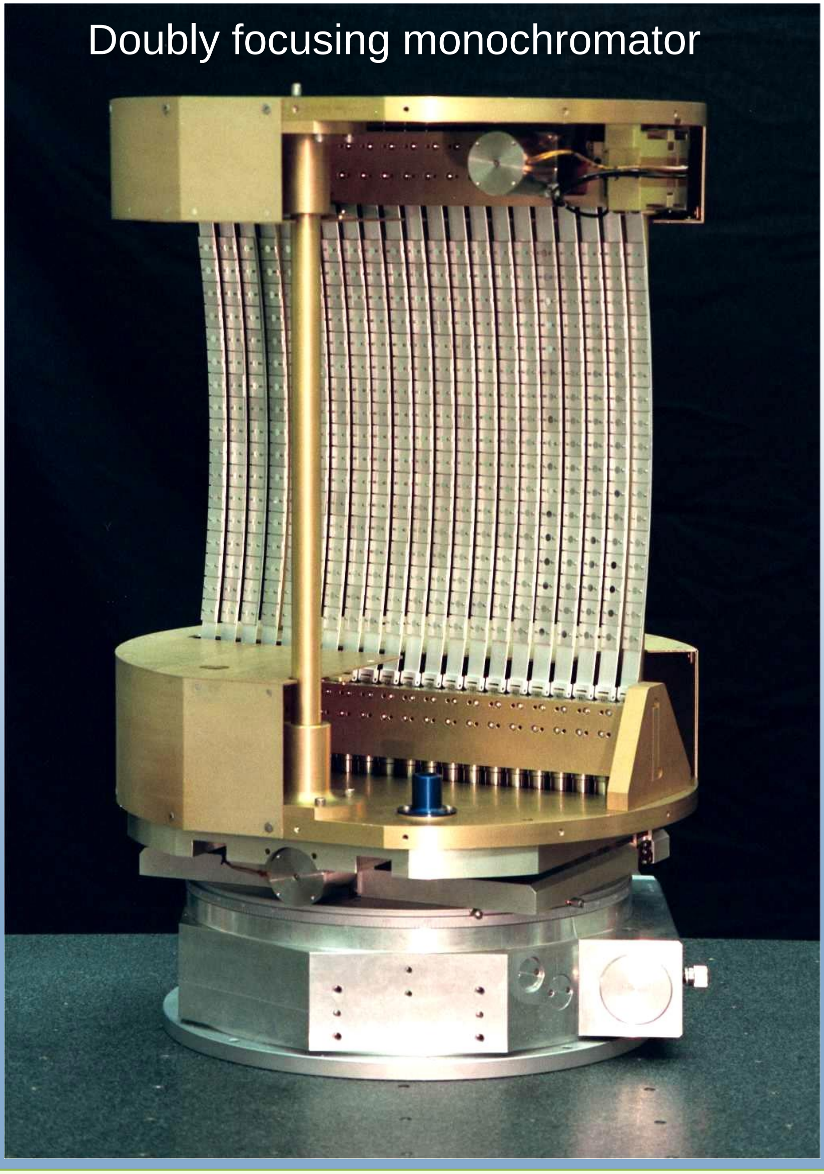
This is manifest in the replacement of a coherent mode by a continuum



Z.-H. Hao and O. Tchernyshyov, PRL **103**, 187203 (2009).
Y. Wan and O. Tchernysnyov, ArXiv 1301.5008v1 (2013)
Z. H. Hao and O. Tchernysnyov, ArXiv arXiv:1301.3261 (2013)

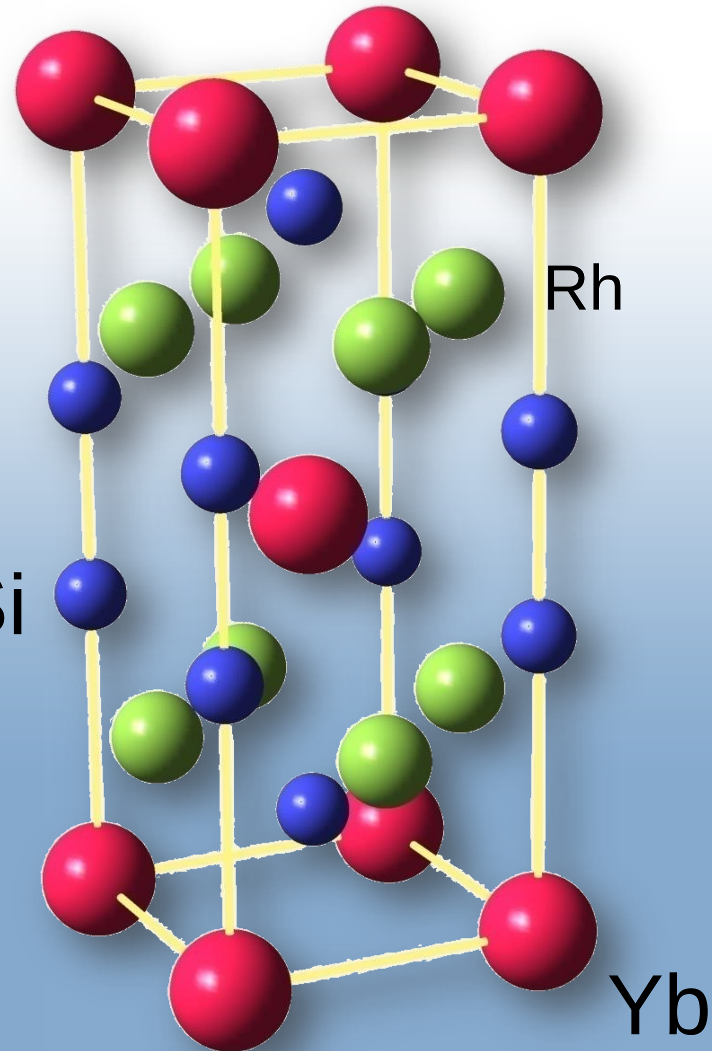

MACS II
May 2014
Kranco

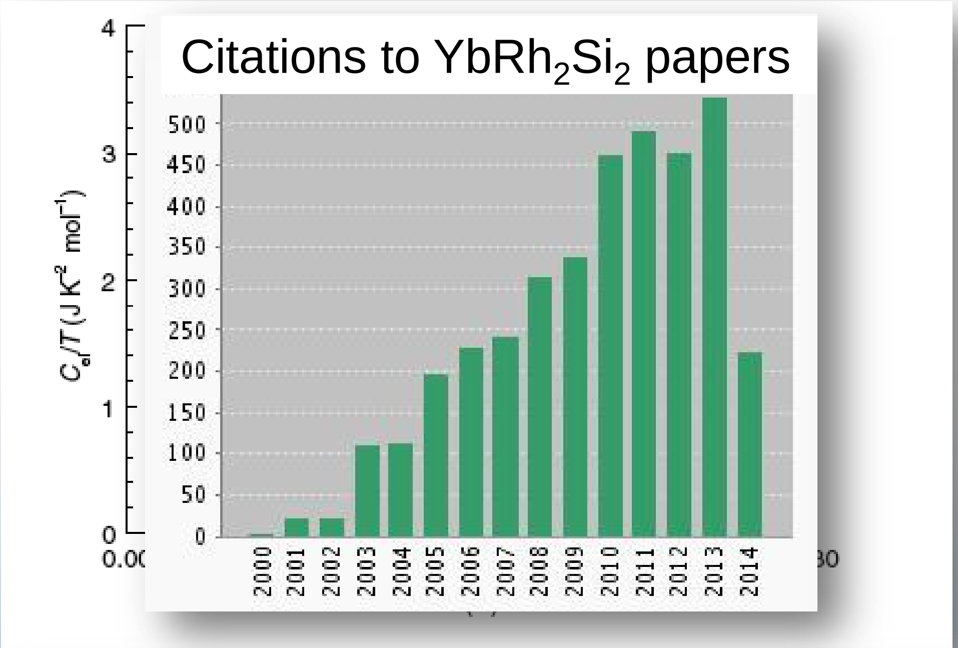
Features of MACS that enhance count rate



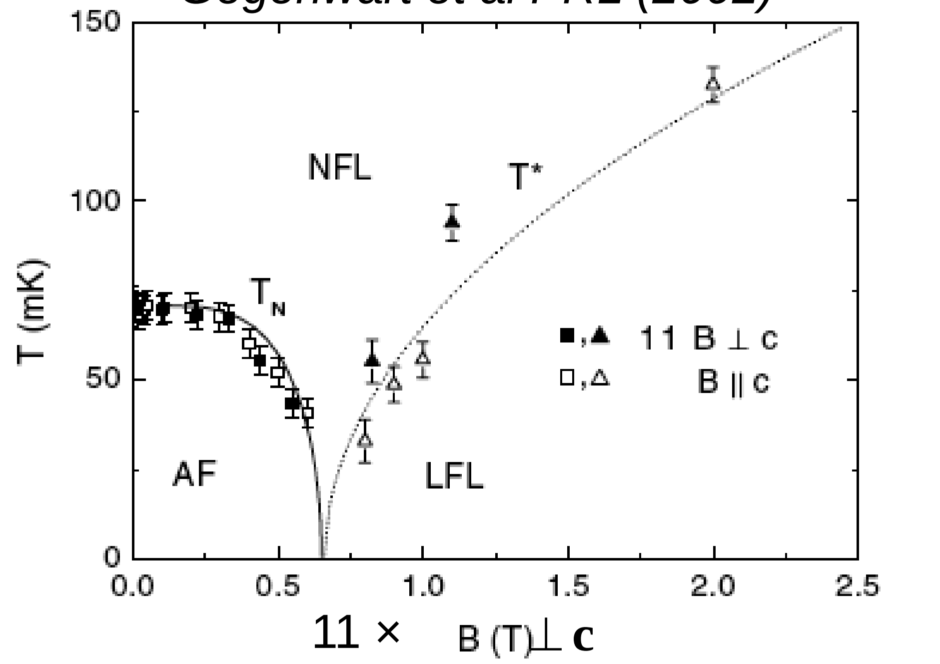
MACS was proposed a decade before kagome magnetism in Herbertsmithite was discovered: Optimizing for efficiency gives good chance of impact.

Field Driven QCP in $YbRh_2Si_2$





Gegenwart et al PRL (2002)



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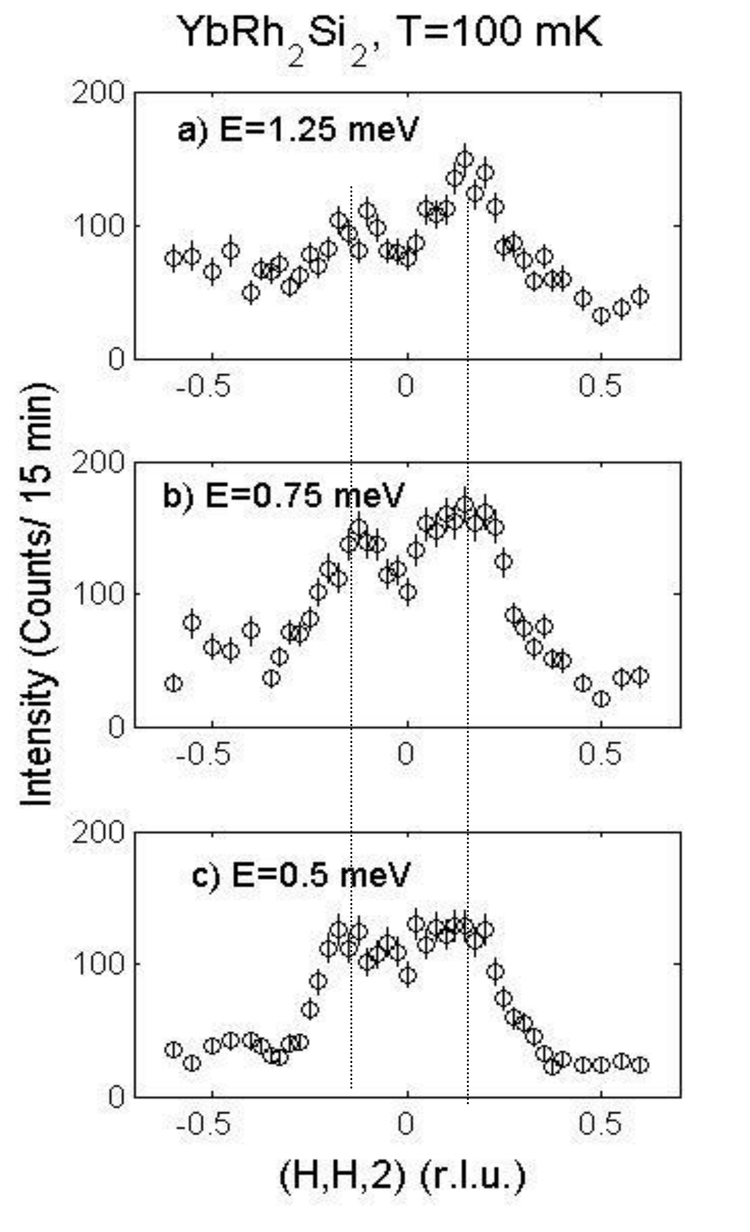
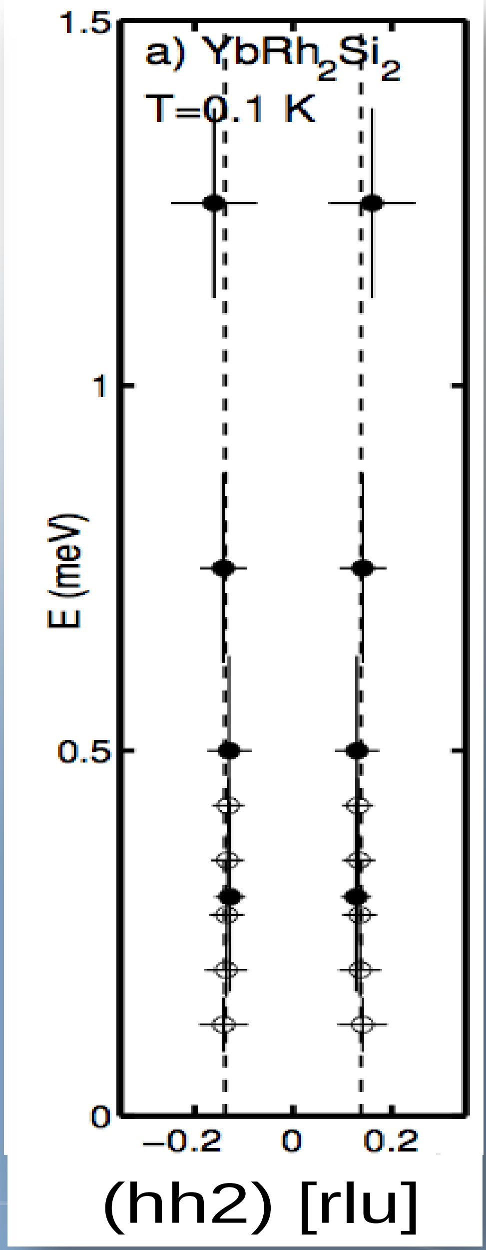
A heavy fermion nesting instability?



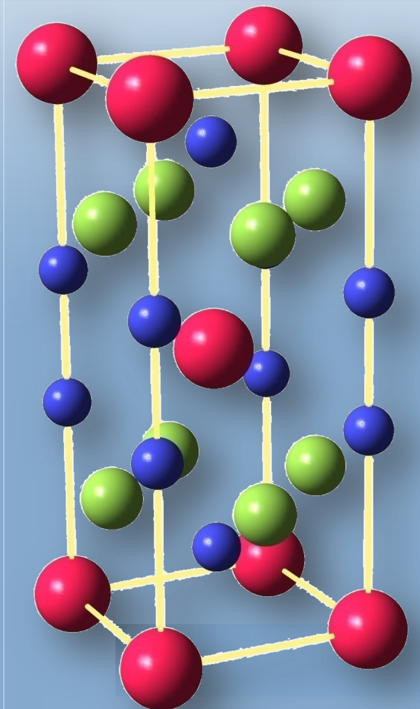


$$\vec{Q}_m = (\delta\delta 0)$$

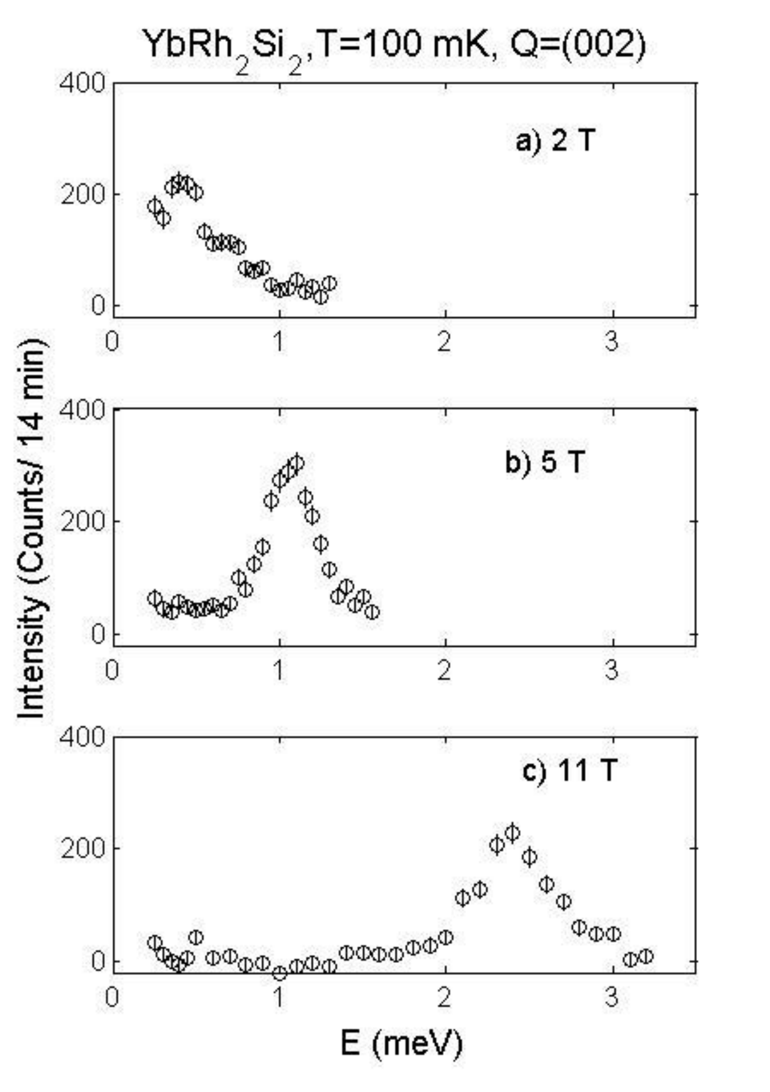
$$\delta = 0.14(4)$$

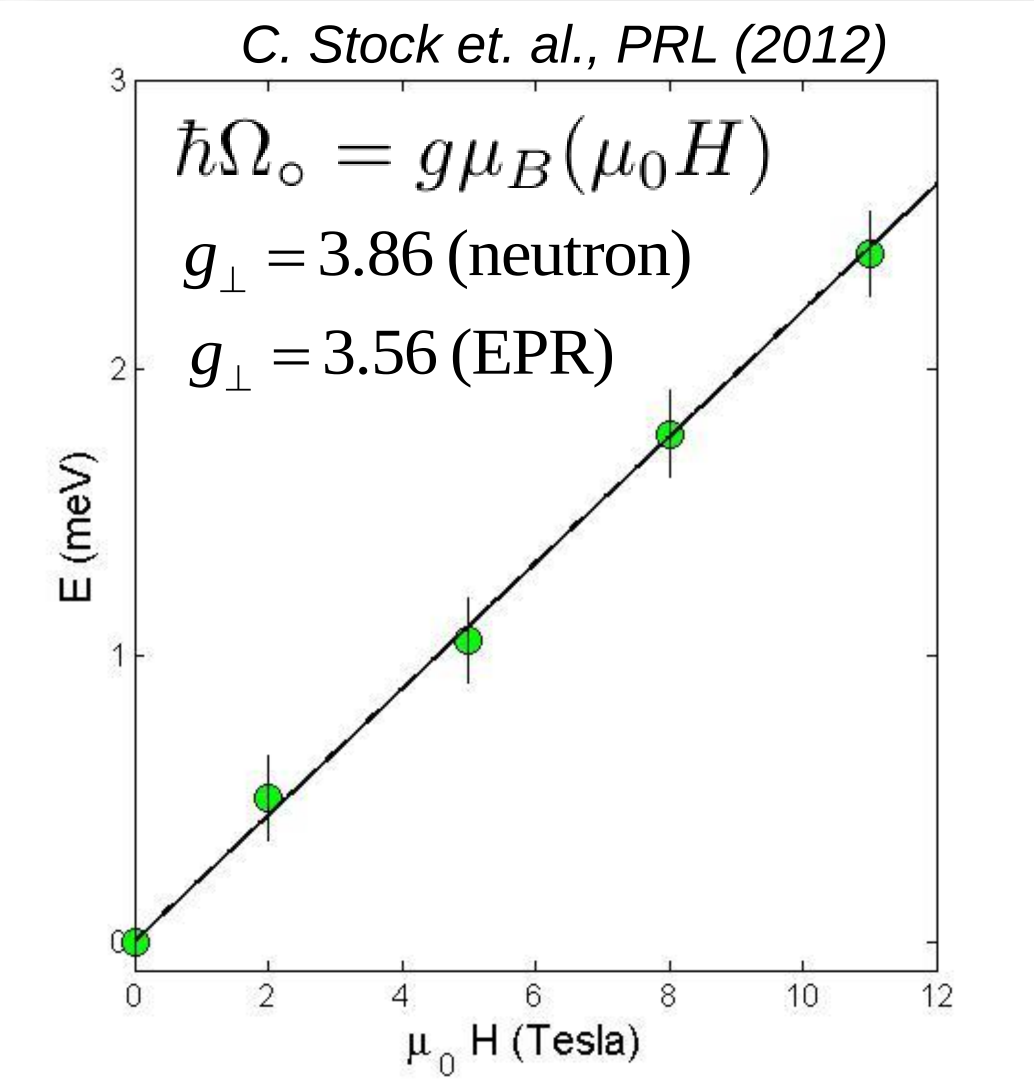
$$\ell \sim 3.6\left(\vec{a}+\vec{b}\right)$$

$$\hbar\Omega \geq 1 \text{ meV}$$



Breaking up the critical state with B





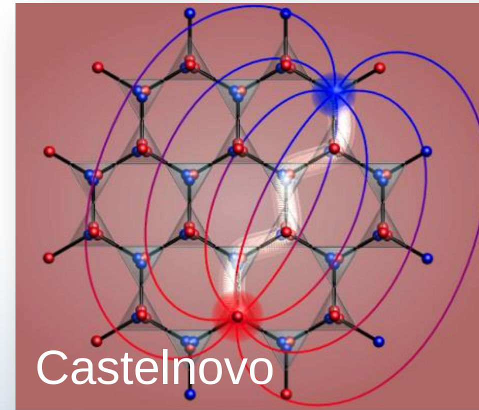
Reliable access to extreme thermodynamic conditions (her low T and high B) is essential for discoveries in hard condensed matter physics

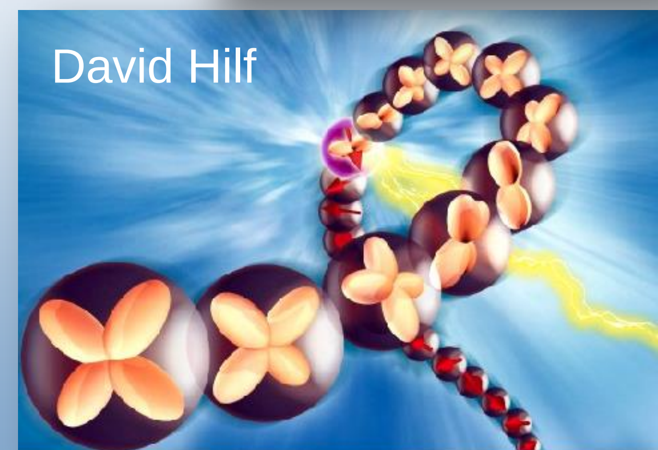
To Impacts HCMP (Millennial Wisdom)

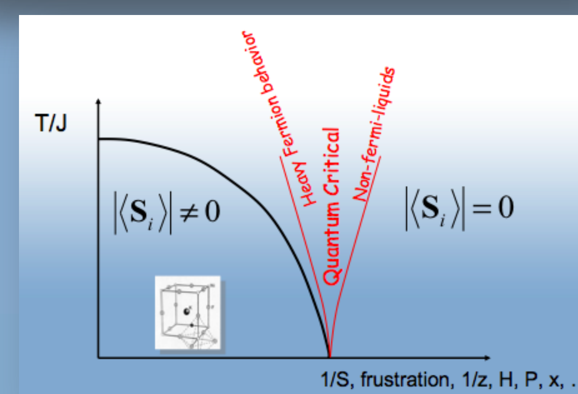
- Link exploratory synthesis with high intensity diffraction
- Do experiments at the interface between science and technology
- Use the power of neutrons to “solve” topical problems in CMP
- Loop in leading theorists to subject data to deserved high level analysis
- Keep pushing the frontiers in instrumentation.
- Ensure stable access to extreme sample environments
- Above all: A passion to identify science that neutrons can impact; then “do it”

Frontiers in Hard Condensed Matter

- **Quantum Spin liquids**
  - Evidence for emergent electrodynamics (artificial light)
  - Hamiltonian + continuum for quantum spin liquid
  - Field driven effective chemical potential
- **Correlated Topological materials**
  - Neutrons as a probe of renormalized bandstructure
  - Systematics of bound state
  - Surface magnetism
- **Linked degrees of freedom**
  - Spin waves + phonons
  - Spin waves + orbitons
  - Macroscopic: Link disparate responses
- **Quantum Critical itinerant electrons**
  - Comprehensive scaling to chart types of criticality
  - Anomalous transport and spin correlations
- **Unconventional Superconductivity**
  - The magnetism within a *d*-superconductor?
  - Image the cooper pair







High Efficiency Instrumentation

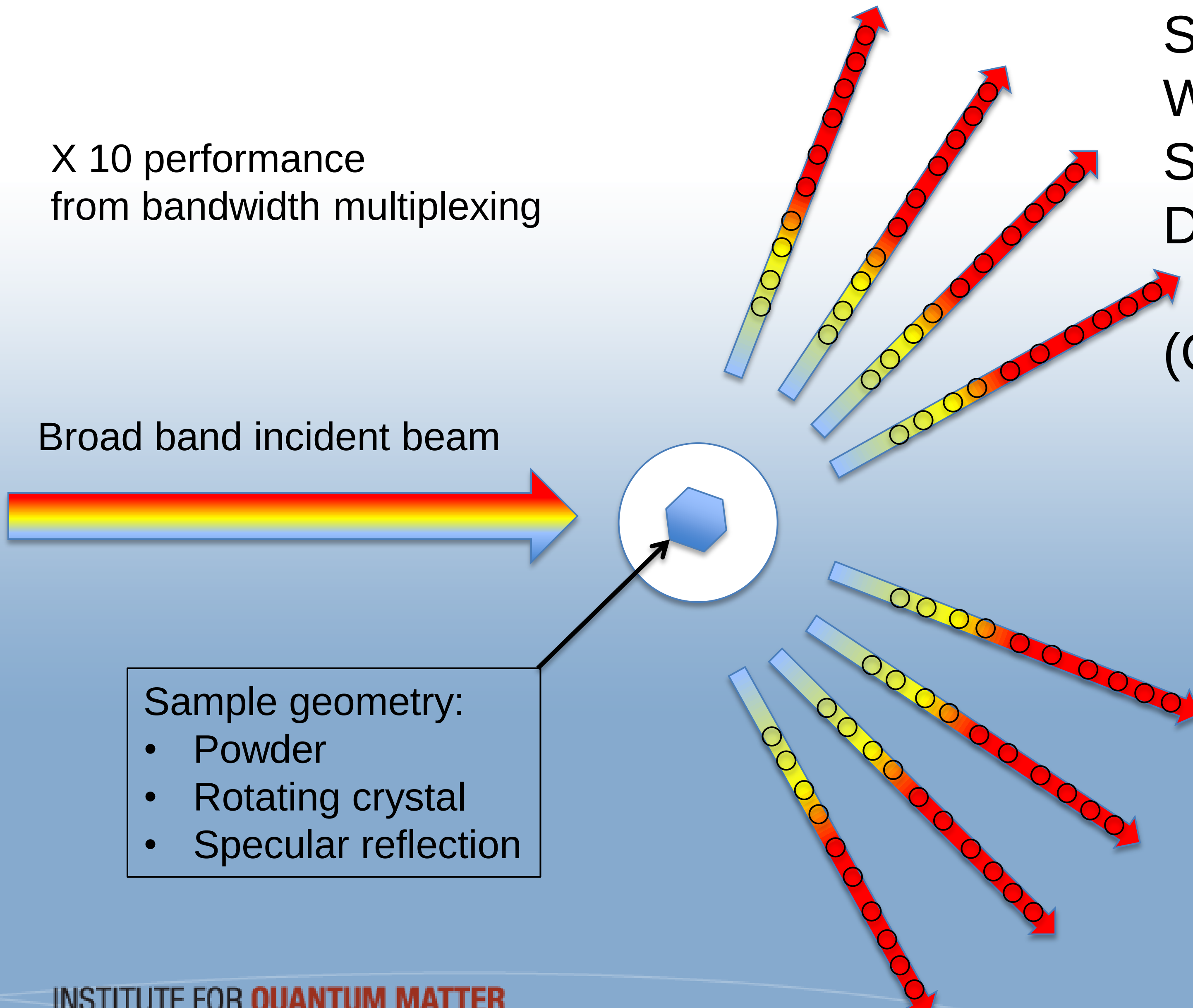
- **Still order(s) of magnitude to gain!**
- **Continue cold source optimization**
- **Focus neutrons onto the sample**
- **Broad incident spectrum for diffraction**
- **Simultaneous detection of**
  - Spectrum or multiple energies
  - Full range of scattering angles
- **Continuous crystal rotation**

Future of CW neutron diffraction

X 10 performance
from bandwidth multiplexing

Simultaneous
Wide Angle
Spectroscopic
Detection

(CANDOR)

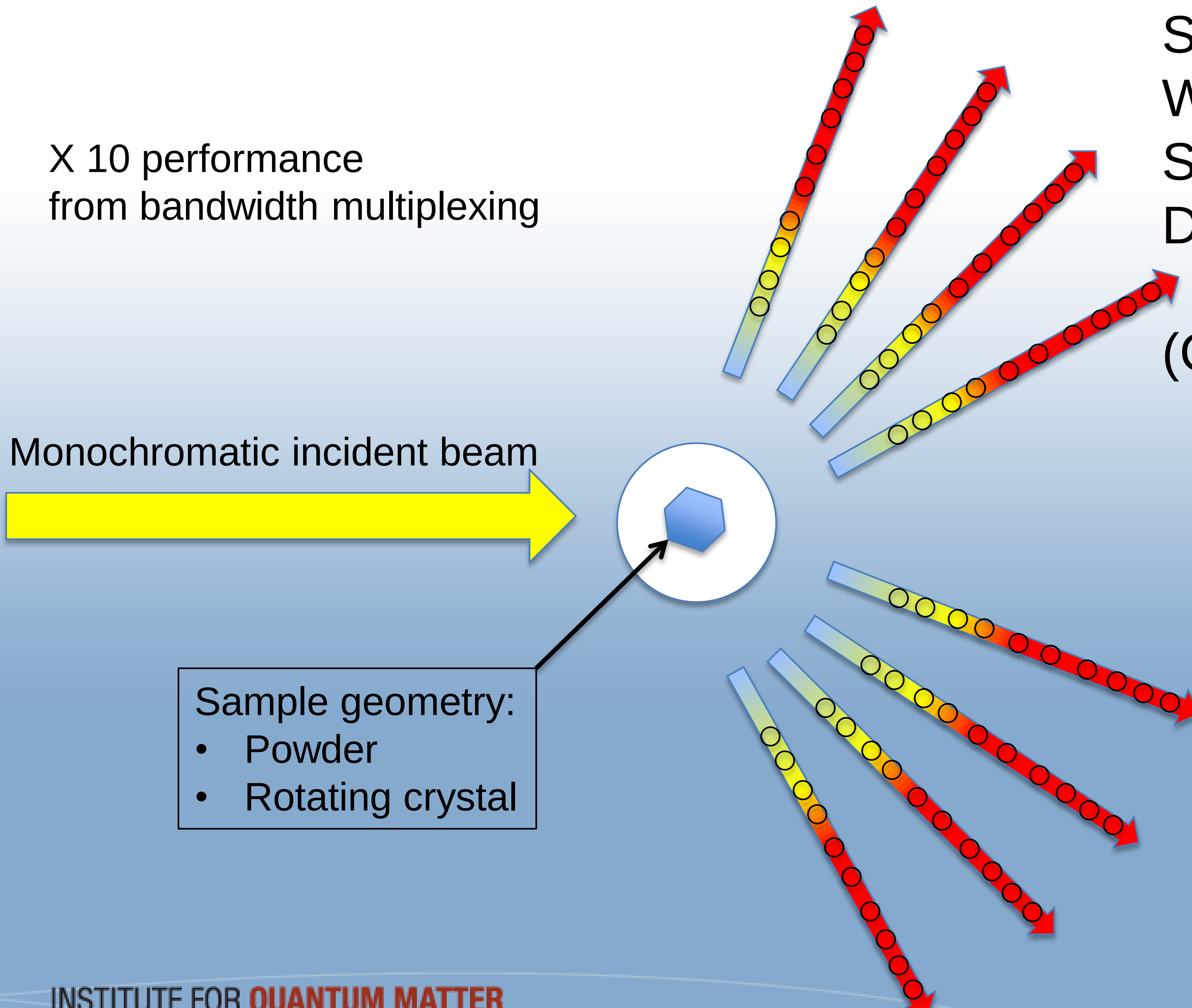


Broad band incident beam

Sample geometry:
- Powder
- Rotating crystal
- Specular reflection

Future of CW neutron spectroscopy

X 10 performance
from bandwidth multiplexing



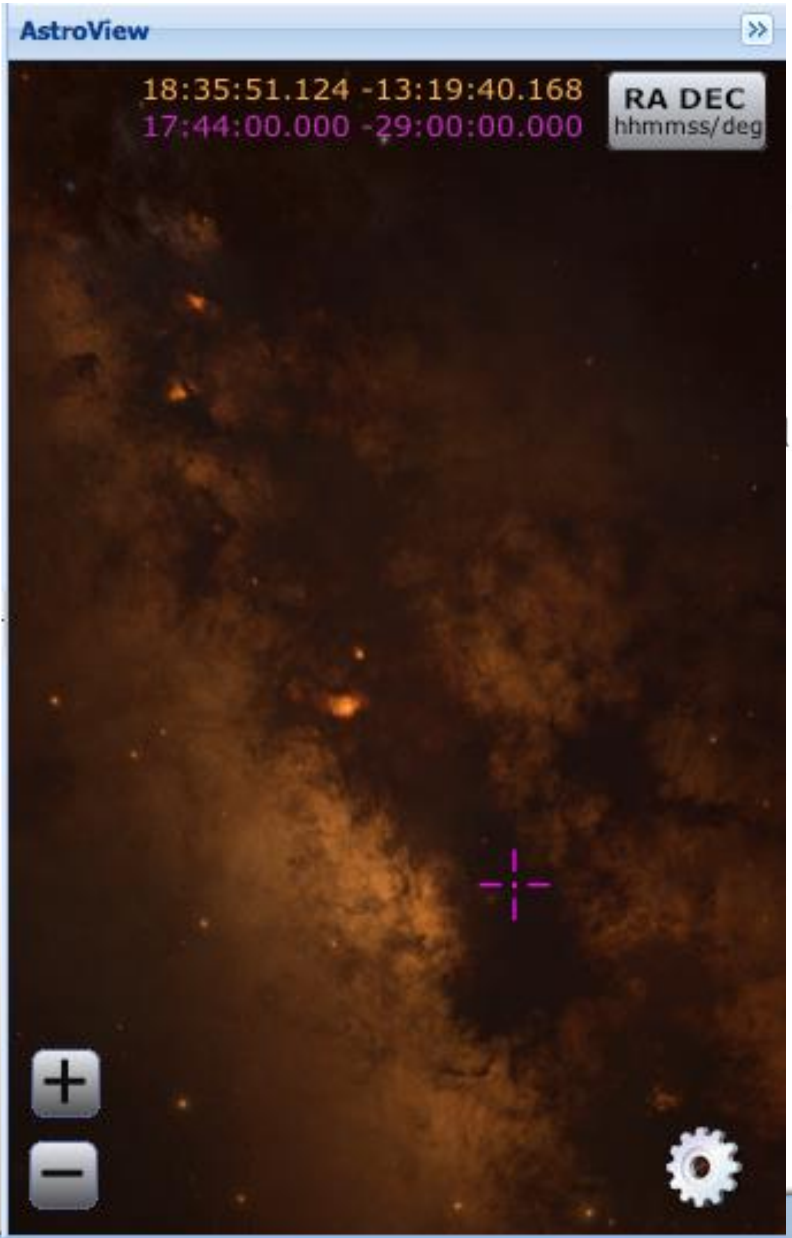
Simultaneous
Wide Angle
Spectroscopic
Detection

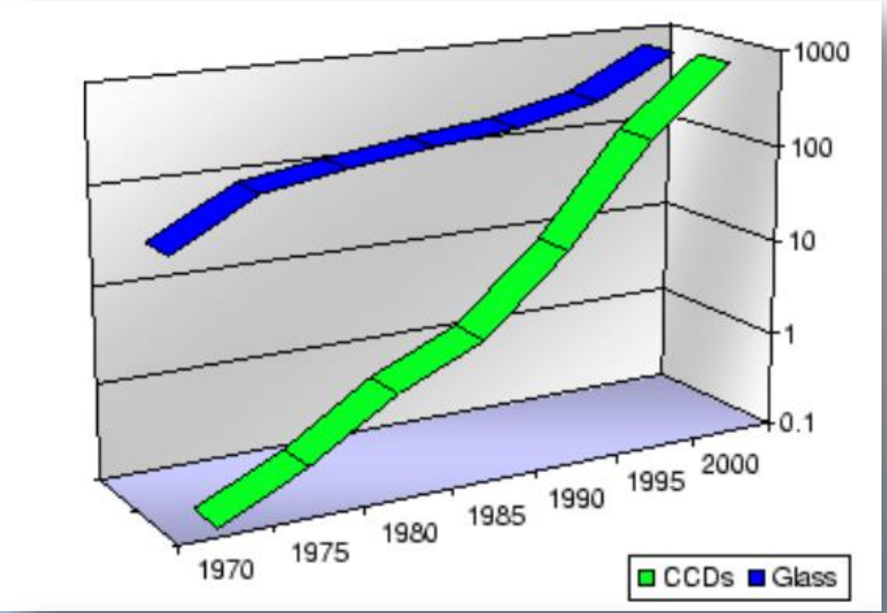
(CANDOR)

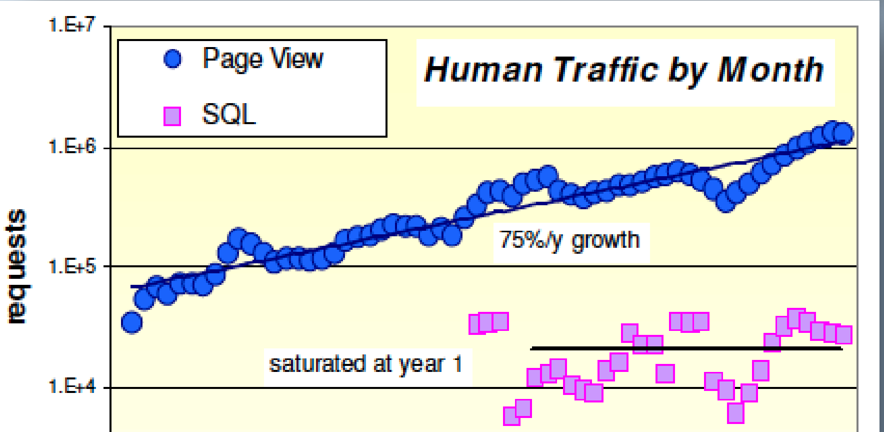
"Big Data" & Neutron Scattering

- **Comprehensive automated data collection:**
- **The "experiment" is <u>an</u> analysis of previously acquired data**
- **After grace period other groups do "experiments" on archived data**
- **Key Benefits:**
  - More scientists converting data to knowledge
  - Encourages collaborations
  - Avoid repetition of experiments
  - Build an archive for posterity
- **Challenges:**
  - Does it work socially?
  - How to select/document sample

US Virtual Astronomical Observatory



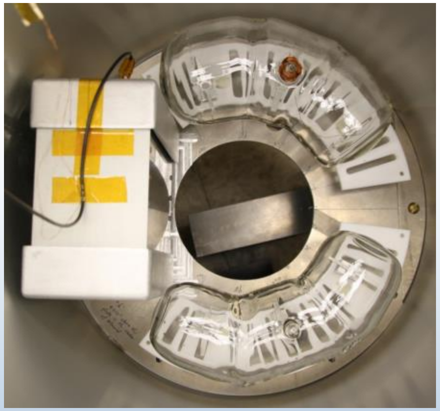




http://arxiv.org/pdf/cs/0701173.pdf

Other critical factors

- **Polarized neutrons**
  - Compact ^{3}He retrofit (MACS)
  - Cryopad capability
  - Larmor labeling



- **Sample environment innovation**
  - New generation of 20 mK systems
  - Beyond 15 Tesla with YBCO tape?
  - Different field geometries
  - Low T and high pressure (0.5,1,2,10 Gpa)

Summary

- **Neutrons: indispensible in Hard CMP**
  - Emergent excitations in spin liquids
  - Quantum critical metals
  - Spin order and fluctuations in superconductors
  - Coupled spin-charge-lattice-orbitals
- **Order(s) of magnitude gains in view**
  - Improved cold source
  - Wide angle spectroscopic detection
  - Wide angle polarization detection
  - Innovative sample environments
- **A new mode of operation**
  - Archived data as virtual spectrometer
  - More scientists to overcome the analysis bottleneck