vortex melting and superconducting transition in high T_c oxides

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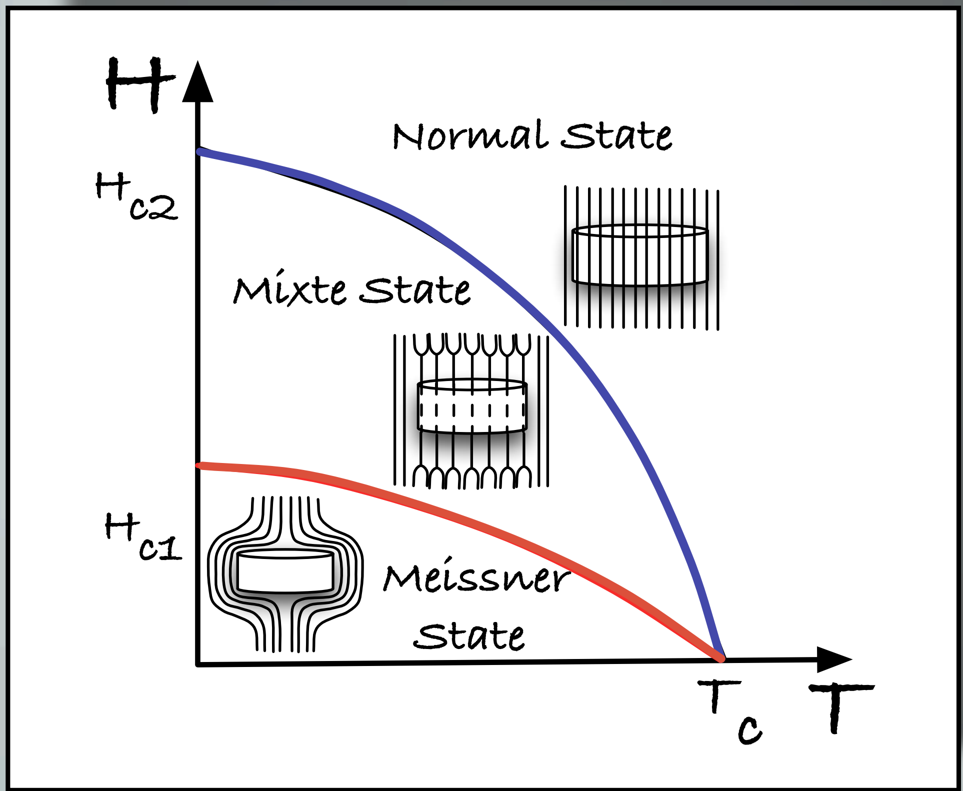
Outline

- Order - disorder transition in the vortex matter
- the normal-superconducting state transition

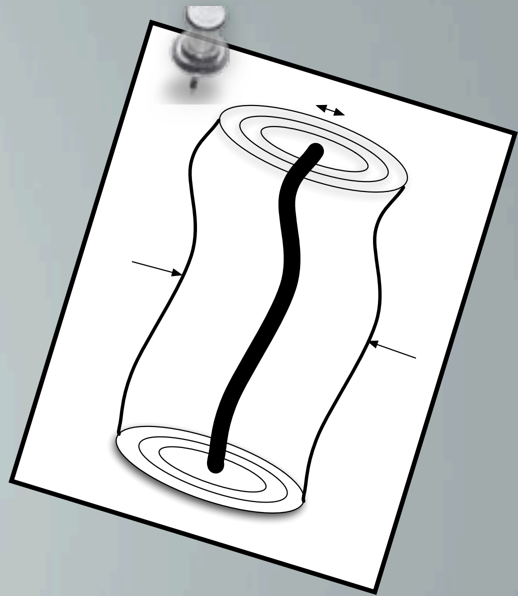
  - influence of correlated disorder - a “simple” model

order-disorder transition in the vortex matter

vortices in type II superconductors



core size : coherence length
~ a few 10A



screening currents
penetration length ~ a few 1000A
-> interacting elastic lines
-> hexagonale lattice
but very sensitive to defects

in high T_c materials $U_{pin} \sim U_{elast} \sim kT$

-> an order-disorder transition can be induced by

increasing H and/or T

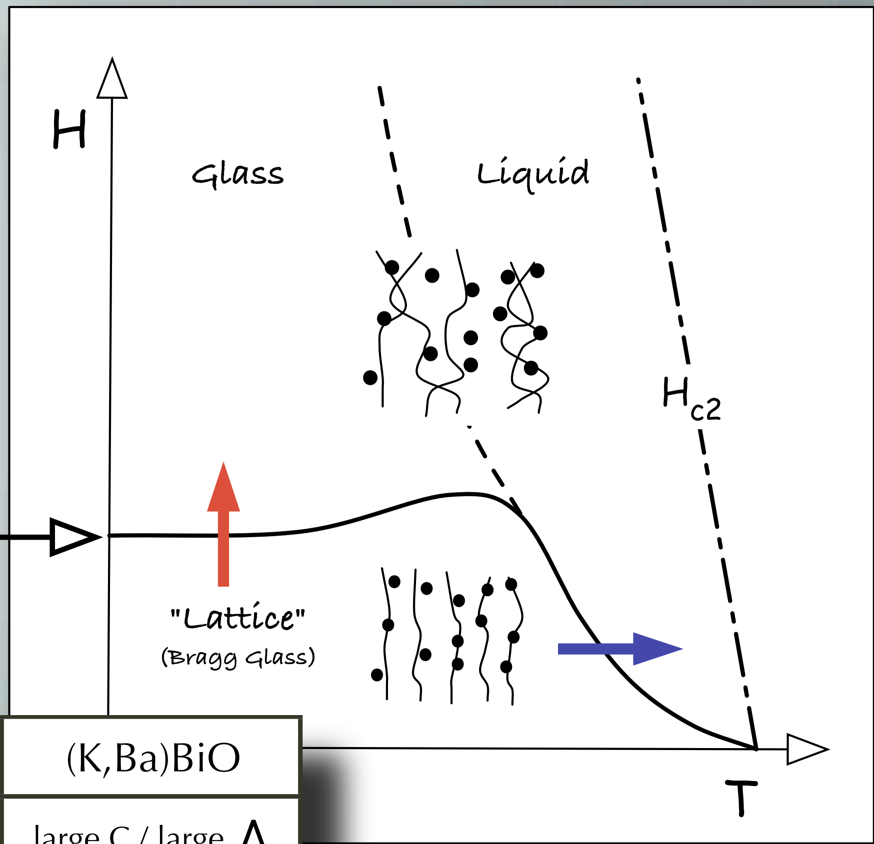
R_a : "correlation length" of the ordered phase (so-called Bragg Glass)

elastic constant

$$R_a \approx \frac{a^4}{\rho^2}\frac{C^2}{\Delta} \propto \frac{1}{B^2}$$

disorder

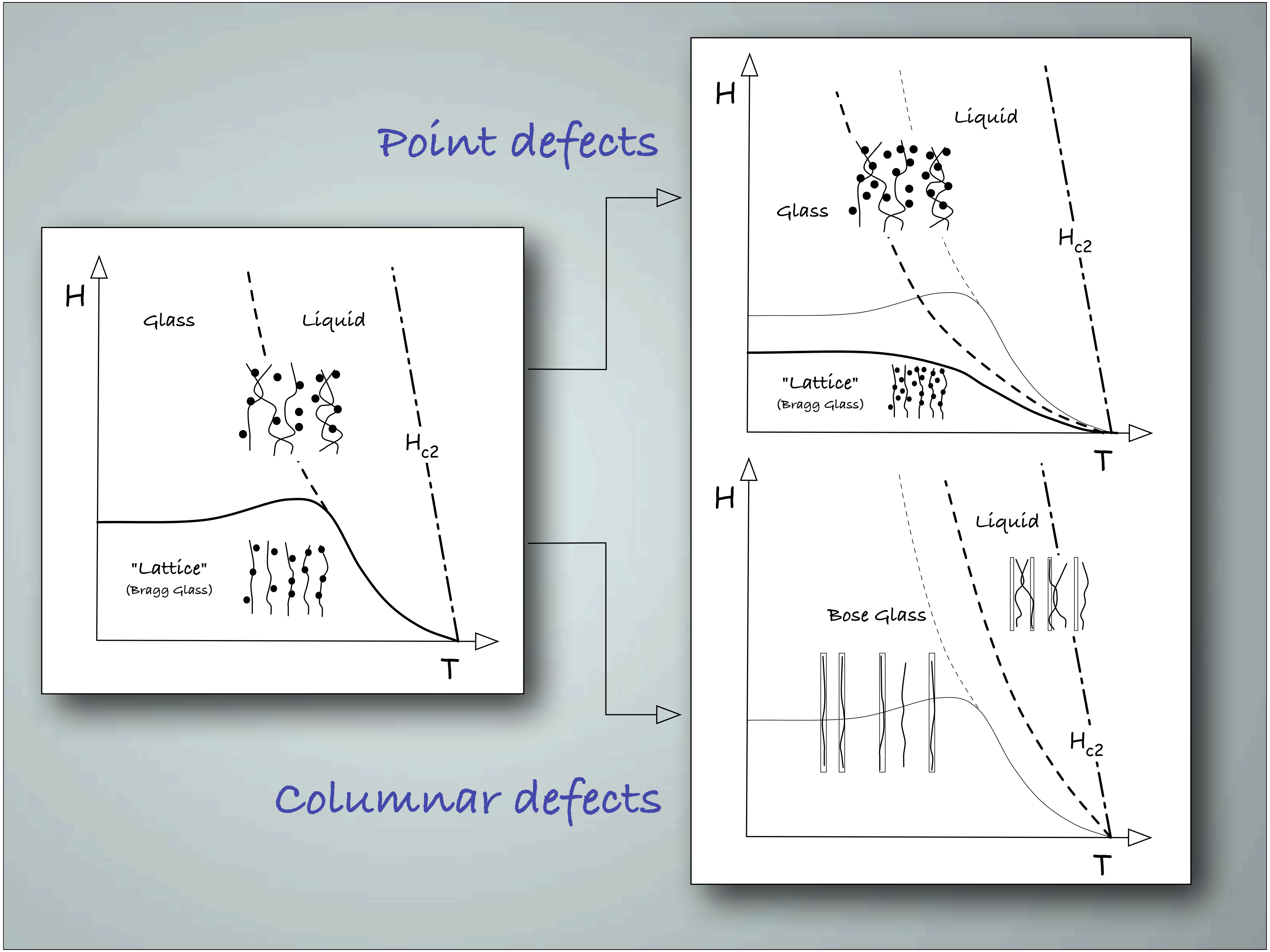
B*(0)



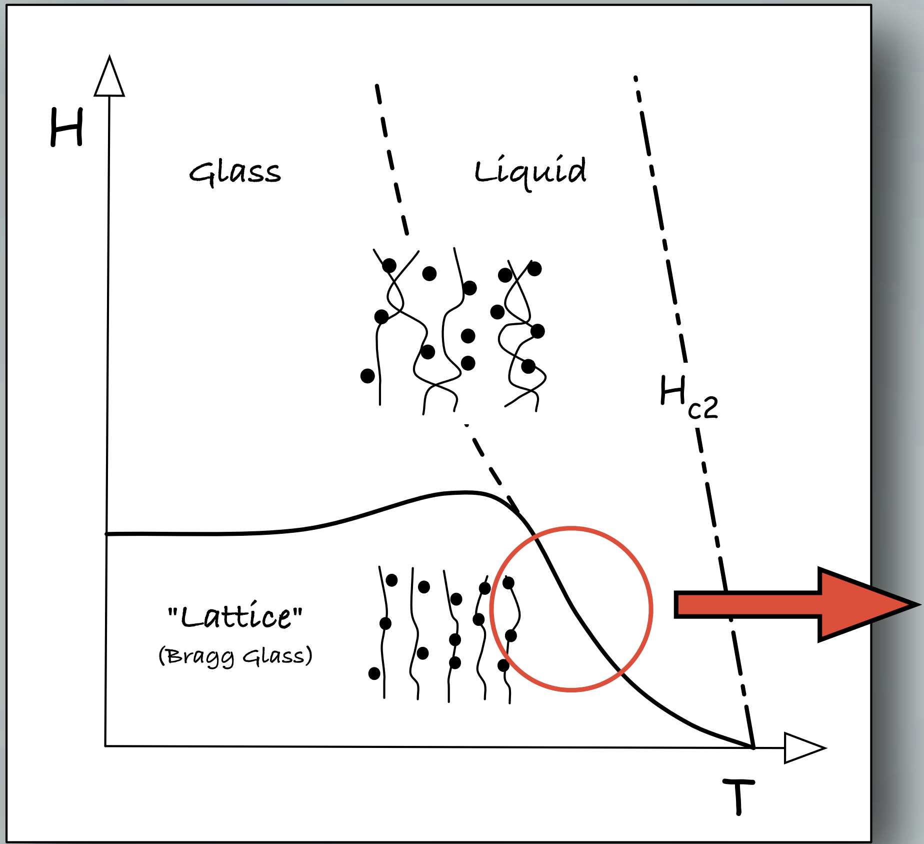
dislocations proliferate into the solid for

$R_Z \sim 20.a_0$ Lindeman criterion

YBaCuO	BiSrCaCuO	(K,Ba)BiO
"large C" / low Δ	very low C / low ∧	large C / large Δ
B* > 30T	B* a few 100G	**B* ~ 1T**



Point defects
Columnar defects
H
T
Glass
Liquid
H_{c2}
"Lattice"
(Bragg Glass)
Bose Glass



Experimental evidence

Sharp jump in the electrical resitivity

+

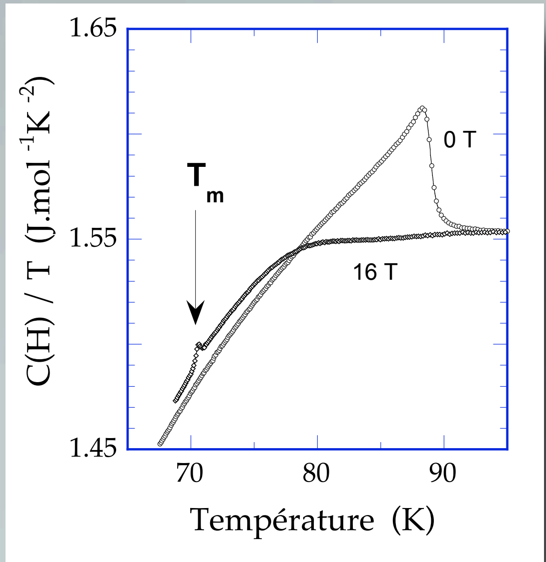
Anomaly in the JPR signal (interplane coupling)

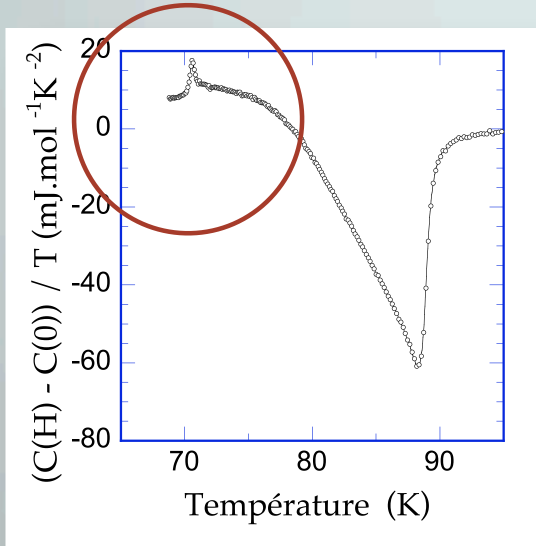
+

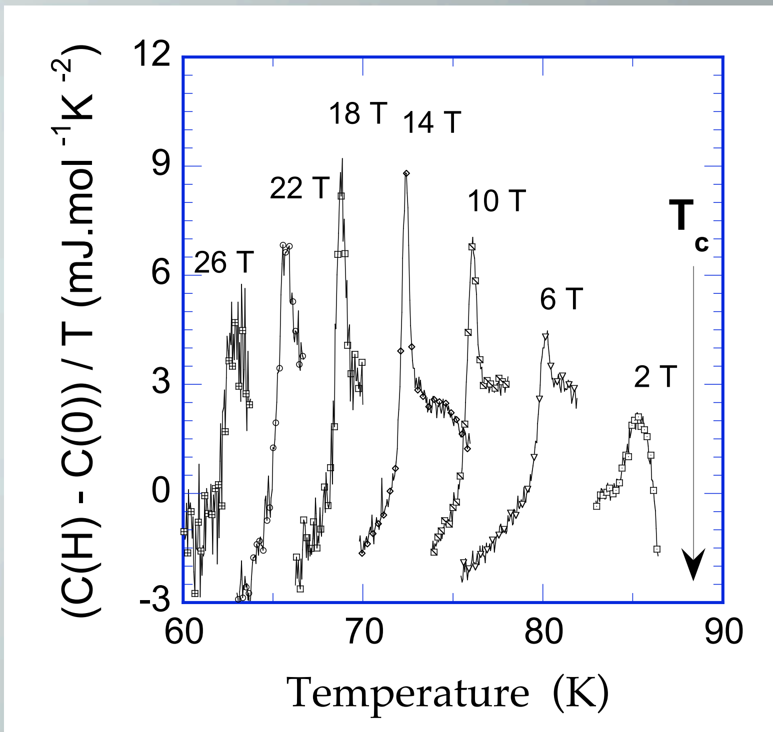
Specific heat jump (YBCO only)

Specific heat anomaly

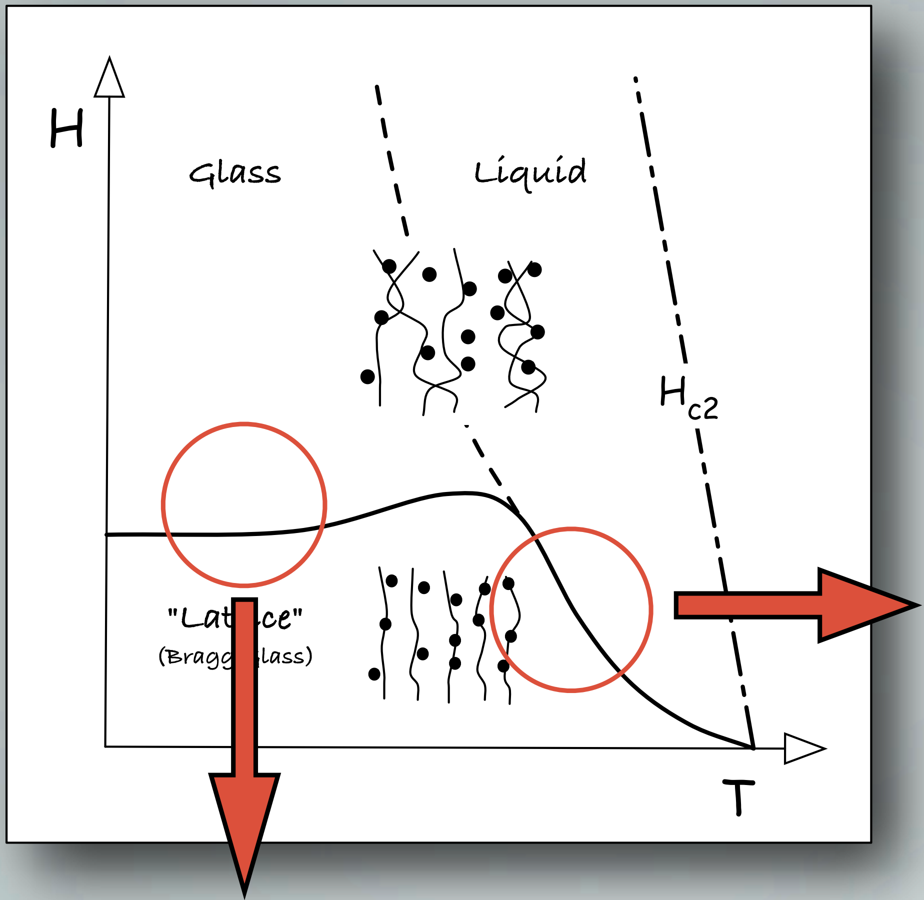
YBaCuO, C.Marcenat et al.







Experimental evidence



Sharp jump in the electrical resitivity

+

Anomaly in the JPR signal (interplane coupling)

+

Specific heat jump (YBCO only)

"Fishtail" effect : sharp increase of Jc

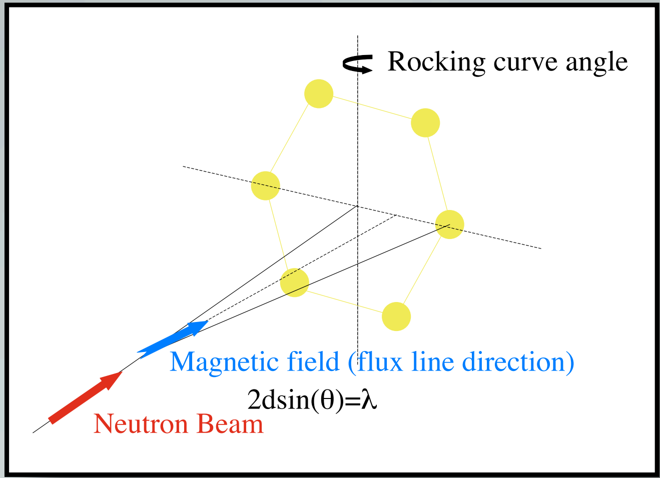
+

Jump in the reversible magnetization (BSCCO only)

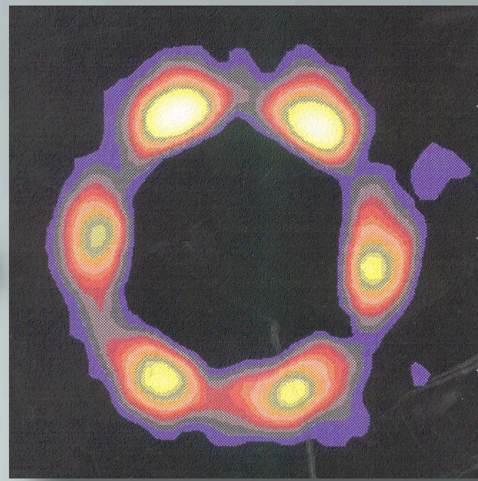
+

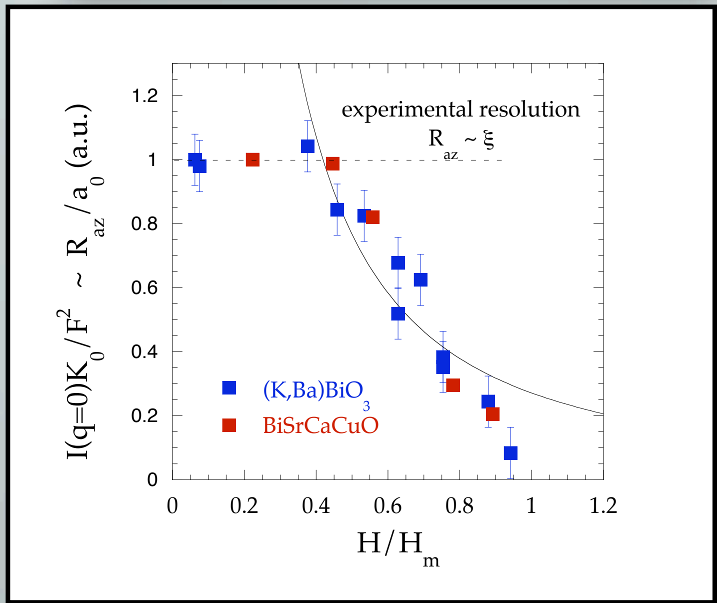
Anomaly in the neutron diffraction intensity

Small angle Neutron scattering



KBBO, 2K-1000G





Klein et al. Nature 01

$I(q=0) \propto R_a$

"correlation length" of Bragg Glass

dislocations proliferate into the solid
for $R_a \sim 20.a_0$

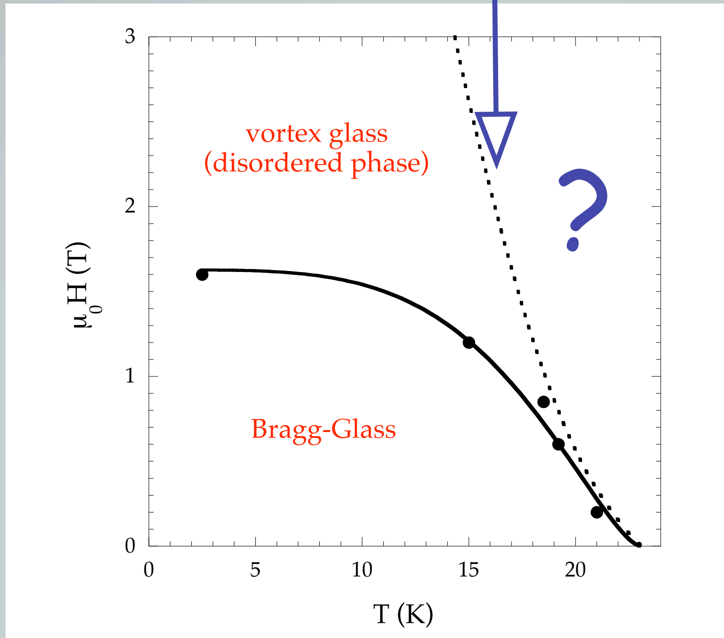
and R_a ->0 in the disordered phase

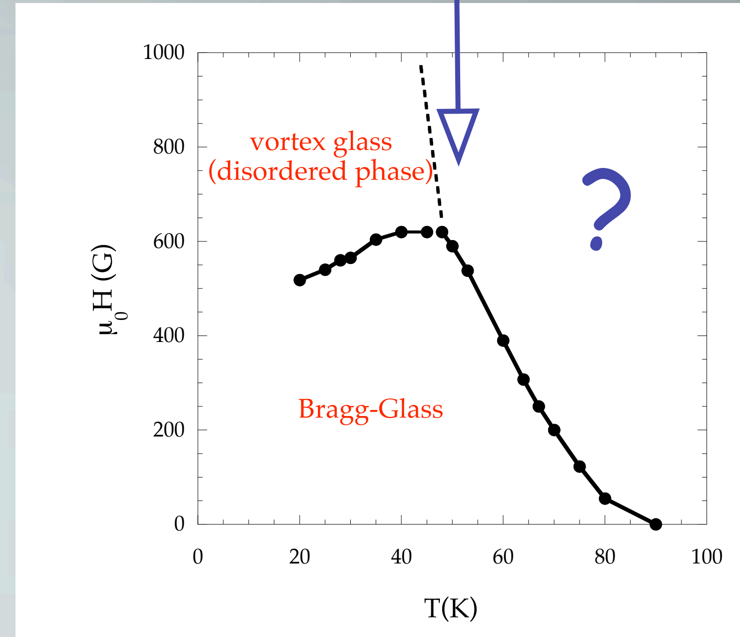
Irreversibility Line

Irreversibility Line

Joumard et al. PRL 99

Avraham et al. Nature 01





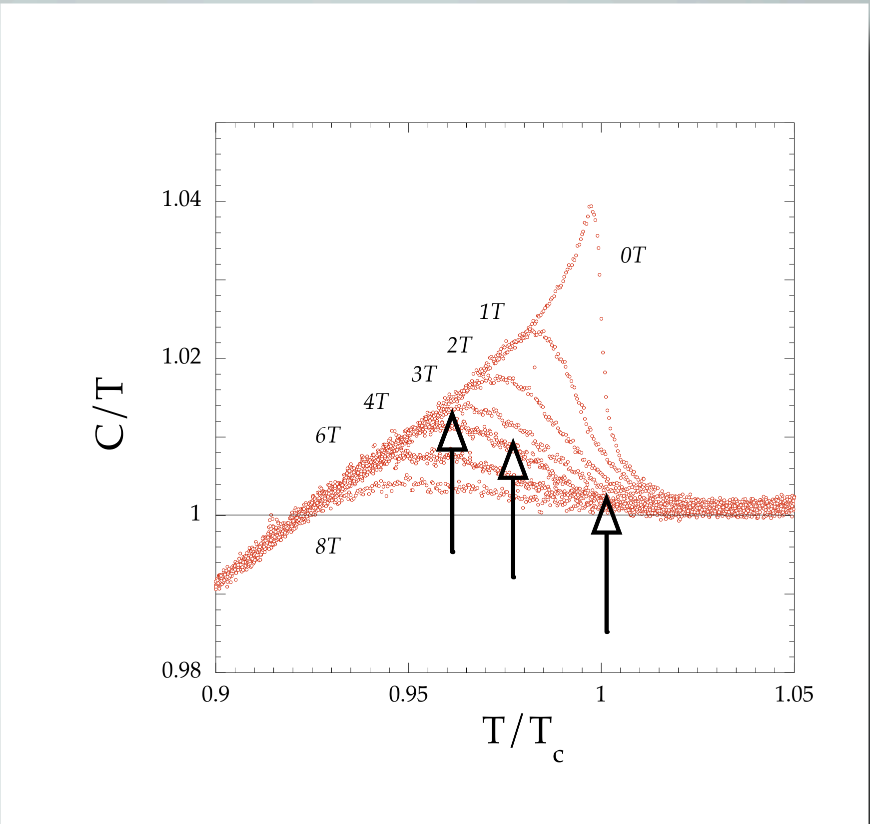
(K,Ba)BiO_3

BiSrCaCuO

What is the exact nature of the so-called "vortex liquid" ???

Where is the H_{c2} line ???

measuring H_{c2}....... specific heat :rapid broadening of the transition due to the presence of strong thermal fluctuation

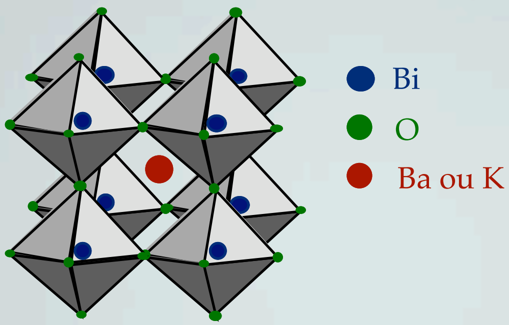


YBaCuO, R.Brusetti et al.

is H_{c2} given by the maximum of C_p, the mid-point or the onset of the transition ??

Need for a system showing less fluctuation : $(K,Ba)BiO_3$

Cubic (Perovskite)
ISOTROPIC structure



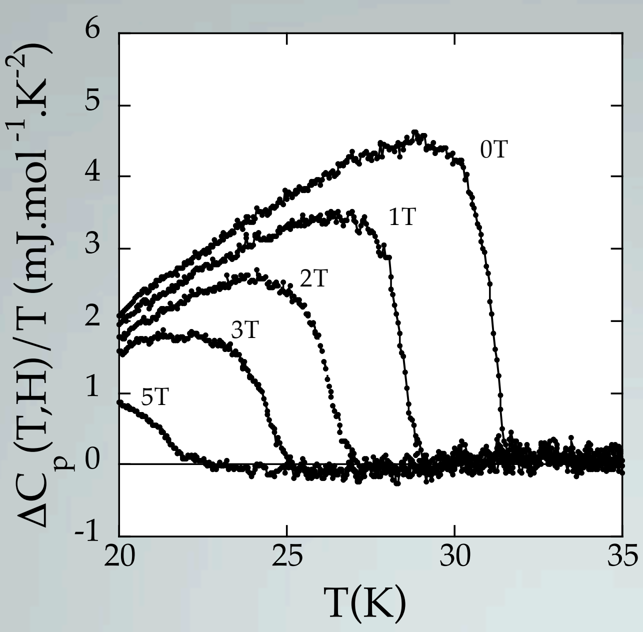
	NbTi	KBaBiO	YBaCuO
T_c(K)	10	30	100
ξ(A)	400	30-40	10
H_{c2}(T)	10	25-30	100
λ(A)	600	2500	4000
Gi	10^{-8}	10^{-5}-10^{-4}	10^{-2}
Qu	10^{-3}	0.1	0.1
J_c/J_0	0.1	10^{-1}-10^{-2}	10^{-2}-10^{-3}

$K_xBa_{(1-x)}BiO_3$

x can be varied from 0.37 to 0.50

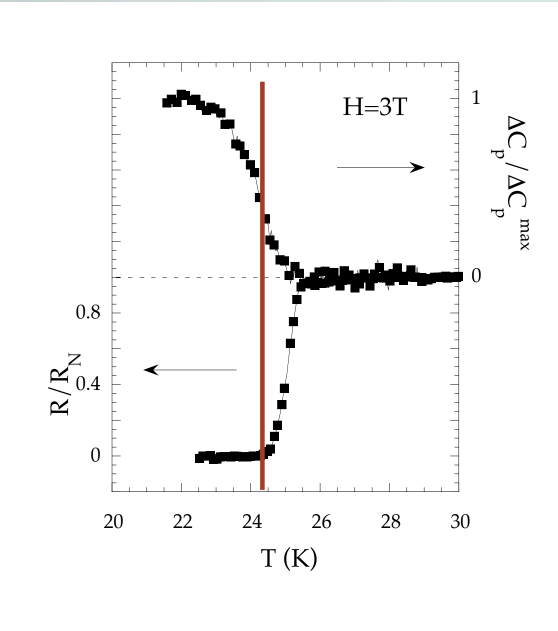
-> very difficult to grow homogeneous single crystals

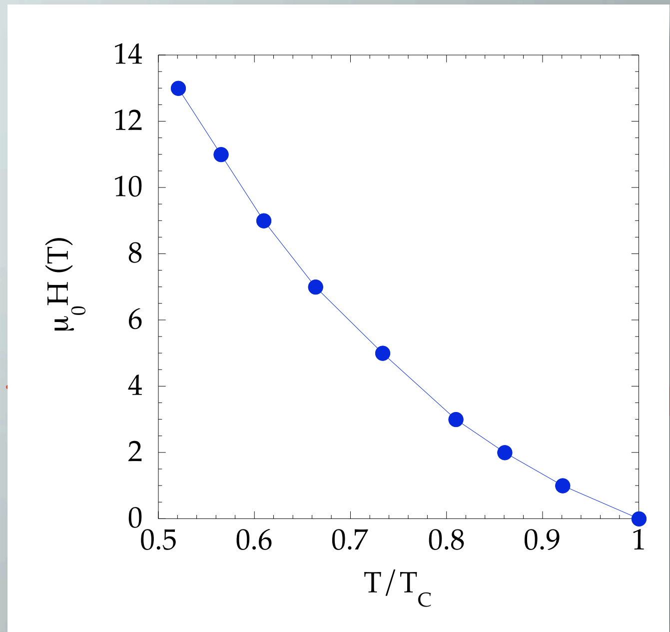
Superconducting to normal state transition

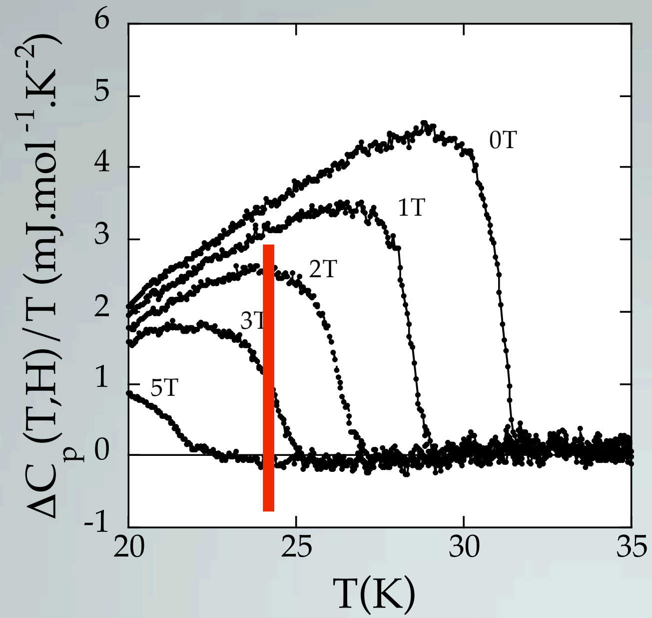


Pristine sample : well defined specific heat jump.
In conventional type II superconductors
the location of the C_p anomaly = $T_{c2}(H)$

UPWARD CURVATURE !!!!







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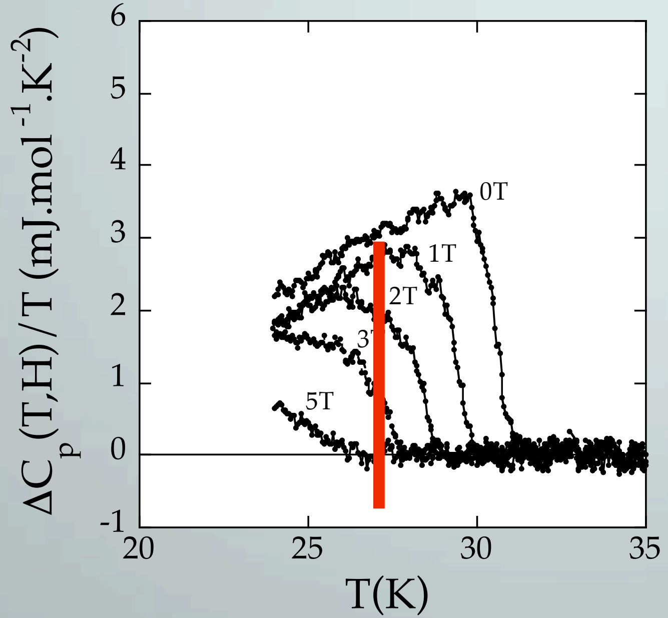
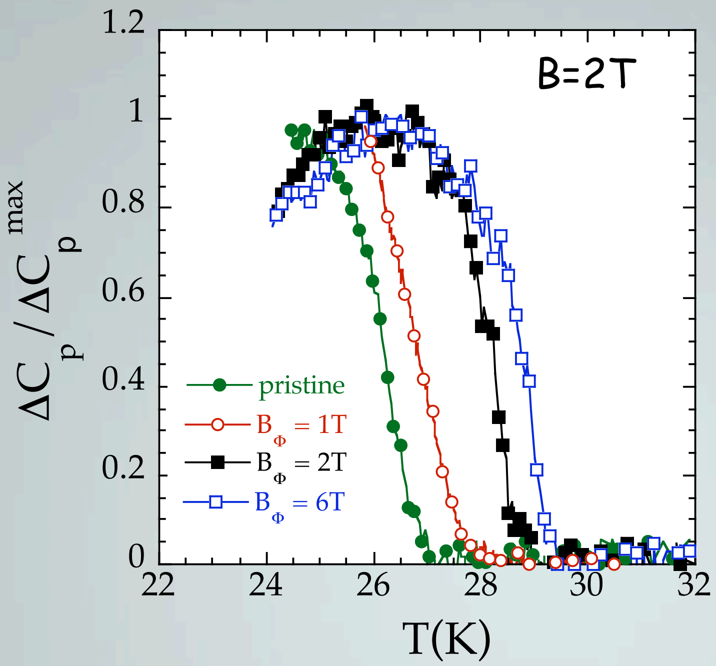
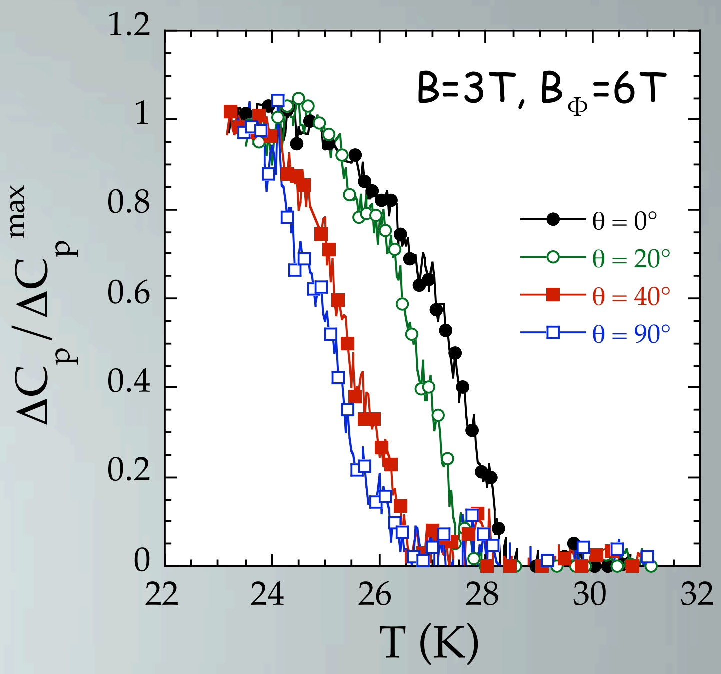


Marcenat et al. PRL 2003

The anomaly remains well defined after
heavy ion irradiation (B_Φ=6T)
i.e. introduction of columnar defects
no change in T_c but.....

the shift is
much less pronounced !!!!





The C_p anomaly progressively shifts towards higher T for increasing irradiation dose

The C_p anomaly progressively shifts back for increasing angles between H and the direction of the tracks

Why is the superconducting transition sensitive to heavy ion irradiation ???

- Decrease of the mean free path : $H_{c2} \sim 1/\xi l$ (dirty limit) ?
  - no change in H_{c2} by electron irradiation (3.2C -> 2K decrease in T_c)
  - in KBBO $l \sim \xi \sim 30A$ in pristine samples and the change in H_{c2} is observed even for $B_\Phi < 1T$ i.e. for $d > 300A \gg l$
  - no significative increase of the normal state resistivity
  - angular dependence

- Surface superconductivity along the traces
  - progressive shift with increasing disorder instead of a « second anomaly » at H_{c3}
  - the radius of the tracks ~ ξ -> only small effect at low T

A “simple” model

the **superconducting transition** i.e. boundary of the H-T diagram

in which long range superconducting order exists is given by :

$$|F_n - F_s| = \alpha\, k_B T / \xi^3$$

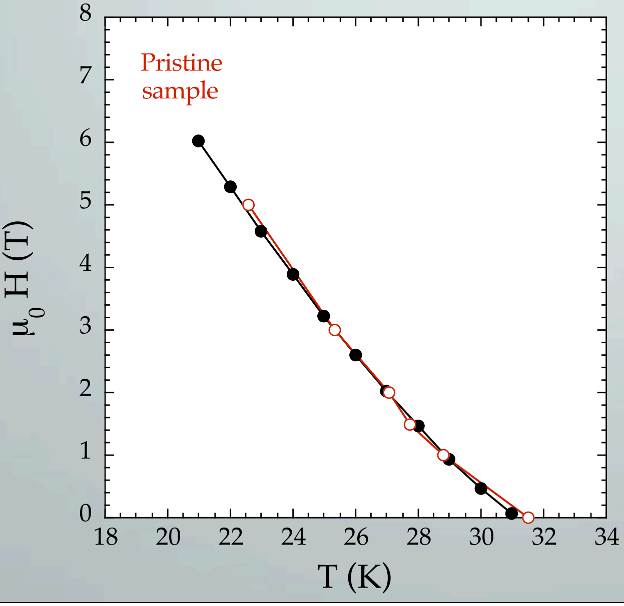
Cooper et al. PRB 1995
Klein et al. PRL 2004

Normal state and superconducting free energy density $-B_c^2/\mu_0(1-B/B_{c2})^2$

$\alpha \approx 1$

coherence length (or $\xi^2 d$ in 2D materials)

=> T(B) curve*



excellent agreement with experimental data with only 1 parameter :

$T_c^{MF} \approx 33\text{-}35K > T_c^* \approx 31.5K$

ξ=30A (H_{c2}), λ=3200A (neutron)

-> positive curvation of the transition line

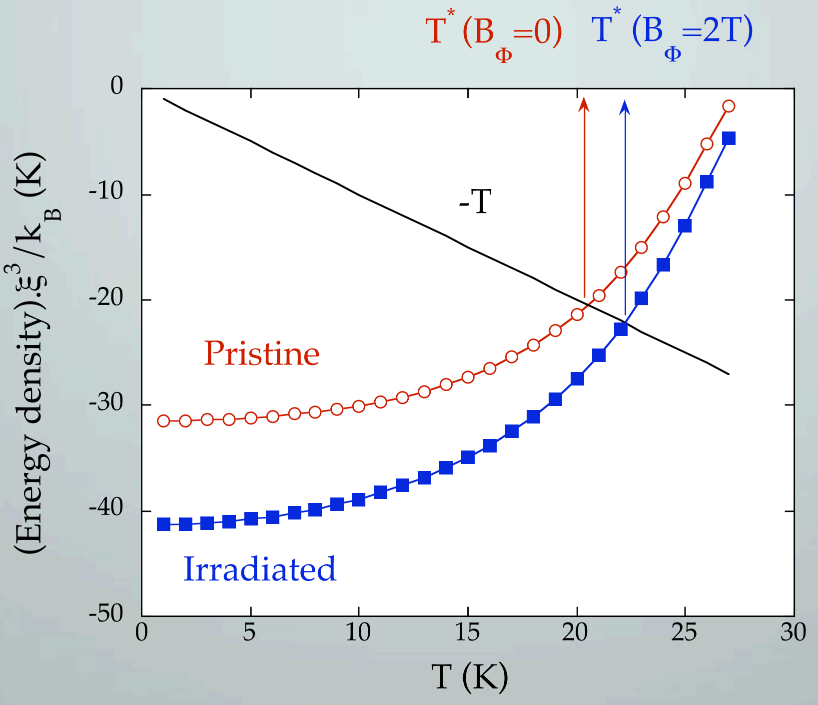
Influence of heavy ion irradiation : decrease of the free energy density

$$F_n - F_s = (F_n - F_s)_0 - n_t U_p (1 - B/B_{c2})$$

\# of pinned vortices

$(B_\Phi/\Phi_0)\ [(1-\exp(-\beta B_\Phi/B))/(\beta B_\Phi/B)]\ f(T/T_{dp})$

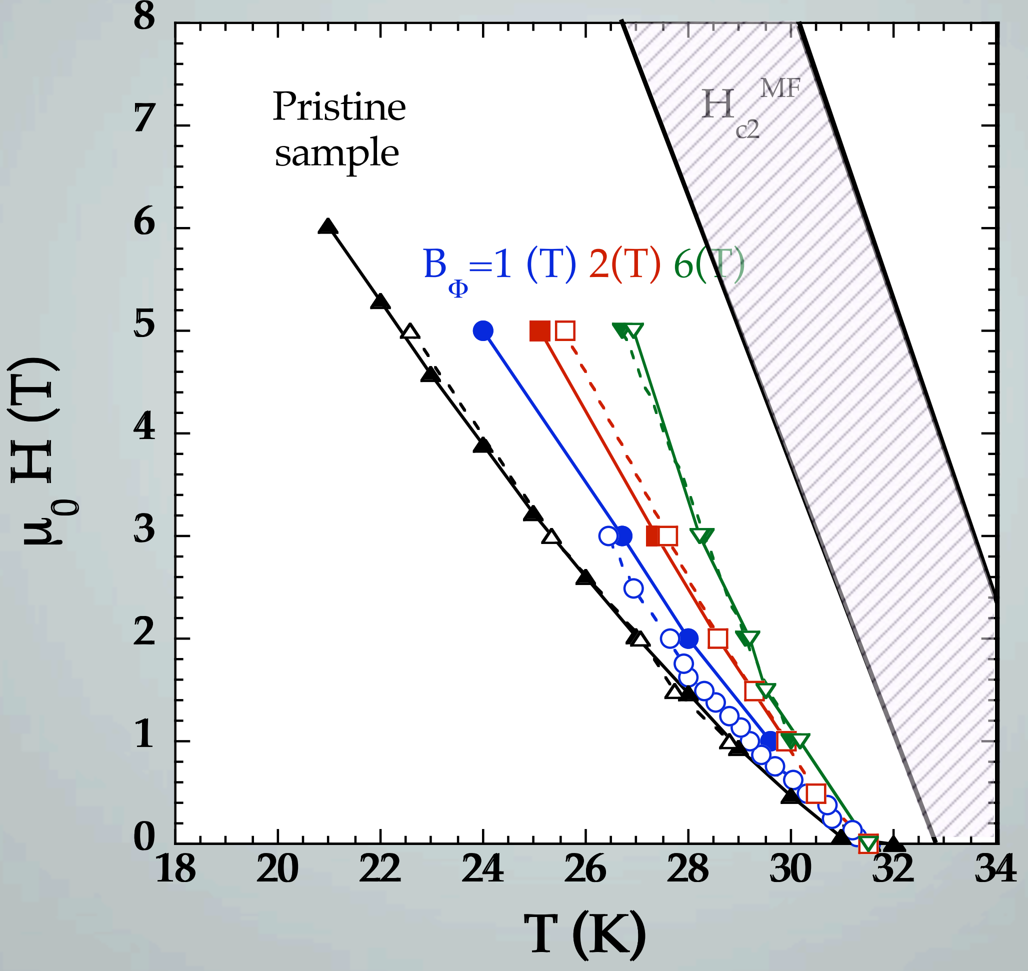
Pinning energy ~ line tension



upward shift of T*

good qualitative agreement
with experimental data

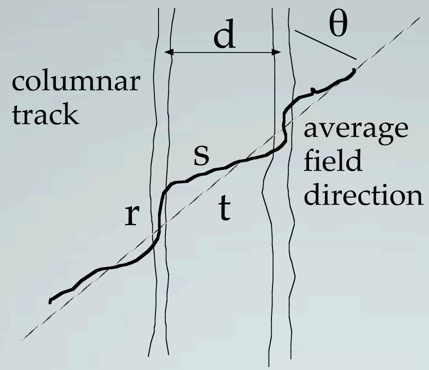
but also very good QUANTITATIVE agreement......



NO ADJUSTABLE PARAMETER

(not a fit)

influence of the angle

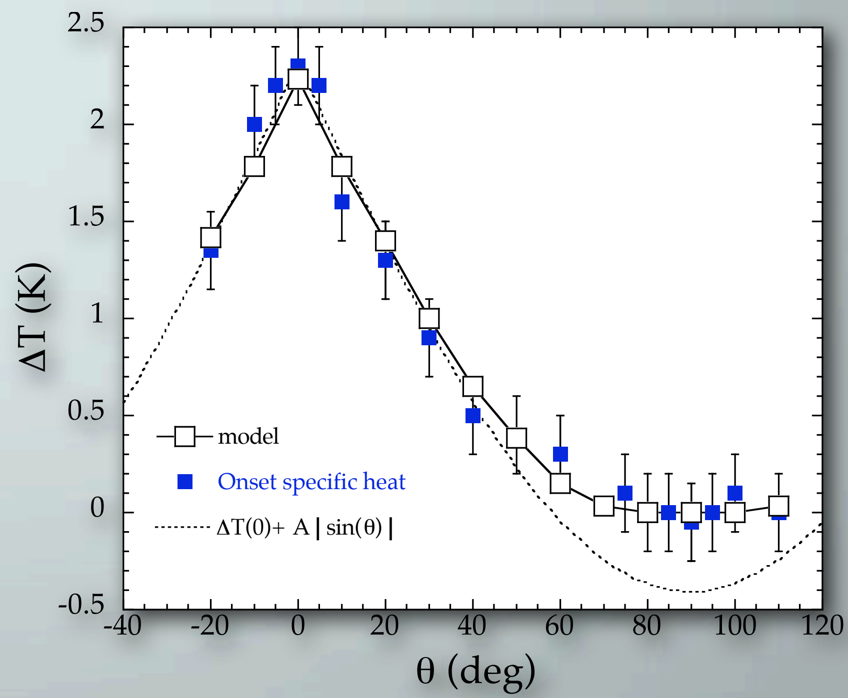


$$U_p(\theta) = [rU_p - (r+s-t)\epsilon_l]/(r+s)$$

minimizing this expression with respect to r leads to

$$U_p(\theta) = U_p \left[1 - \frac{2s/d\sin(\theta) + (\cos(\theta)-1)\epsilon_l/U_p}{\cos(\theta) + \epsilon_l/U_p\, s/d\sin(\theta)}\right]$$

-> recalculating T* using this new Up(θ) value :



Conclusion

- The vortex matter is a perfect system to study the influence of disorder on elastic systems :

  an order-disorder transition can be induced by increasing either T (thermal fluctuation) or H (effective disorder)

- But little is know on the the normal / superconducting transition in presence of (strong) thermal fluctuations :

  there is no liquid phase in KBBO : the vortex glass directly "sublimates" in to the normal state in which superconducting fluctuations exists

  a simple model ($|F_n - F_s| = k_B T/\xi^3$) gives a very good quantitative description of the influence of heavy ion irradiation on this transition in KBBO

  WHAT ABOUT IN OTHER HIGH T_c OXIDES ????