Thin film growth of chiral magnet $YbNi_3Al_9$

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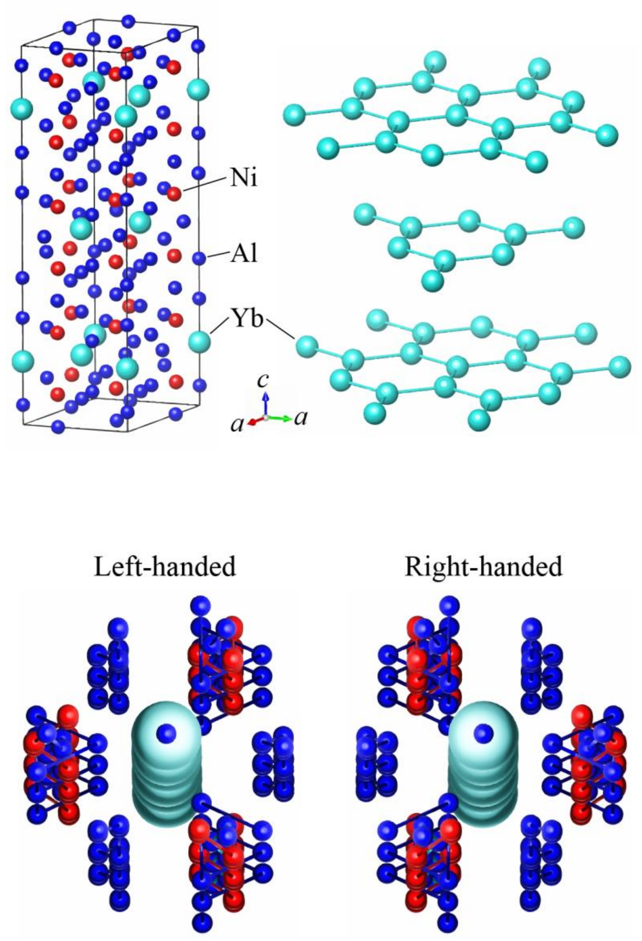
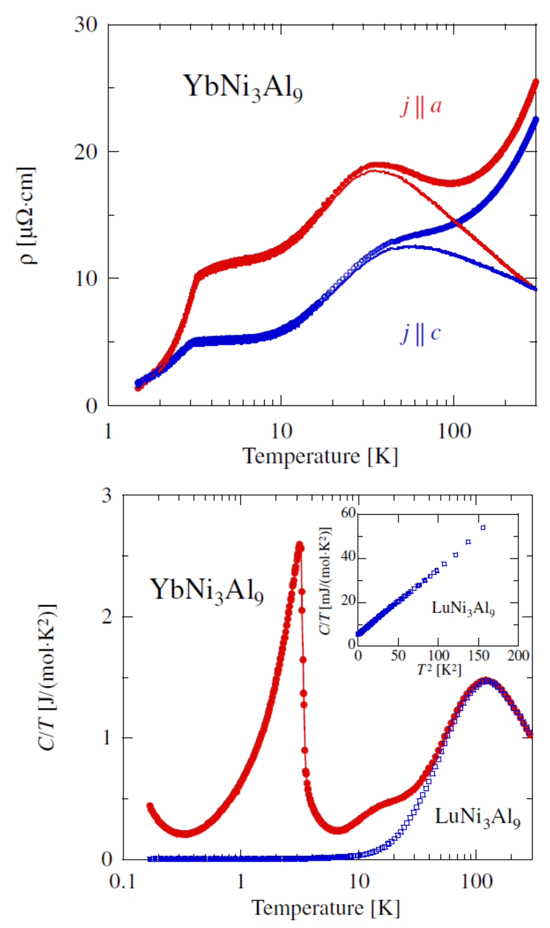
Heavy fermion chiral magnet $YbNi_3Al_9$

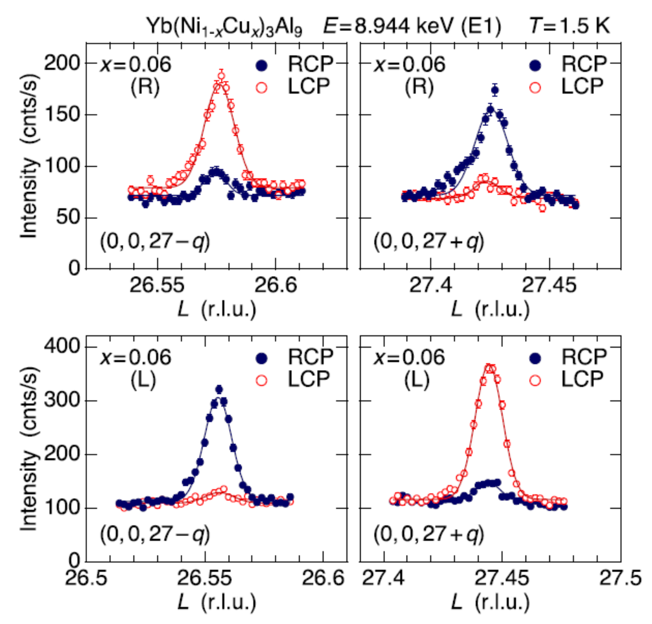


Crystal structure
- ✔ Trigonal
- ✔ *R*32 (Sohncke space group)
- ✔ a = 7.2731 Å, c = 27.582 Å



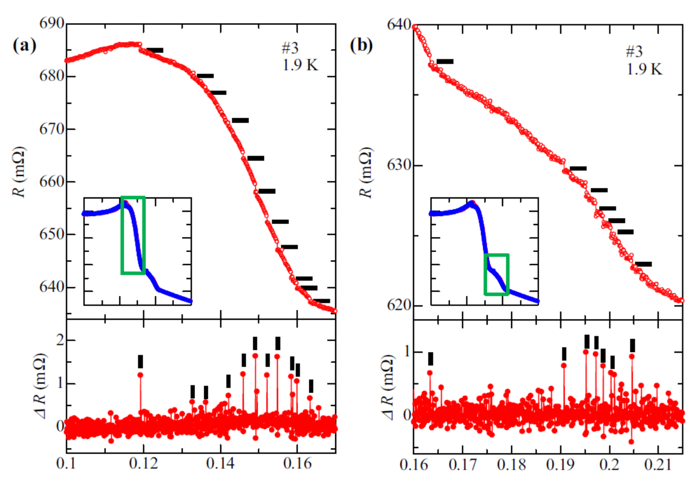
T. Yamashita *et al*., JPSJ **81**, 034705 (2012).

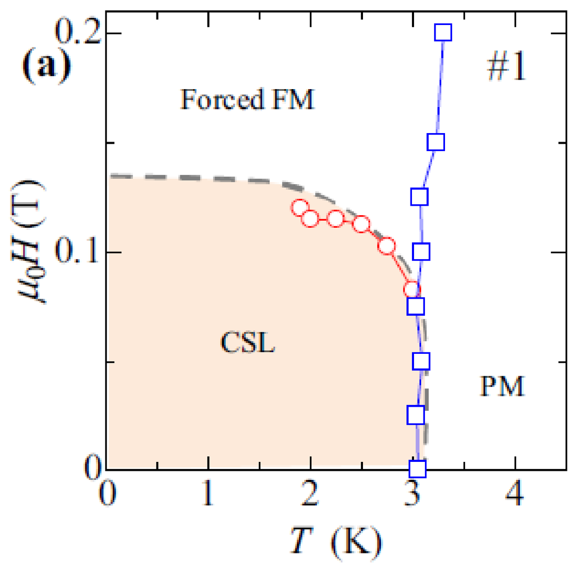
Heavy fermion
- ✔ Dense Kondo effect
- ✔ Large electronic specific heat coefficient
  γ = 100 mJ/K²•mol



T. Matsumura *et al*., JPSJ **86**, 124702 (2017).

- ✔ Chiral magnet
  T_m = 3.4 K
  q = (0, 0, ~0.82)
  L_0 ~ 3.4 nm
- ✔ Formation of the chiral soliton lattice (CSL)





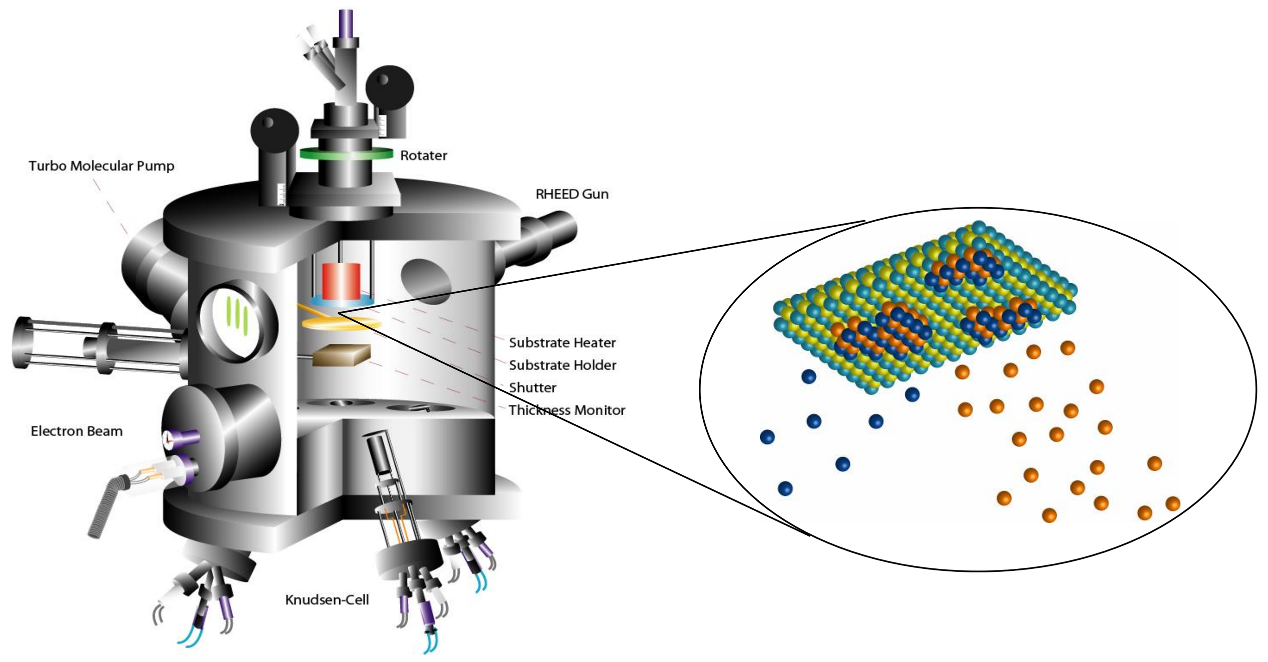
R. Aoki *et al*., PRB **97**, 214414 (2018).

Motivation

- ✔ Utilizing chiral spin order for device applications
- ✔ Carrier density control by applying a strong electric field
  ➡ Control material parameters (e.g. T_m, H_c)

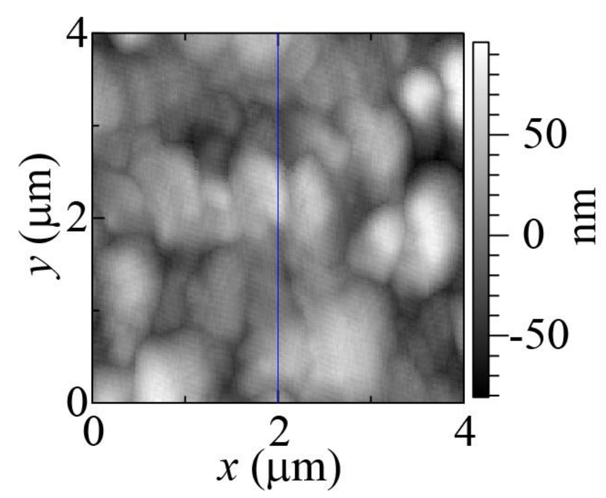
➡ Establishing a method for thin film growth of chiral magnets

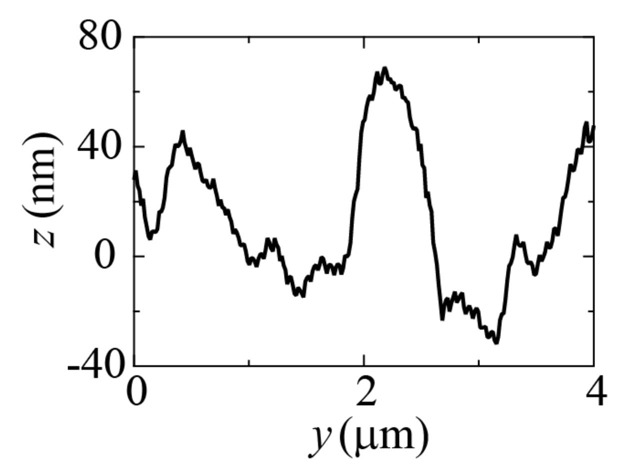
Thin film growing methods



Fabrication of thin films by molecular beam epitaxy (MBE)
- ✔ High vacuum : 2 X 10^{-6} Pa
- ✔ Stoichiometric atomic deposition rate ratio
  Yb:Ni:Al = 1:3:9
- ✔ Slow deposition rate : ~ 0.2 Å/sec
- ✔ c − plane sapphire substrate
- ✔ Substrate temperature : 750℃
- ✔ Film thickness : 200 nm

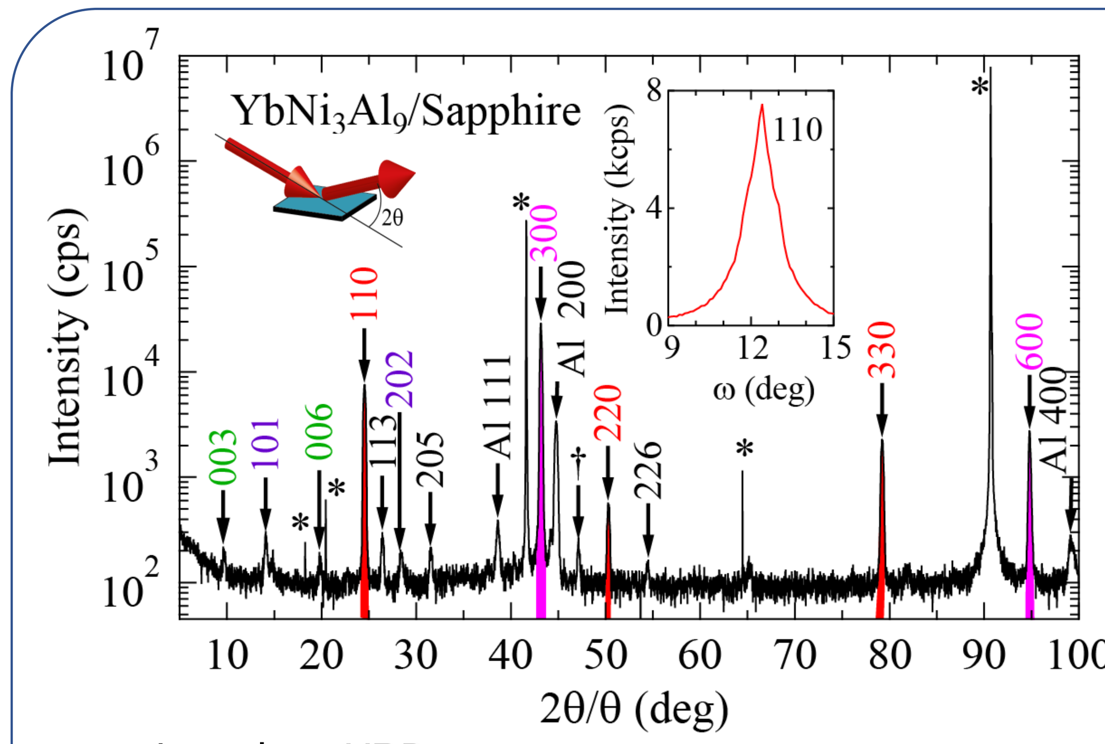
Surface flatness



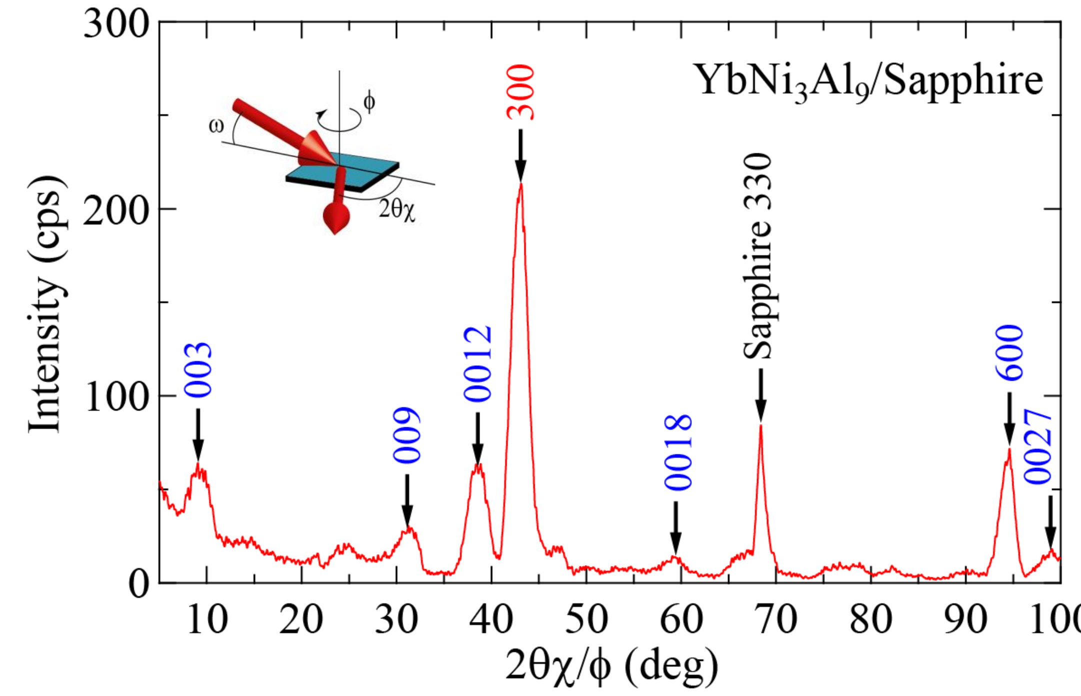


AFM image showed …
- ✔ An island-like morphology on the surface
  Typical size of 0.5–1 mm in diameter
- ✔ The island height : 40 ~ 120 nm

Film orientation

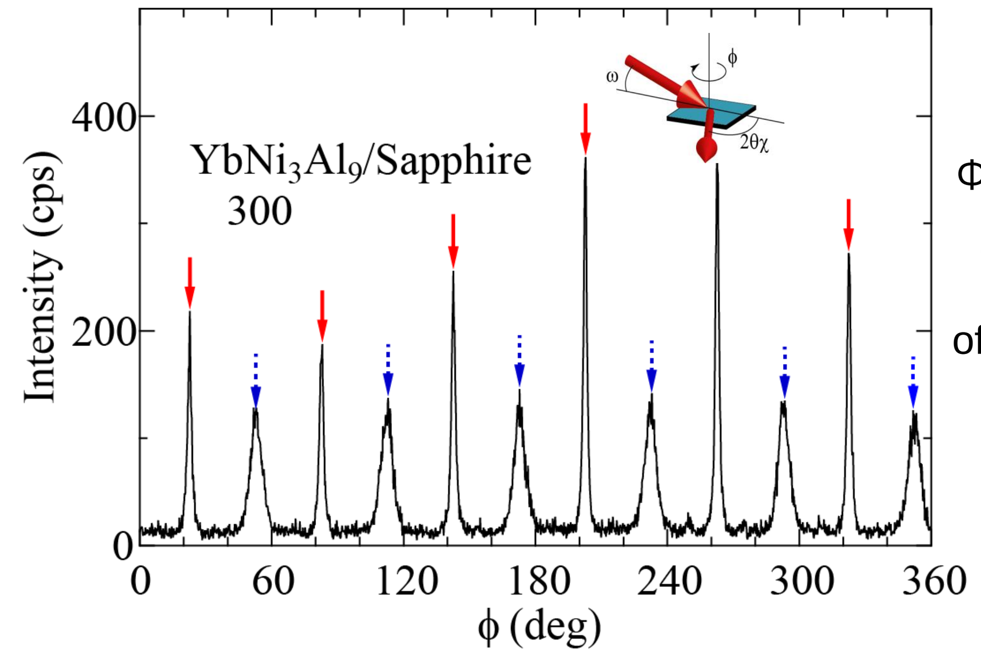


Interplane XRD
- ✔ hh0 and 3h00 main peaks
- ✔ High orientation : 0.73° FWHM of the rocking curve
  ➡ Uniaxial orientation perpendicular to the surface



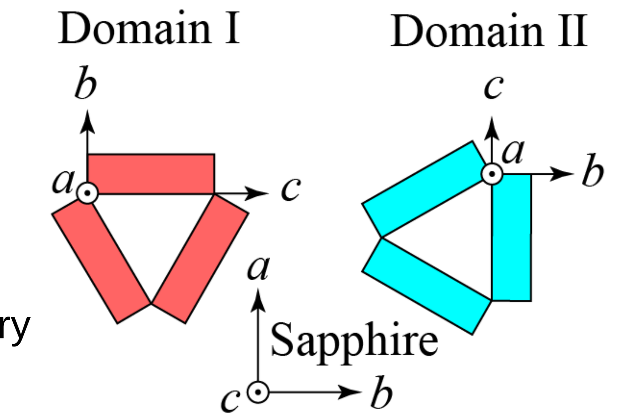
Inplane XRD
- ✔ 3h00 and 00l main peaks

Epitaxial domains



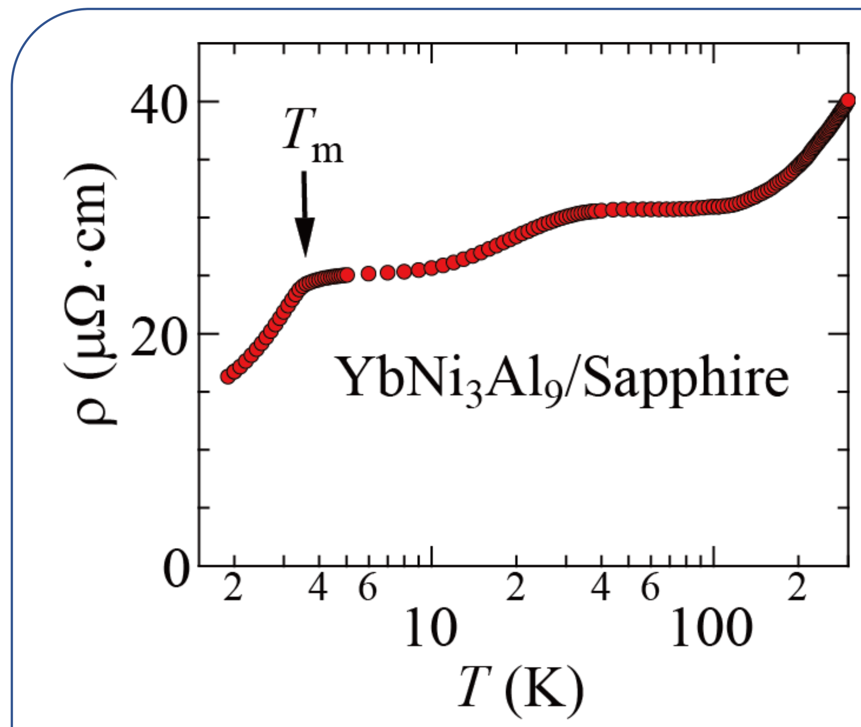
Φ scan
- ✔ Two sets of six peaks
  ➡ Reflect six-fold symmetry of the substrate

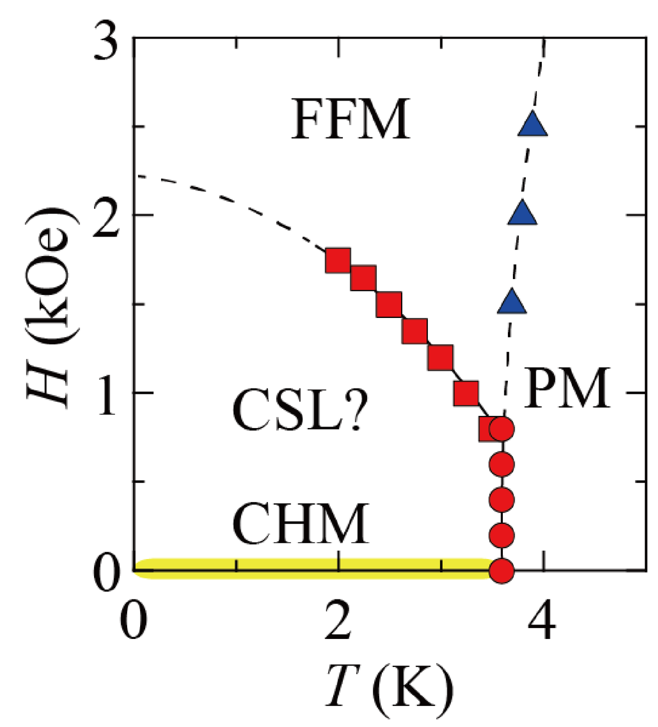
* a [100]

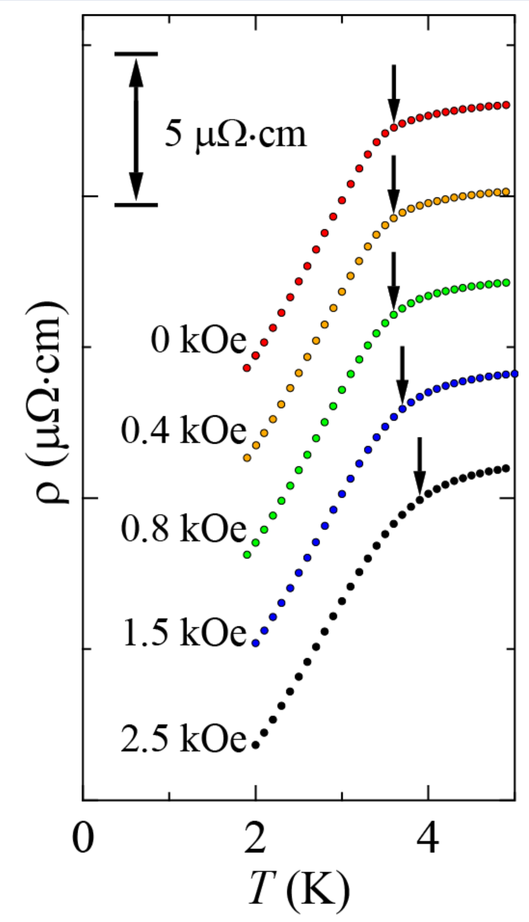


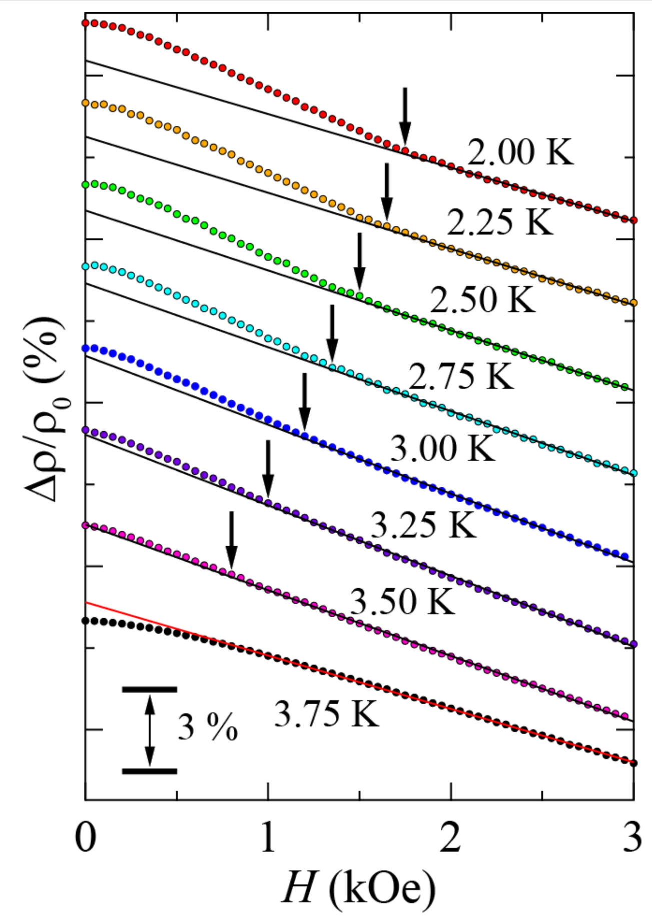
Domain I	Domain II
$a_{YbNi_3Al_9} \parallel c_{sapphire}$	$a_{YbNi_3Al_9} \parallel c_{sapphire}$
$b_{YbNi_3Al_9} \parallel a_{sapphire}$	$b_{YbNi_3Al_9} \parallel b_{sapphire}$
$c_{YbNi_3Al_9} \parallel b_{sapphire}$	$c_{YbNi_3Al_9} \parallel a_{sapphire}$

Magnetic phase diagram









- ✔ ρ has a maximum at ~40 K.
  ➡ Dense Kondo effect
- ✔ Kink at T_m = 3.6 K
  ➡ Chiral helimagnetic (CHM) order
- ✔ Negative magnetoresistance (MR)
- ✔ The slope of the MR exhibits a finite change at the critical field H_c
  ➡ Phase transition between an ordered and forced ferromagnetic (FFM) states.
- ✔ The $H – T$ phase diagram qualitatively reproduced that of bulk crystals.
  ➡ Chiral soliton lattice (CSL) state probably arises even in thin films

Summary and future prospects

- ✔ We have achieved in growing thin films of the heavy fermion chiral magnet $YbNi_3Al_9$.
- ✔ Chiral soliton lattice (CSL) state probably arises even in thin films.
- ✔ The establishment of a thin film growth method paves way for device applications (e.g. multivalued memory using the topological CSL state)
- ✔ Carrier density control with the use of electric fields may be available in thin films.