

Title: Phase Transitions in Planar Pyrochlores

Date: Apr 22, 2010 01:15 PM

URL: <http://pirsa.org/10040083>

Abstract: Frustrated pyrochlore magnets with Ising-like moments have attracted much attention due to the spin ice and spin liquid disordered states these materials display at low temperatures. We recently focused attention on $\text{Er}_2\text{Ti}_2\text{O}_7$ and $\text{Yb}_2\text{Ti}_2\text{O}_7$ which possess local XY, or planar, moments on the pyrochlore lattice - a network of corner sharing tetrahedra. I will describe our neutron scattering experiments in which magnetic long range order is destroyed by application of a (110) magnetic field in the XY antiferromagnetic pyrochlore $\text{Er}_2\text{Ti}_2\text{O}_7$, and experiments in which unexpected field-induced magnetic order is observed in its ferromagnetic counterpart, $\text{Yb}_2\text{Ti}_2\text{O}_7$.

Phase Transitions in Planar Pyrochlores

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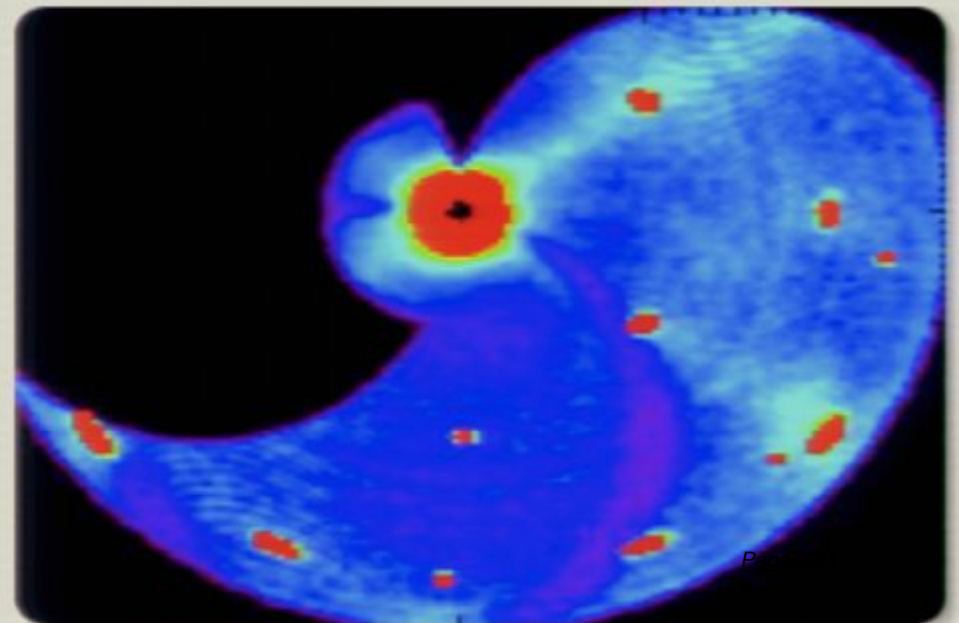
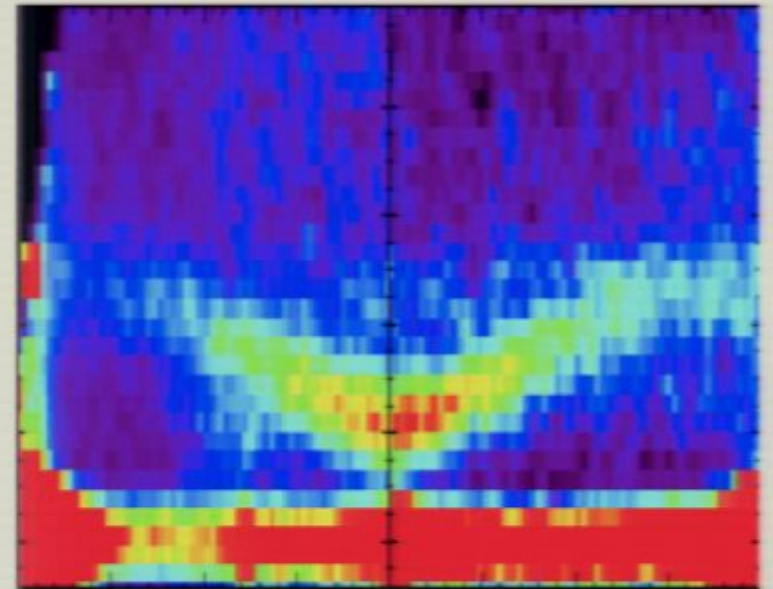
¹McMaster University

²St. Francis Xavier U

³NIST

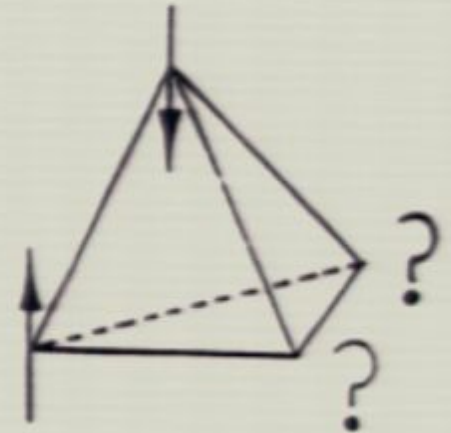
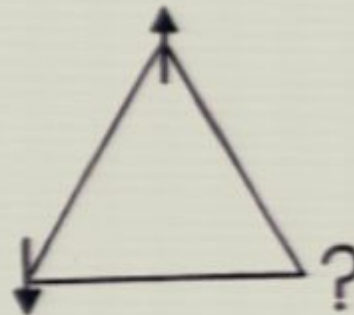
⁴Dalhousie U

⁵HZ Berlin



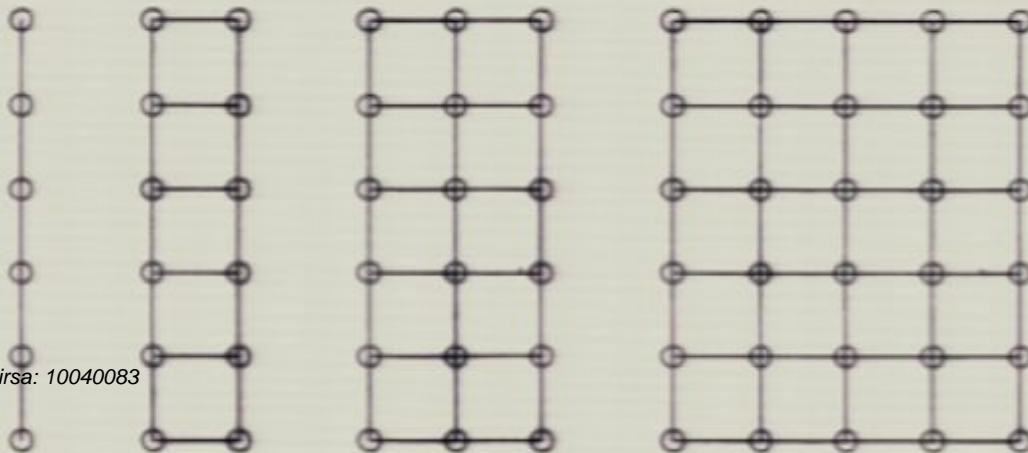
Routes to Exotica

Geometrical Frustration



Quantum Fluctuations:

$S=1/2$ H *Transverse*

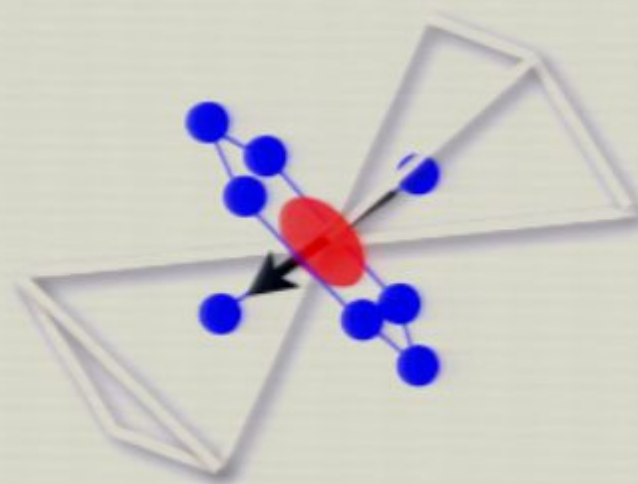
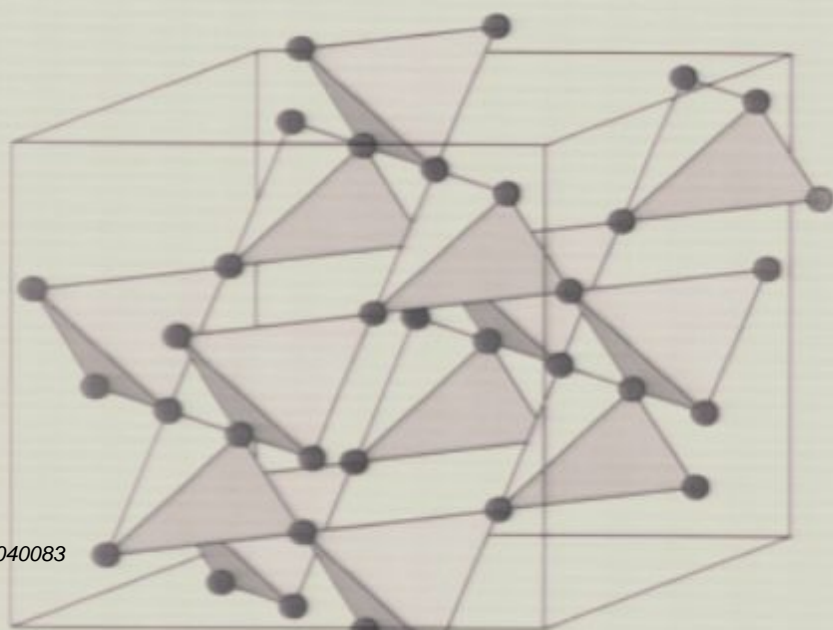


Low Dimensional Structures



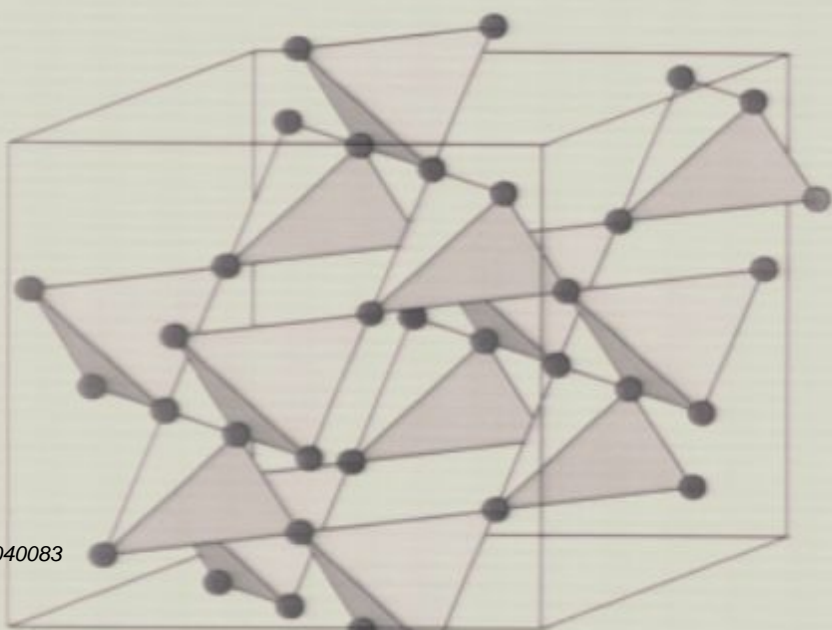
Cubic Pyrochlores:

- Spins on a network of corner-sharing tetrahedra
- $A_2Ti_2O_7$
- A site is RE^{3+} (many magnetic possibilities)

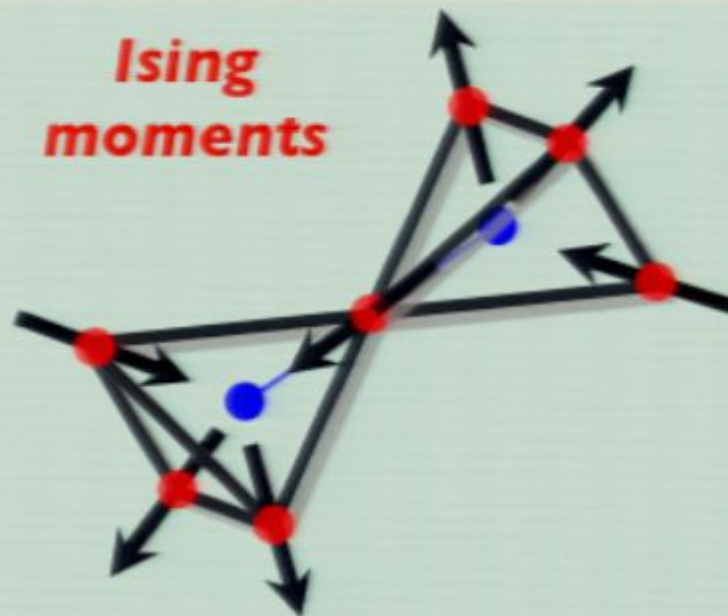


Cubic Pyrochlores:

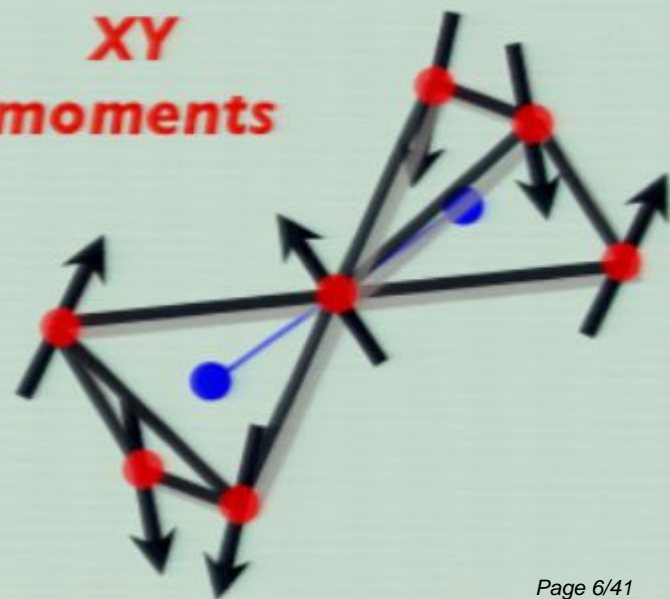
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Ising moments

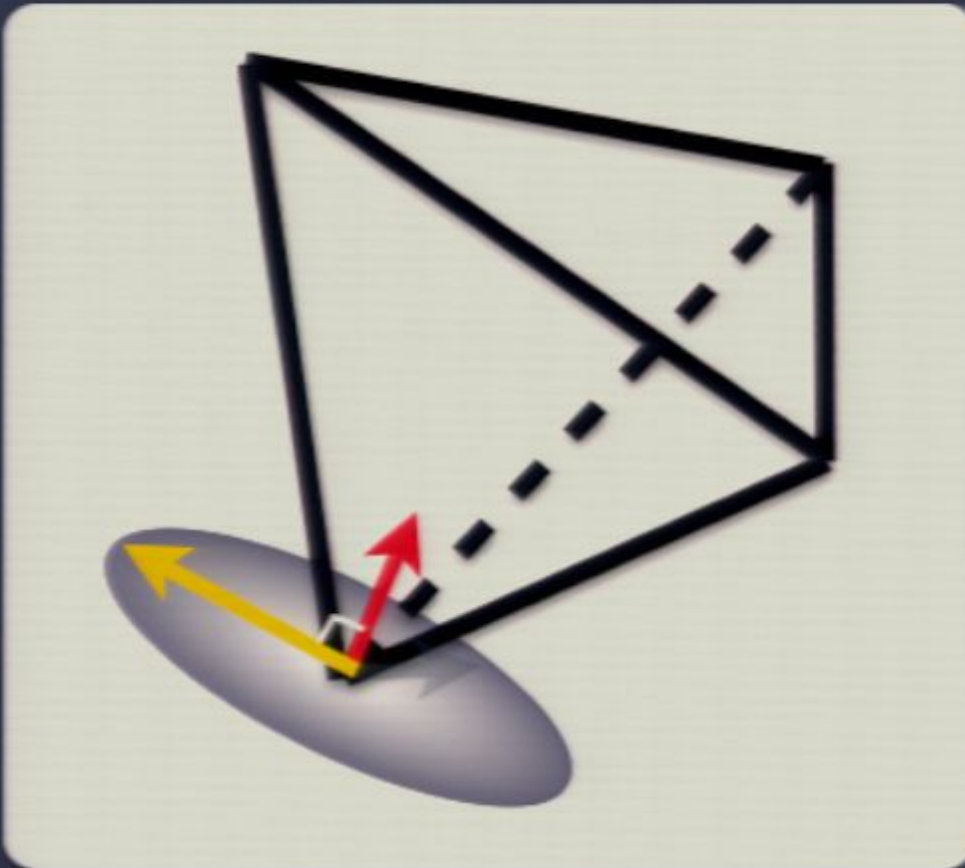


XY moments



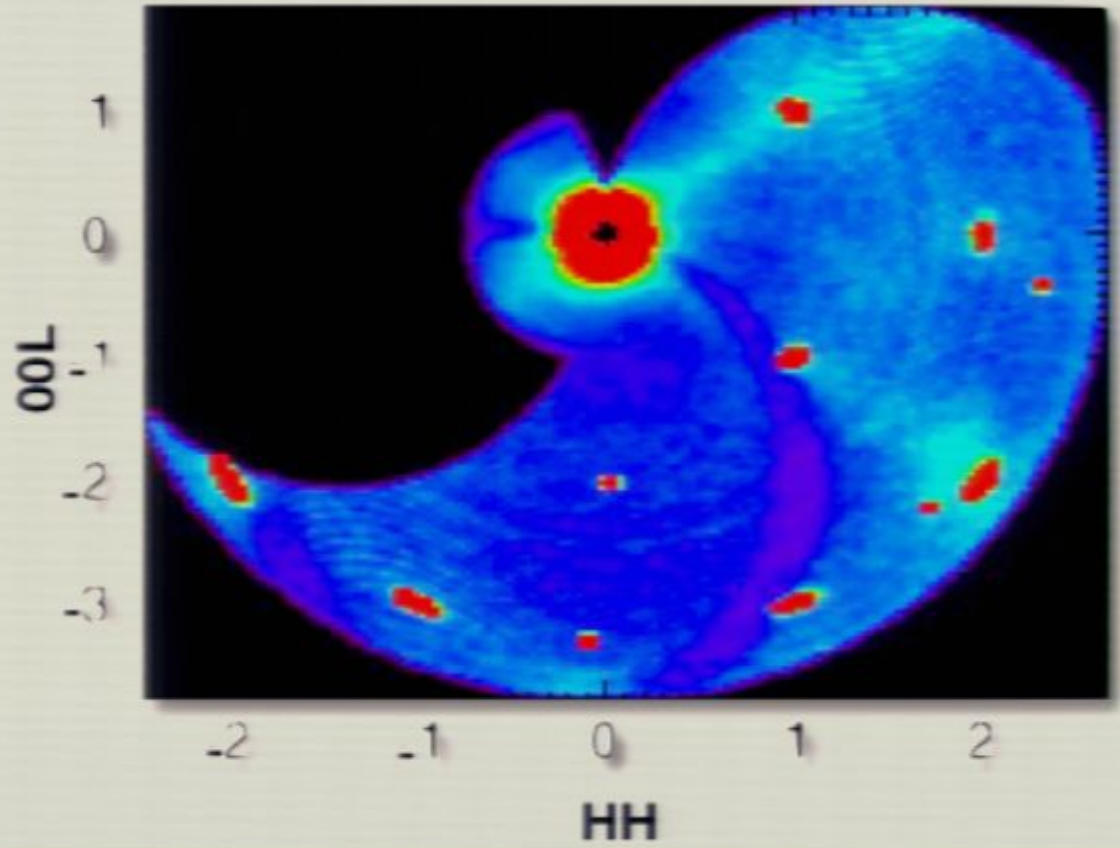
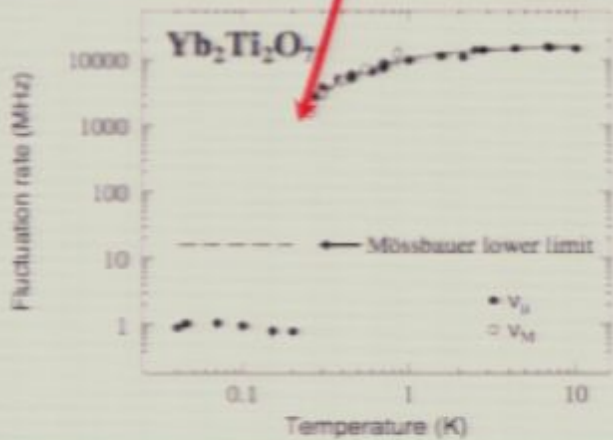
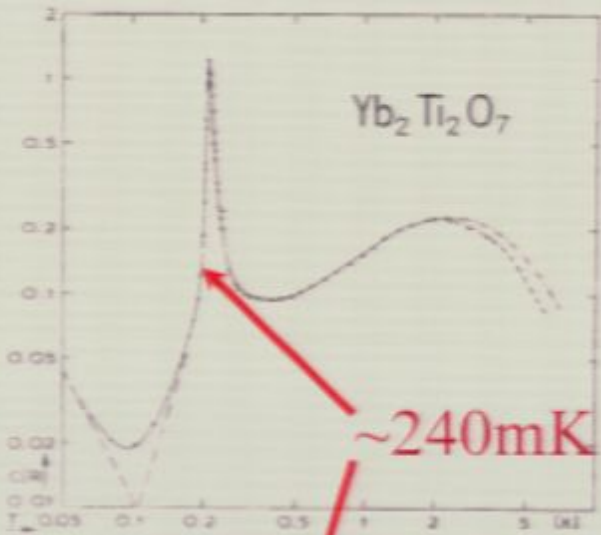
$\text{Yb}_2\text{Ti}_2\text{O}_7$ (Ferromagnet)
and
 $\text{Er}_2\text{Ti}_2\text{O}_7$ (Antiferromagnet)

Spin Anisotropy



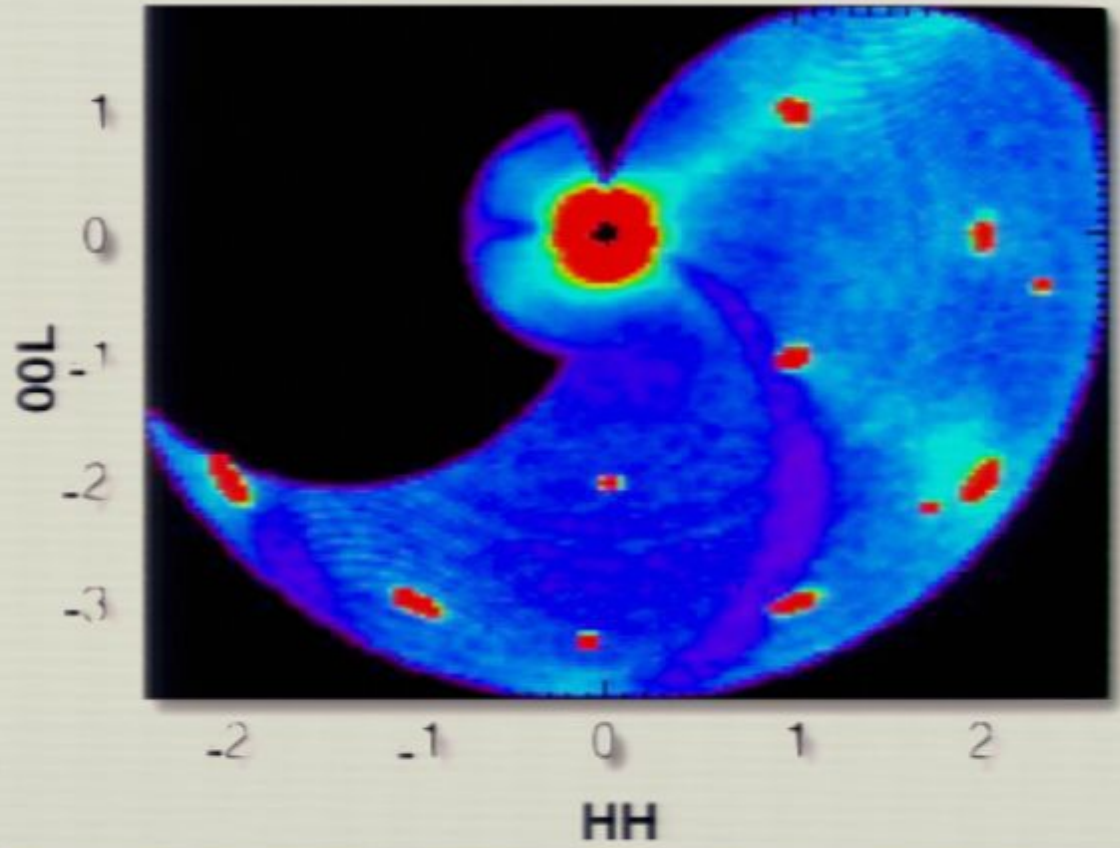
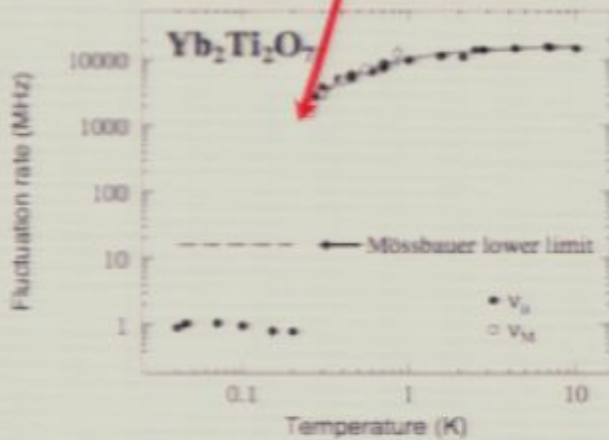
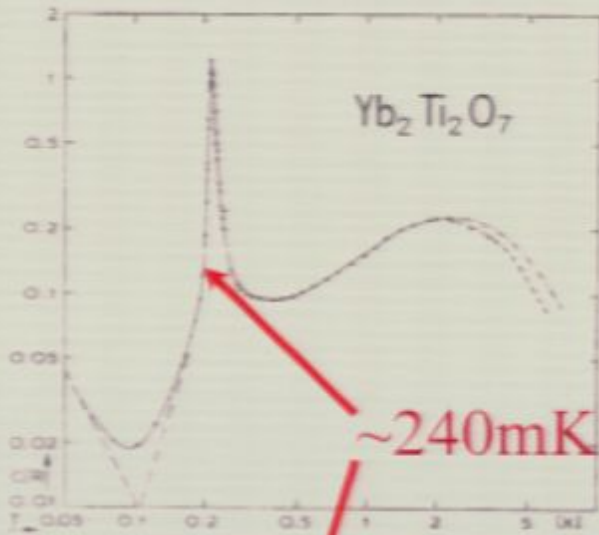
- Effective $S=1/2$ ground state doublet
- $g_{\text{sing}} = 1.79$
- $g_{\text{planar}} = 4.27$
- i.e. **XY anisotropy**

$\text{Yb}_2\text{Ti}_2\text{O}_7$



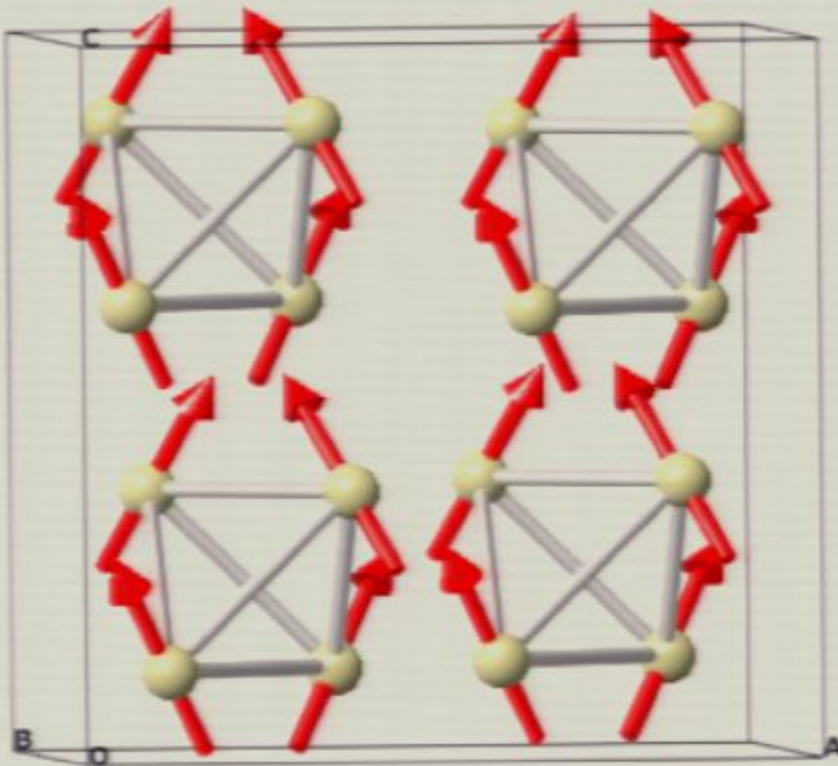
- **Ferromagnetic XY pyrochlore**
 $\theta_{\text{CW}} \sim +0.6 \text{ K}$ $g^{\perp}/g^{\parallel} \sim 2.4$
- **First order transition at $T_c = 240\text{mK}$**
- **Rods of scattering seen previously by Bonville *et al.***

$\text{Yb}_2\text{Ti}_2\text{O}_7$



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Classical Ferromagnetic Exchange XY Pyrochlore Orders!

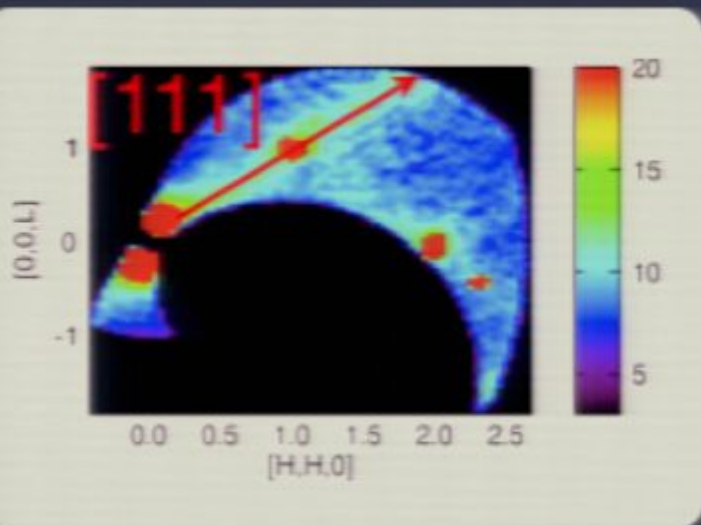


Confine spins to **easy planes**

Maximize moment along

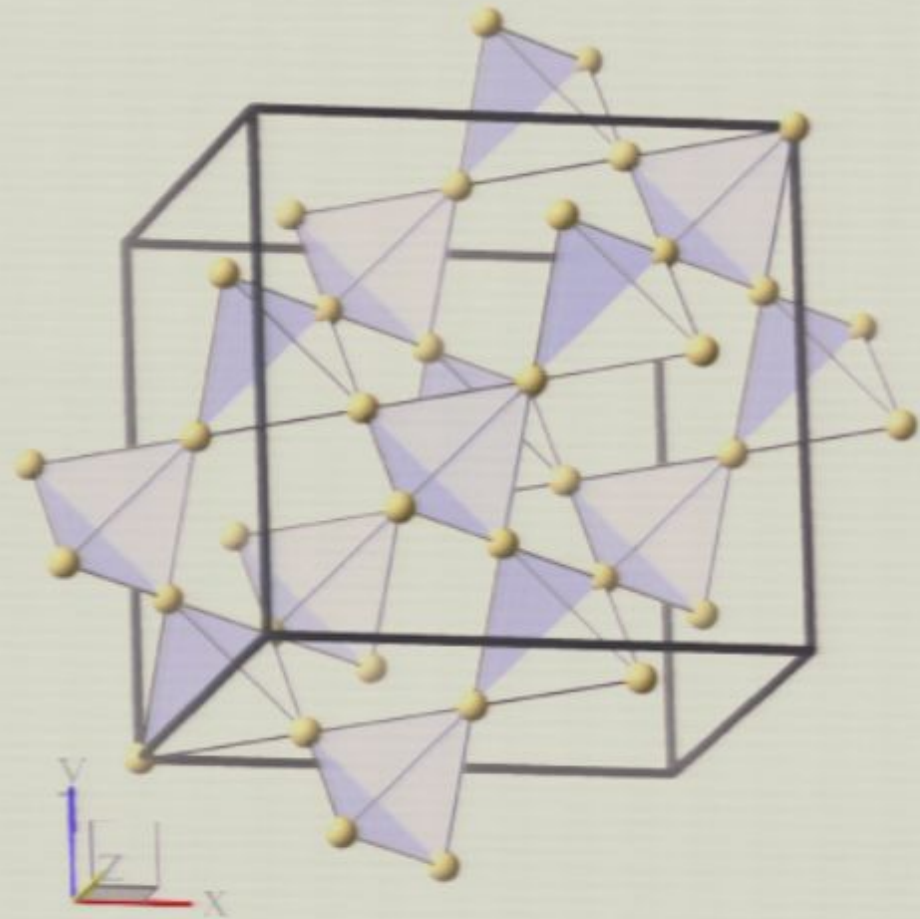
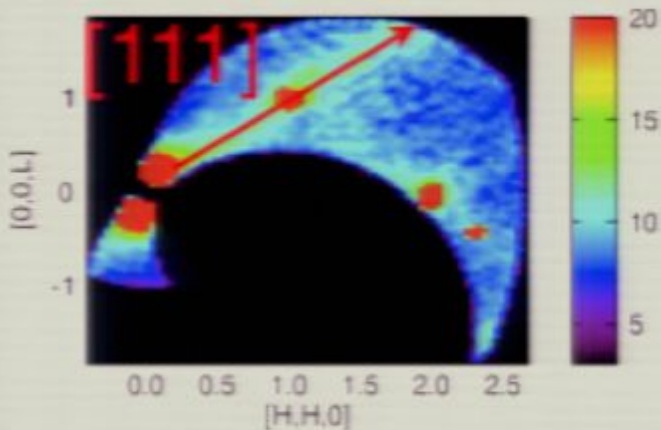
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Pyrochlore Lattice



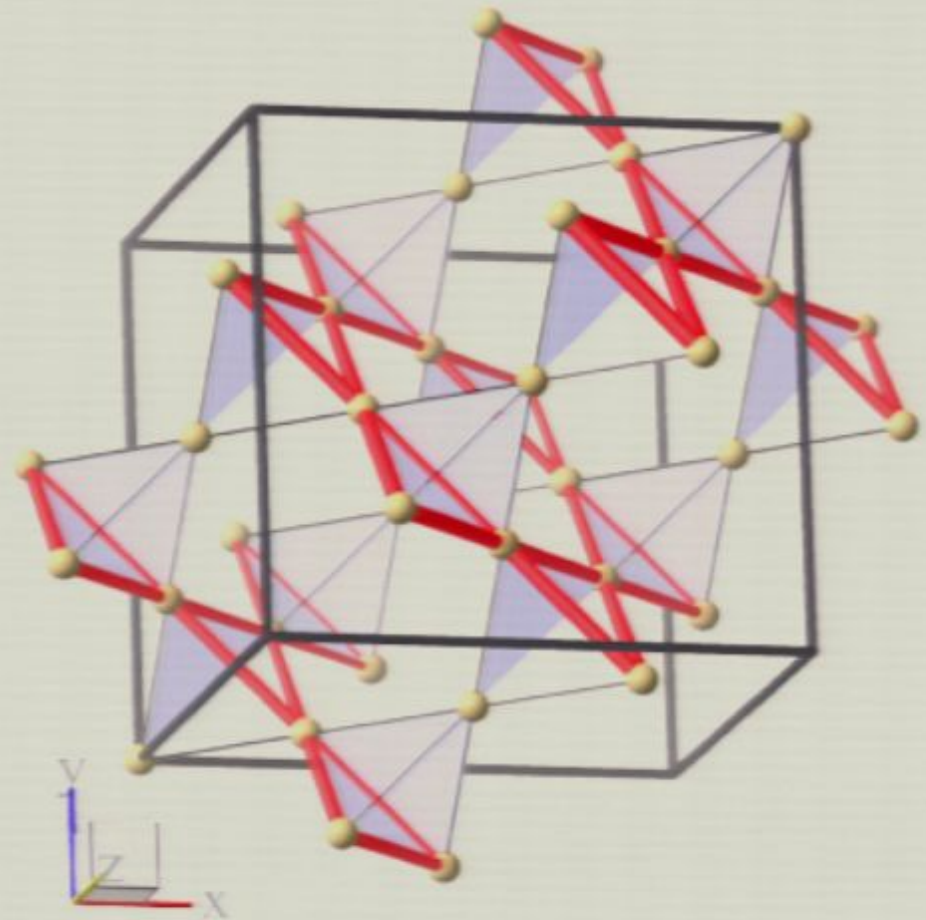
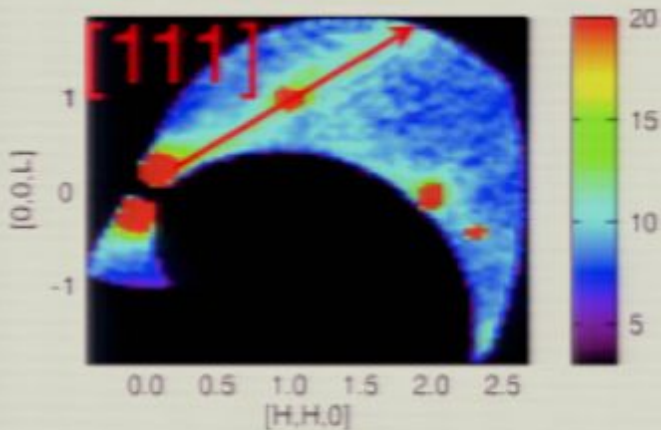
The (111) planes of the Pyrochlore structure are interleaved **Kagome** and **triangular** planes

Pyrochlore Lattice



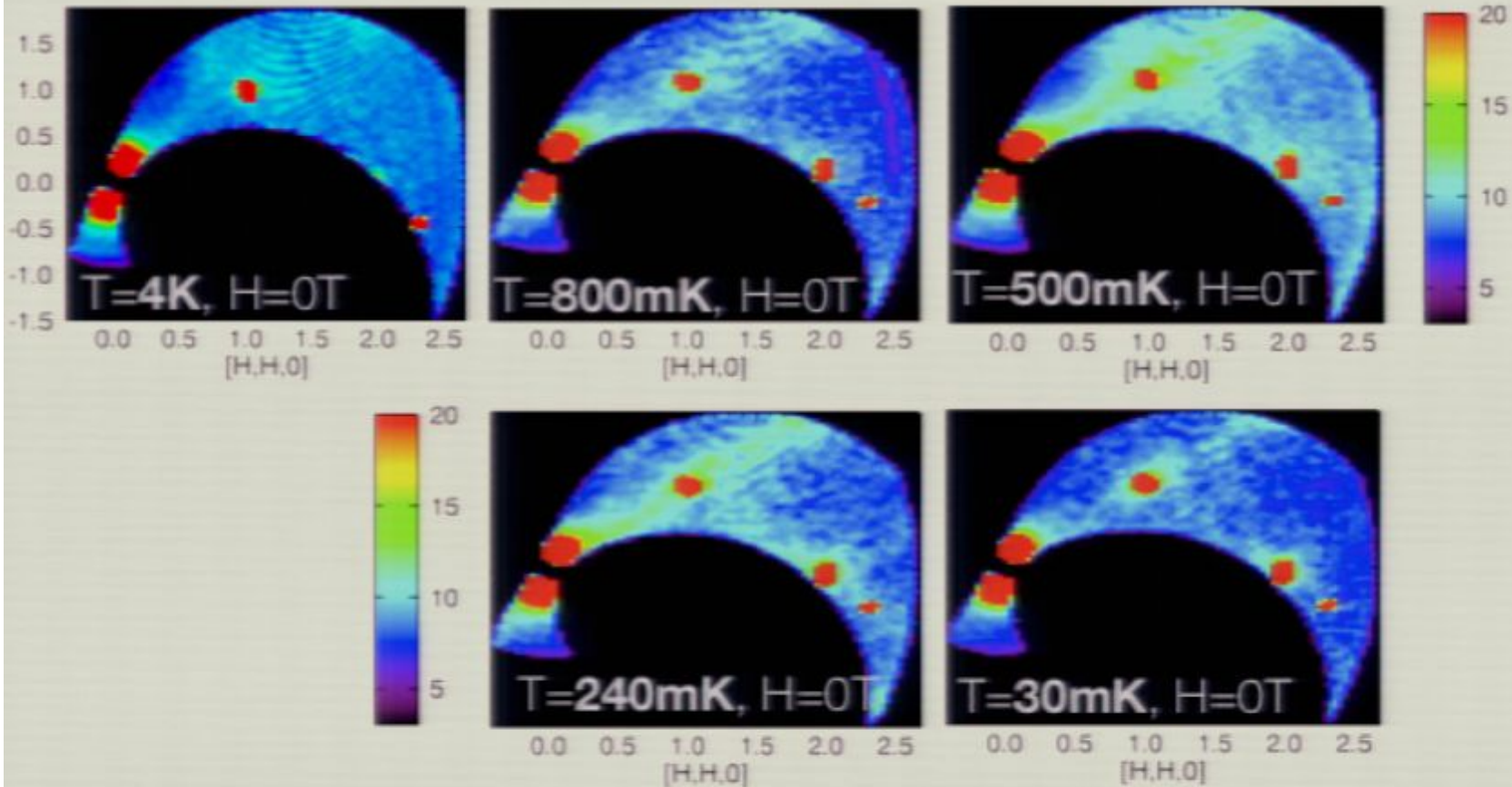
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Pyrochlore Lattice



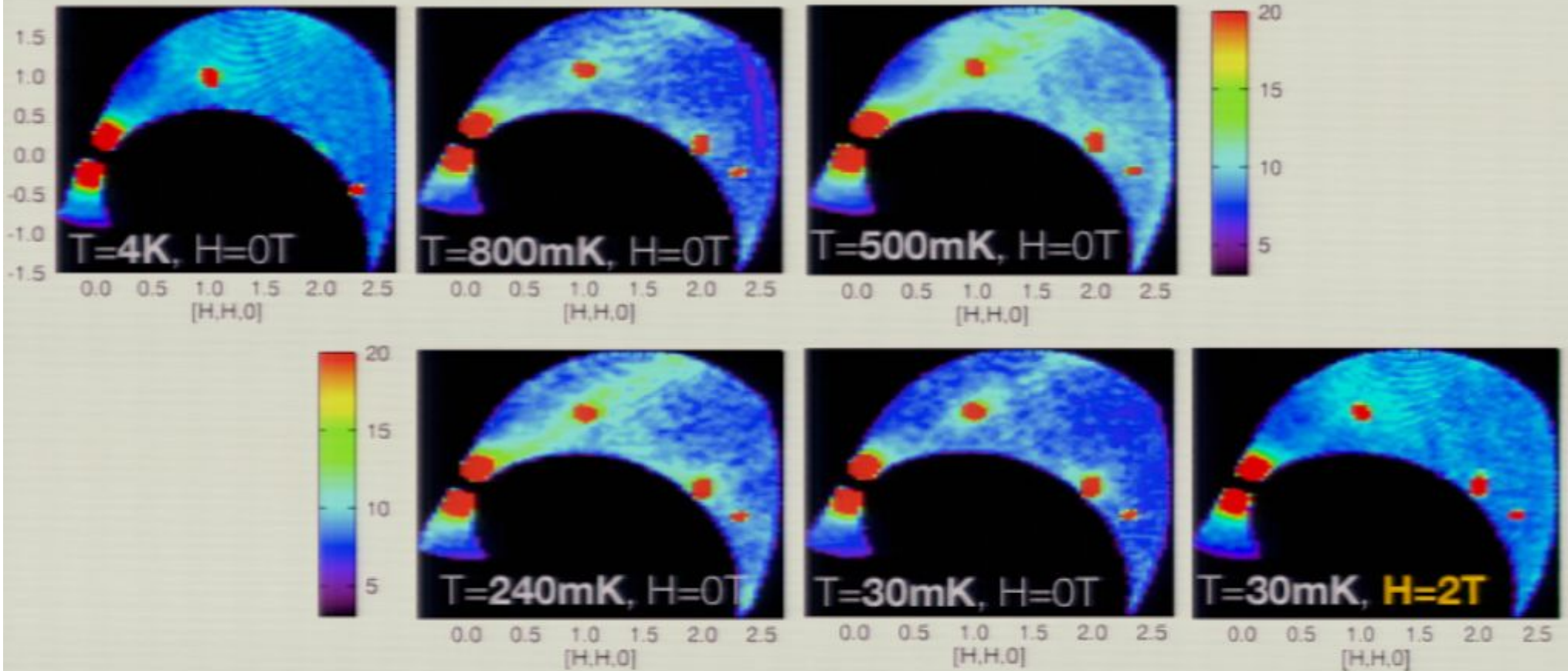
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Diffuse Rods - Elastic Maps



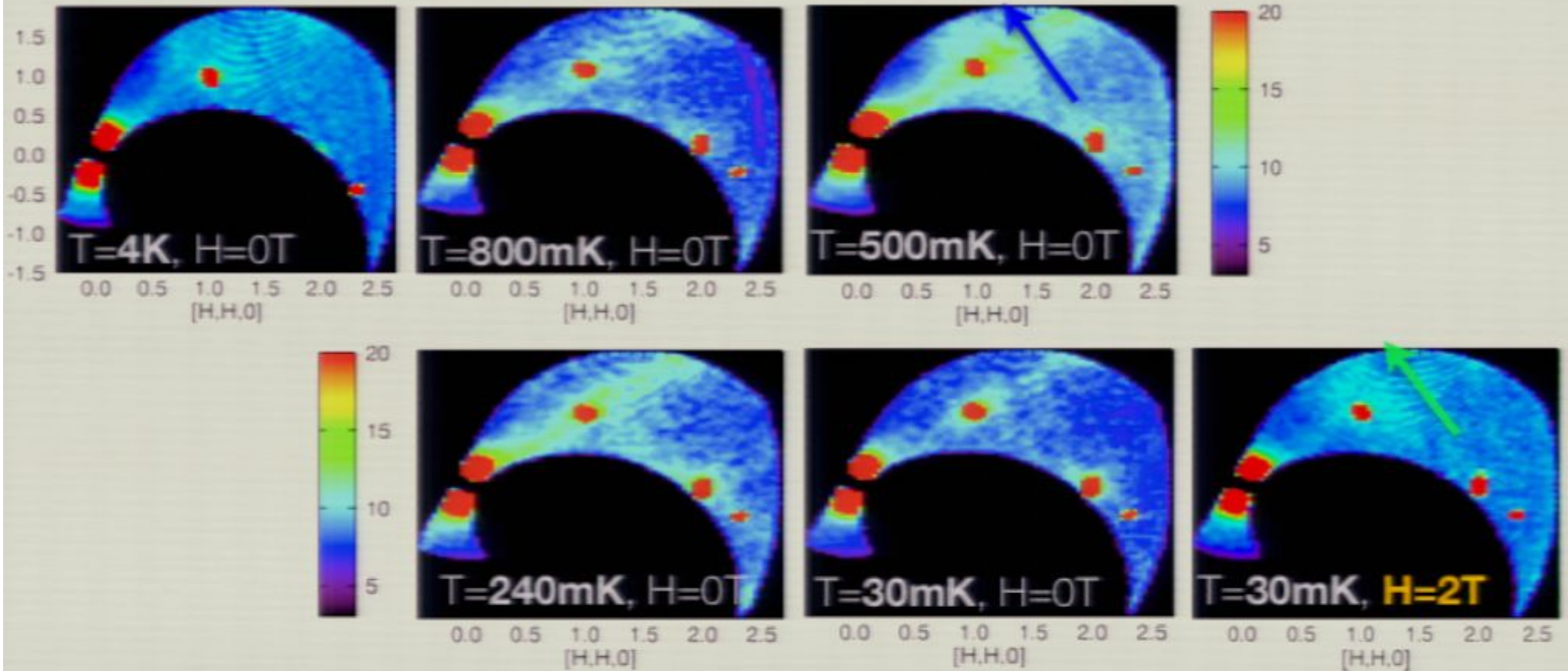
Presence of rods indicates that there is a **disordered direction**

Diffuse Rods - Elastic Maps



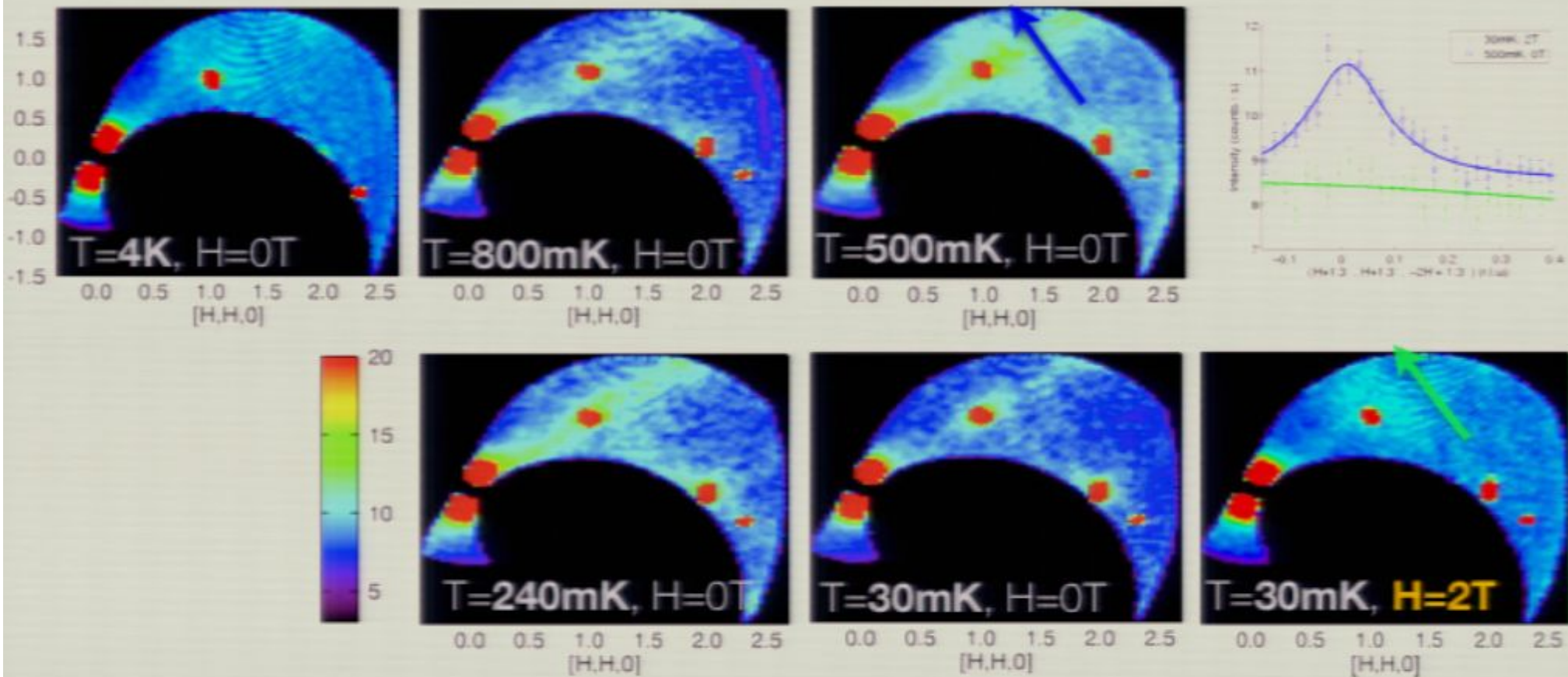
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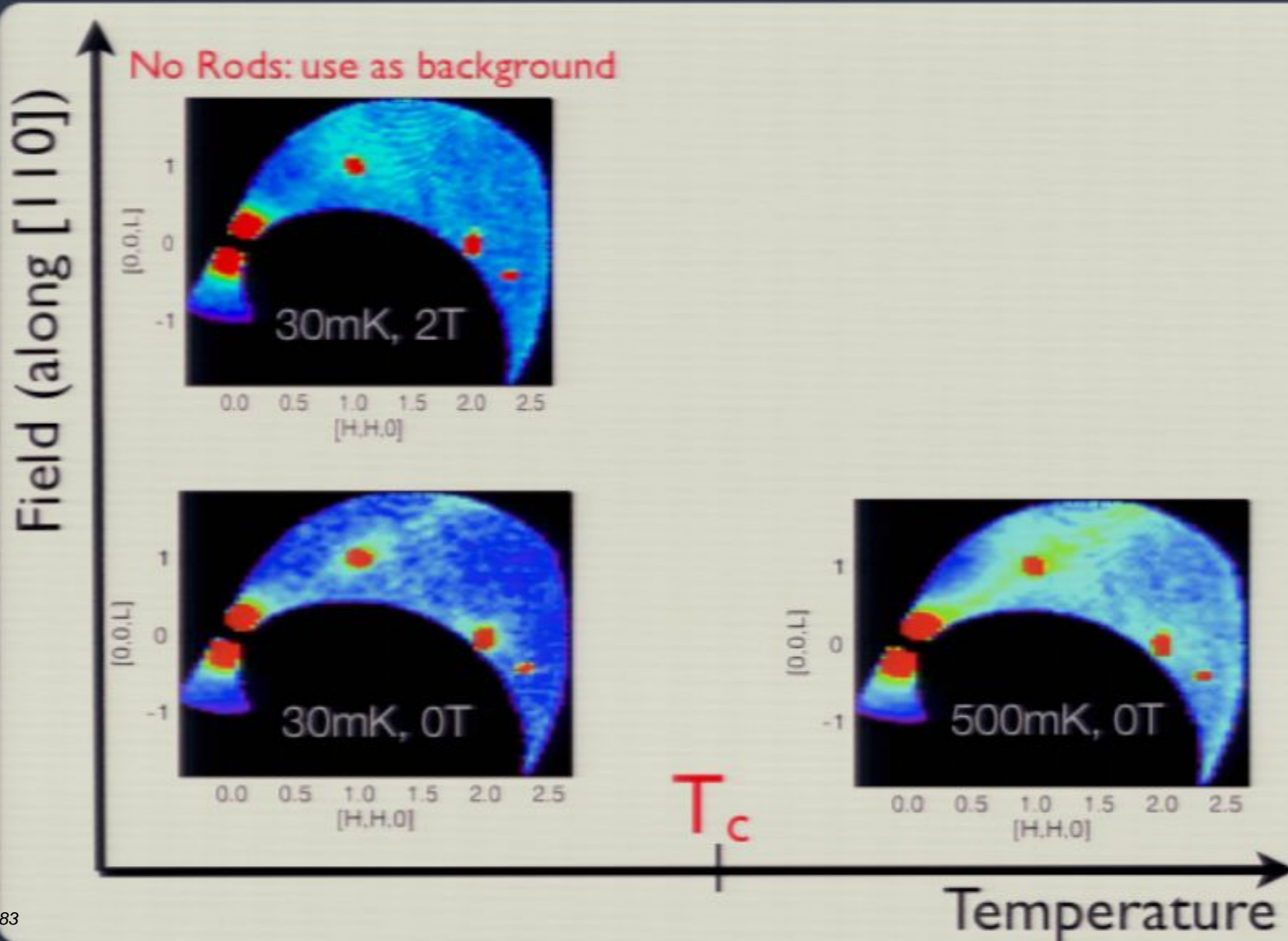
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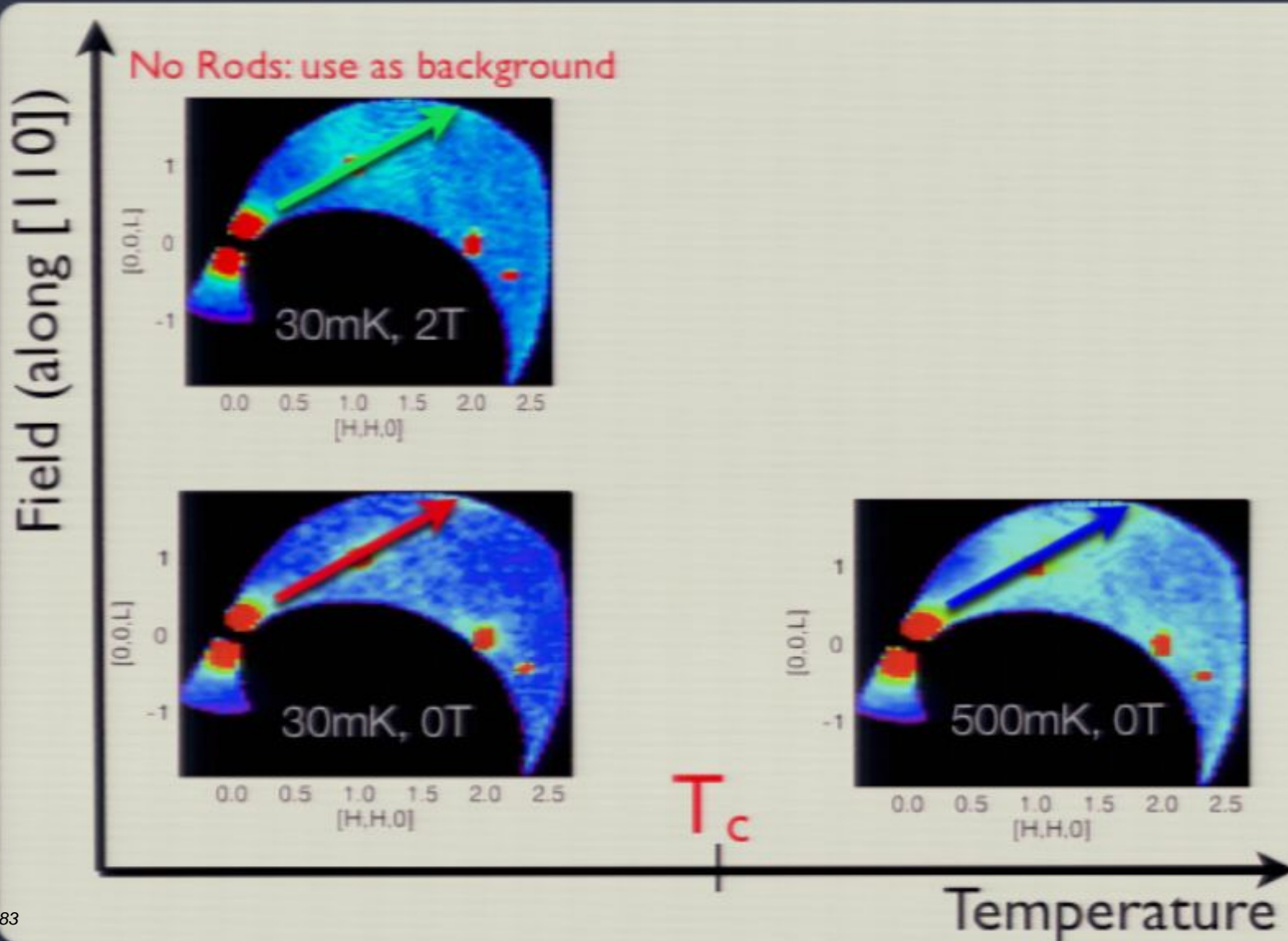


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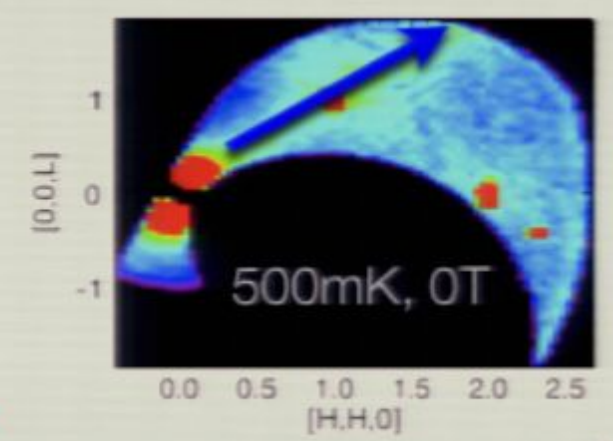
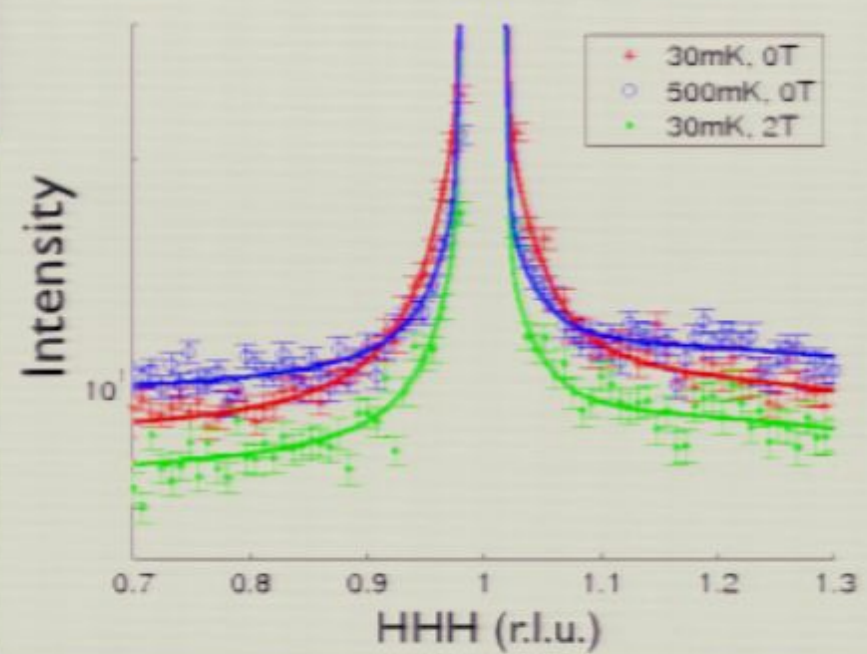
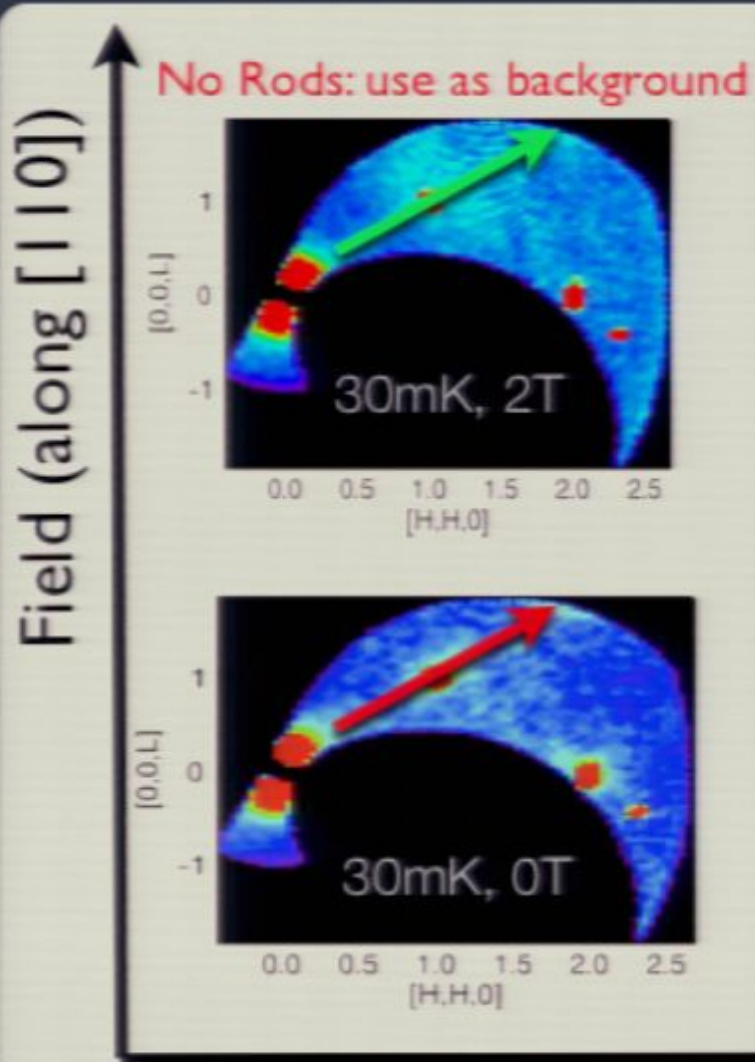
Nature of Correlations below T_c



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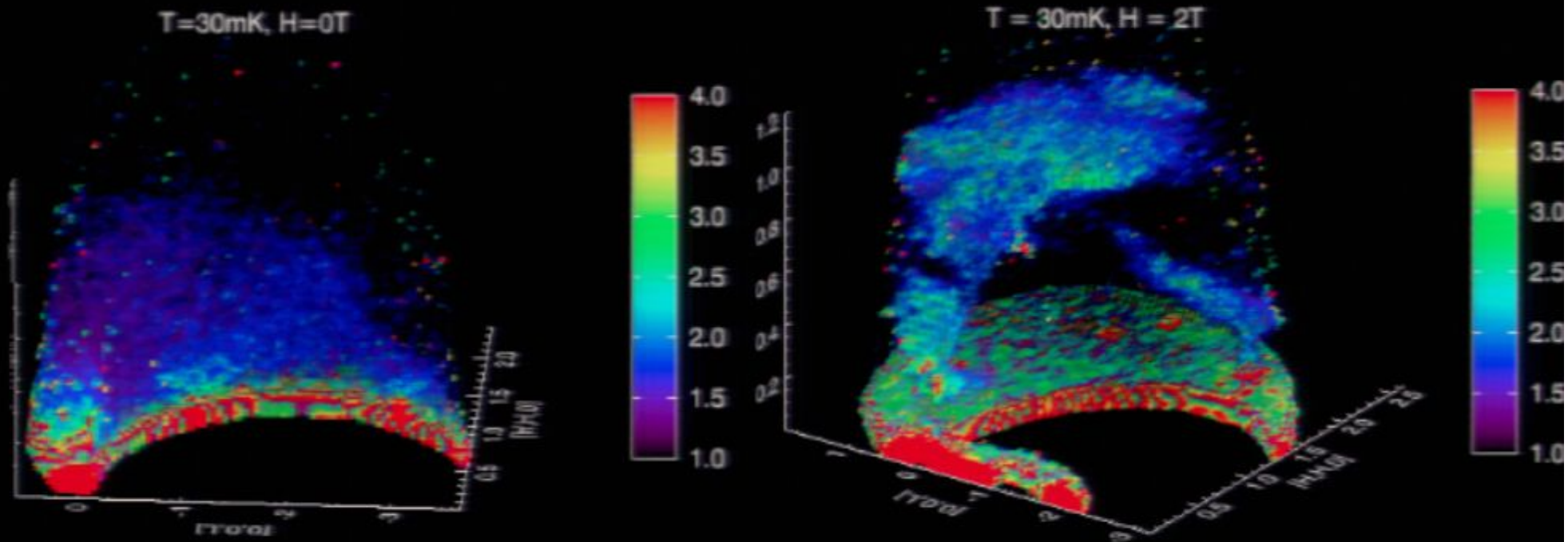
Nature of Correlations below T_c



T_c

Temperature

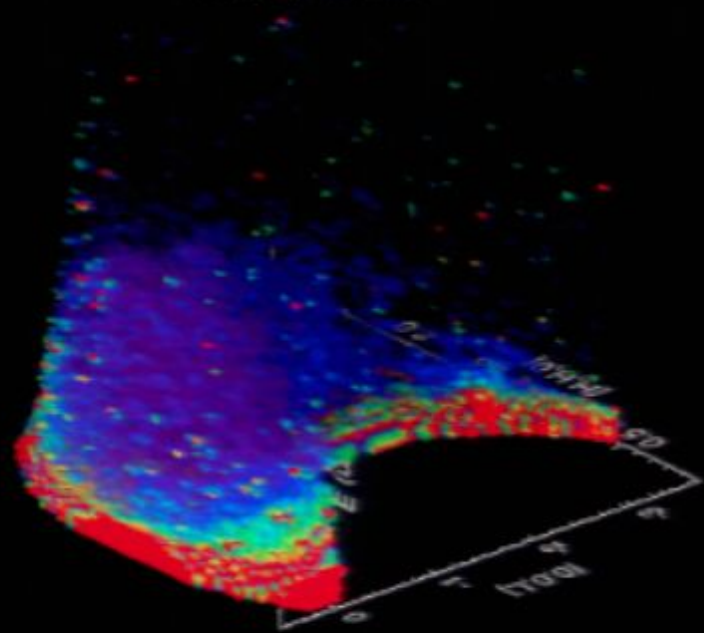
Development of Long Range Order



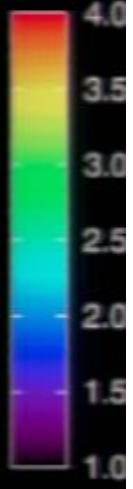
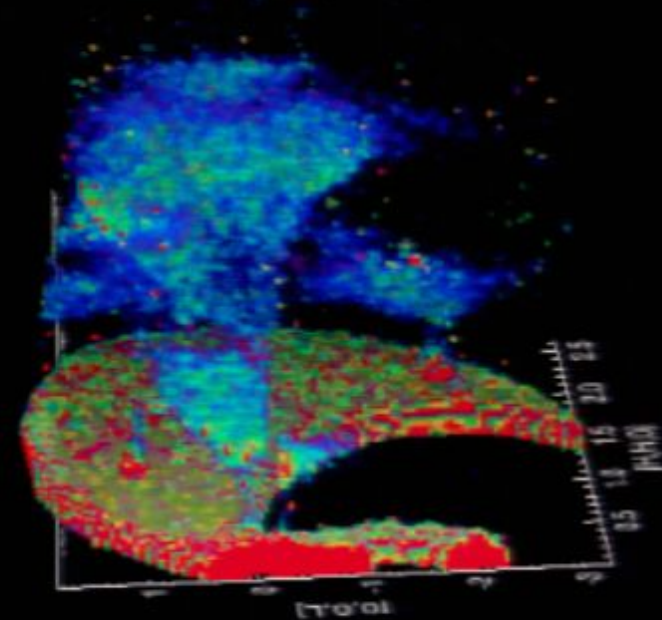
The appearance of **spin waves** indicates that the field-induced state is **long range ordered**

Development of Long Range Order

T=30mK, H=0T



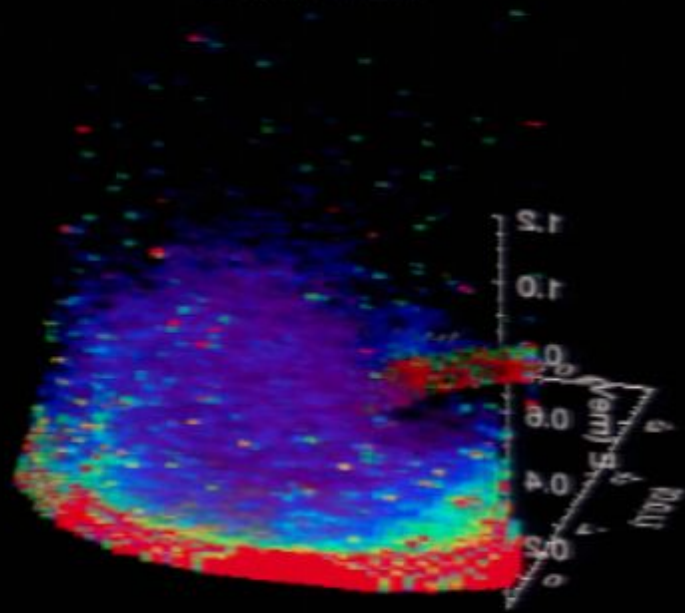
T = 30mK, H = 2T



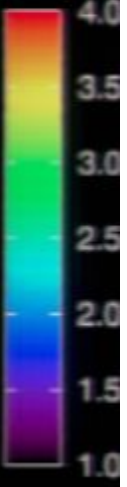
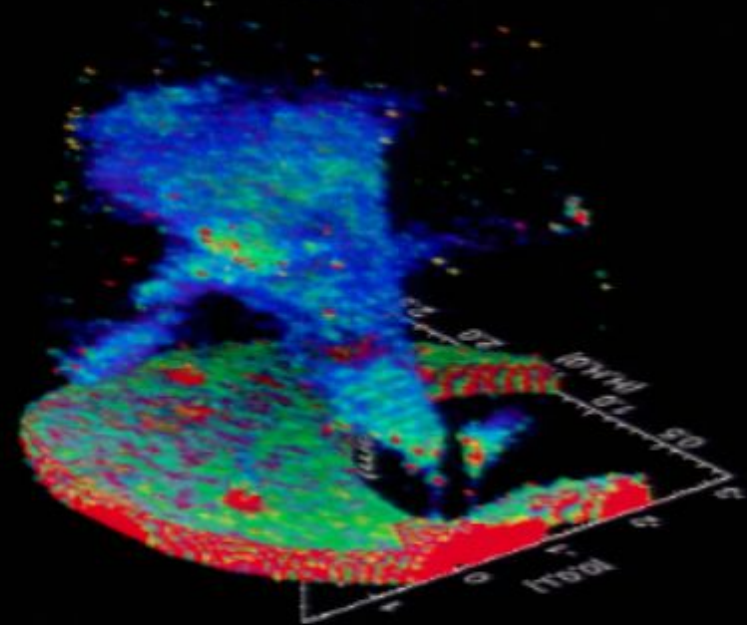
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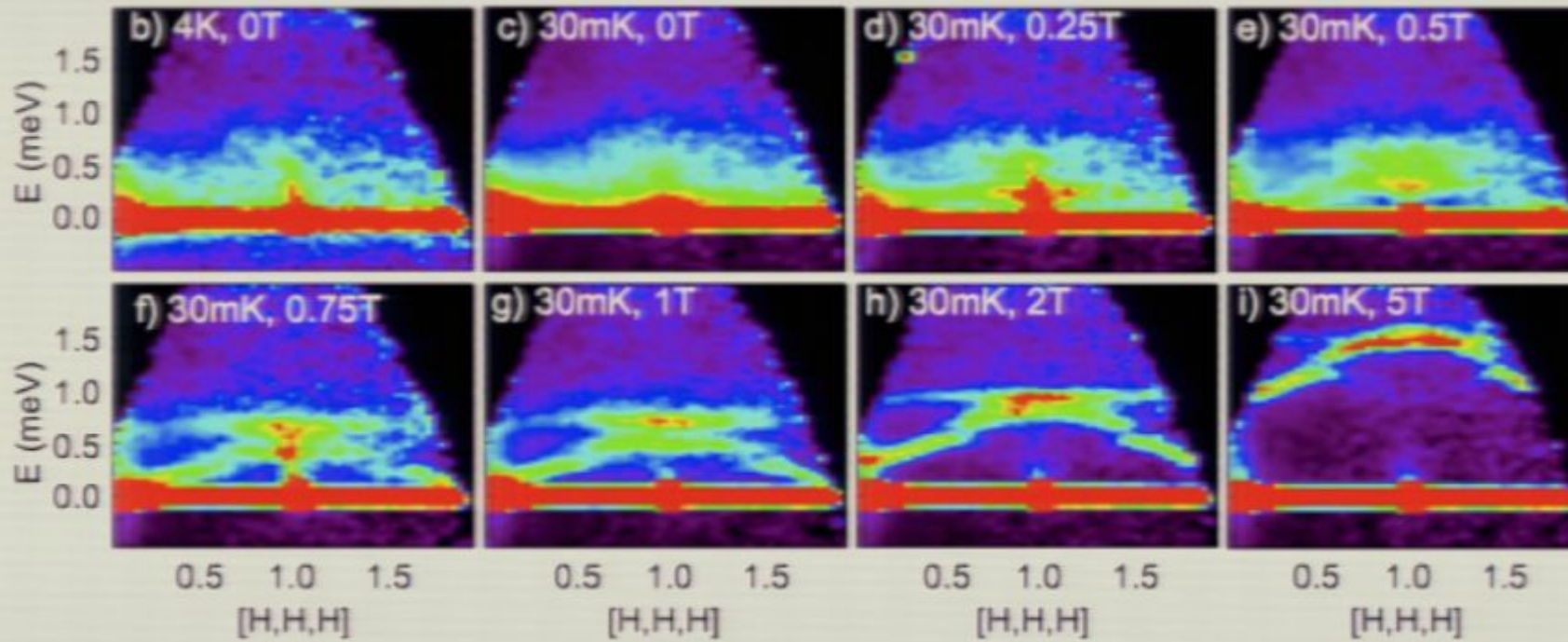
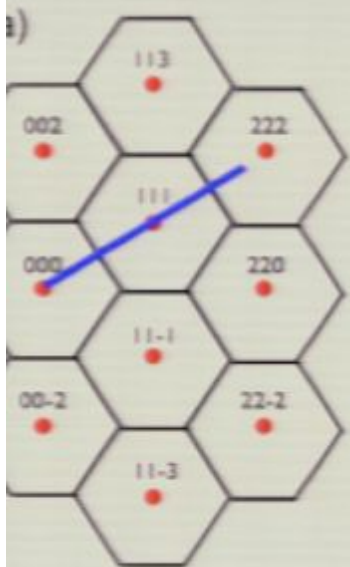
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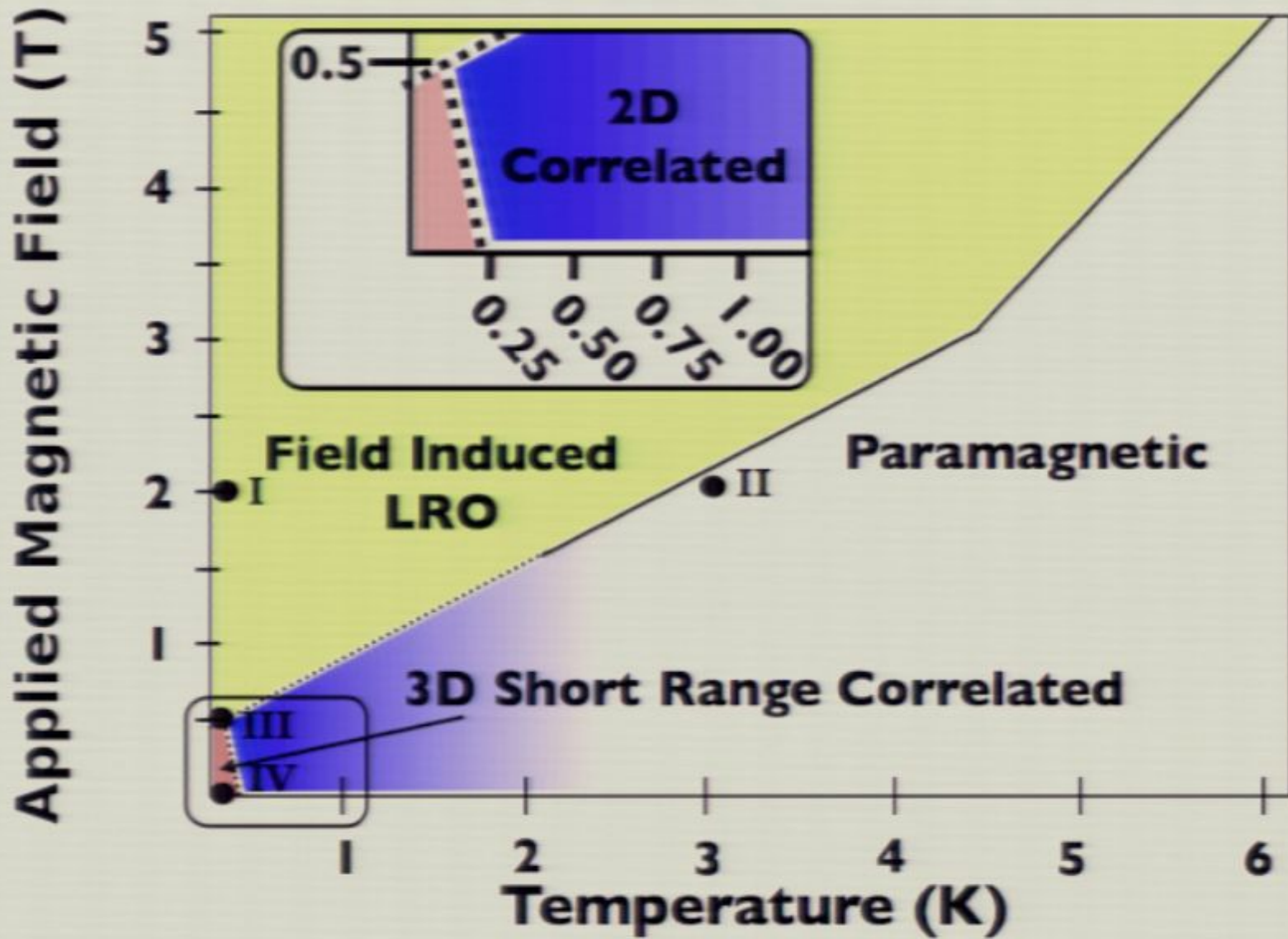


The appearance of **spin waves** indicates that the field-induced state is **long range ordered**

Weak magnetic field // [110] induces LRO:

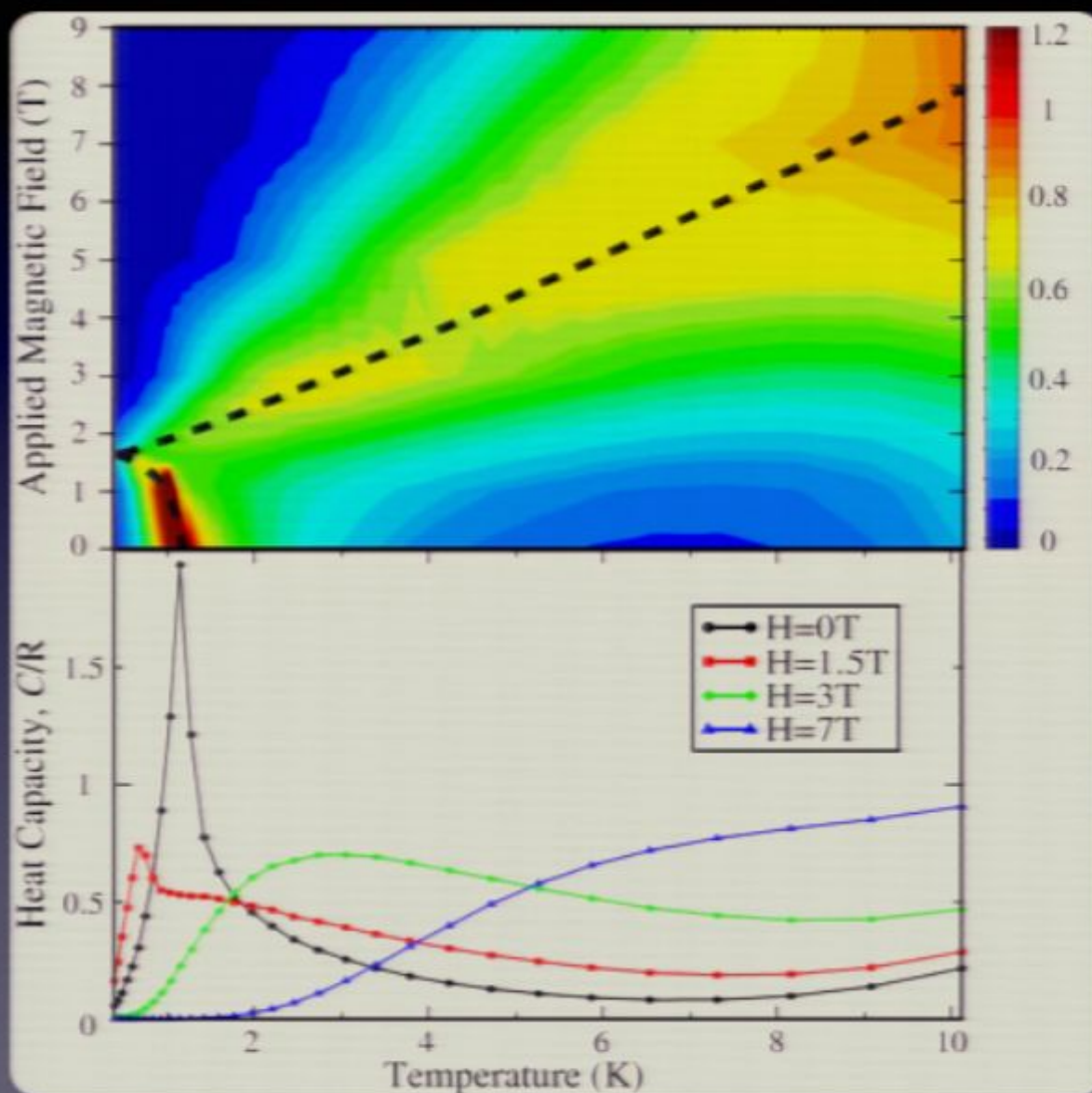
appearance of long-lived spin waves at low T and moderate H



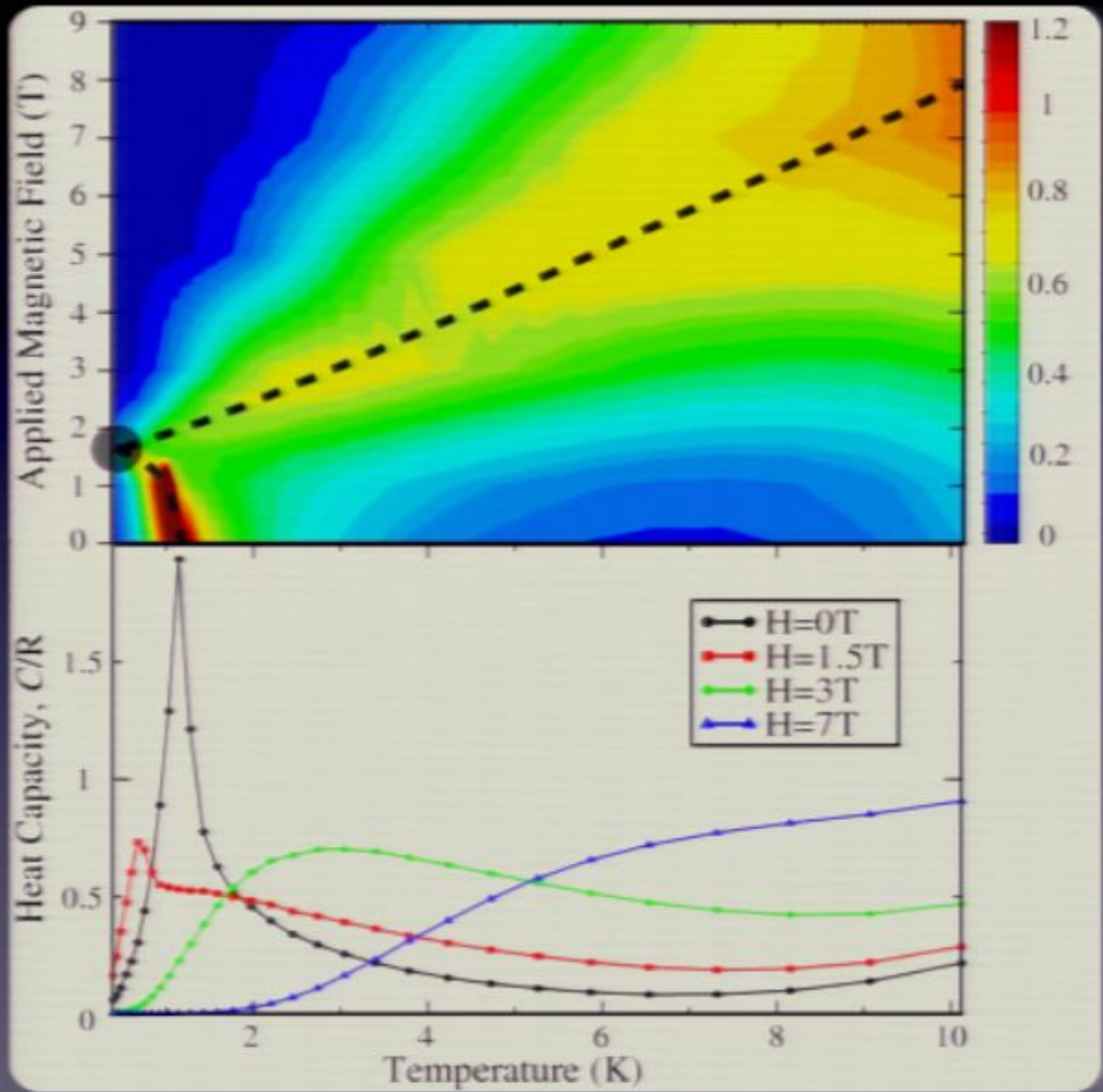


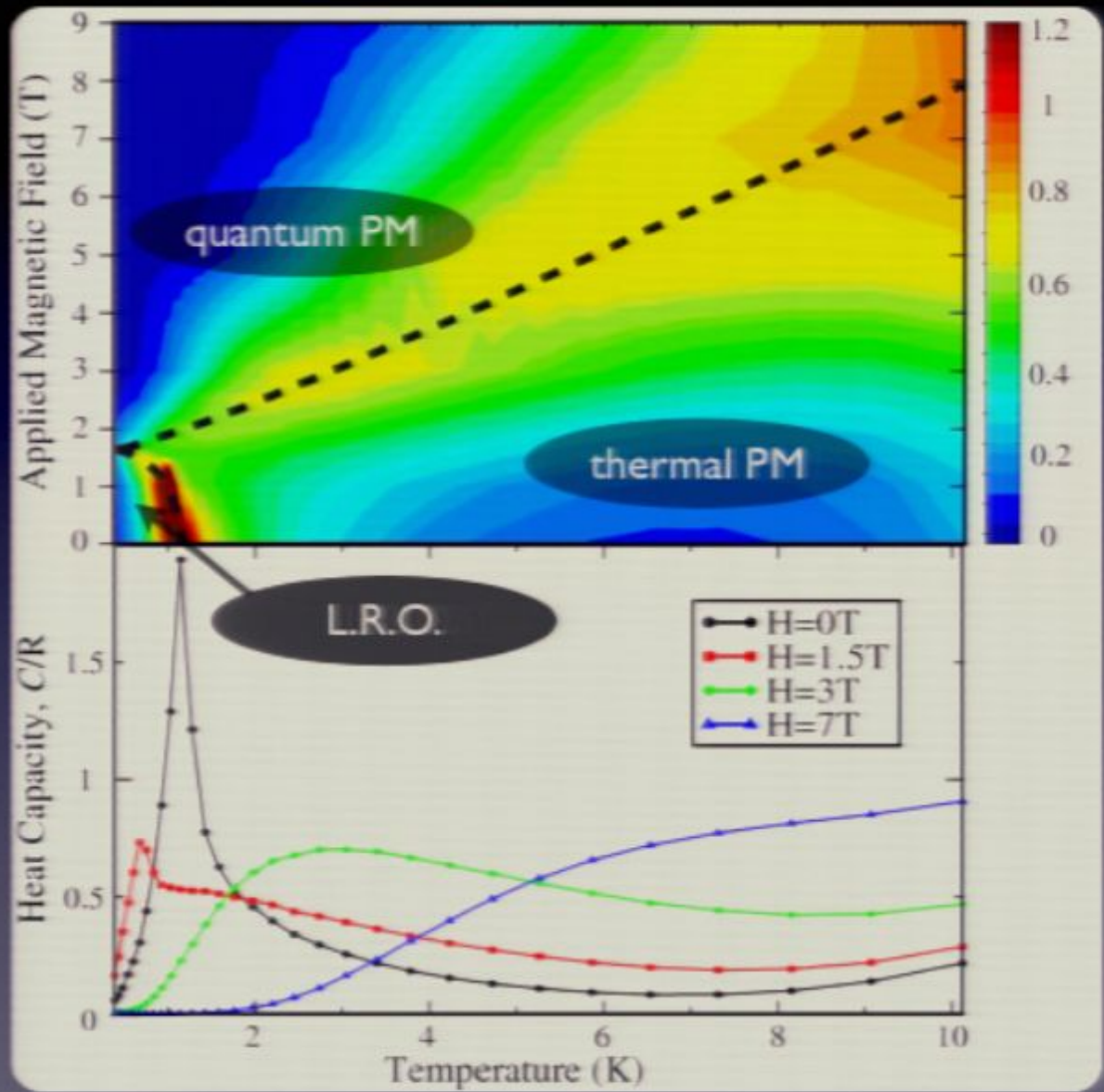
K. A. Ross, J. P. C. Ruff, C. P. Adams, J. S. Gardner, H. A. Dabkowska, Y. Qiu, J. R. D. Copley, and B. D. Gaulin, Phys. Rev. Lett. 103, 227202 (2009)

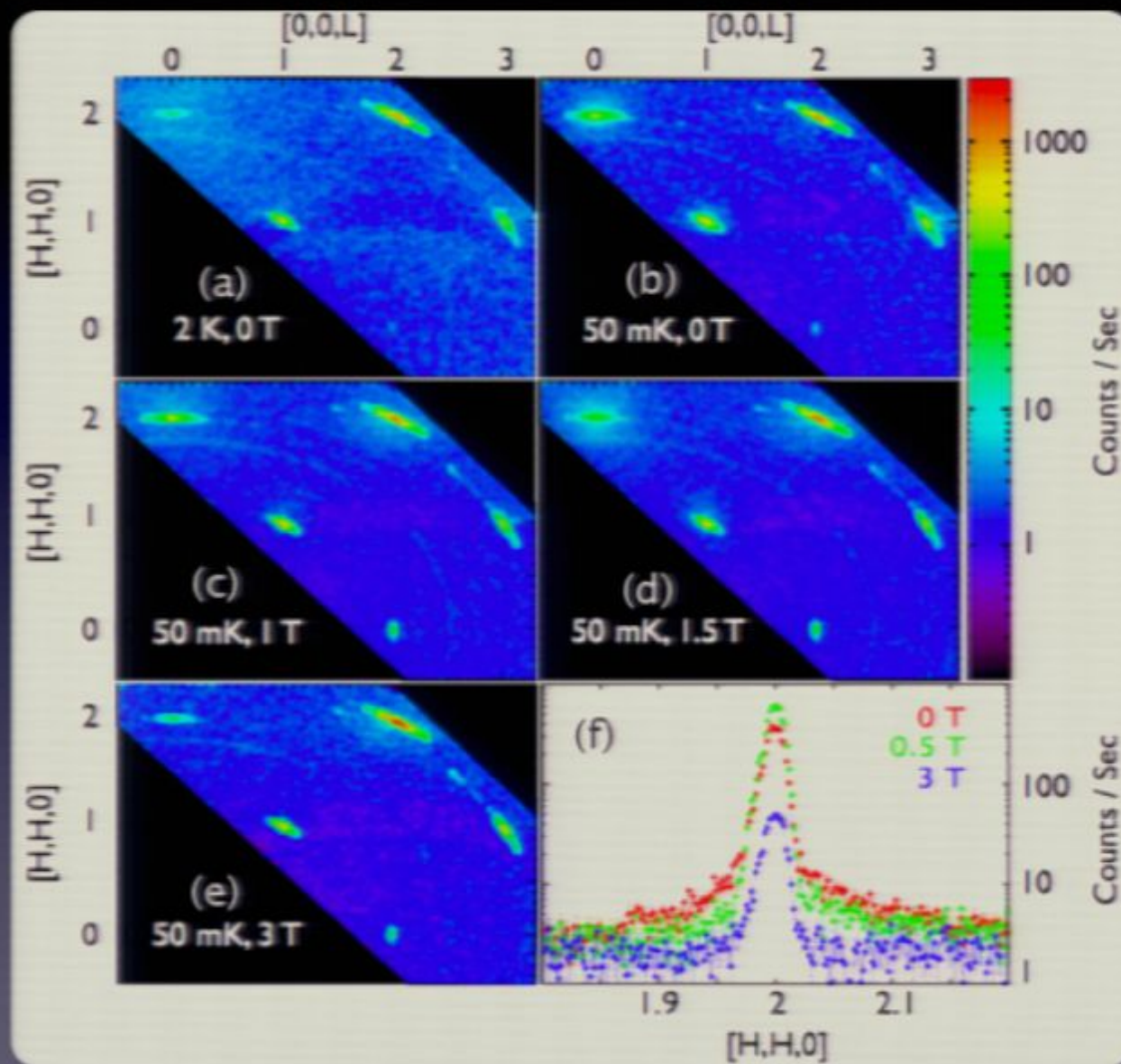
AF planar pyrochlore: $\text{Er}_2\text{Ti}_2\text{O}_7$

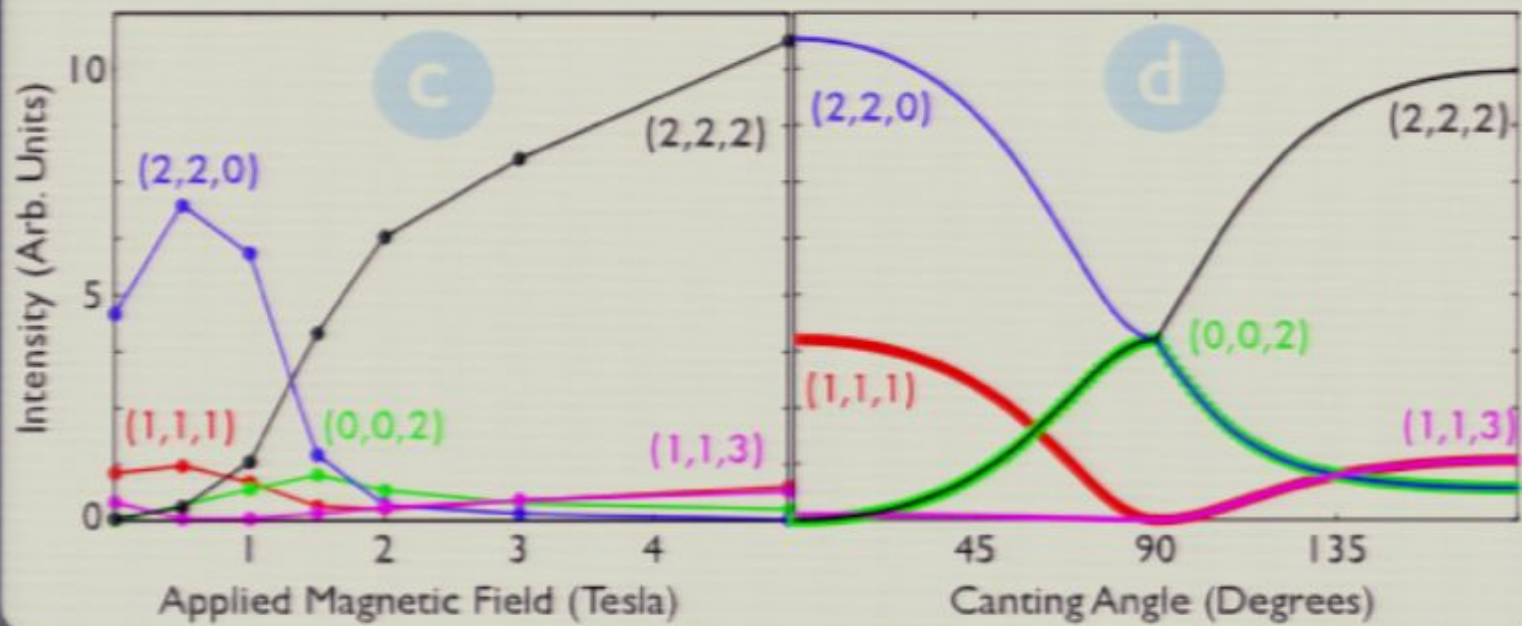
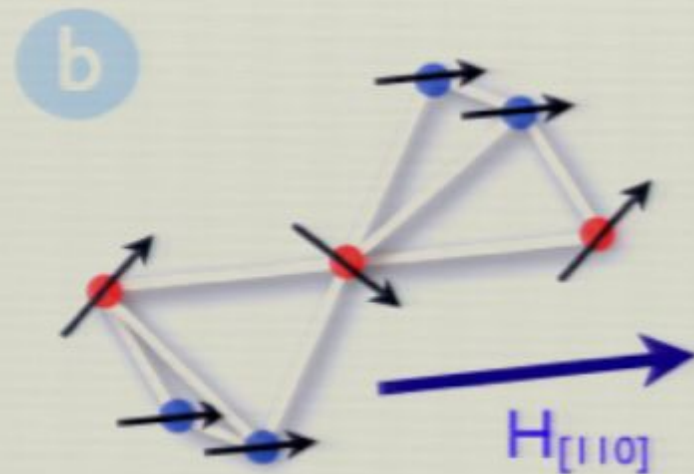
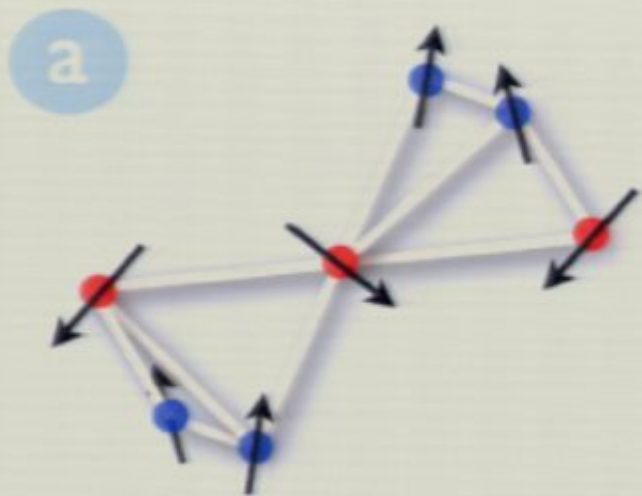


QCP

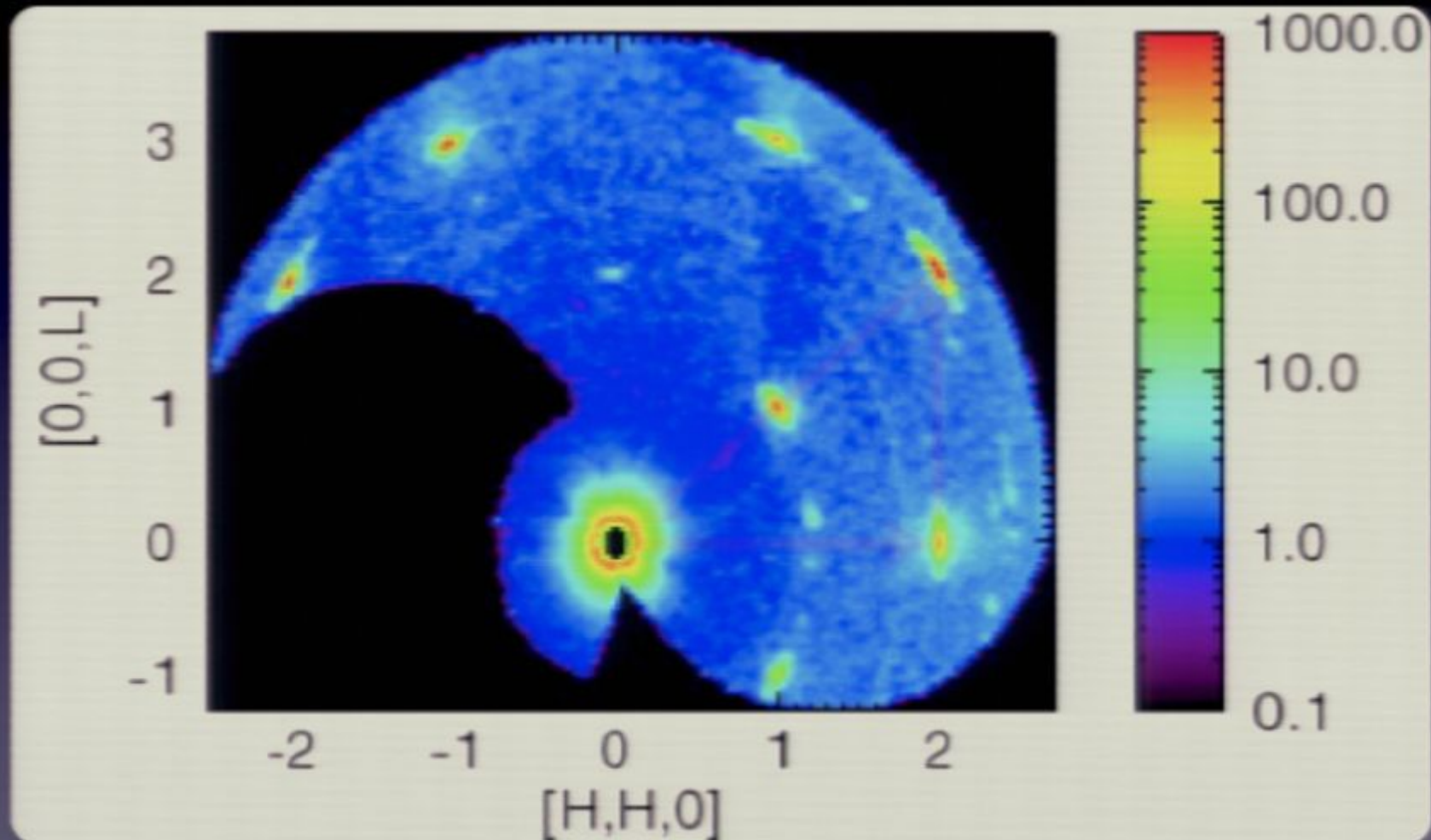




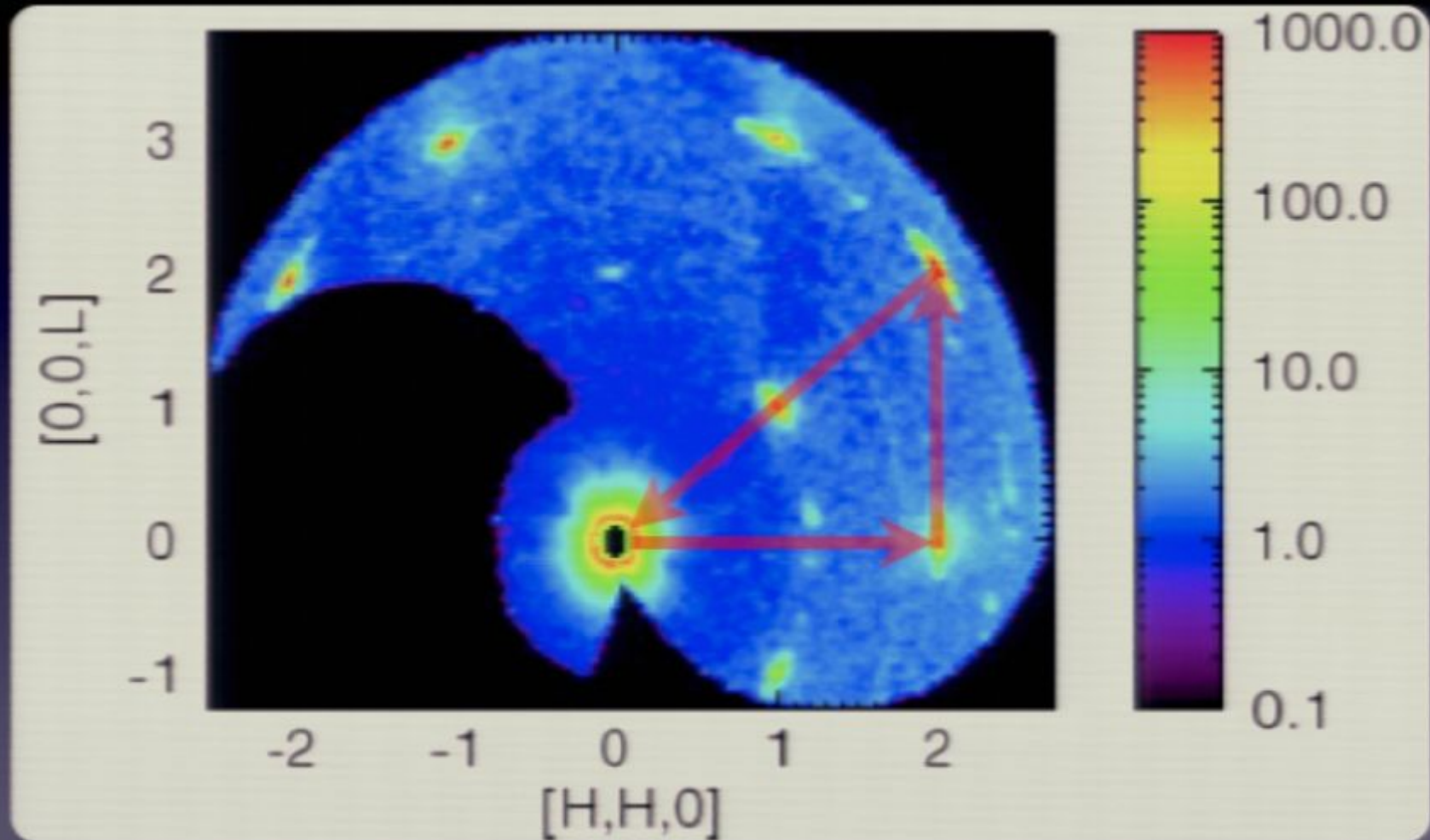




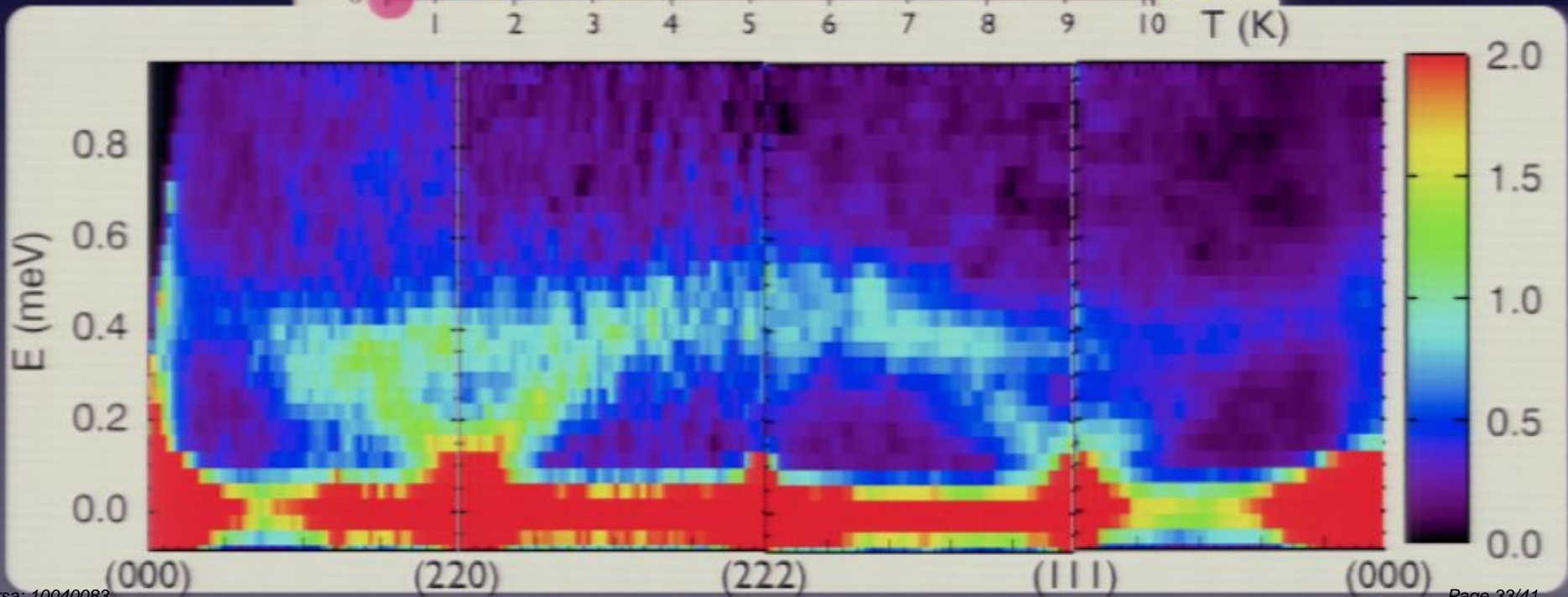
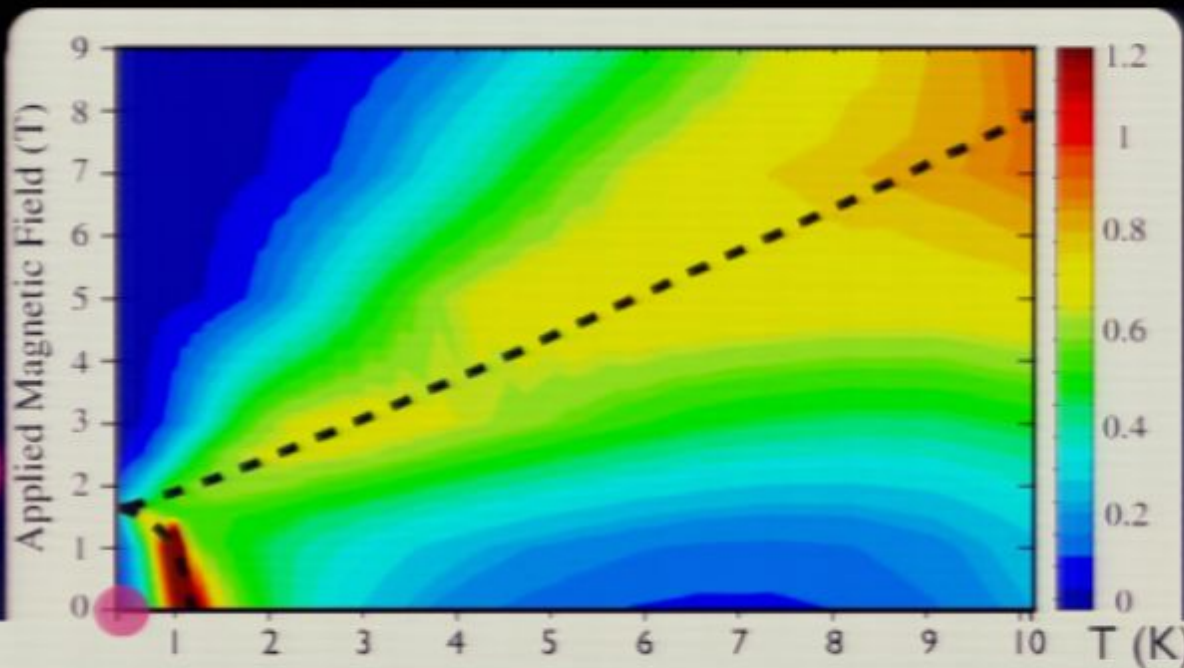
$\text{Er}_2\text{Ti}_2\text{O}_7$ @ 50 mK



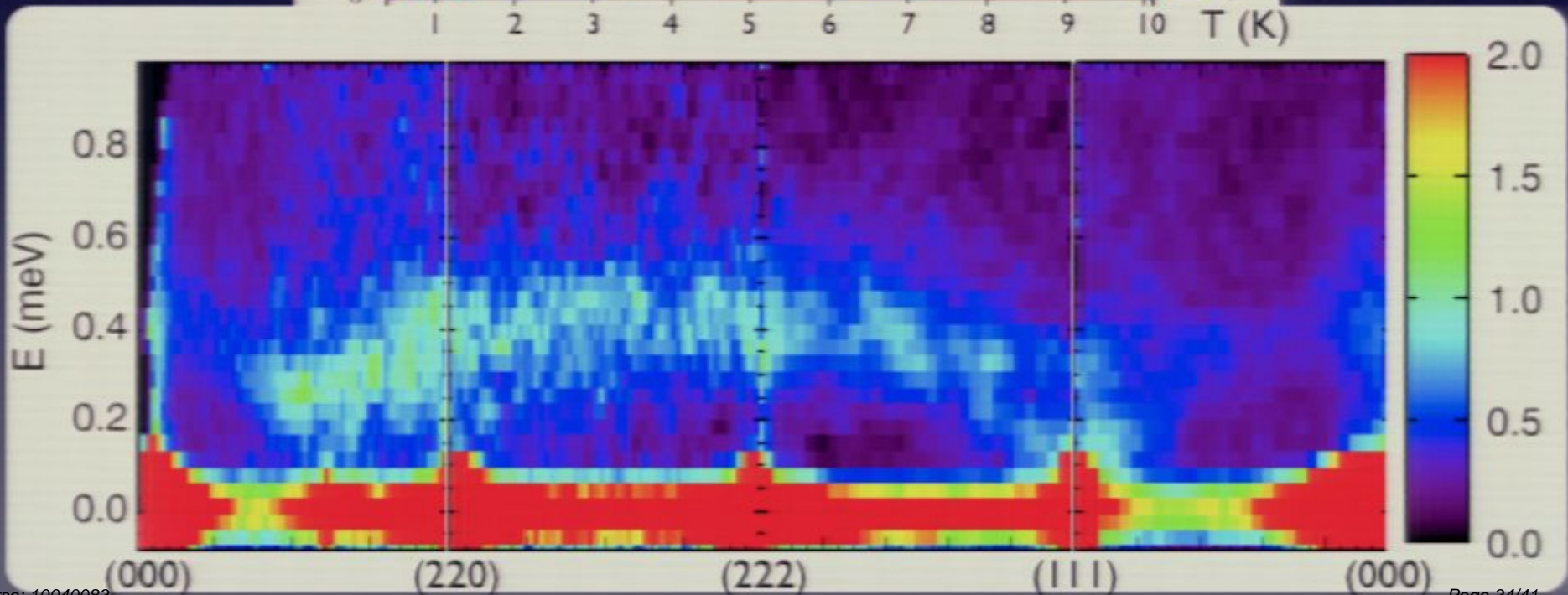
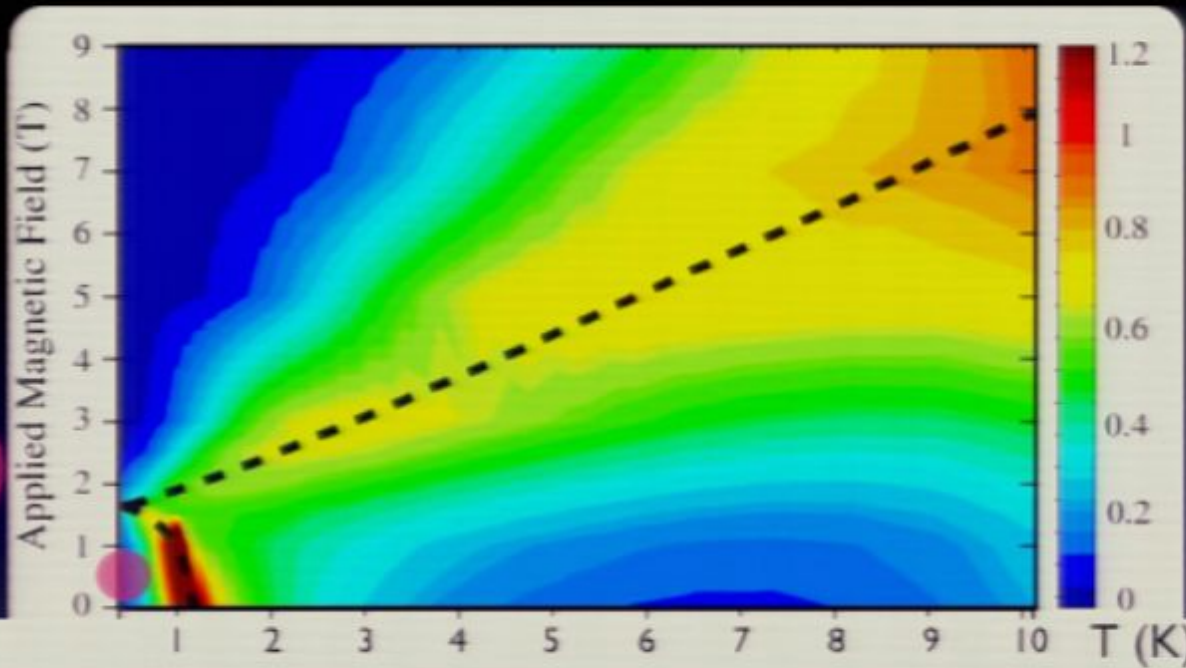
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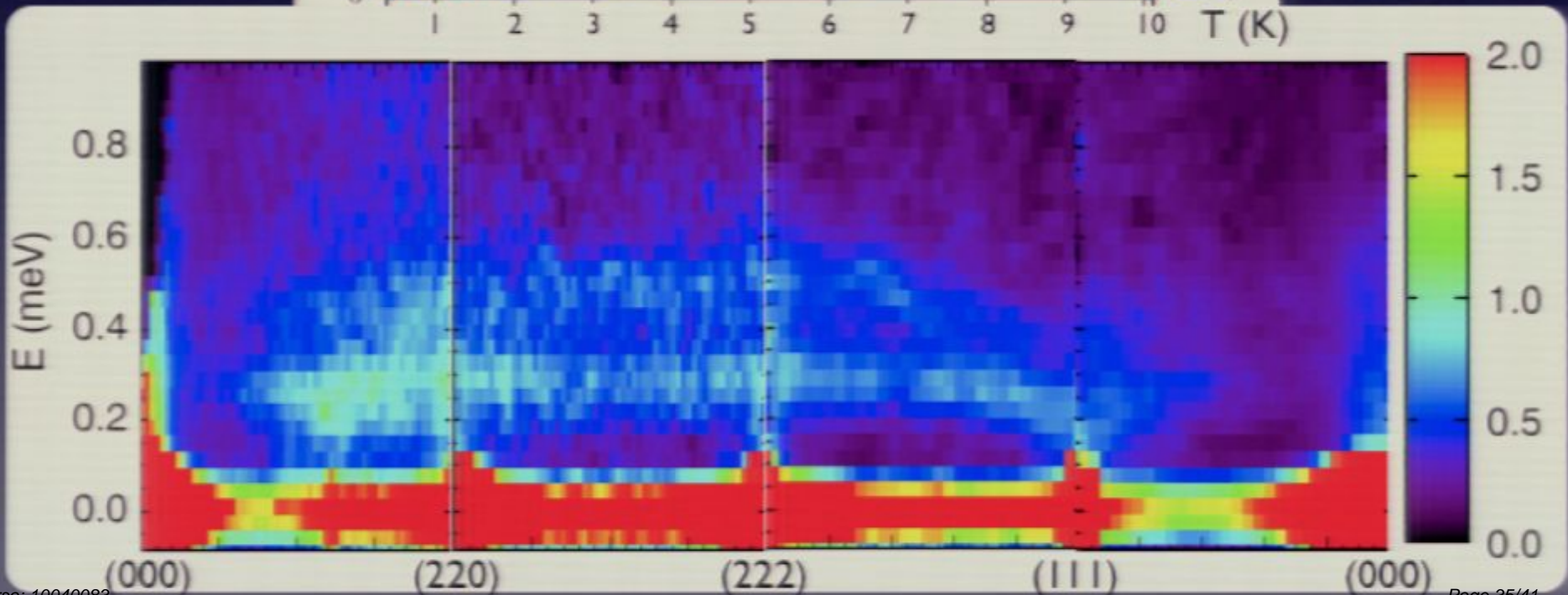
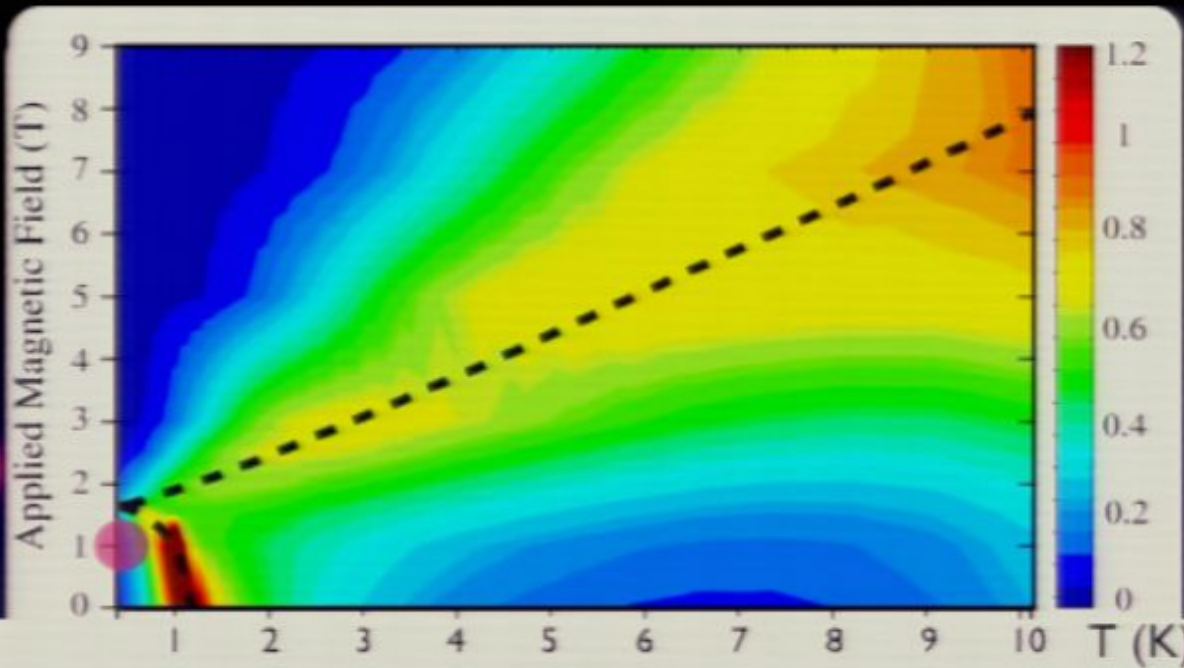
50 mK, 0 T



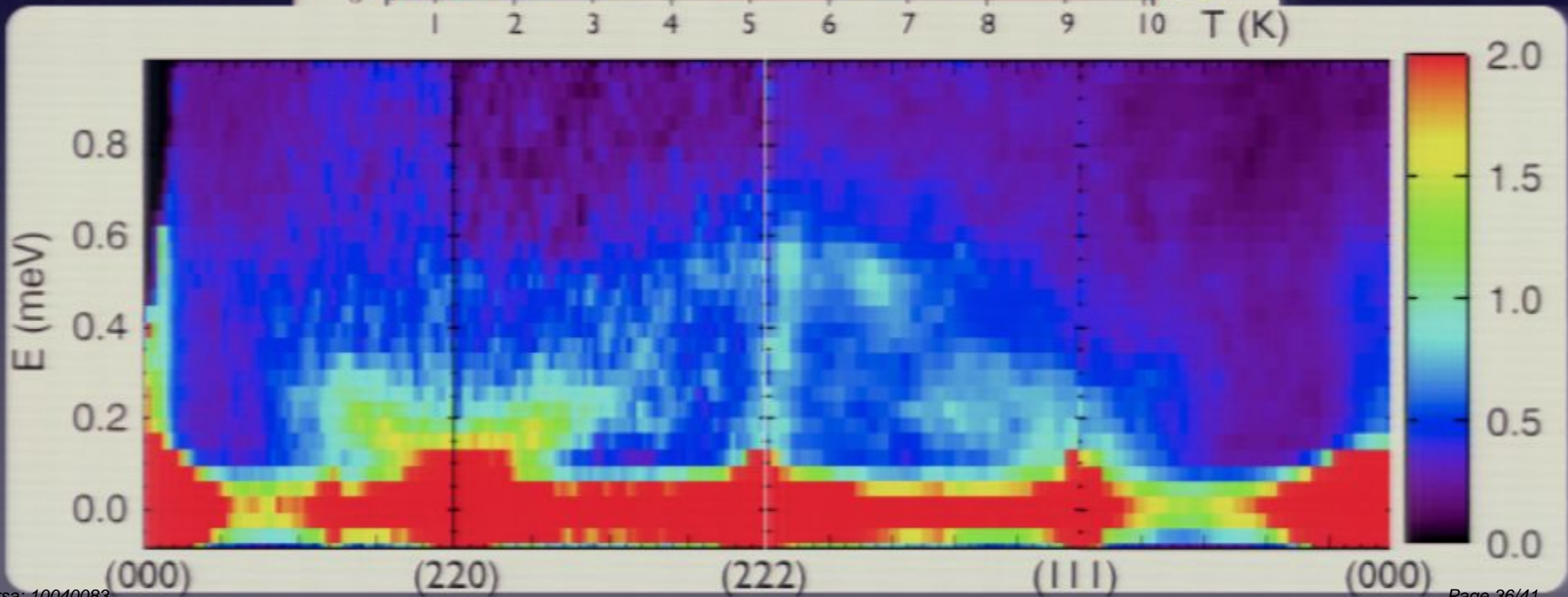
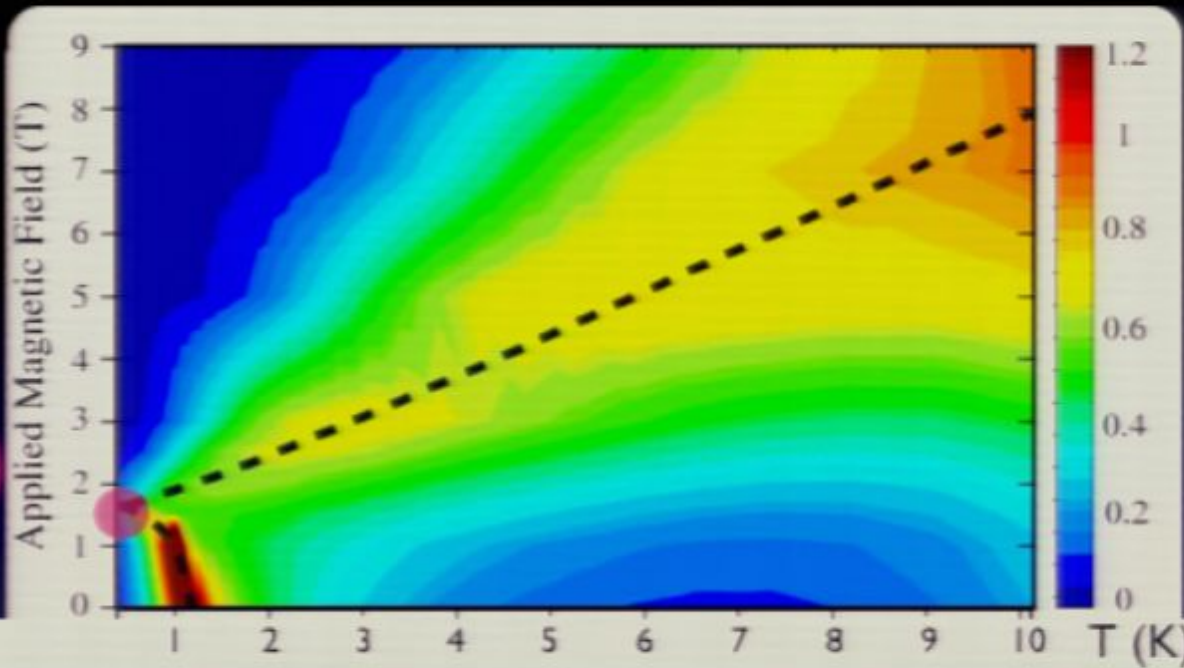
50 mK, 0.5 T



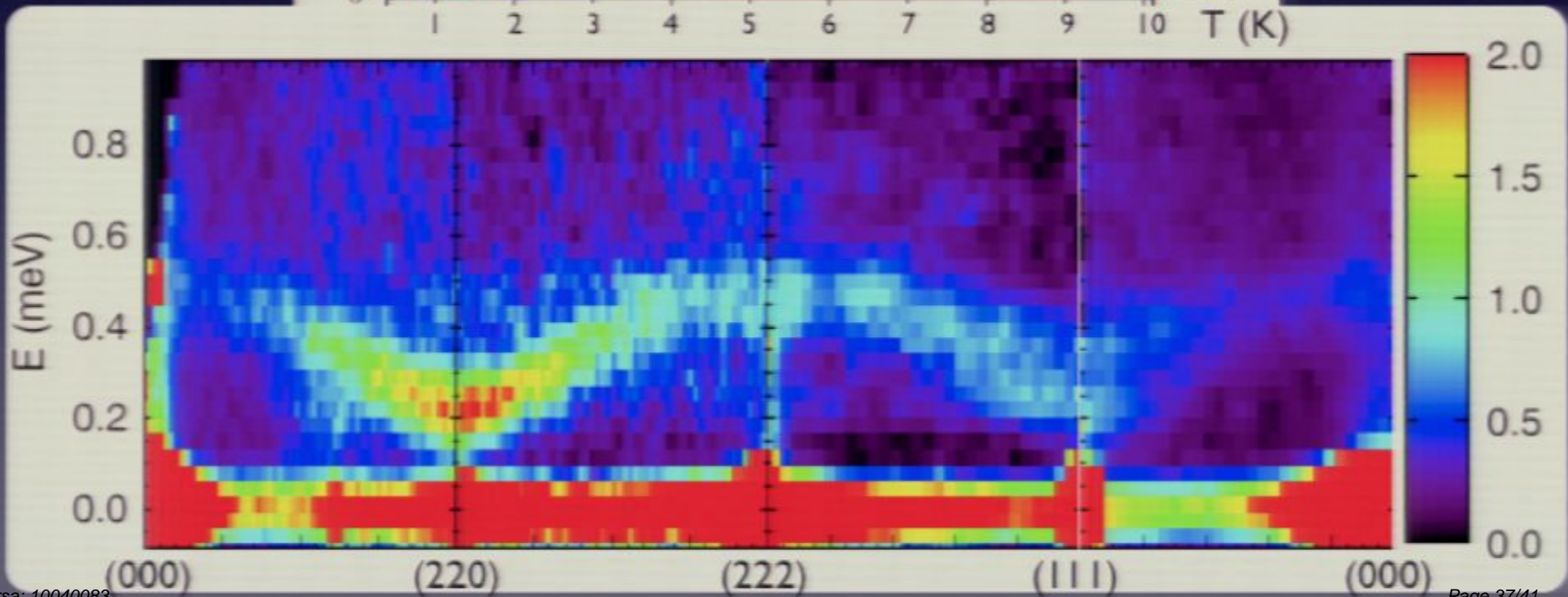
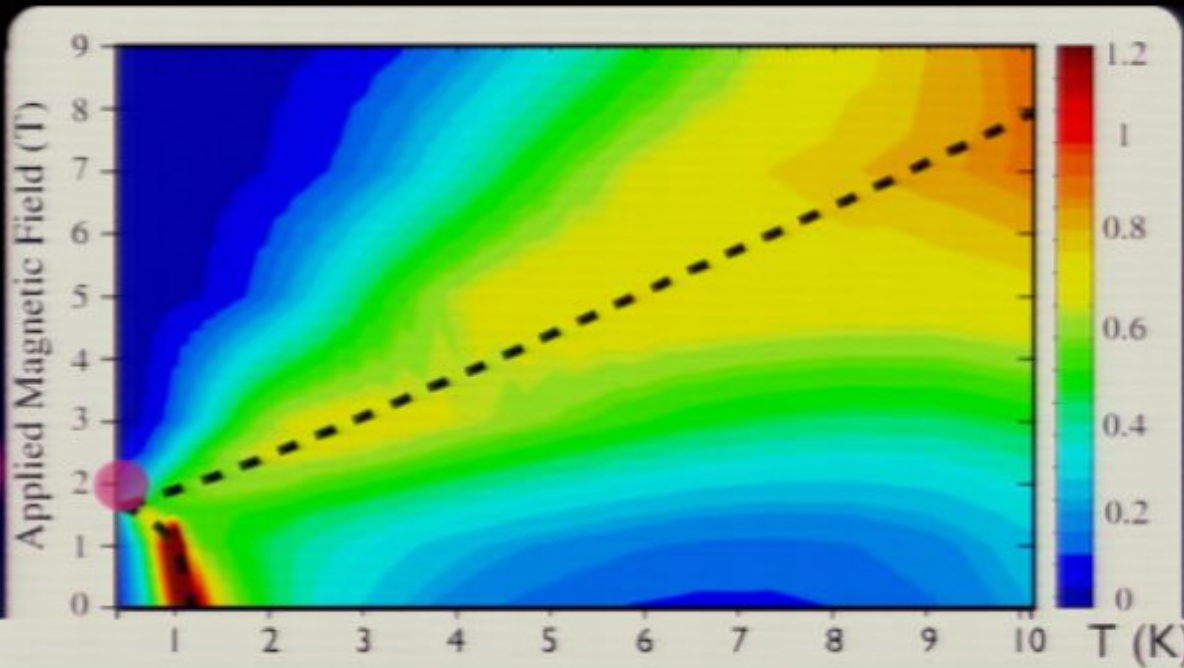
50 mK, 1.0 T



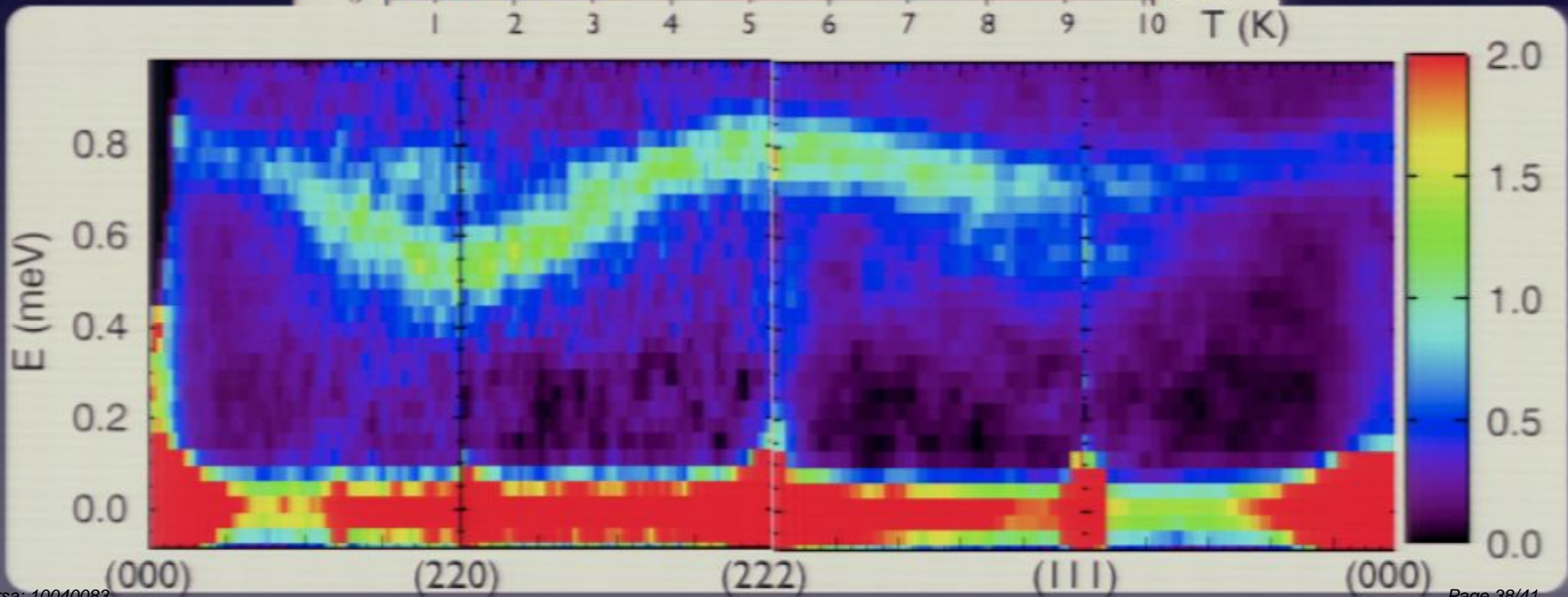
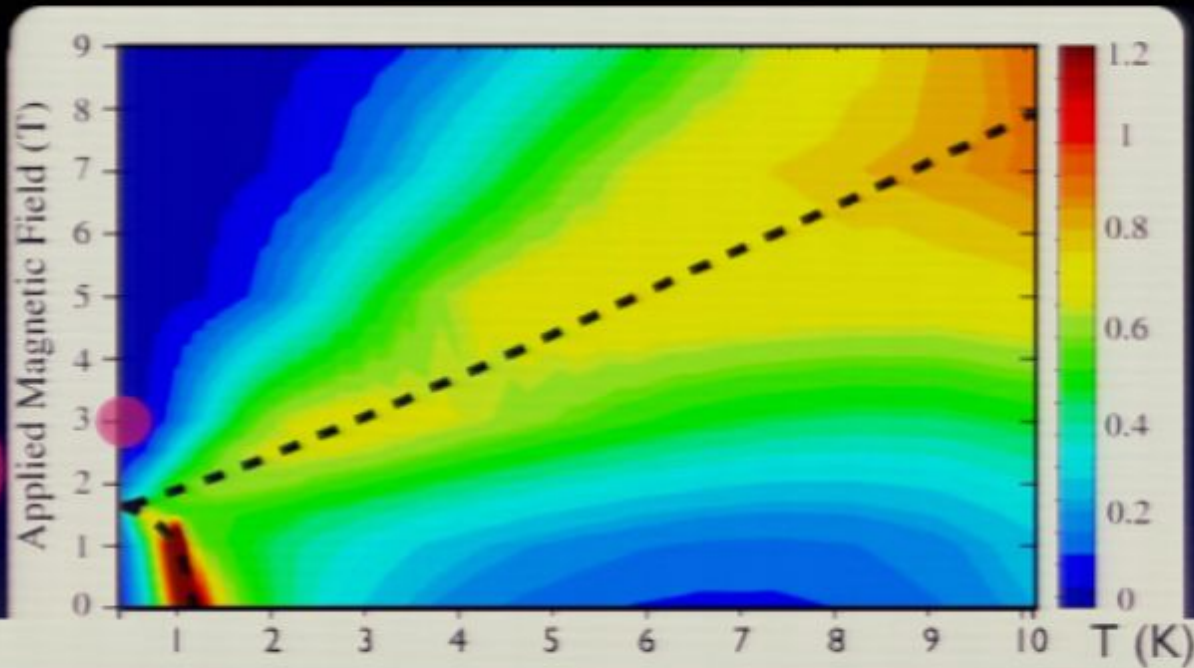
50 mK, 1.5 T

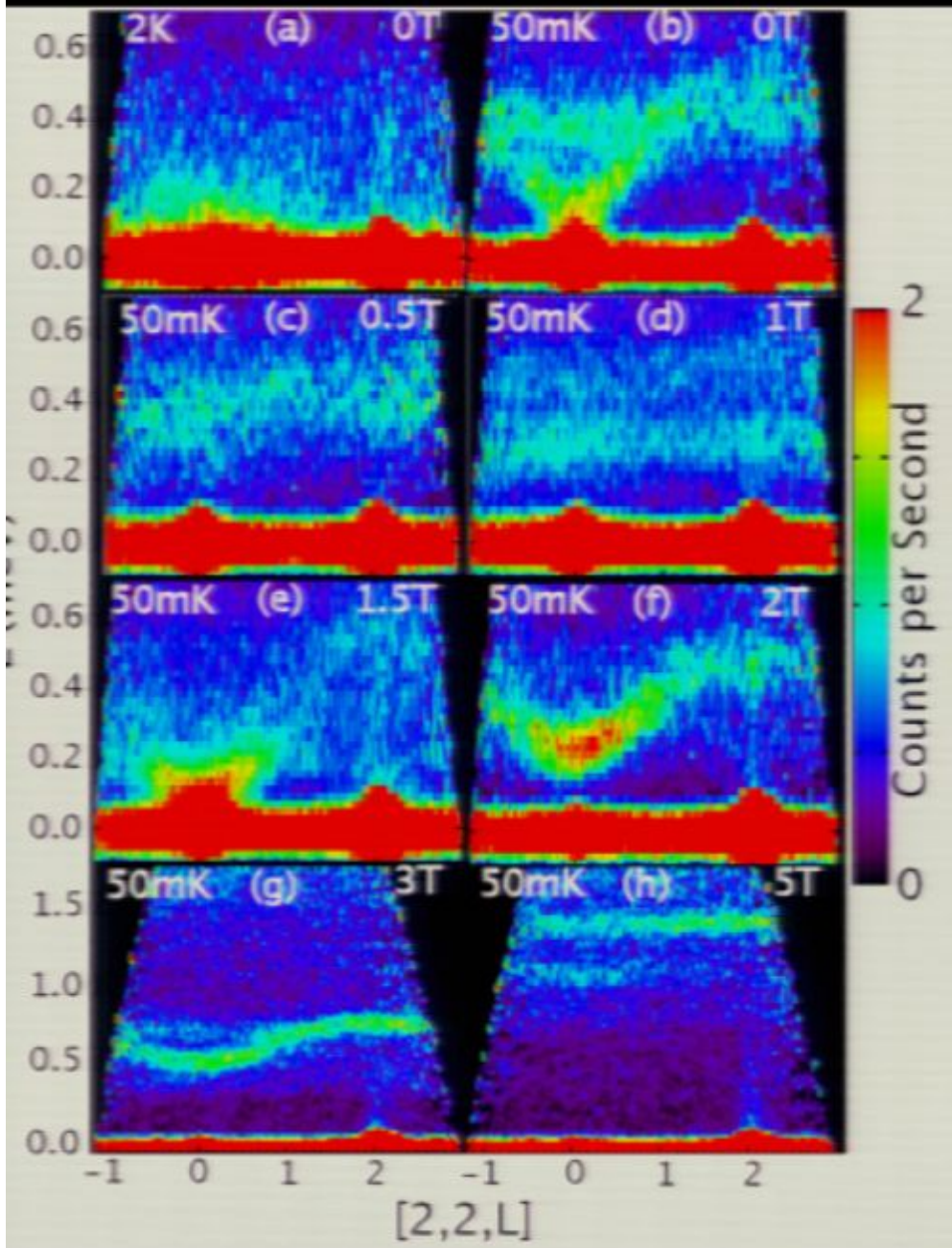


50 mK, 2.0 T

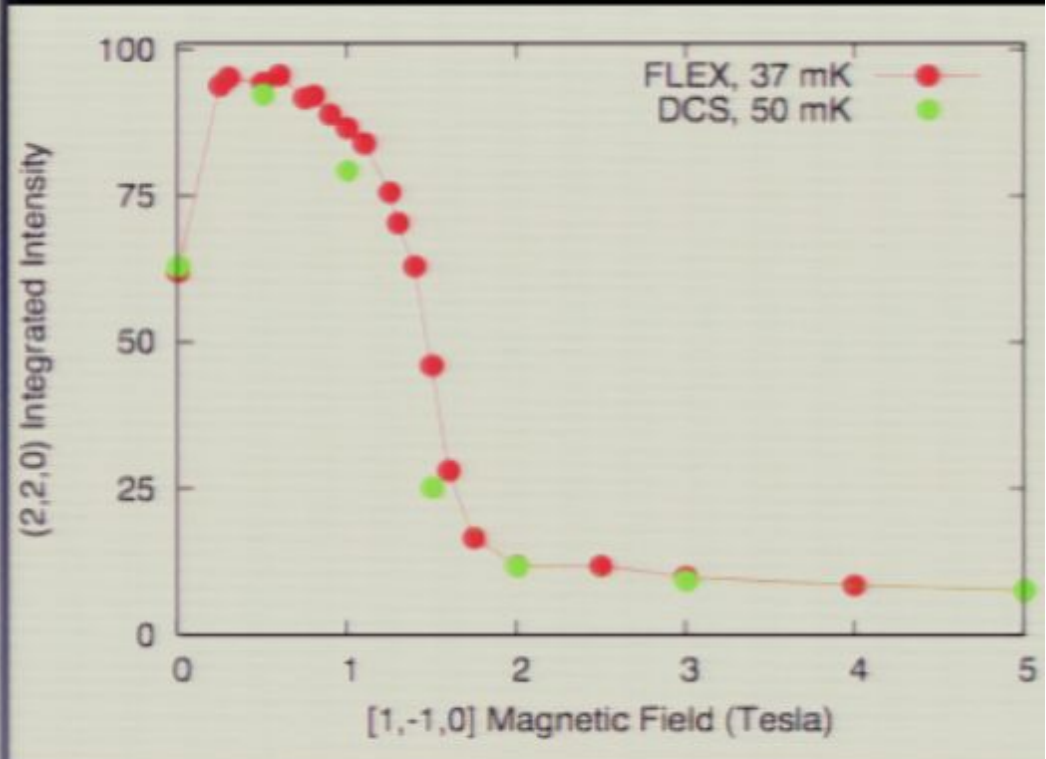


50 mK, 3.0 T





Er₂Ti₂O₇





Kate Ross



Jacob Ruff



Pat Clancy

- *Renaissance in neutron science with figures of merit increases ~ 100
TOF techniques well suited to exotic magnetism as it measures very effectively
across wide dynamic range in Q and E*

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3D long range order-by-disorder, destroyed by [110] magnetic field*



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