A simple model for the influence of heavy ion irradiation on the superconducting transition line in (K,Ba)BiO_3

- T.Klein, S.Blanchard, J. Marcus,

Laboratoire d'Etudes des Propriétés Electroniques des Solides, CNRS, Grenoble-France

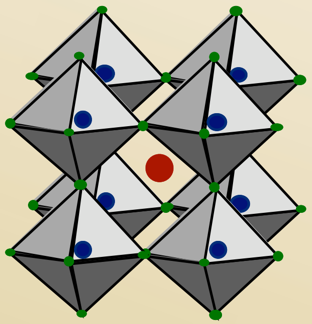
- C.Marcenat

Commissariat à l'Energie Atomique, DRFMC-SPSMS, Grenoble-France

- C.J.van der Beek, M.Konczykowski

Laboratoire des Solides Irradiés, Ecole Polytechnique, Palaiseau-France

Cubic (Perovskite)
ISOTROPIC structure

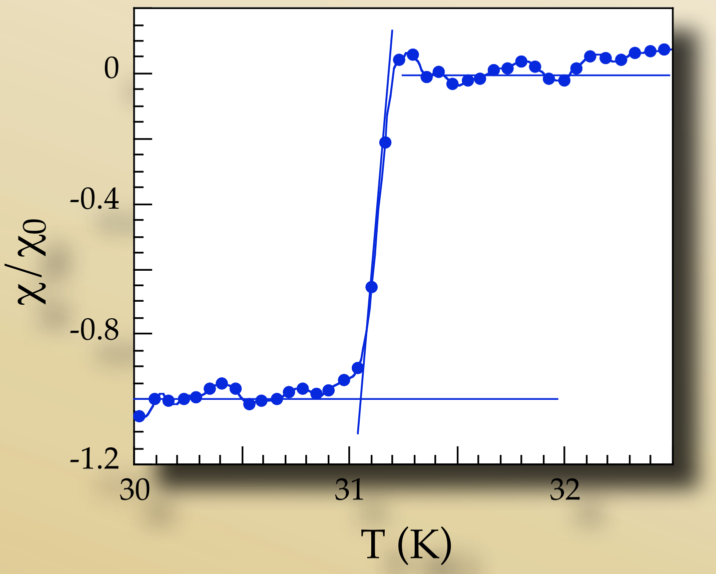


	NbTi	KBaBiO	YBaCuO
T_c(K)	10	30	100
ξ(A)	400	30-40	10
H_{c2}(T)	10	25-30	100
λ(A)	600	2500	4000
Gi	10^{-8}	10^{-5}-10^{-4}	10^{-2}
Qu	10^{-3}	0.1	0.1
J_c/J_0	0.1	10^{-1}-10^{-2}	10^{-2}-10^{-3}

$K_xBa_{(1-x)}Bi0_3$

x can be varied from 0.37 to 0.50
-> very difficult to grow
homogeneous single crystals

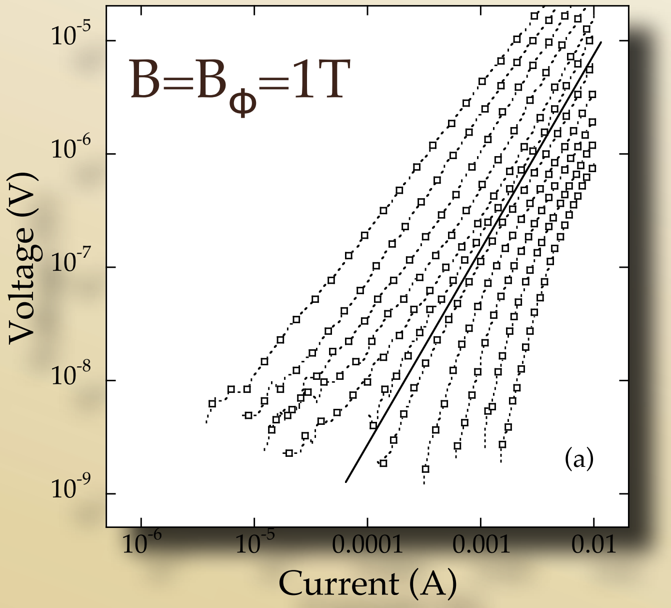
-> "new" (2001) batch with very
sharp transitions

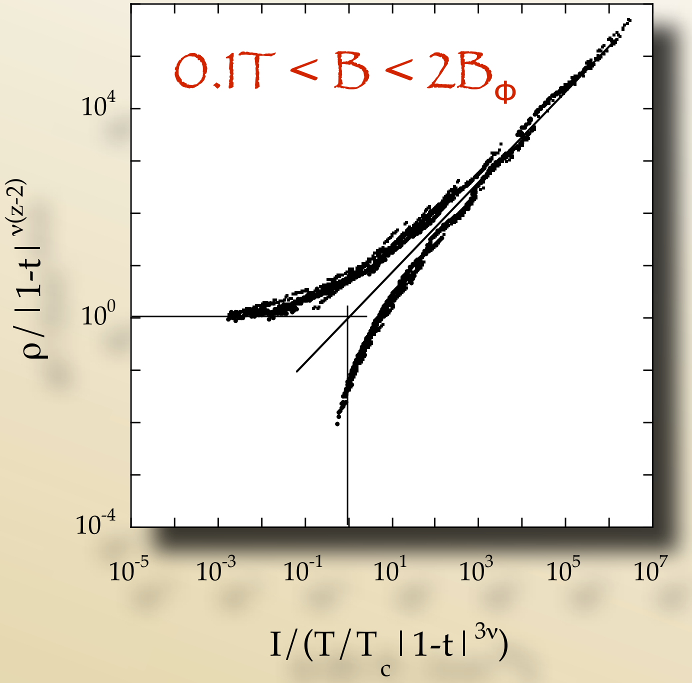


“evidence” for Bose glass melting.....

(transport measurements)

Scaling properties of the I-V characteristics





$$E.\xi_{perp}^{z+1} \approx f(J.\xi_{perp}\xi_{par})$$

$$\xi_{par} \approx \xi_{perp}^{2} \text{ (screened interactions)}$$

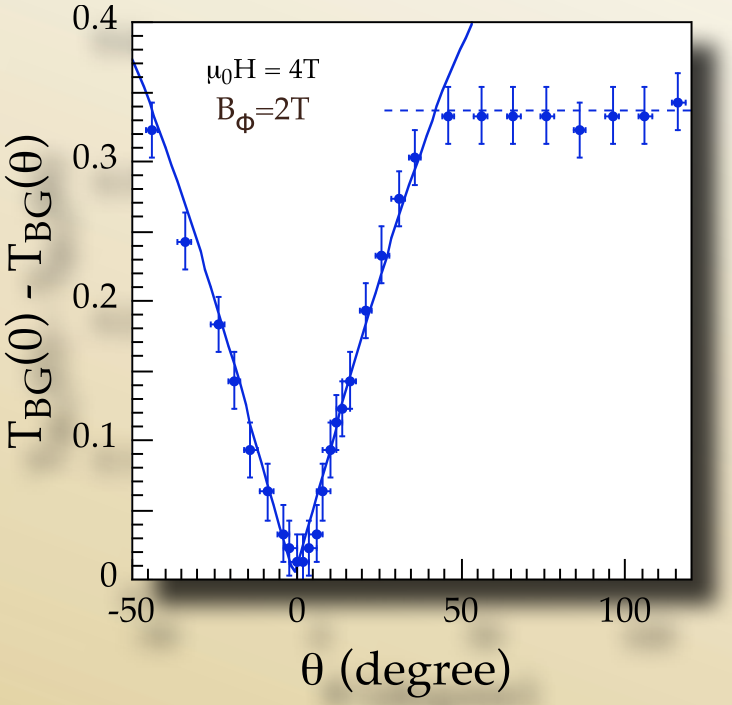
with $\xi_{par} \approx (T-T_{BG})^{-\nu}$

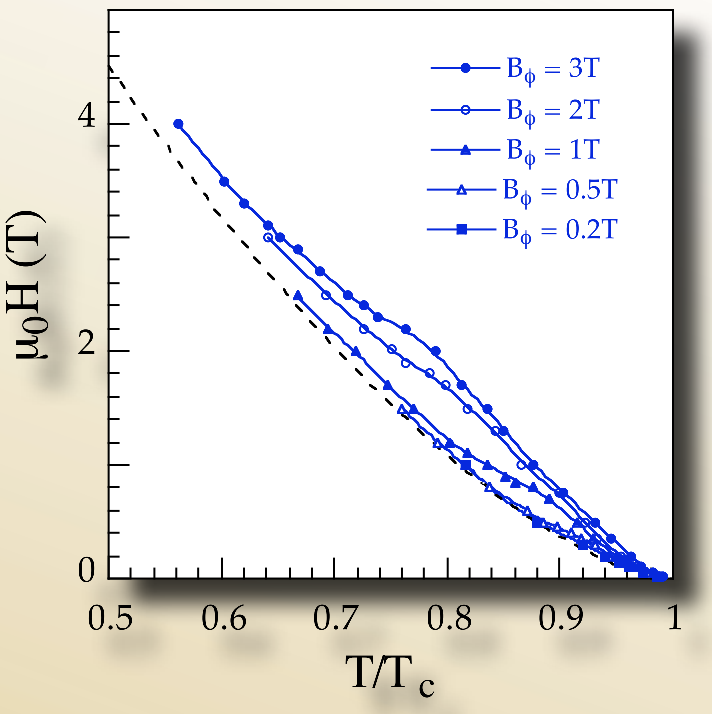
ν~1 and z~4.8

in <u>very good agreement</u>

with numerical simulations

(Lidmar et al. Europhys Lett. 1999)





T_{BG} defined as the temperature for which ρ-> 0

$$T_{BG}(0)-T_{BG}(\theta)\sim\sin(\theta)^{1/\nu}$$

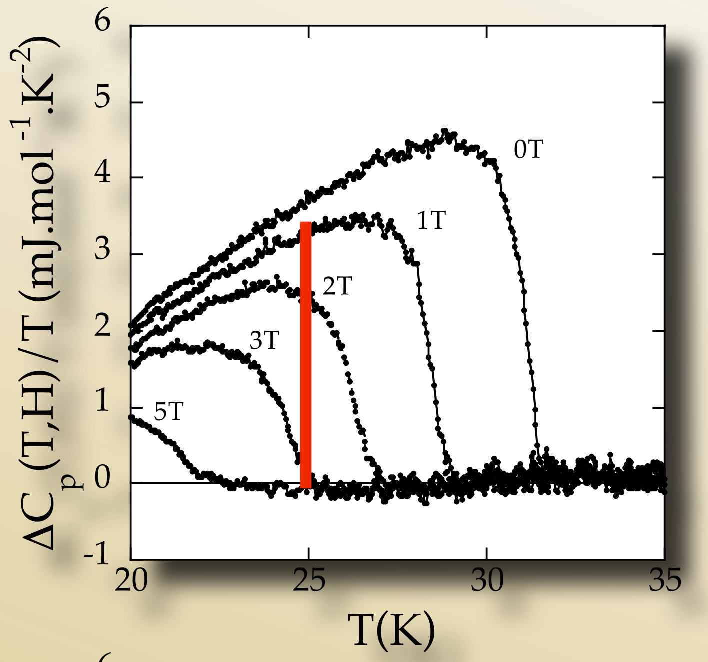
as expected for the BG melting transition

Progressive upward shift of T_{BG}

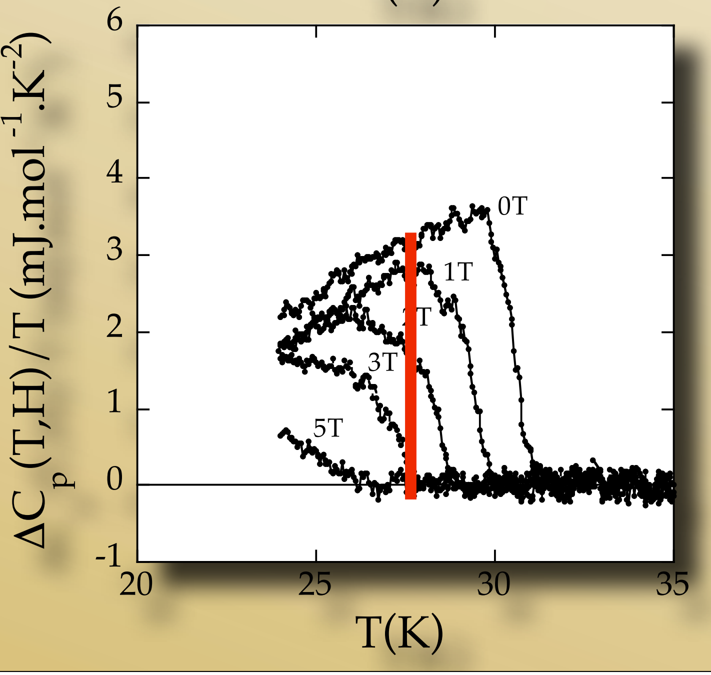
-> HII reduces the wandering of the vortices promoting the solid state

see also Blanchard et al. (poster)
dynamical properties of the BG
(half loop excitations)

Specific heat measurements.....

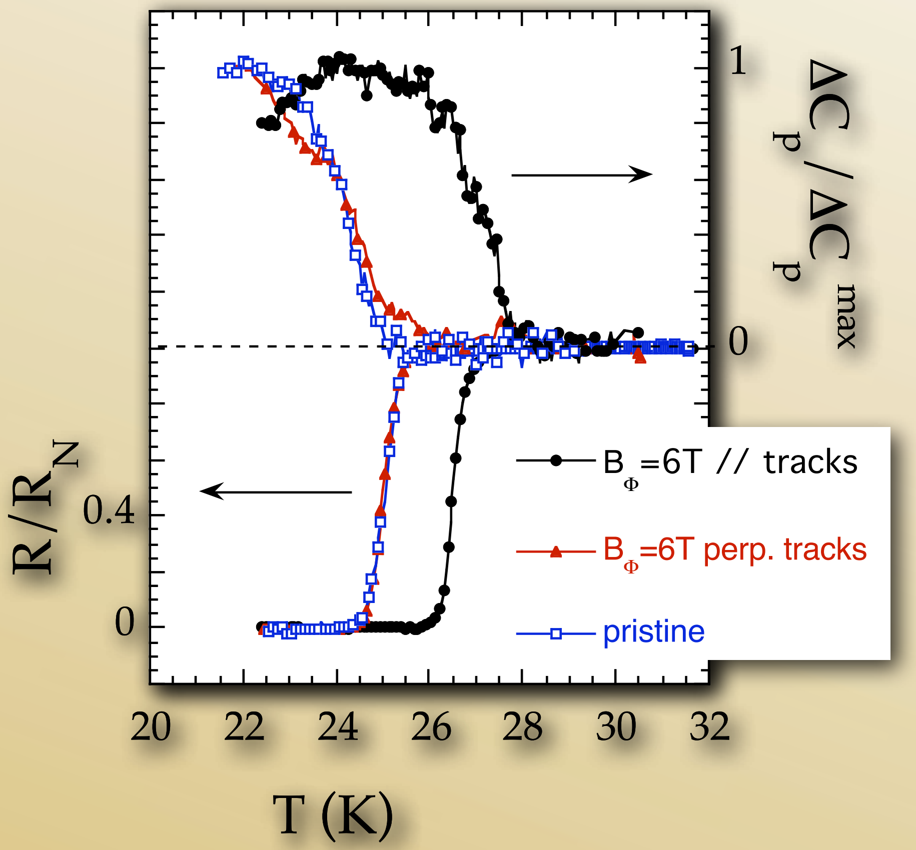


Pristine sample : well defined specific heat jump. In conventional type II superconductors the location of the C_p anomaly = $T_{c2}(H)$



The anomaly remains well defined after heavy ion irradiation (B_Φ=6T)
no change in T_c but.....

the shift is
much less pronounced !!!!



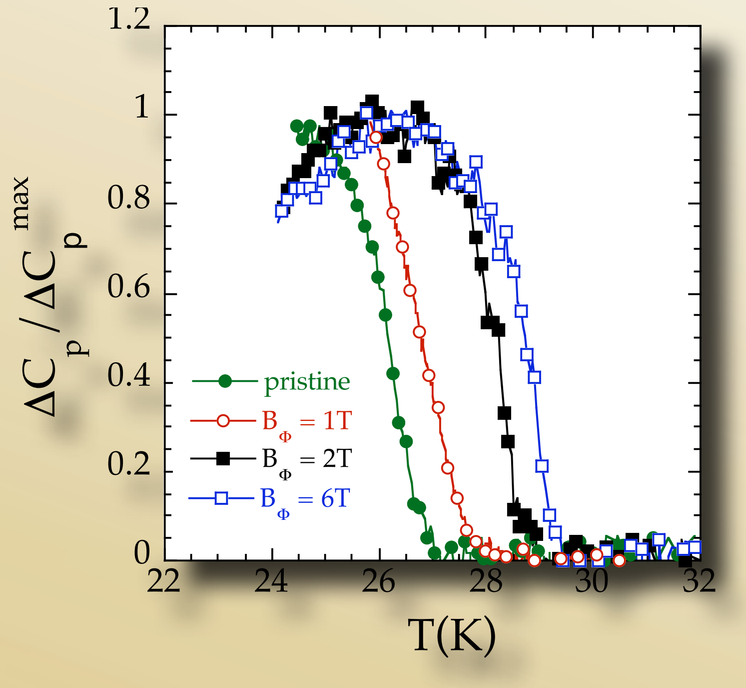
The « melting » transition deduced from transport data is closely related to the superconducting jump observed in specific heat measurements

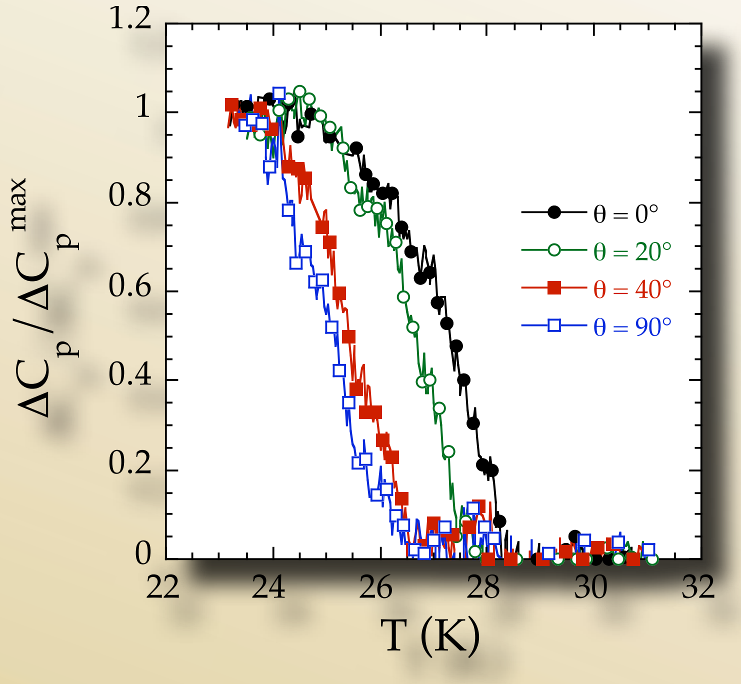
The Cp anomaly :

(i) shifts consistently with the resistive transition in presence of columnar defects

(ii) shifts back to the position of the pristine sample for H perpendicular to the tracks

The C_p measurements show all the characteristic properties
of the Bose-Glass melting transition !!!!





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

The specific heat measurements show that **T_{BG} is NOT a transition between two vortex states** (Bose Glass -> Liquid) but is directly related to the

superconducting transition

-> why is this transition sensitive to heavy ionirradiation ???

- ***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 $d > 300A >> l$

  - no significative increase of the normal state resistivity

- ***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.....

Cooper et al. PRB 1995 : ***Resistive*** transition line in cuprates is given by :

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

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

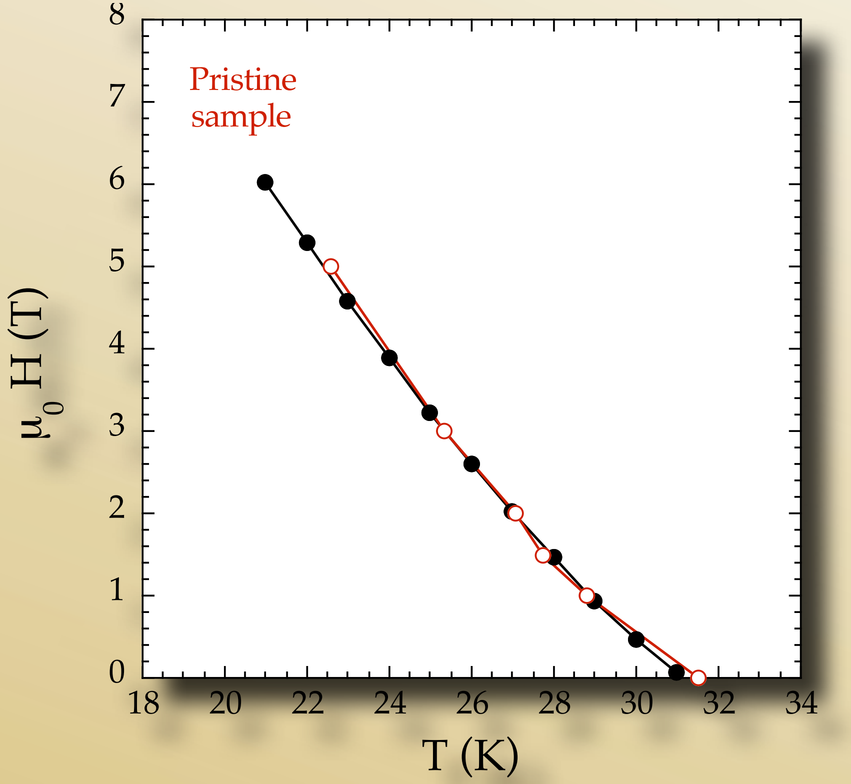
Let's assume that this criterion gives the

THERMODYNAMIC TRANSITION

-> here associated with the specific heat jump

i.e. boundary of the H-T diagram

in which long range superconducting order exists



excellent agreement with
experimental data
with only 1 parameter :

$T_c^{MF} \approx 34\text{-}35K > T_c^* \approx 31.5K$

ξ=30A (H_{c2}), λ=3200A (neutron)

-> positive curvation of the

transition line

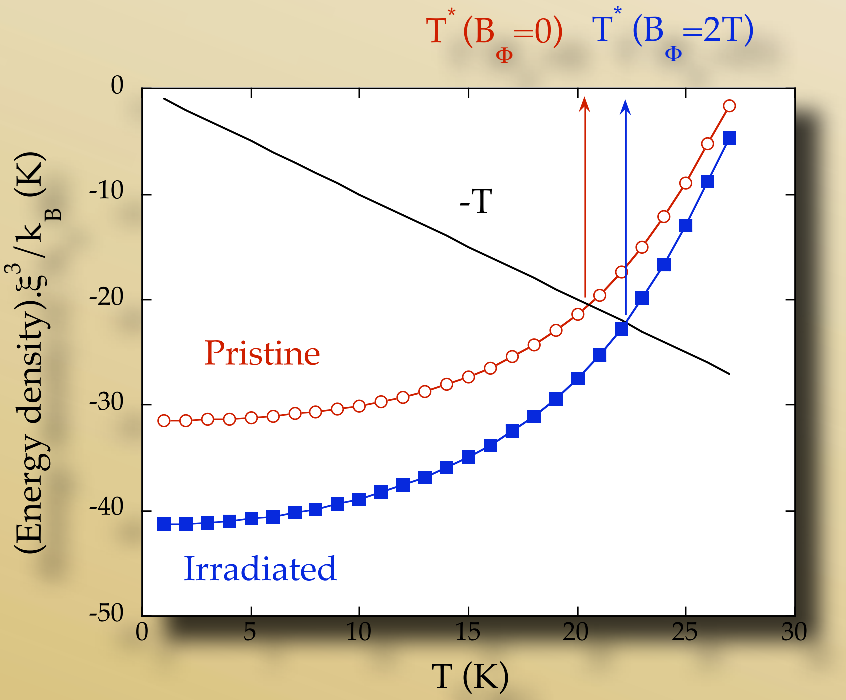
Influence of heavy ion irradiation : decrease of the free energy density

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

Pinning energy (in KBBO ≈ 0.8 ϵ_l)

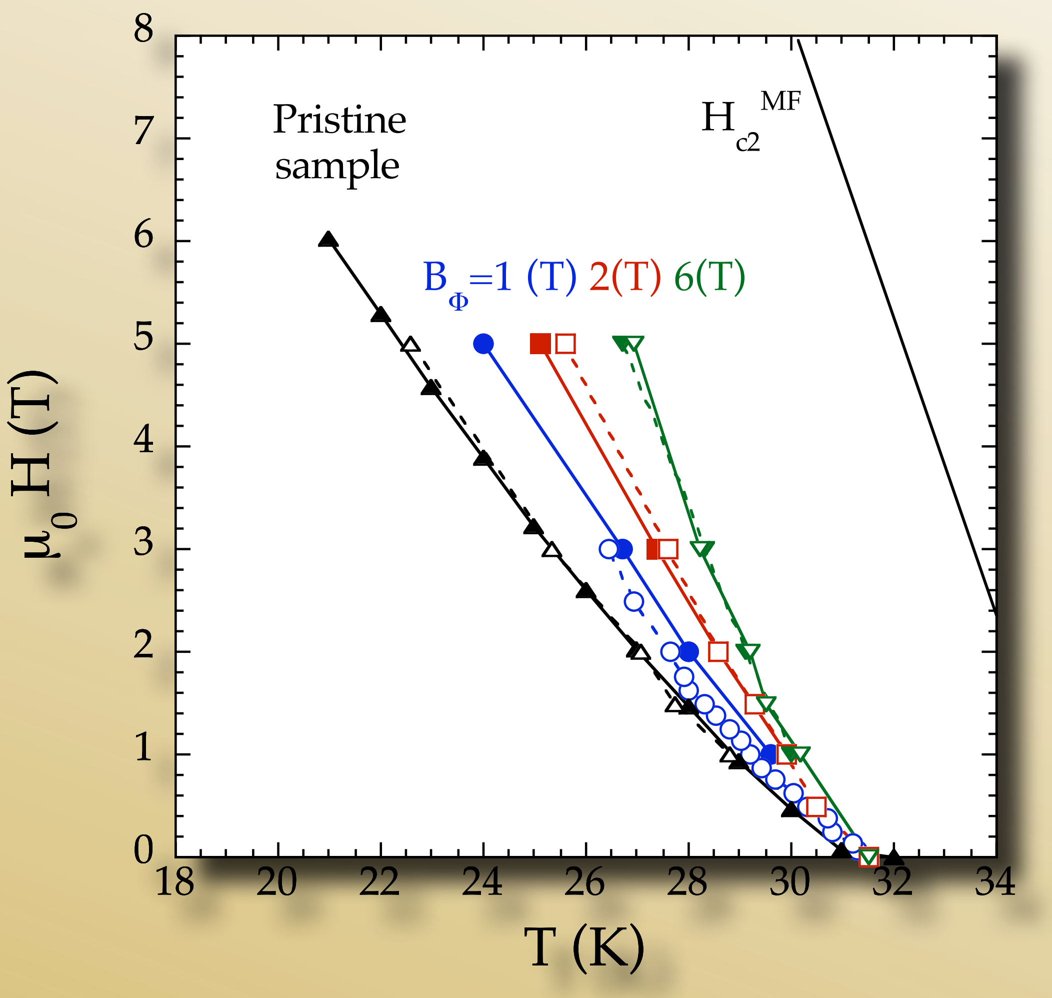
# of pinned vortices

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

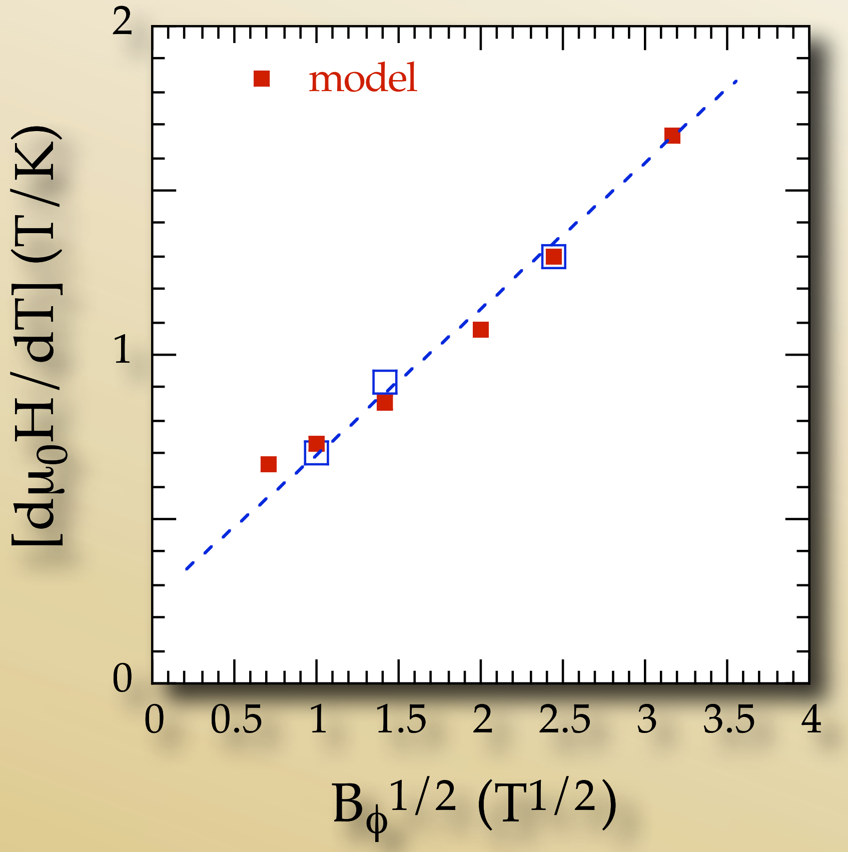


Upward shift of T*

good qualitative agreement with experimental data but also very good QUANTITATIVE agreement......



NO ADJUSTABLE PARAMETER (not a fit)



In the BG glass melting "scenario"

$dH/dT \sim 1 + AB_\phi^{1/2}$

(single vortex - many line approximation)

with $A \sim 1/\xi Gi^{1/2}$

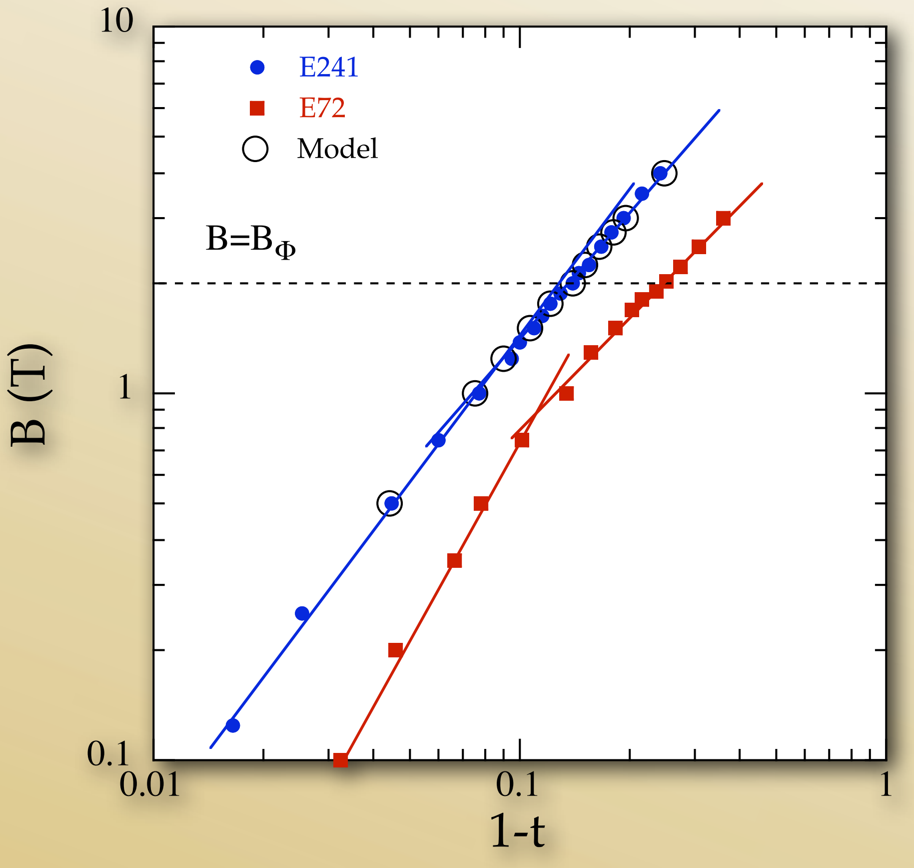
expected to be much larger than the experimental value in KBBO

The predicted behaviour

is very close to a $B_\phi^{1/2}$ law

in good quantitative agreement

with experimental data



break in the slope in the B vs 1-t plot

matching field effect

-> good agreement with the model (O)

(saturation of n_t -> B_{Φ}/Φ_0 for $B >> B_{\Phi}$)

This break was much ***more pronounced*** in

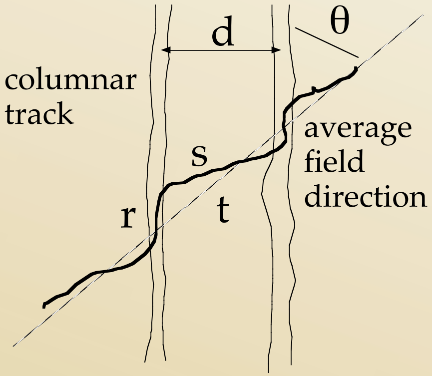
the previous samples (E72)

-> worse sample quality

influence of point defects

not explicitely taken into account ?

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

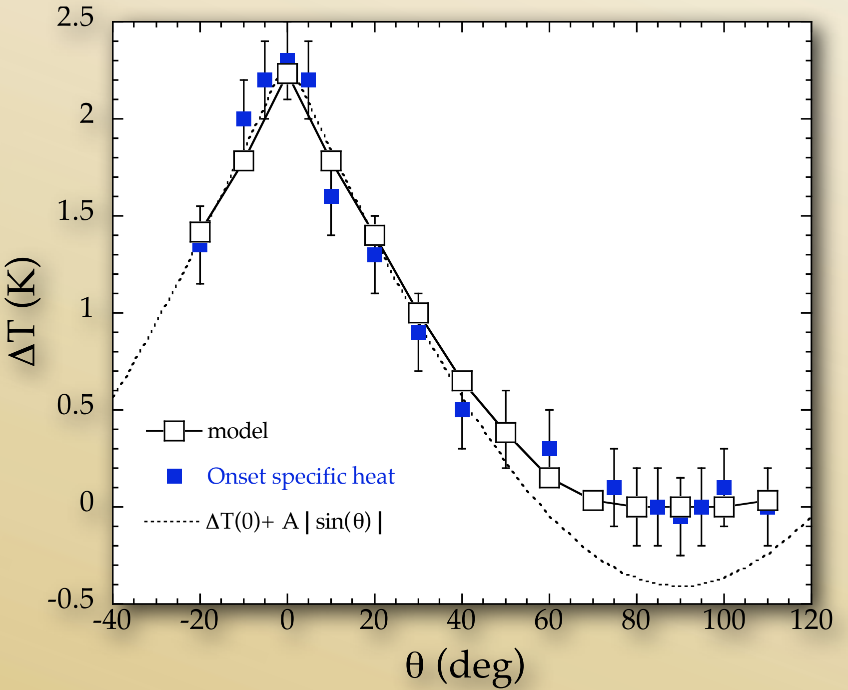
$$U_p(\theta) = U_p\left[1 - \frac{2s/d\sin(\theta) + (\cos(\theta)-1)\epsilon_l/U_p}{\cos(\theta) + \epsilon_l/U_p s/d\sin(\theta)}\right]$$

$\Delta T = 0$ for $\theta_t \sim 2(U_p/\epsilon_l)^{1/2}$

-> $U_p/\epsilon_l \sim 0.8$

(and $s/d \sim 1$)

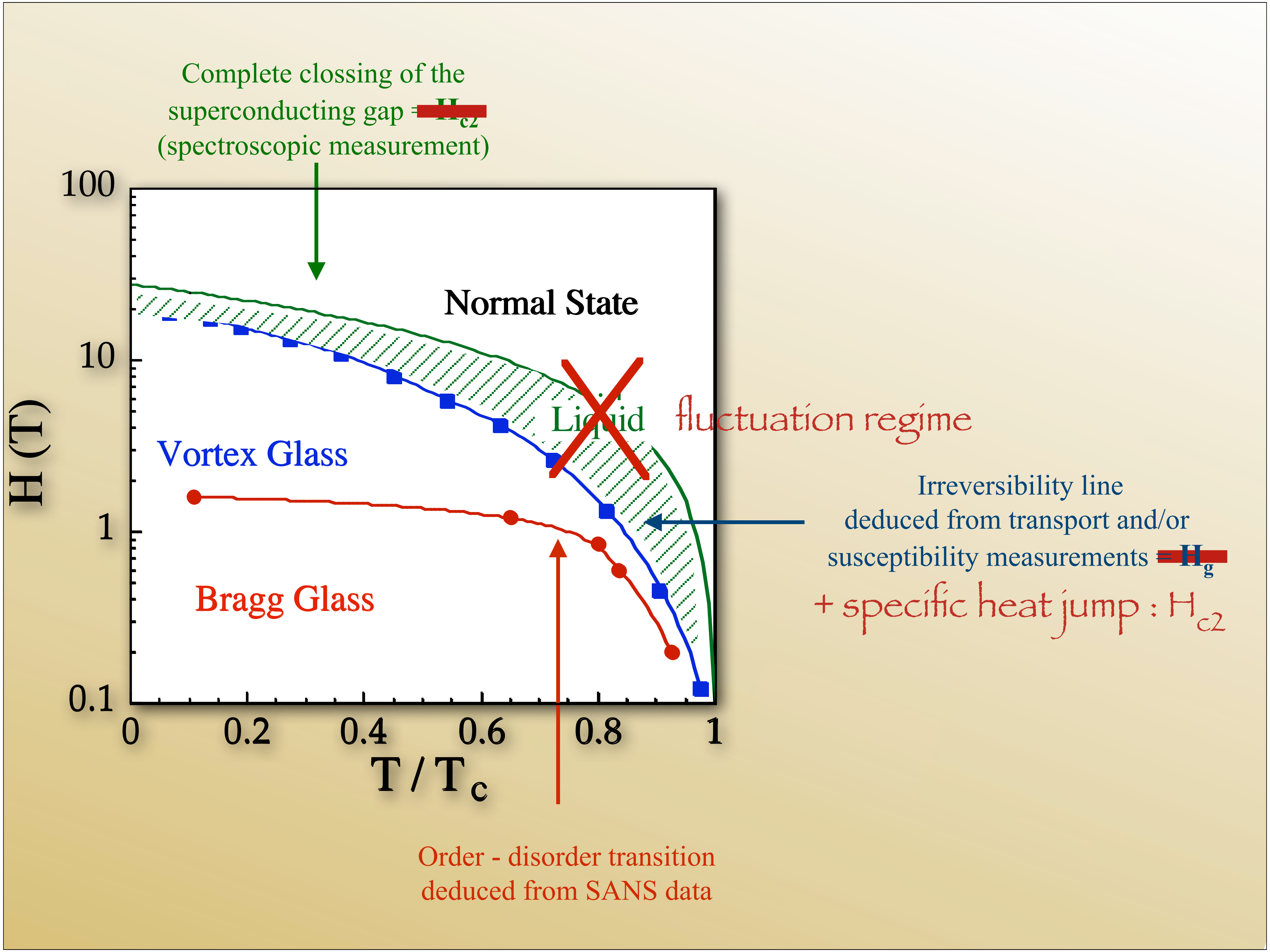
-> recalculating T* using this new Up(θ) value :



The calculated angular dependence is very close to the sin(θ) value previously obtained by transport measurements

Conclusion

- This 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 the transition line
- ***ASSOCIATED WITH THE ONSET OF LONG RANGE SUPERCONDUCTING ORDER***
- related to thermal fluctuations : the order of magnitude of T_{c2}^{MF}-T* can be estimated from the GL expansion of the free energy densities (C.Marcenat/C.Bourbonnais) : $\mathbf{T_{c2}^{MF}}$**-T* ~2.Ci$^{1/2}$ ~1-2K** (Brout criteria)
- WHAT ABOUT THE BOSE GLASS MELTING IN OTHER HIGH T_c OXIDES ????



Complete clossing of the
superconducting gap = Hc2
(spectroscopic measurement)
100
10
1
0.1
H (T)
0
0.2
0.4
0.6
0.8
1
T / Tc
Normal State
Liquid
fluctuation regime
Vortex Glass
Bragg Glass
Irreversibility line
deduced from transport and/or
susceptibility measurements = Hg
+ specific heat jump : Hc2
Order - disorder transition
deduced from SANS data