

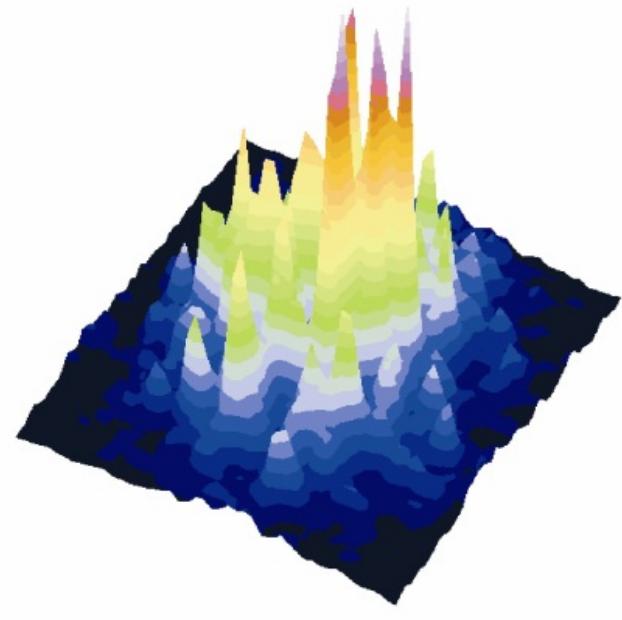
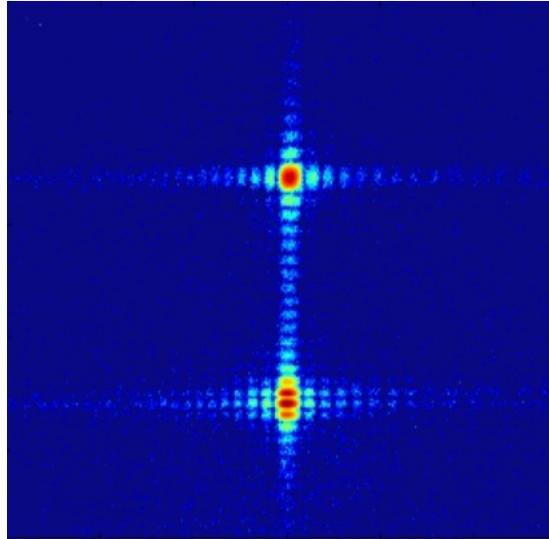
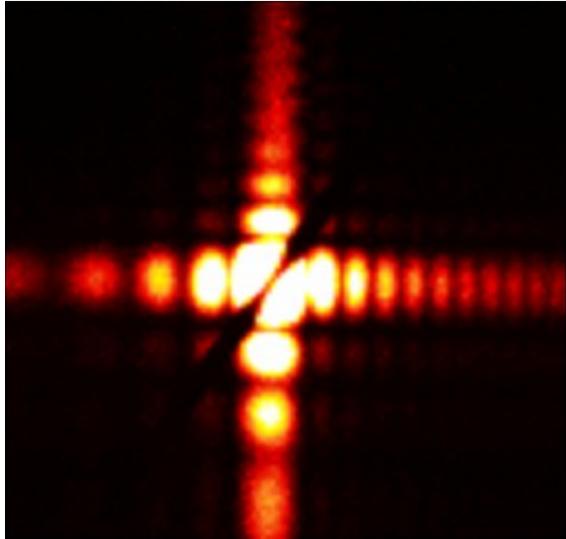
# Le glissement d'une onde de densité de charge observé par diffraction cohérente de rayons X

*E. Pinsolle*

*Vincent Jacques*

*N. Kirova*

*David Le Bolloc'h*



# Comment obtenir un faisceau X cohérent à partir d'une source synchrotron faiblement cohérente ?

Faisceau:

sa taille:  $\sigma$

Cohérence transverse:  $\xi_t$

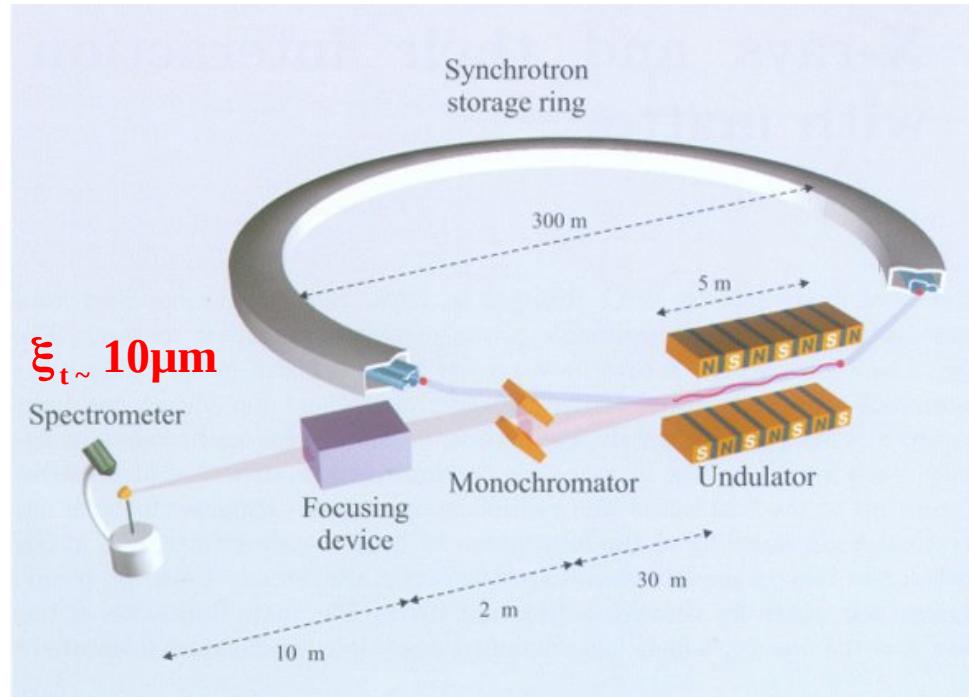
Faisceau cohérent:  $\xi_t \sim \sigma$

Cohérence transverse d'un faisceau  $\xi_t$

- ▪  $\xi_t = d \lambda / 2S$

Lignes de lumière plus longues ( $d \nearrow$ )

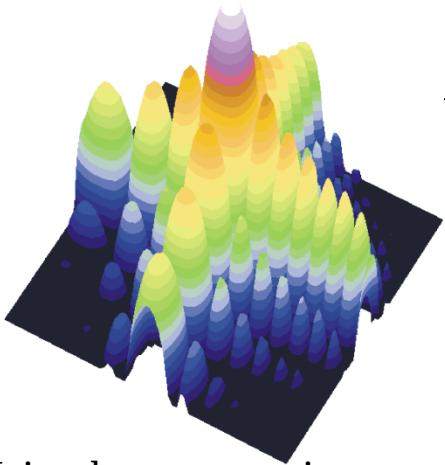
Taille des sources plus petite ( $S \searrow$ )



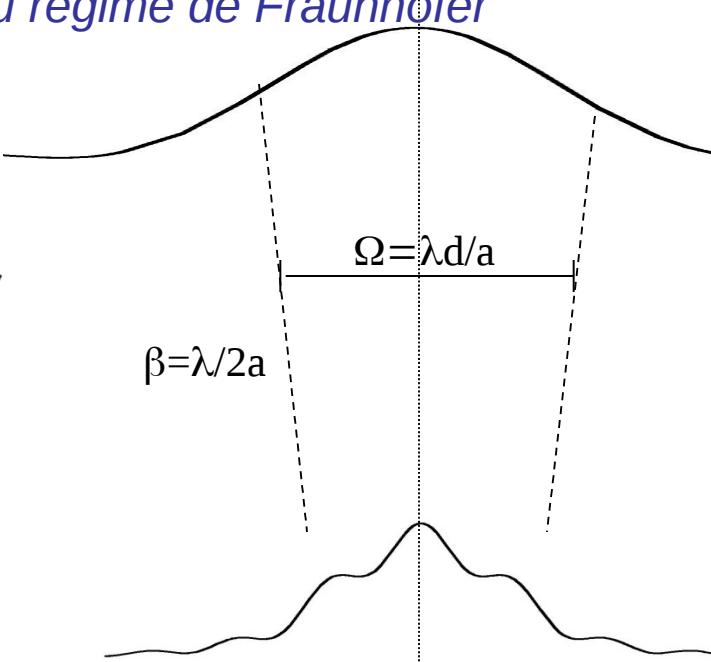
Faisceaux X plus stables

Moins d'abération optique:  
Meilleure définition des éléments optiques (mirrors)  
/meilleure focalisation

# Du régime de Fresnel au régime de Fraunhofer

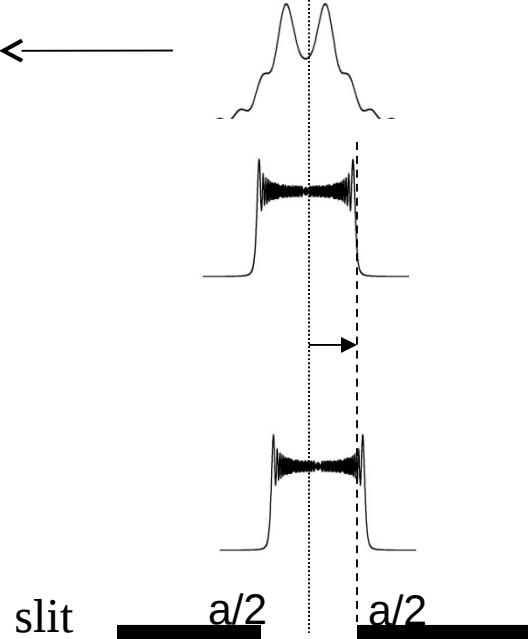


Heisenberg uncertainty :  
 $\Delta x \Delta p > 1$



Dark point position=  $a^2/4\lambda$

$a=20\mu\text{m}$  ;  $E=1\text{keV}$ ;  $d=8\text{ cm}$

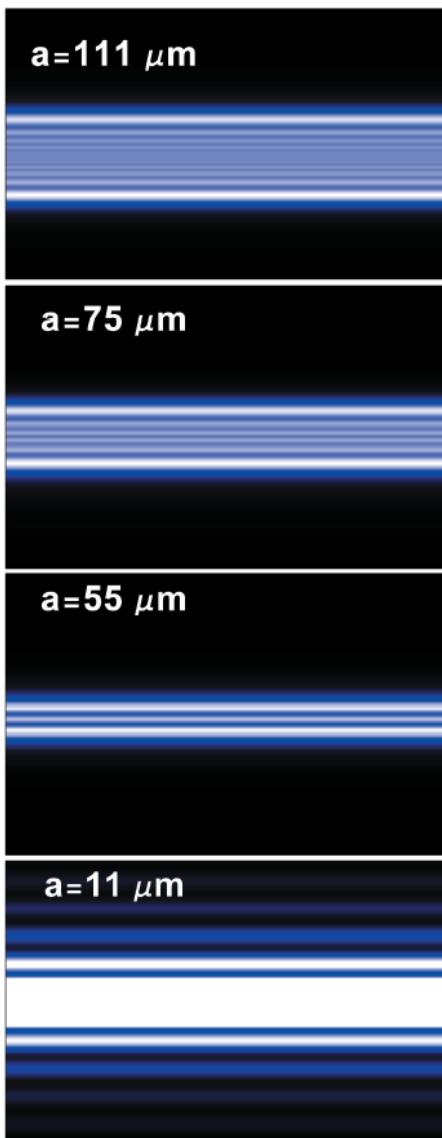


Le régime Fraunhofer (à grande distance)

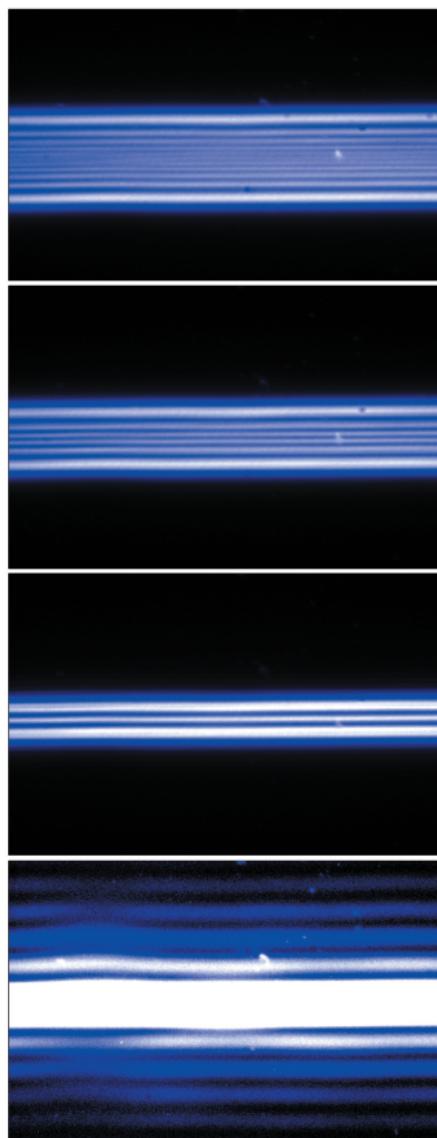
Dark point  
 $a^2/4\lambda$

# Du régime de Fresnel au régime de Fraunhofer

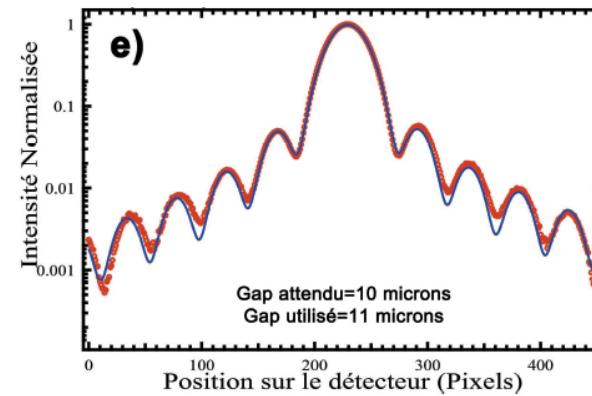
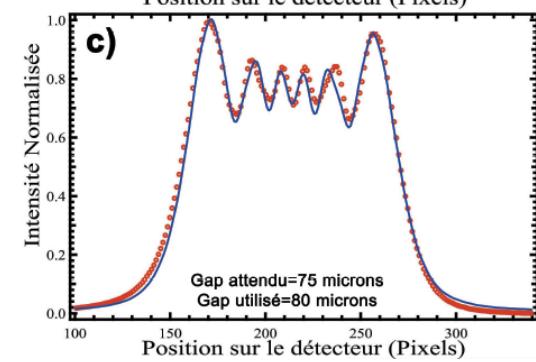
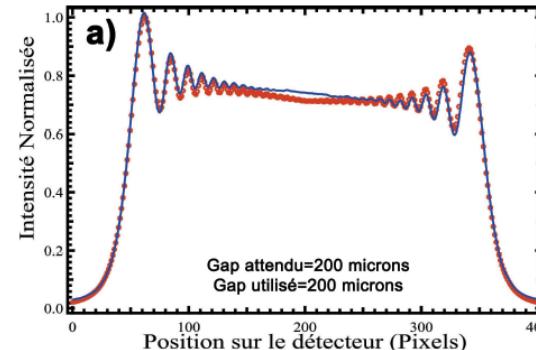
Simulations



Expériences



Using the Gaussian Shell model

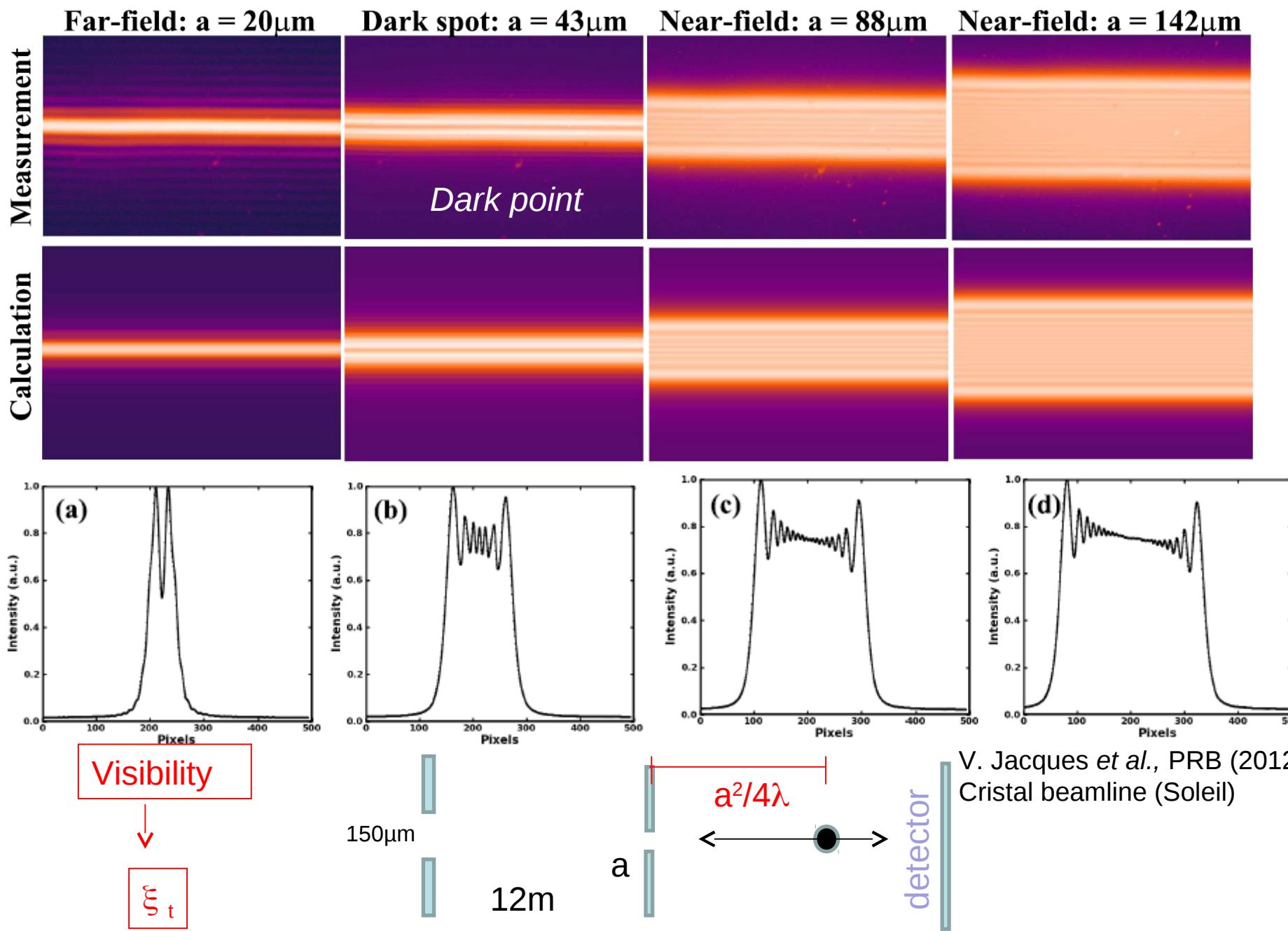


$$V = \beta \frac{\sin(\frac{\pi b}{\eta})}{\frac{\pi b}{\eta}}$$

$\beta > 90\%$

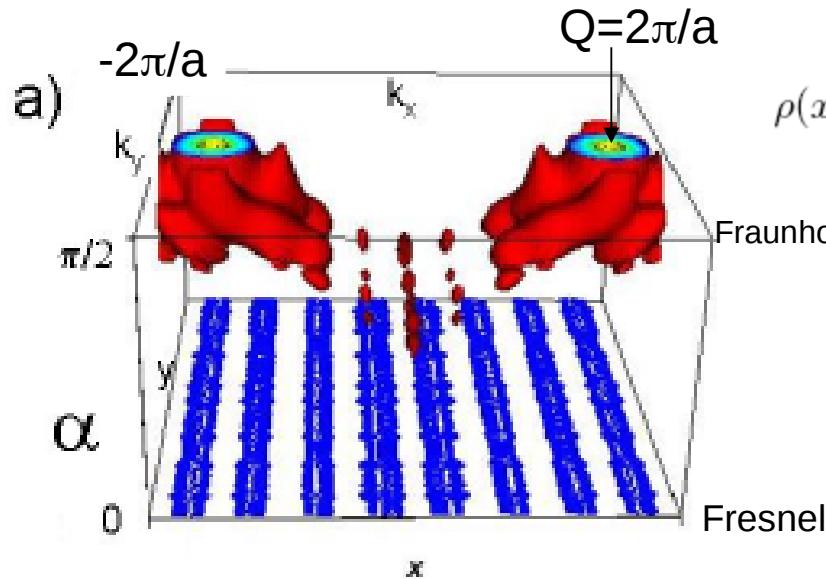
# From the Fresnel to the Fraunhofer regime

$E=7\text{keV}$

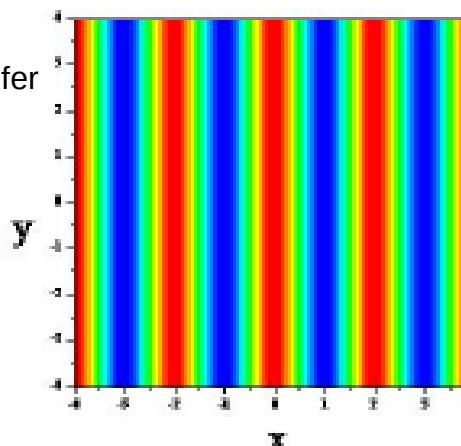


La diffraction cohérente ? A quelle fin ?

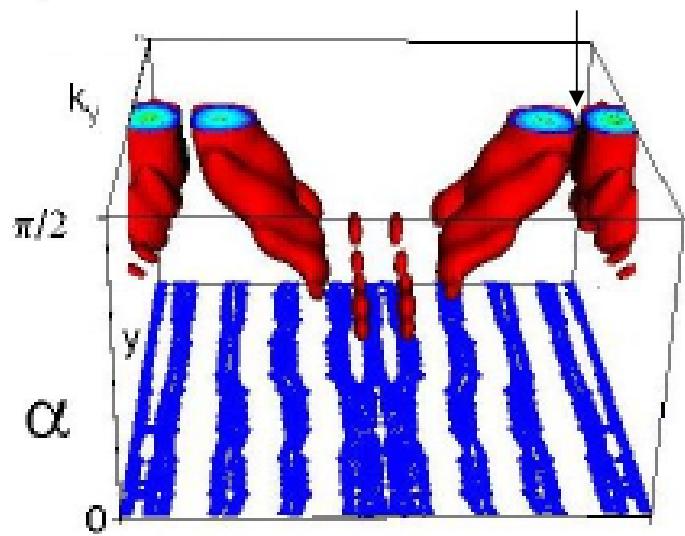
Un faisceau cohérent est très sensible à tous les défauts de phase de la matière



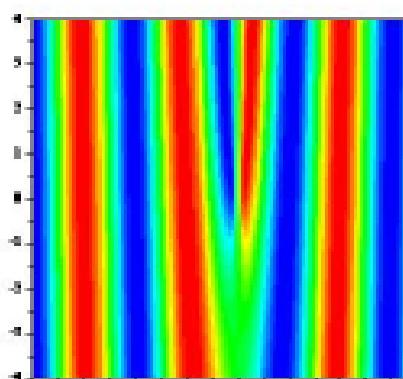
$$\rho(x, y) = \rho_0 \cos(q_0 x) \quad q_0 = \frac{2\pi}{a}$$



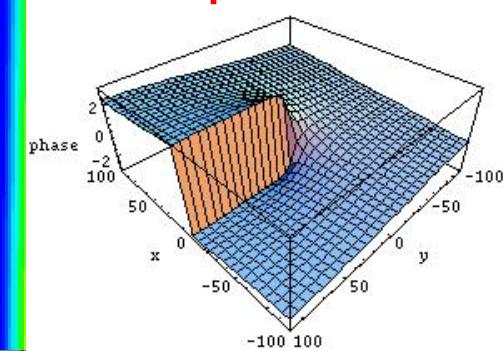
c) Destructive interference at  $Q=2\pi/a$



$$\text{dislocation } \rho(x, y) = \rho_0 \cos[q_0 x + \varphi(x, y)]$$



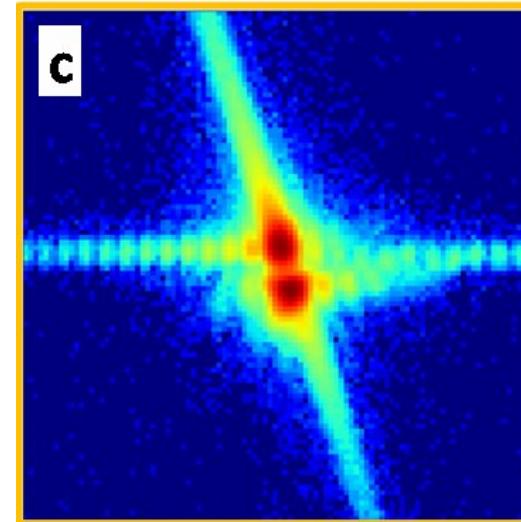
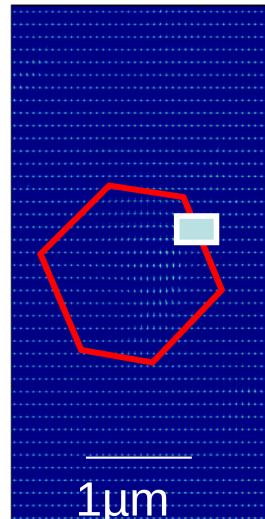
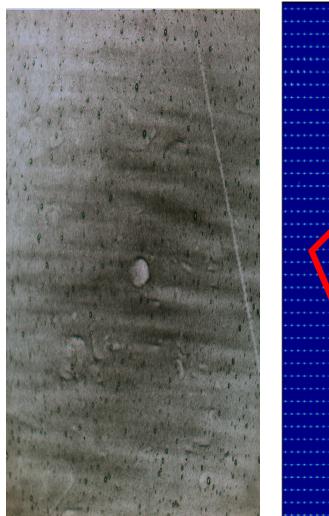
$\varphi(r)$



$$A_1 + A_2 = 0 \text{ at } Q=2\pi/a$$

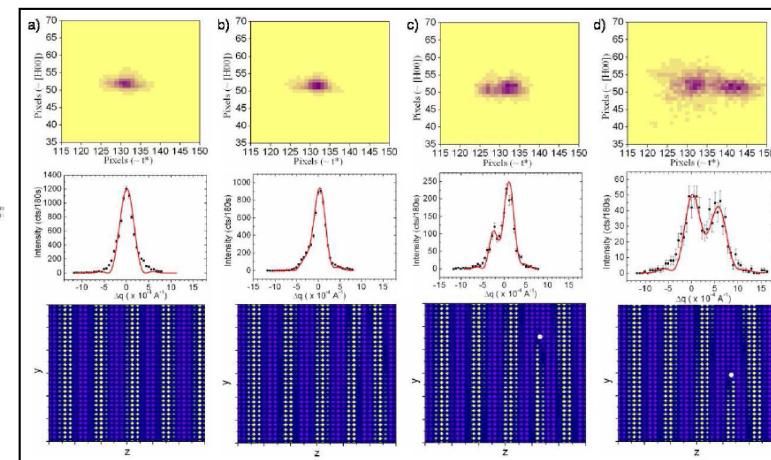
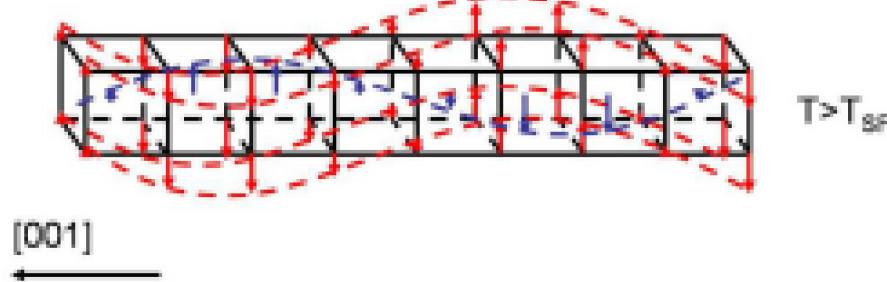
Evidences expérimentales:

## Une dislocation dans le silicium



Jacques et al., Phys. Rev. Lett. **106**, 065502 (2011)

## In chromium (SDW)

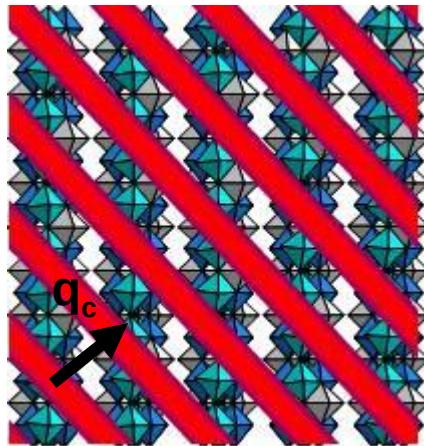


V.L.R. Jacques et al., Eur. Phys. J. B 70, 317-325 (2009).

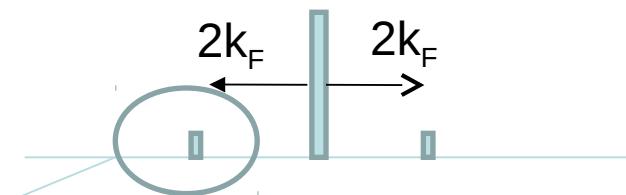
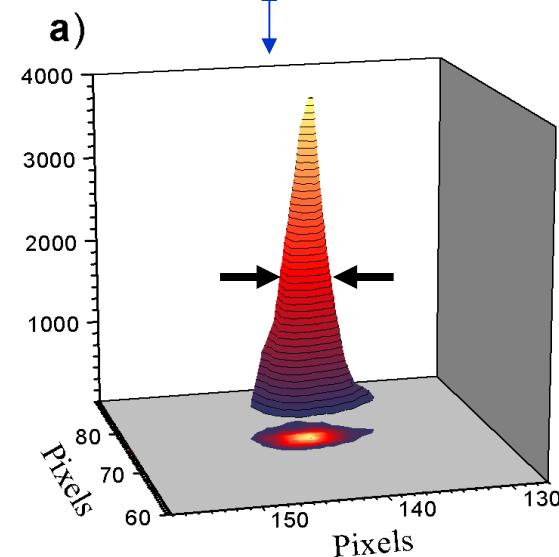
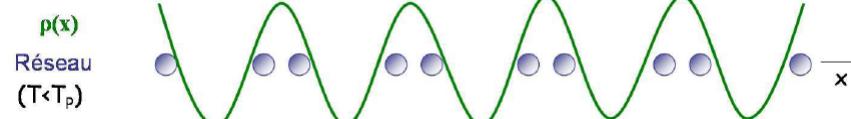
Dislocation in Charge Density Wave also...

Observé aussi dans une onde de densité de charge:

Blue bronze  $K_{0.3}MoO_3$



Transition métal-isolant  
Modulation de la charge ~ distortion périodique des positions atomiques



La phase !

CDW: l'importance de la phase  $\rho = \rho_o + \Delta \cos[q_c r + \varphi(r)]$



Screened charged defects ? By adjusting the phase

Fukuyama-Lee-Rice hamiltonian

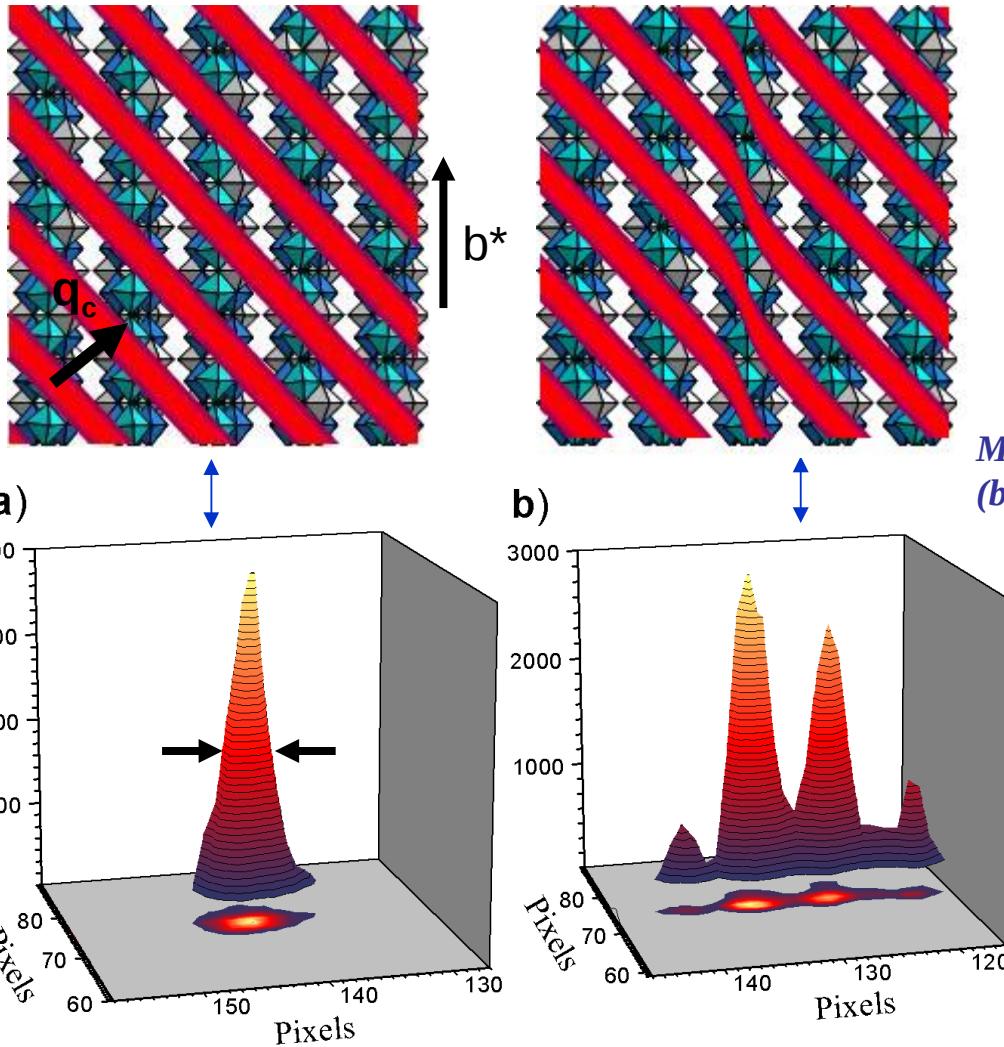
$$H = \int_0^{L_s} dx \left\{ \frac{1}{2} \bar{v}_F \Phi_x^2 - V_0 \sum_i \delta(x - x_i) \cos(\Phi + Qx) - F\Phi \right\}. \quad (1)$$

$$\frac{e}{\pi} E = \frac{\hbar v_F}{2\pi} \left( \frac{\partial^2 \varphi}{\partial x^2} + \alpha \left( \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} \right) \right)$$

La diffraction cohérente est bien adaptée à l'étude des ODC

# Charge density waves: A dislocation of an electronic modulation probed by coherent diffraction

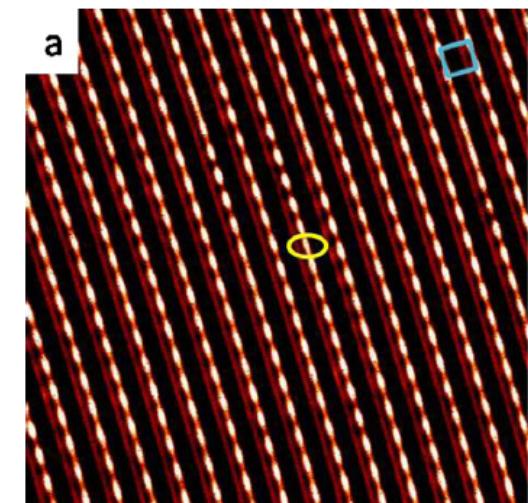
Blue bronze  $K_{0.3}MoO_3$



CDW dislocation !  
Embedded at few  $\mu m$  from the surface

Mixte dislocation  
(between a screw and an edge)

Existence of CDW dislocation  
confirmed by STM:

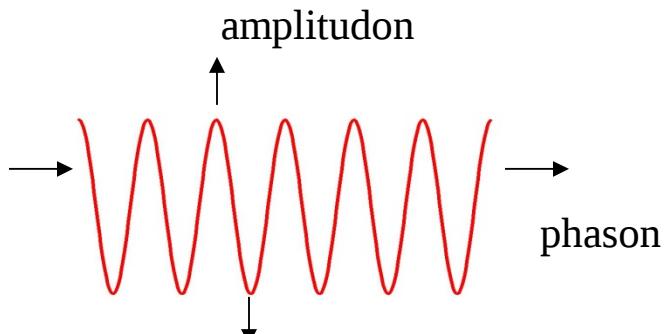


Le Bolloc'h et al. PRL 2005

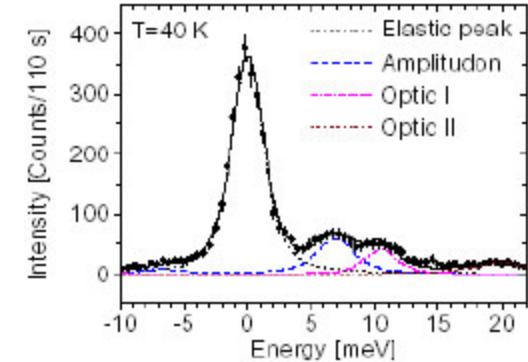
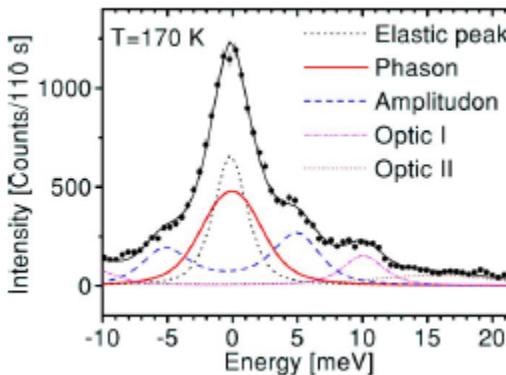
What about dynamics ?

Brazovkii,Brun et al., PRL 108, 096801 (2012)

## La dynamique d'une ODC:



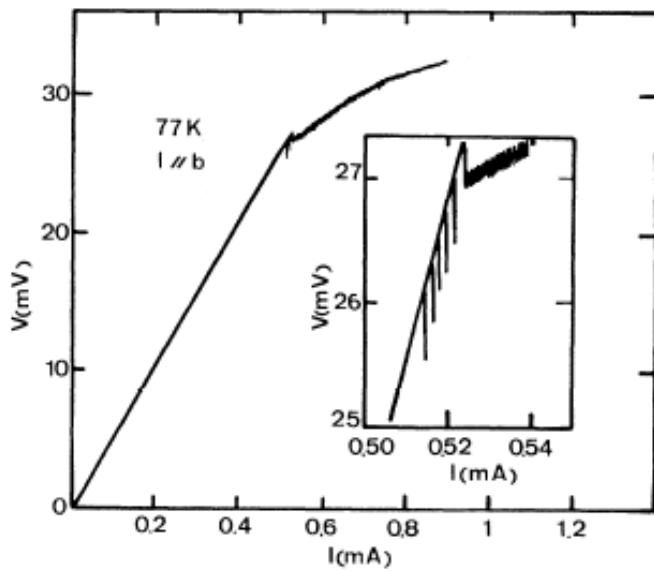
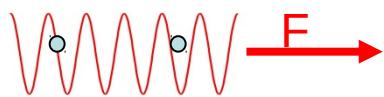
## Une ODC est un objet élastique



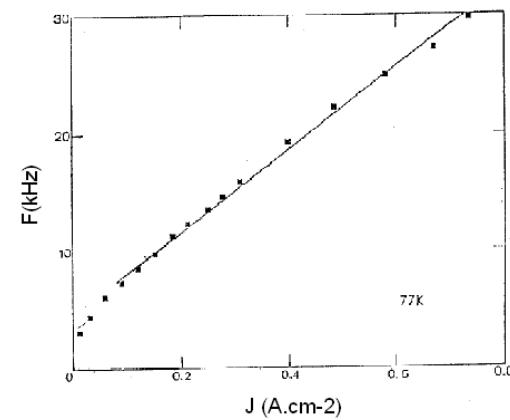
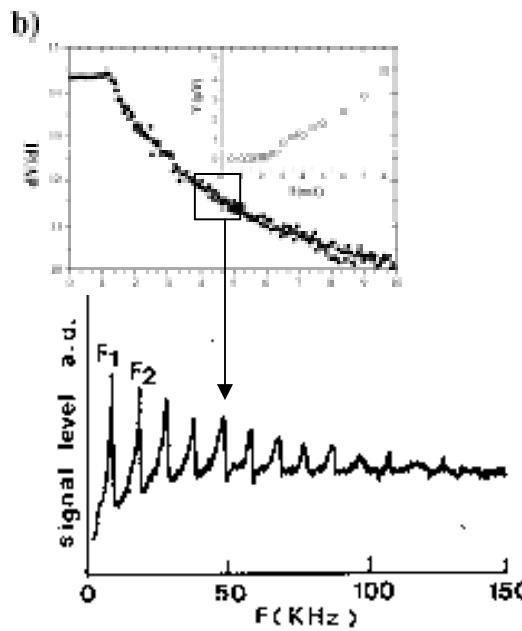
Hennion, Pouget prl(87) Inelastic neutrons  
Ravy et al. PRB (2004) Inelastic X Rays

## Une ODC peut glisser sous l'effet d'un courant électrique:

Incommensurate but pinned by defects



## Pulsed electrons source



$$\nu = 10-100 \text{ kHz}$$

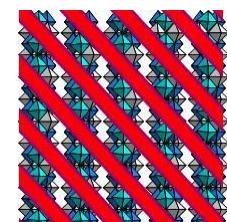
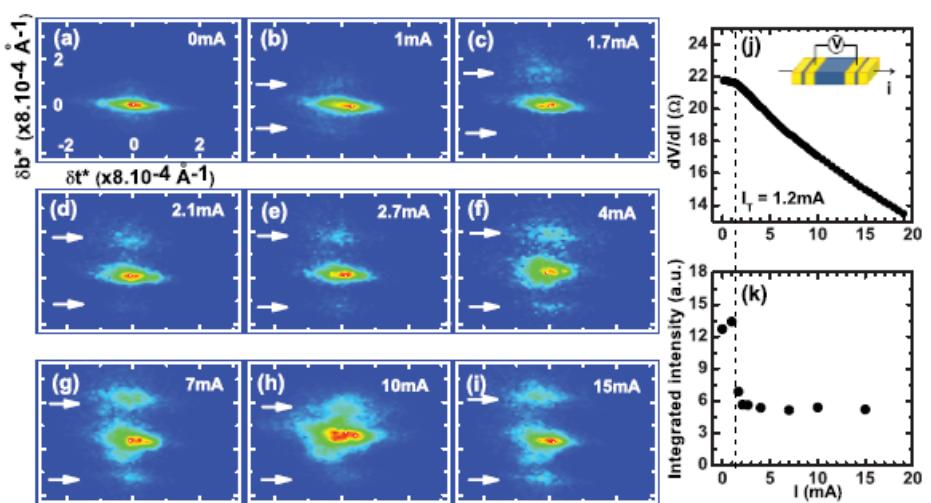


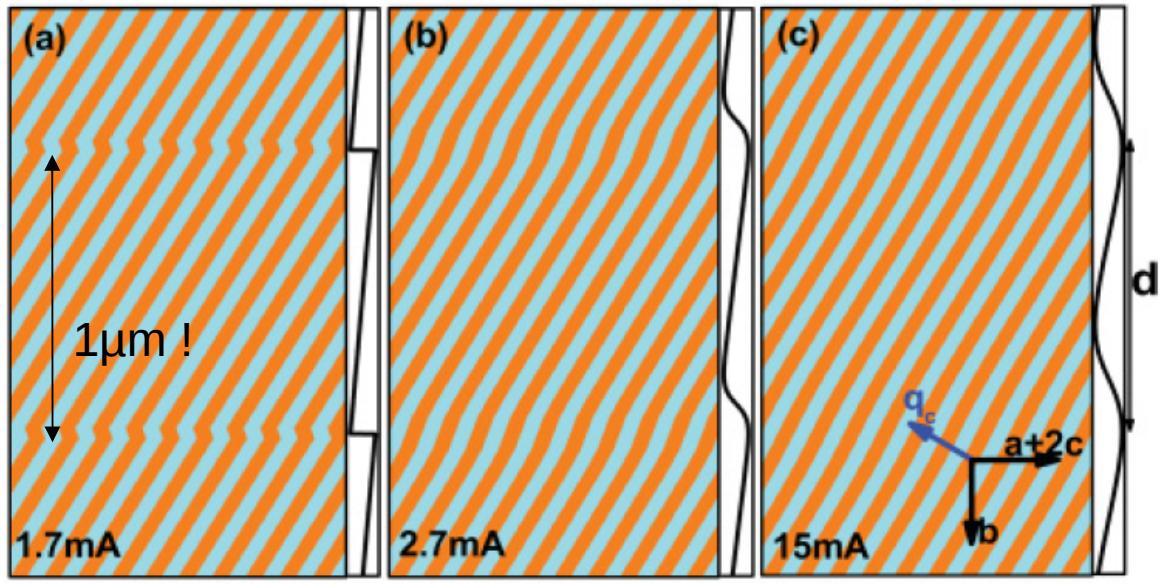
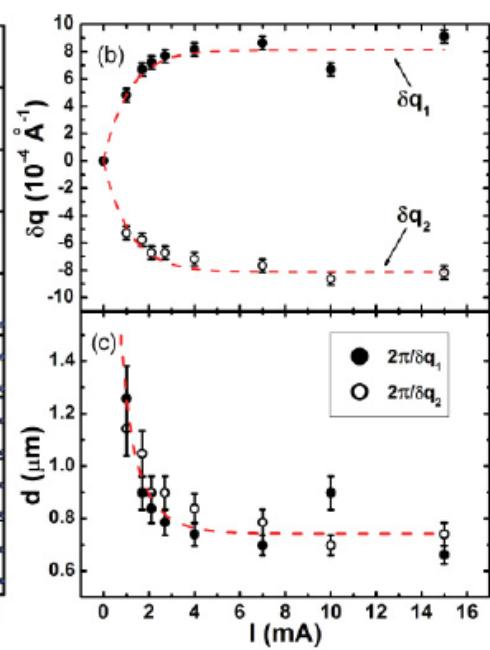
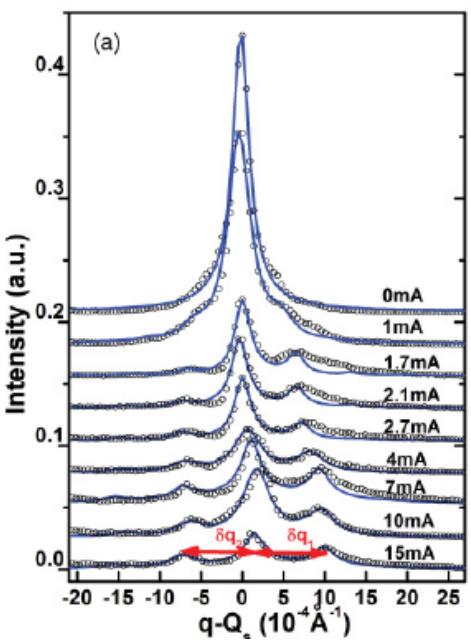
Fig. 25. Fourier transform of the noise voltage at 77 K ( $I = 2I_0$ ). (From [75])

# a large-periodicity soliton lattice in a current-driven electronic crystal

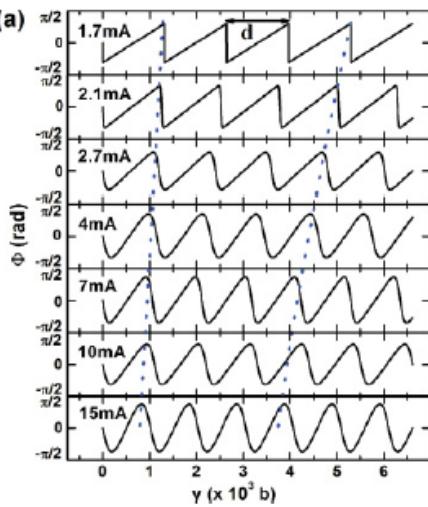
V. Jacques et al., PHYSICAL REVIEW B 85, 035113 (2012)



$$\rho = \rho_o + \Delta \cos[q_c r + \varphi(r)]$$



$$\Phi(y) = \frac{\pi\alpha}{d}y - \sum_n 2\alpha t g^{-1}[e^{(y-nd)/l_0}]$$



# Le glissement d'une ODC: comportement d'un object élastique soumis à une force en présence de défauts ponctuels répartis aléatoirement

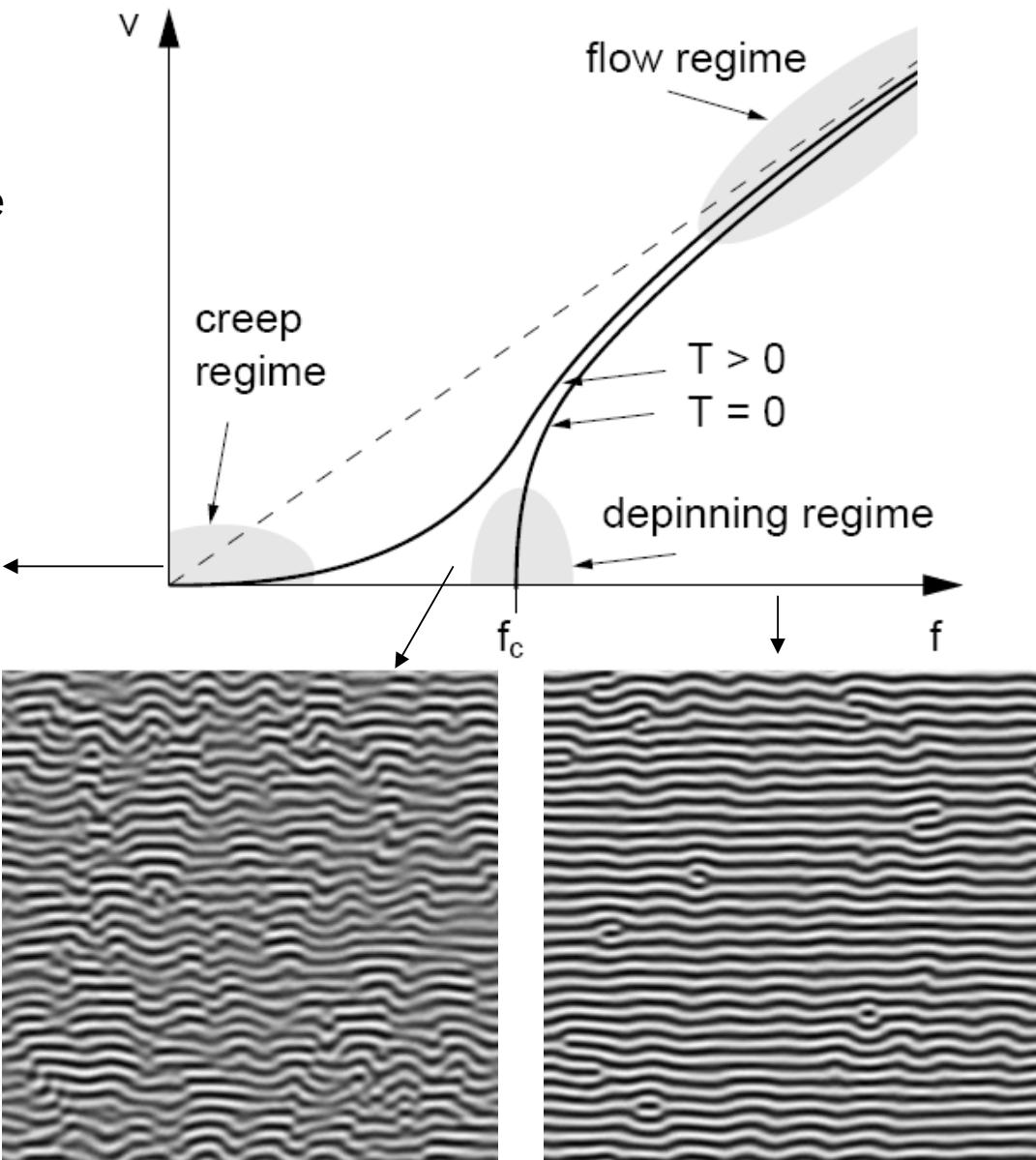
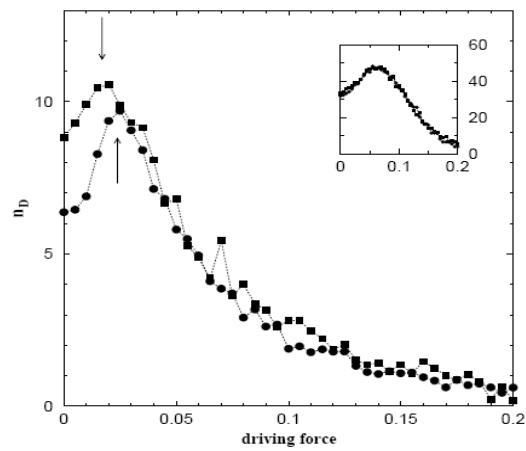
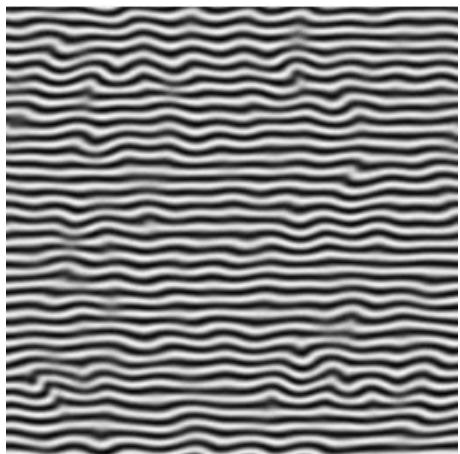
Dislocation motion (mechanical force  $F$ )

Domain wall motion (magnetism  $B$ )

Sliding vortices (supercondonctors  $E$ )

Sliding charge density wave ( $E$ )

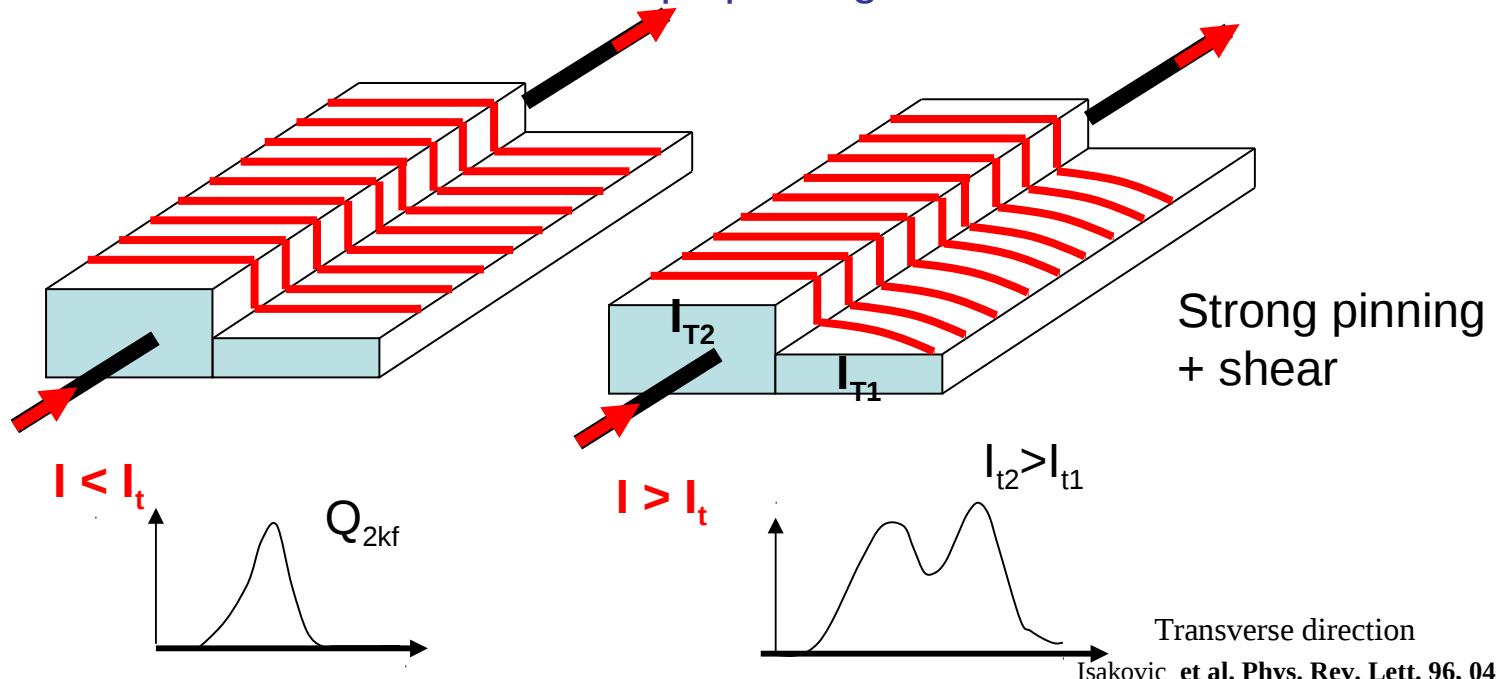
→ Physical properties driven by the phase



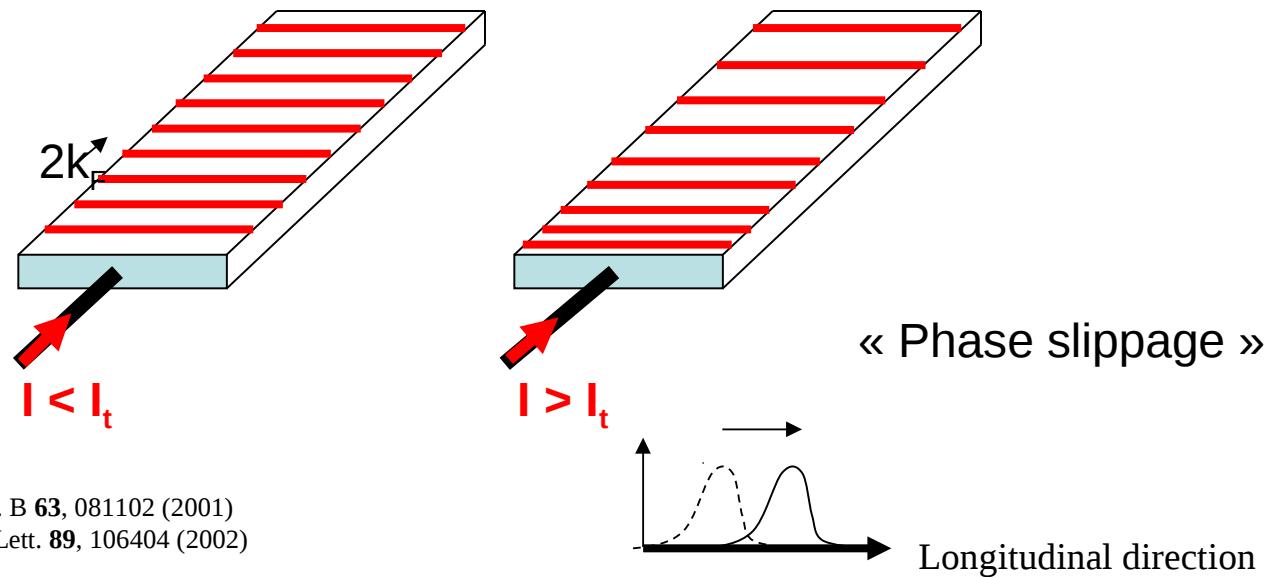
The motional ordering

Karttunnen et al. PRL 99

## 1. Extrinsic defects: the role of surface steps pinning



## 2. Electrons conversion: conduction electrons $\rightarrow$ condensed electrons

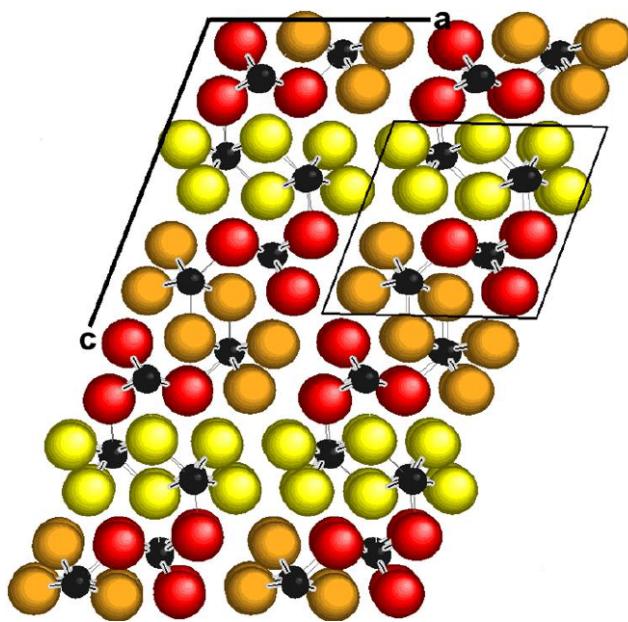


# L'expérience à Troika (ESRF)

$$q_{cdw} = (0, 2k_F, 0)$$

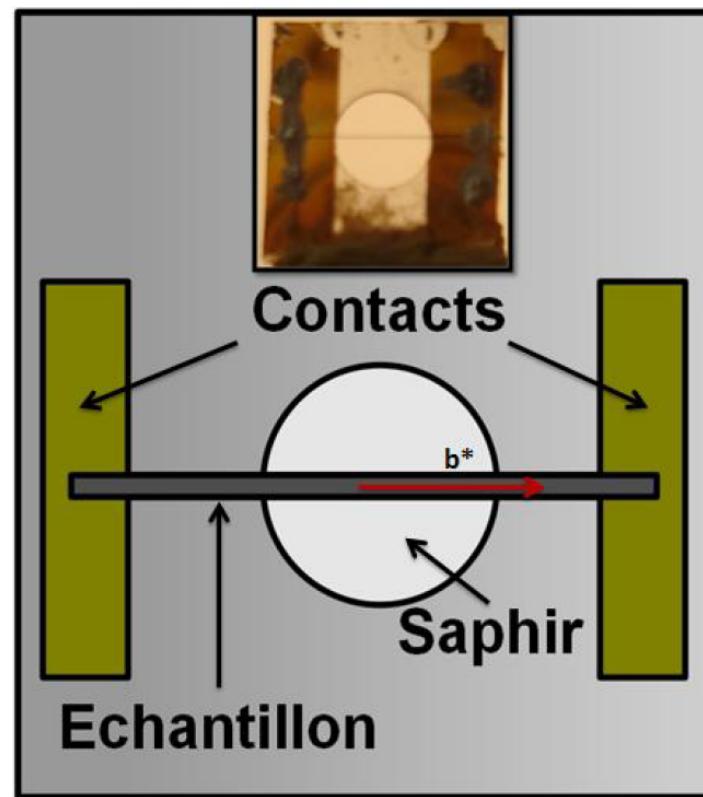
$$2k_F = 0.24b^*$$

NbSe<sub>3</sub>



T=120K

Coherent Beam  
size =  $10 \times 10 \mu\text{m}$

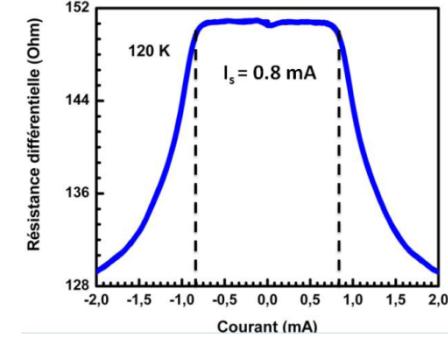


5mm\*2μm\*40μm

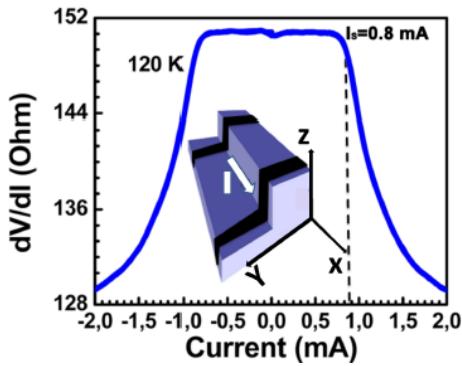
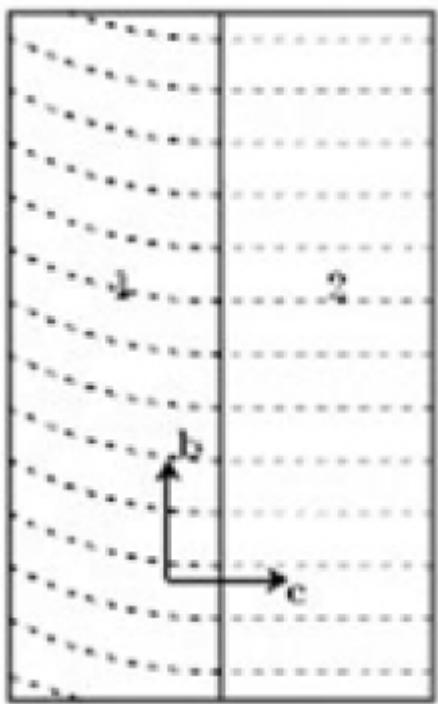
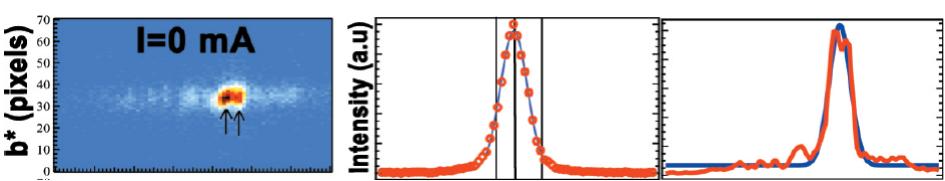
$\Delta t = 10\text{s}$

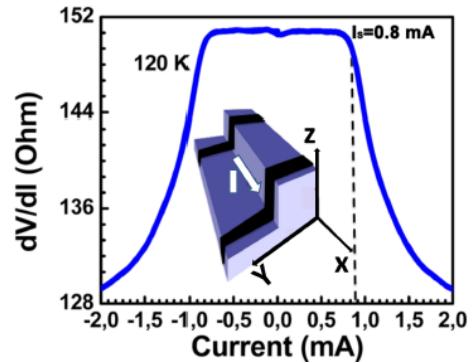
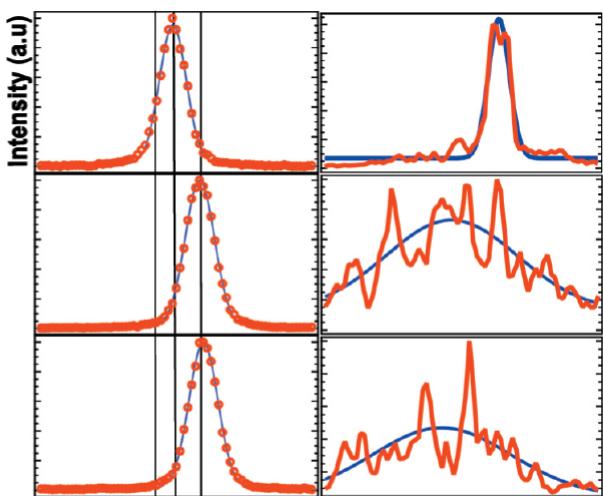
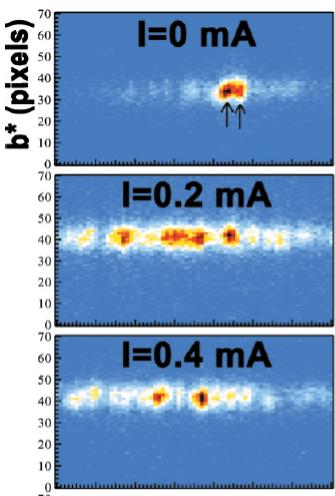
*In situ* resistivity  
measurements

$I_s = 0.8\text{ mA}$

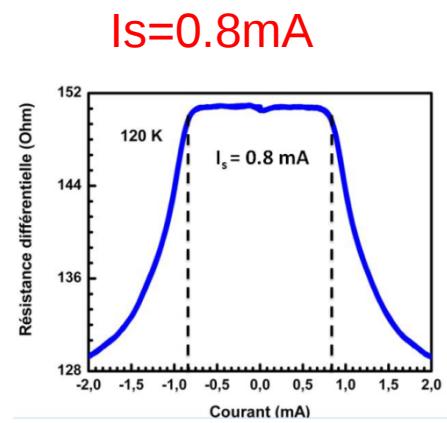
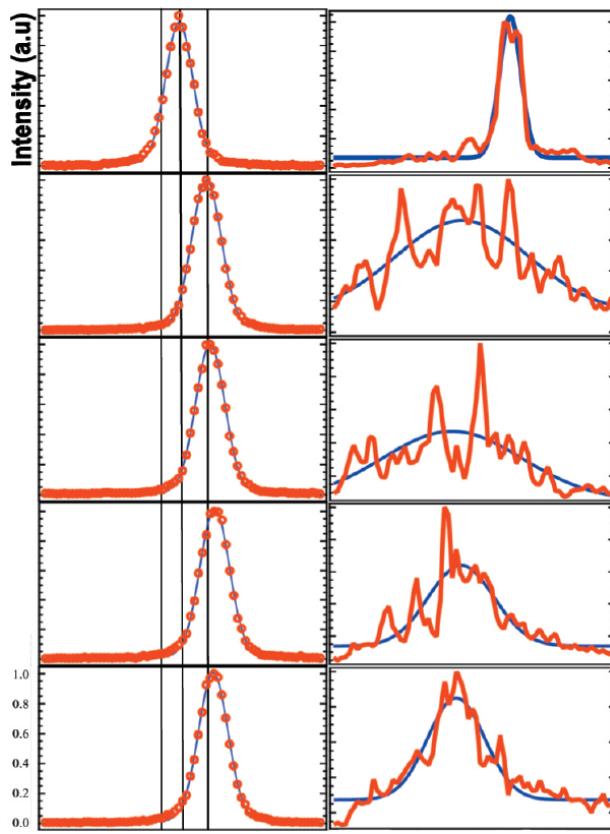
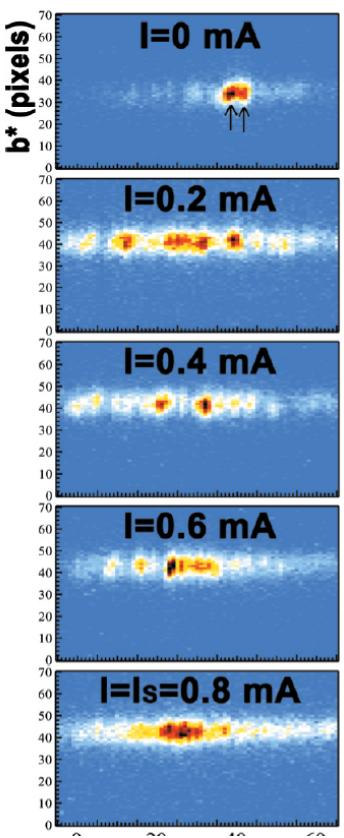


Controlled the sample T

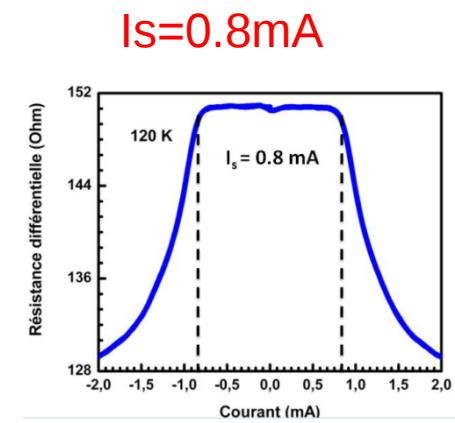
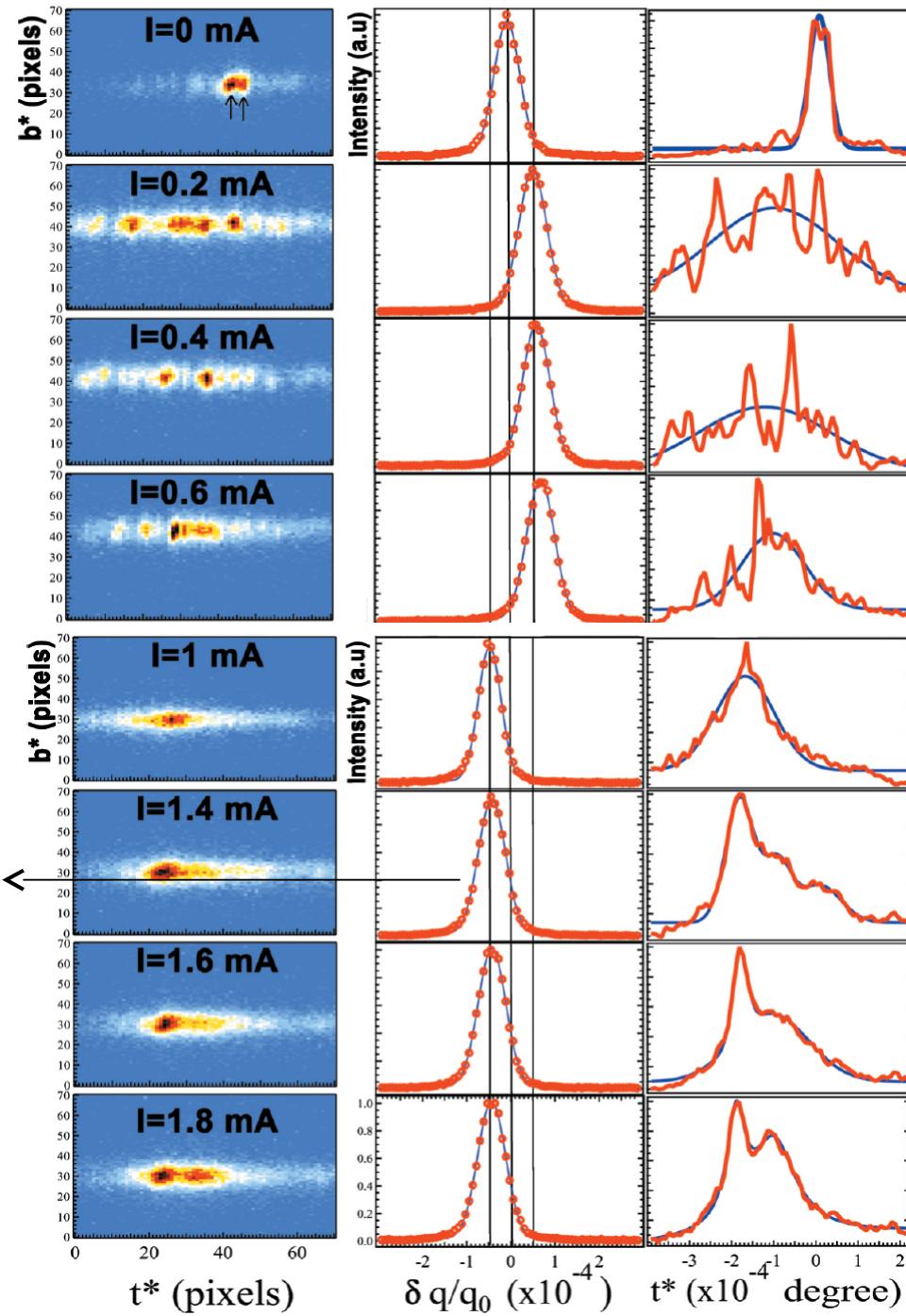




Speckles in the soft direction;  
CDW dislocation/Creep



Contraction of  
the CDW:  
Phase slippage



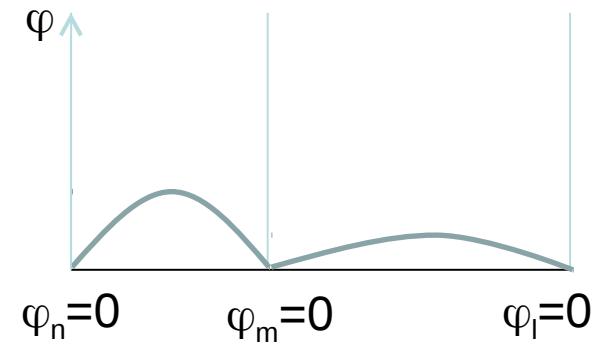
→ 2 Smooth curves:  
Time average  
( $v \sim 0.1 \mu\text{m/s}$ )

# Interpretation

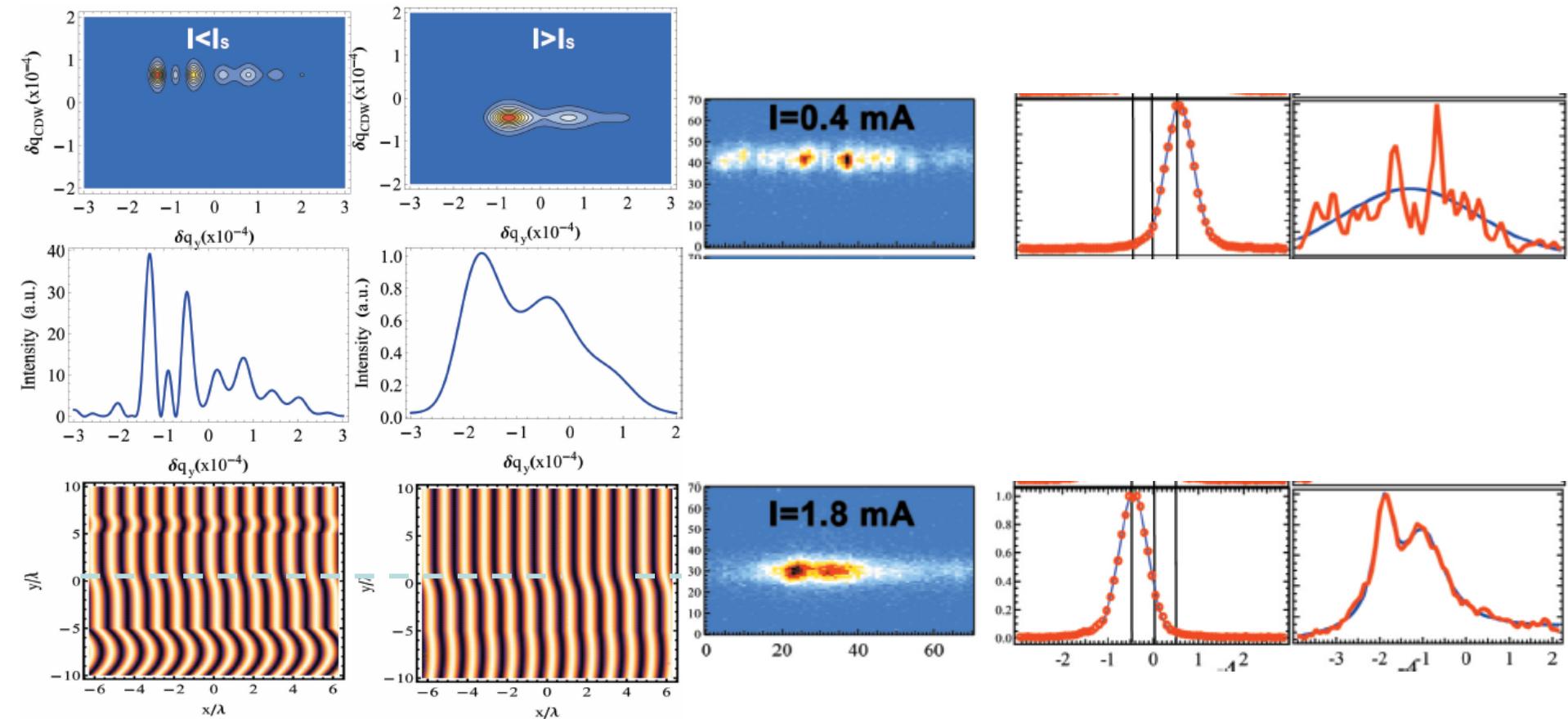
Elastic model:

$$\frac{e}{\pi} E = \frac{\hbar v_F}{2\pi} \left( \frac{\partial^2 \varphi}{\partial x^2} + \alpha \left( \frac{\partial^2 \varphi}{\partial y^2} + \frac{\partial^2 \varphi}{\partial z^2} \right) \right)$$

$$\frac{e}{\pi} E = \frac{\hbar v_F \alpha}{2\pi} \frac{\partial^2 \varphi}{\partial y^2}$$



$$\varphi(y) = \frac{eE}{\alpha \hbar v_F} (y - d_n)(y - d_m) \quad \text{for } y \in [d_n, d_m]$$



*Acknowledgments*

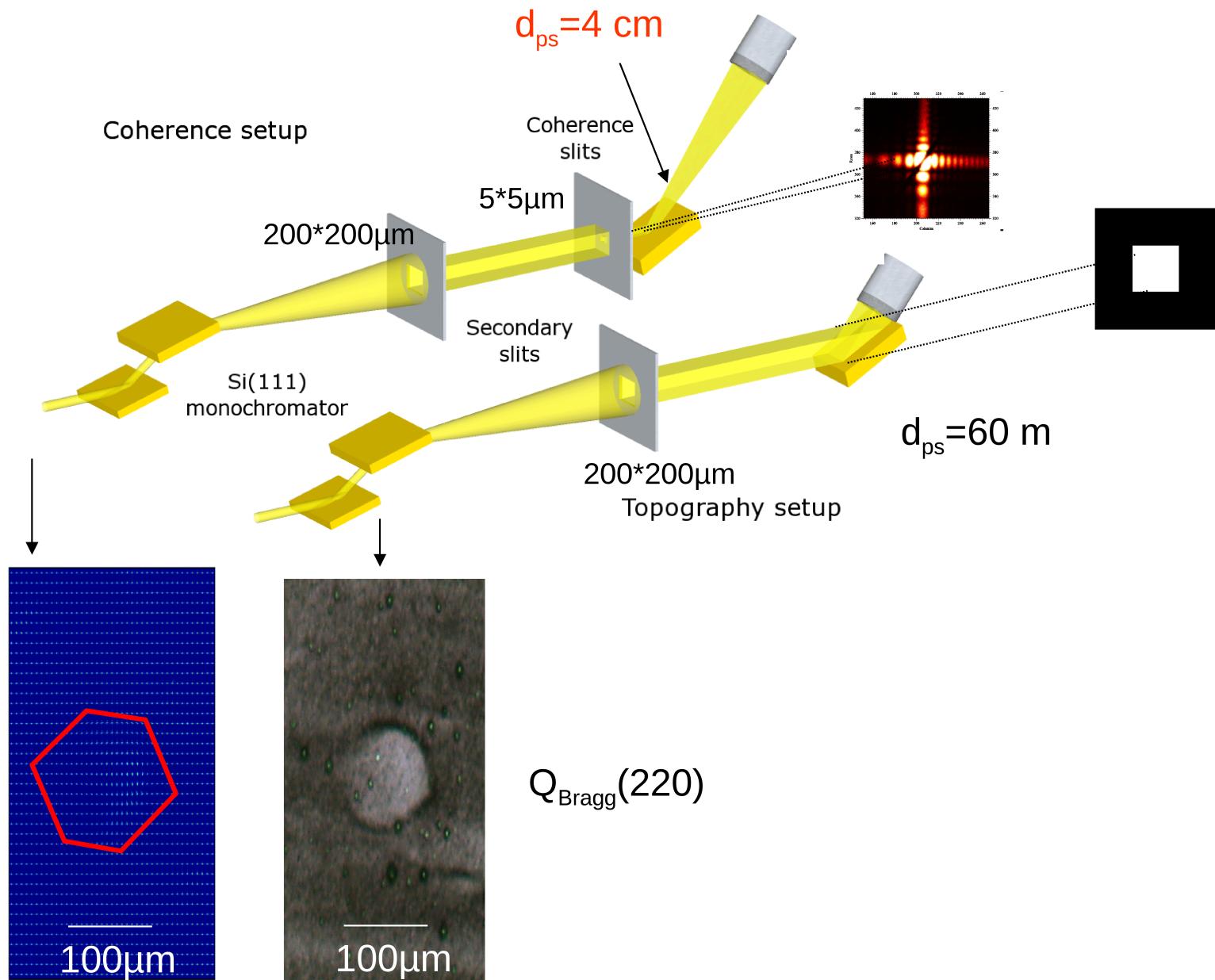
E. Pinsolle (phD)

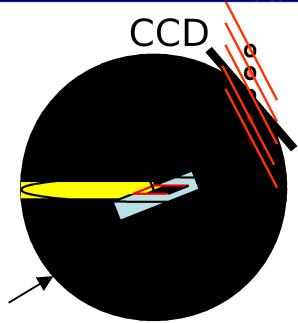
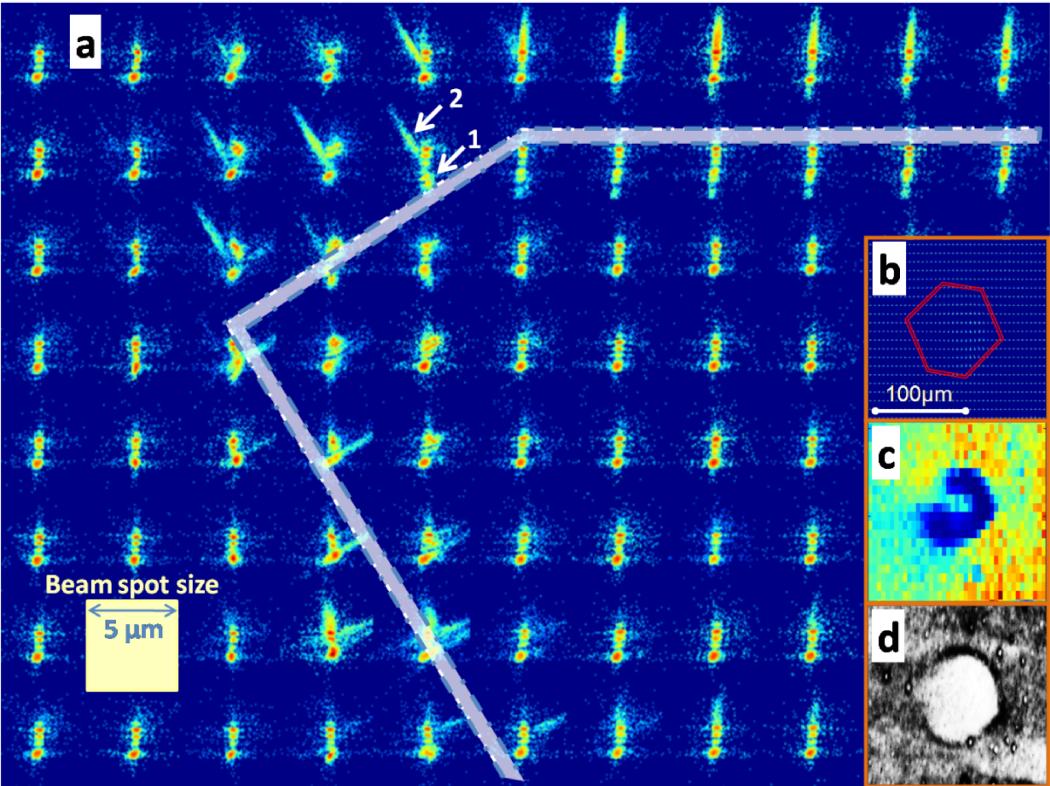
V. Jacques (LPS)

N. Kirova (LPS), P. Monceau (IN.), Shichenko (IN)

Troika (ESRF), ID20 (ESRF), Soleil (S. Ravy)

# I. Dislocation loops in silicon : $r \sim 50/150\mu\text{m}$





$b=1/2[110]$  dislocation developing along a  $[-112]$  direction into two partials –  $b_1=1/6[121]$  and  $b_2=1/6[21-1]$ .

