CDW COLLECTIVE MOTION IN 2D SYSTEMS

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in collaboratin with

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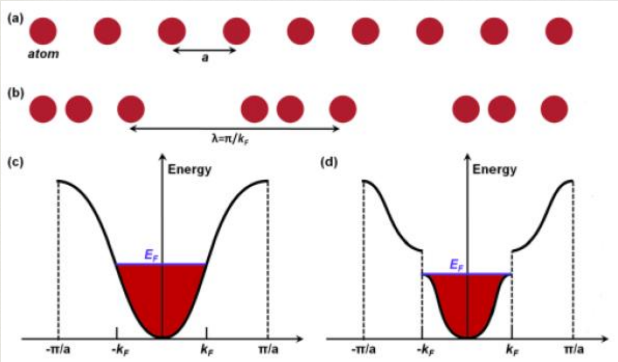
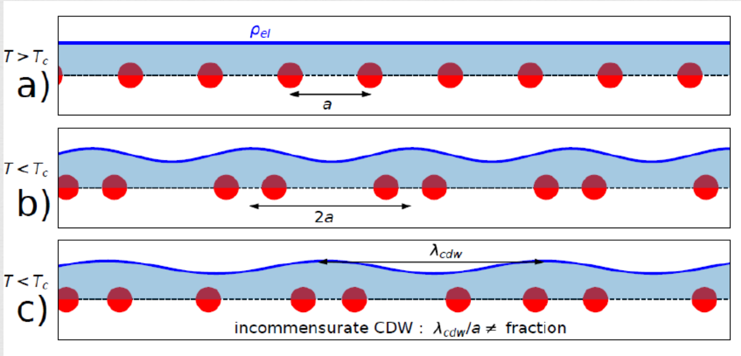
OUTLINE:

1. CDW sliding, what is it and how it looks in 1D compounds
2. Main 2D systems revealing the CDW ordering.
3. Searching for the CDW sliding in TMD and QH systems
4. CDW sliding in compounds RTe_3 family. Comparison with 1D case
5. “Time” effect
6. Conclusion

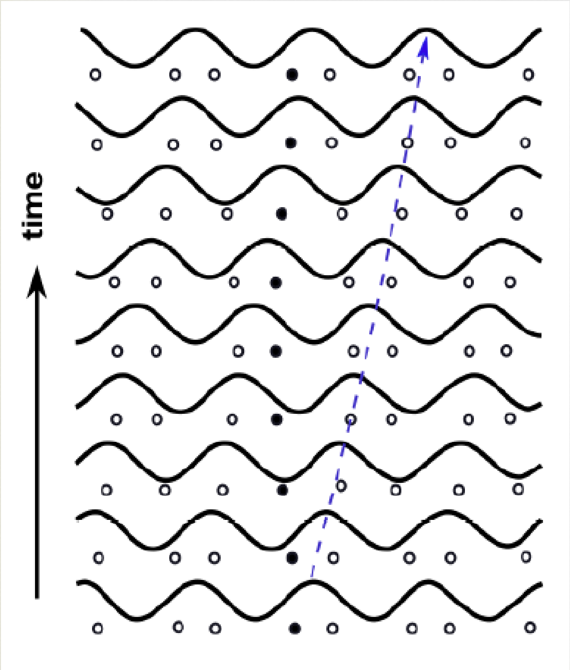
TRANSITION TO THE CDW STATE (1D CASE)





$$\rho(x) = \rho_0 \cos(Q \cdot x + \phi(x))$$

IN ELECTRIC FIELD



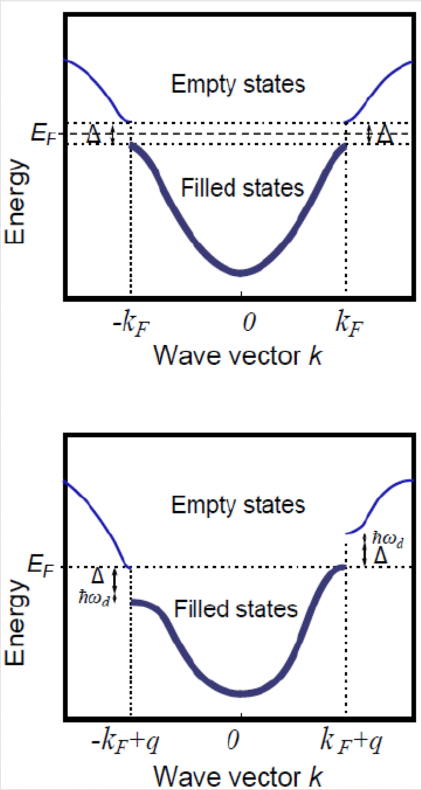
$$q = m_b V_d / \hbar$$

New FS sheets

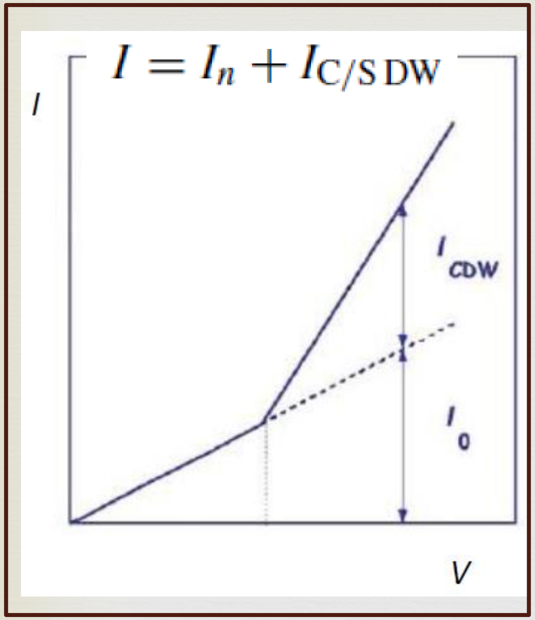
$$(-\pi/k_F) + q$$

$$(+\pi/k_F) + q$$

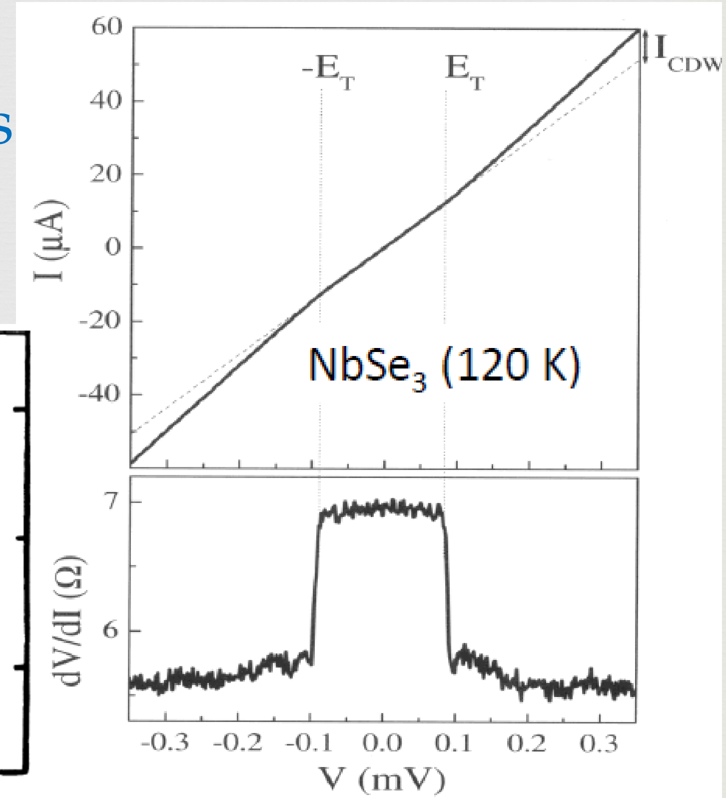
$$\langle J_{CDW} \rangle = -n_c(0) e V_d$$

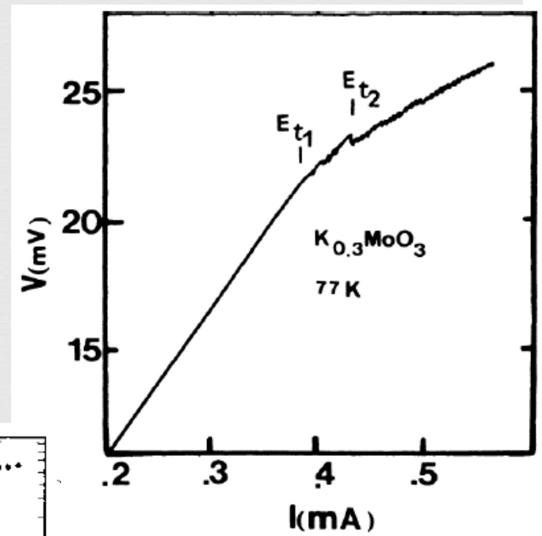


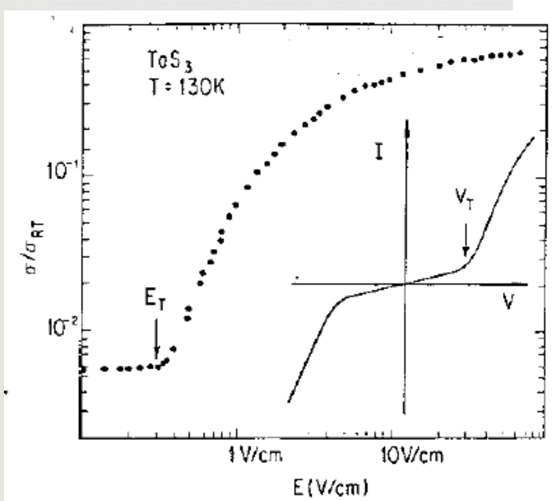
HOW IT LOOKS IN EXPERIMENT



dc IV characteristics



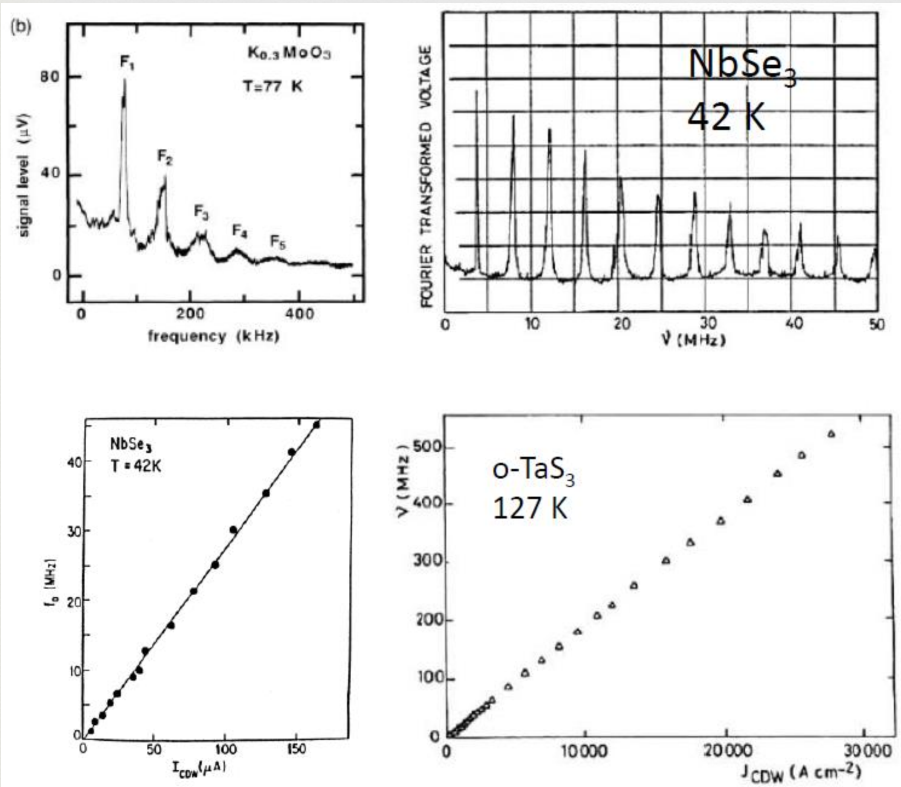




Sharp drop of differential resistance at threshold electric field

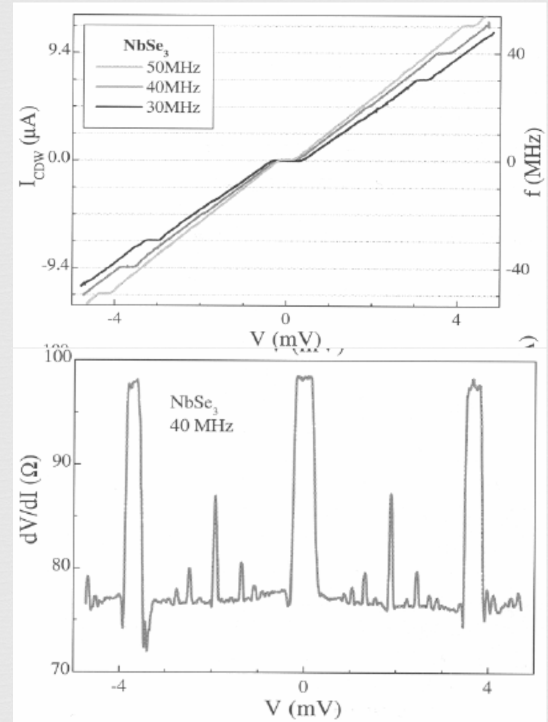
HOW IT LOOKS IN EXPERIMENT

Narrow band noise

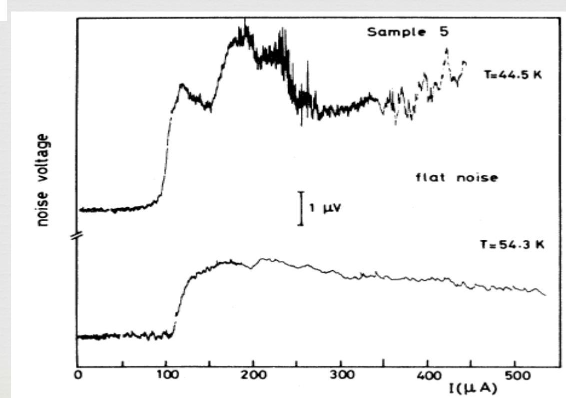


P. Monceau (1990)

Shapiro steps



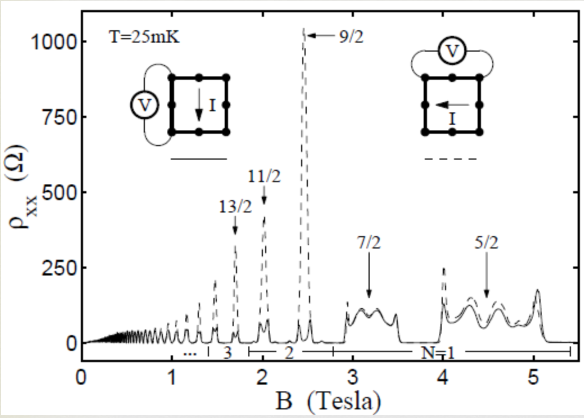
Broad band noise



P. Monceau (1982)

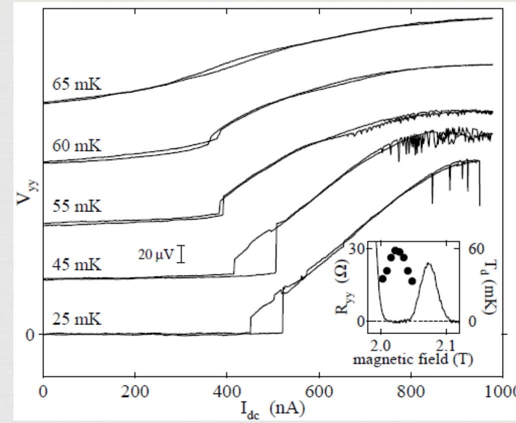
MAIN 2D SYSTEMS REVEALING THE CDW ORDERING (AND SLIDING?)

GaAs/AlGaAs heterostructures



M. P. Lilly, et al., Phys. Rev. Lett. 82, 394 (1999)

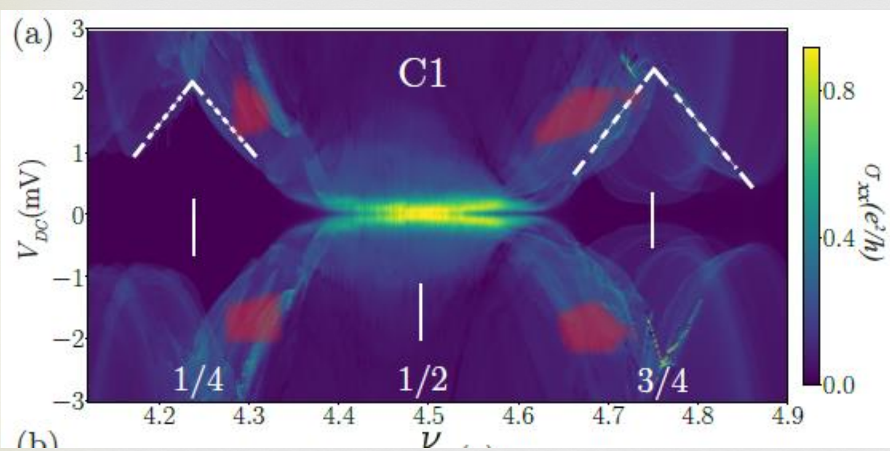
Near half-integer Landau fillings $\nu = 9/2; 11/2; 13/2$ with Landau levels $N > 1$ at certain current a sharp transition to a conducting state is observed. These phenomena are suggestive of the depinning of a charge density wave state.

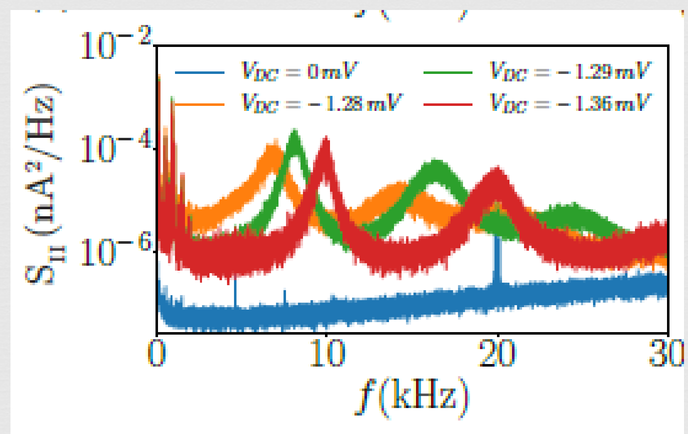


K. B. Cooper, et al., PRB 60, R11285 (1999)

The same effect in Corbino geometry

K. Bennaceur, et al., Phys. Rev. Lett., 120, 136801 (2018)

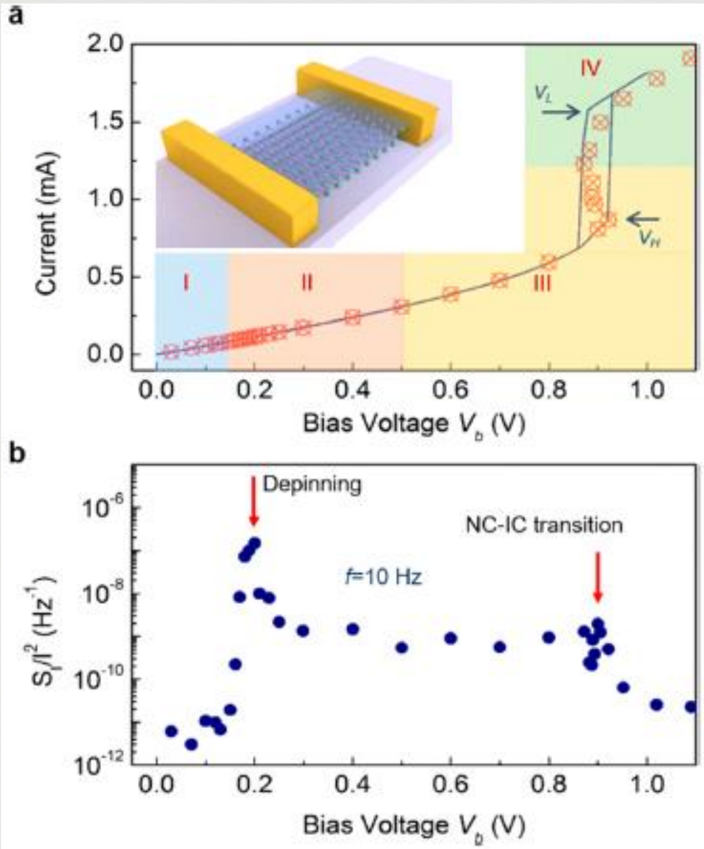




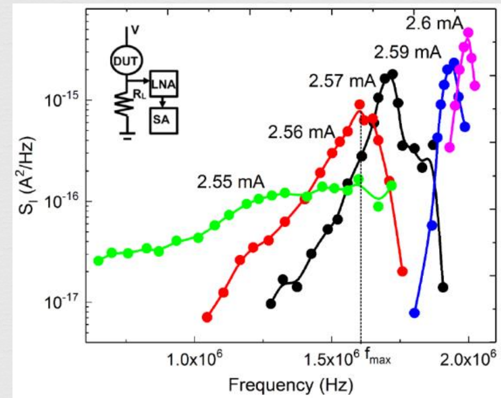
However, the frequency of periodic voltage is much lower than that originating from the sliding CDW picture

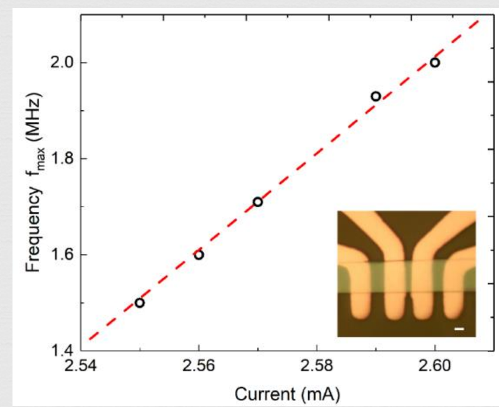
Transition metal dihalcogenides (TMDC)
MX_2 (M=Nb, Ta, Mo, Ti; X=Se, S)

BBN in 1T-TaS_2



NBN in 1T-TaS_2





G. Liu, et al., Nano Lett., 18, 3630 (2018) *A. Mohammadzadeh, et al., Appl. Phys. Lett. 118, 223101 (2021).*

No direct contribution of the CDW motion (if it is motion).

Some indication of sliding-like effects also in

2D organic compounds *(T. Mori, et al., Phys. Rev. B 79, 115108 (2009))*
manganites *(A.Wahl, et al., Phys. Rev. B 68, 094429 (2003))*

but…

Now we know only one family of compounds which demonstrates all characteristic features of the CDW sliding

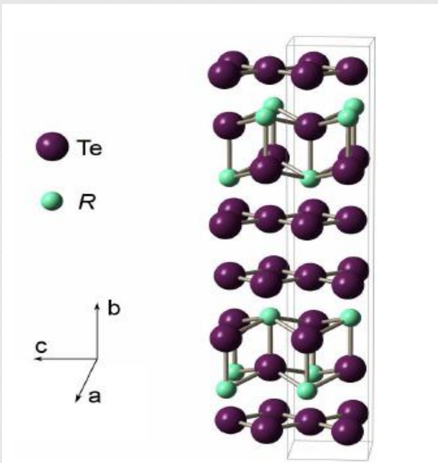
RTe_3 (R = Y, La, Ce, Nd, Sm, Gd, Tb, Ho, Dy, Er, Tm)

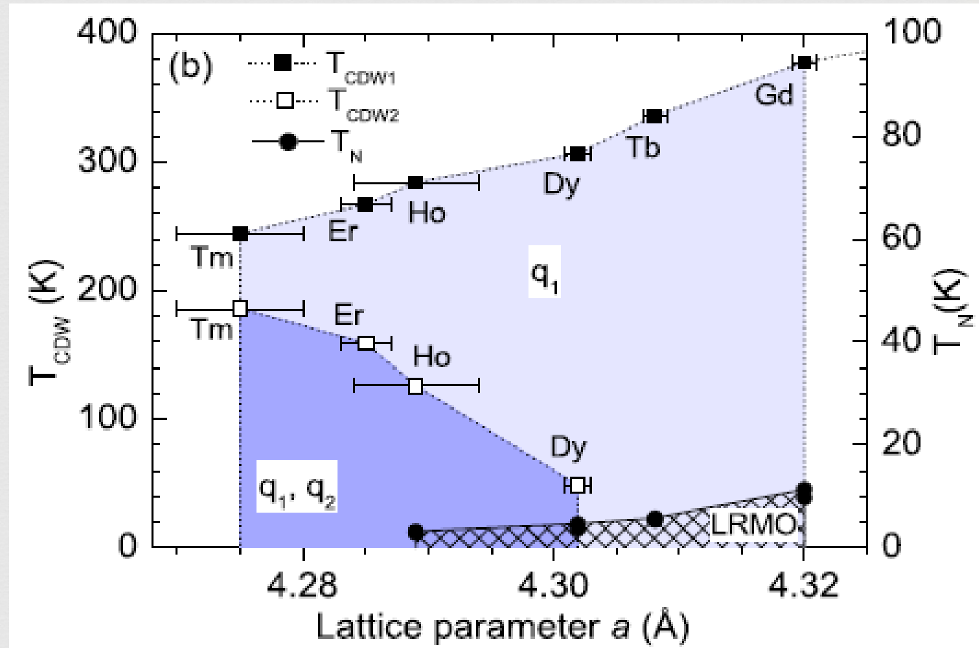
$\underline{R\mathrm{Te}_3}$

(R=Y, La, Ce, Nd, Sm, Gd, Tb, Ho, Dy, Er, Tm)

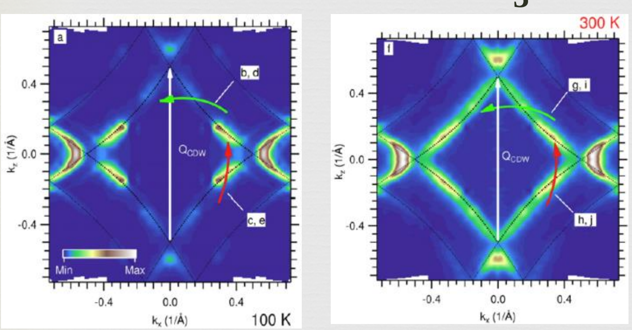
Layered quasi-two dimensional compounds

Crystal structure
– weak orthorhombic





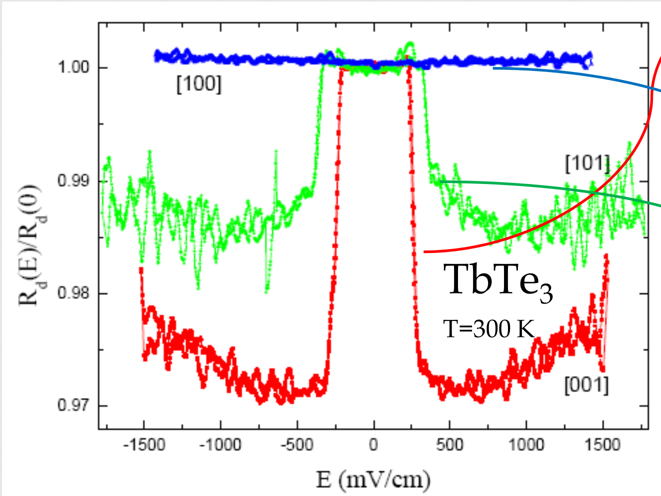
Fermi surface for TbTe_3.

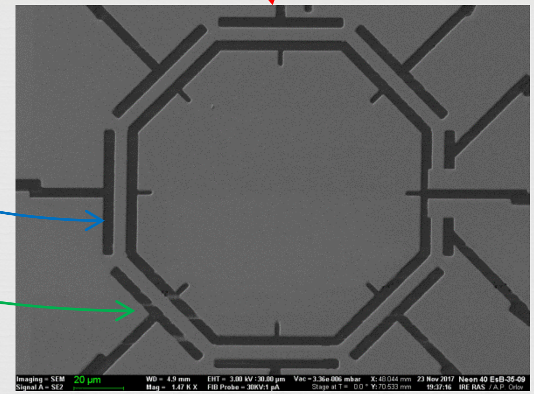


(**F. Schmitt et al., New Journal of Physics 13, 063022, 2011**)

Incommensurate CDW below the temperature T_{CDW1} through the whole R series with a wave vector $\mathrm{Q}_{\mathrm{CDW1}}$ =(0,*0,* ~2/7*c). For the heavier R (Dy, Ho, Er, Tm) atoms *a* second CDW occurs at low temperature T_{CDW2} with the wave vector $\mathrm{Q}_{\mathrm{CDW2}}$ = (~2/7*a**,0,0) *perpendicular* to Q_{CDW1}**

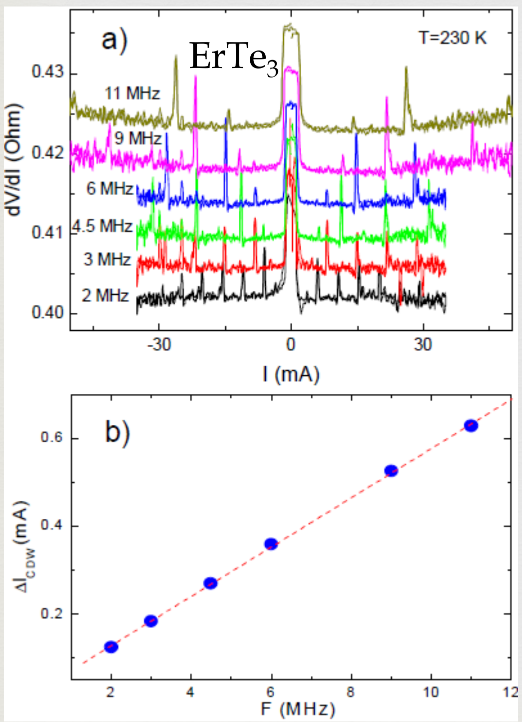
CDW sliding





(SSC. 188, 67 (2014))

Sliding is possible only along the CDW wave vector



PRB, 93, 235141 (2016)

following $\frac{j_c}{f_0} = 2e$

number of chains per cross-section

1.90×10^8

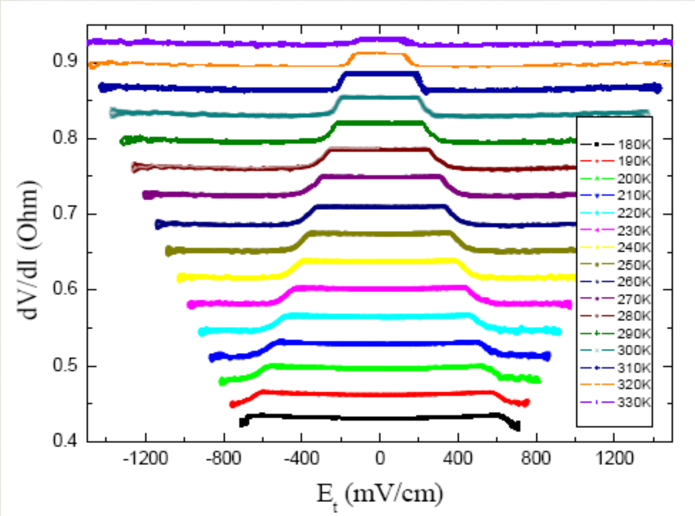
number of unit-cells per cross-section-

1.96×10^8

TbTe$_3$

"hidden" 1D character

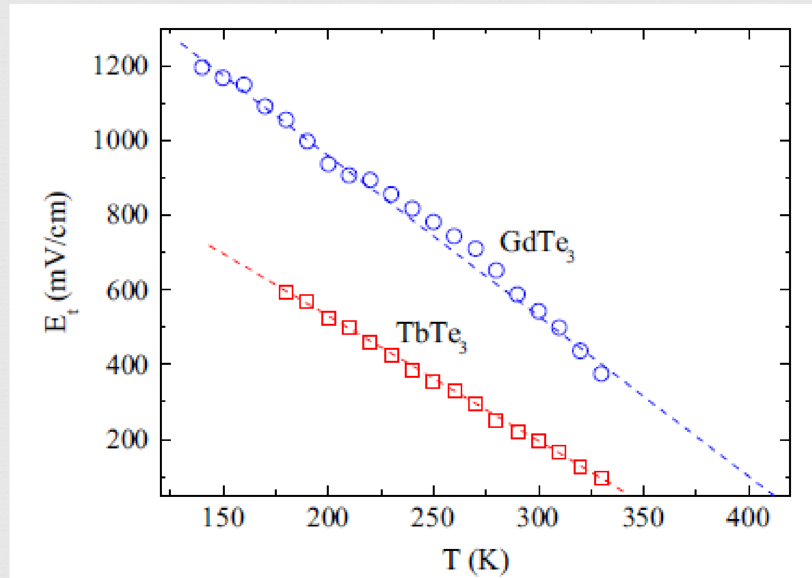
In contrast to 1D case



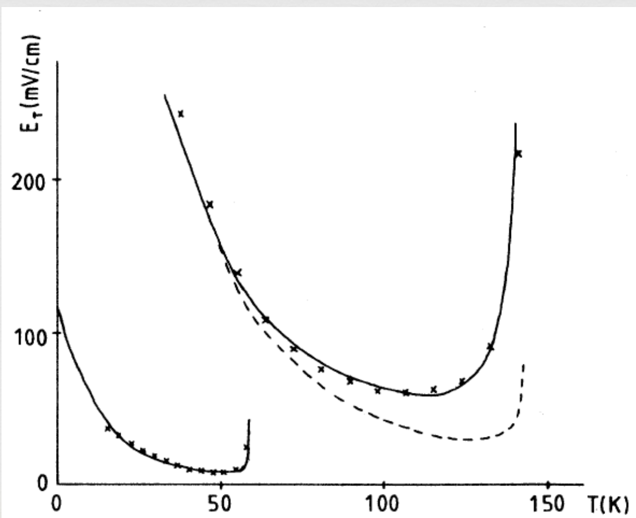
linear $E_t(T)$

$$E(T) = E(0)(1 - \frac{T}{T_0})$$

$$T_0 \approx 1.08 T_{CDW}$$



1D case – exponential dependence

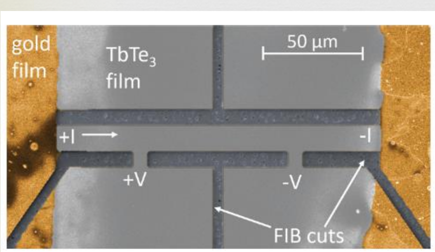


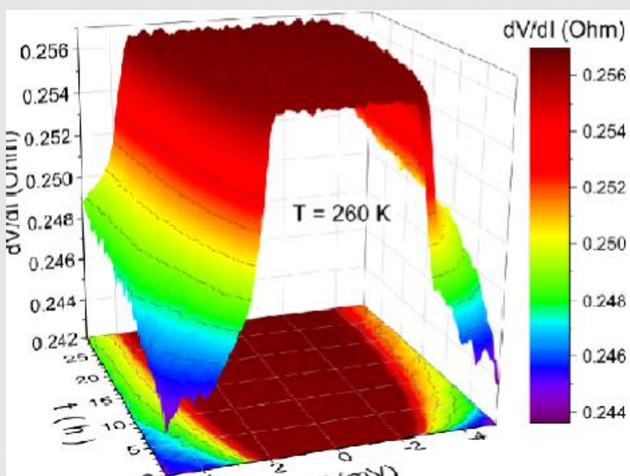
K. Maki, PRB, 13, 9640 (1989)

NEW PUZZLING EFFECT IN THE CDW SLIDING –
- TIME EVOLUTION OF THE THRESHOLD ELECTIC FIELD

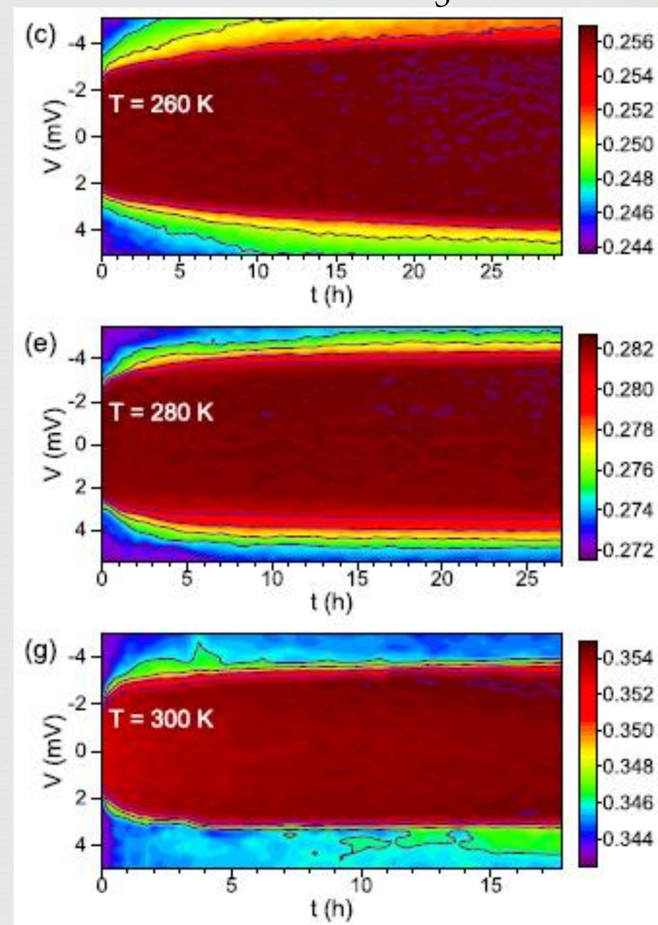
E_t increases significantly if the sample is kept at a fixed T_{expt} below T_{CDW} a sufficiently long time.
(that was never observed in 1D system)

Procedure:
cooling the sample from $T > T_{CDW}$ down to a given temperature T_{expt} and measuring *IV* curves with a time interval of 30 minutes during several tens of hours
and
that at different T_{expt} in the range 220–330 K.
(below 220 K effect is very weak)





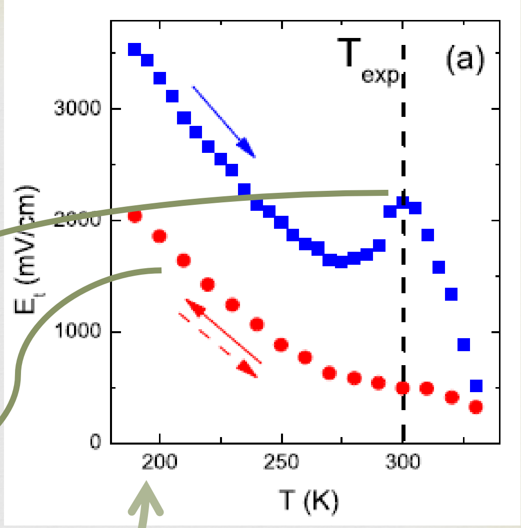
$TbTe_3$



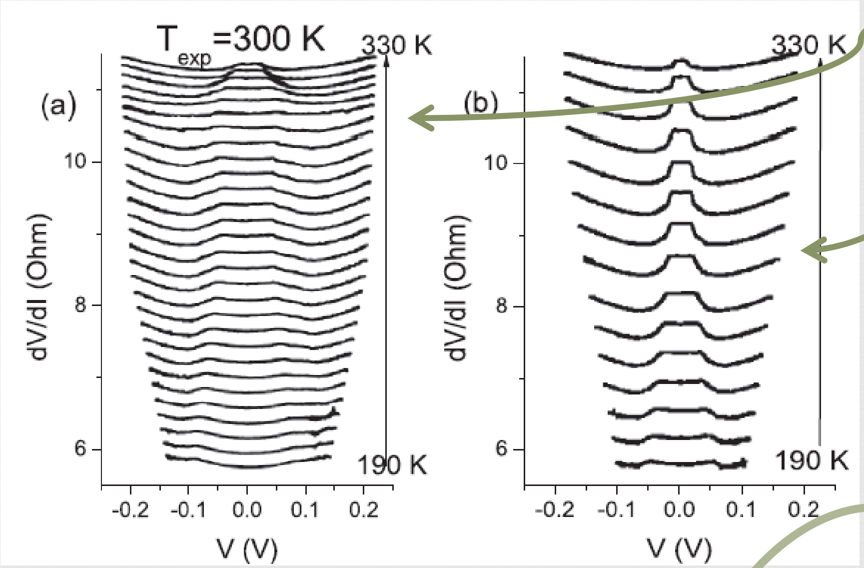
PRB **101**, 155144 (2020)

AFTER EXPOSITION ($TbTe_3$)

T-dependence of E_t ⟶ *peak effect*



No any change in resistance and the CDW transition temperature

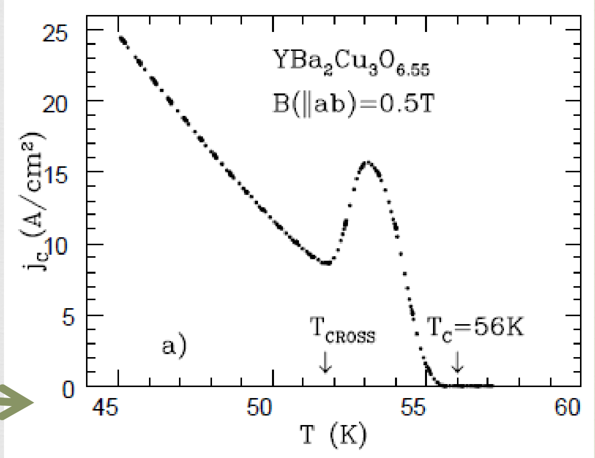


Like to superconductors?

Effect is completely reversible:
the initial state can be easy restored by increase of temperature 20-30 K above T_{expt}

melting of what?

melting of Larkin domains



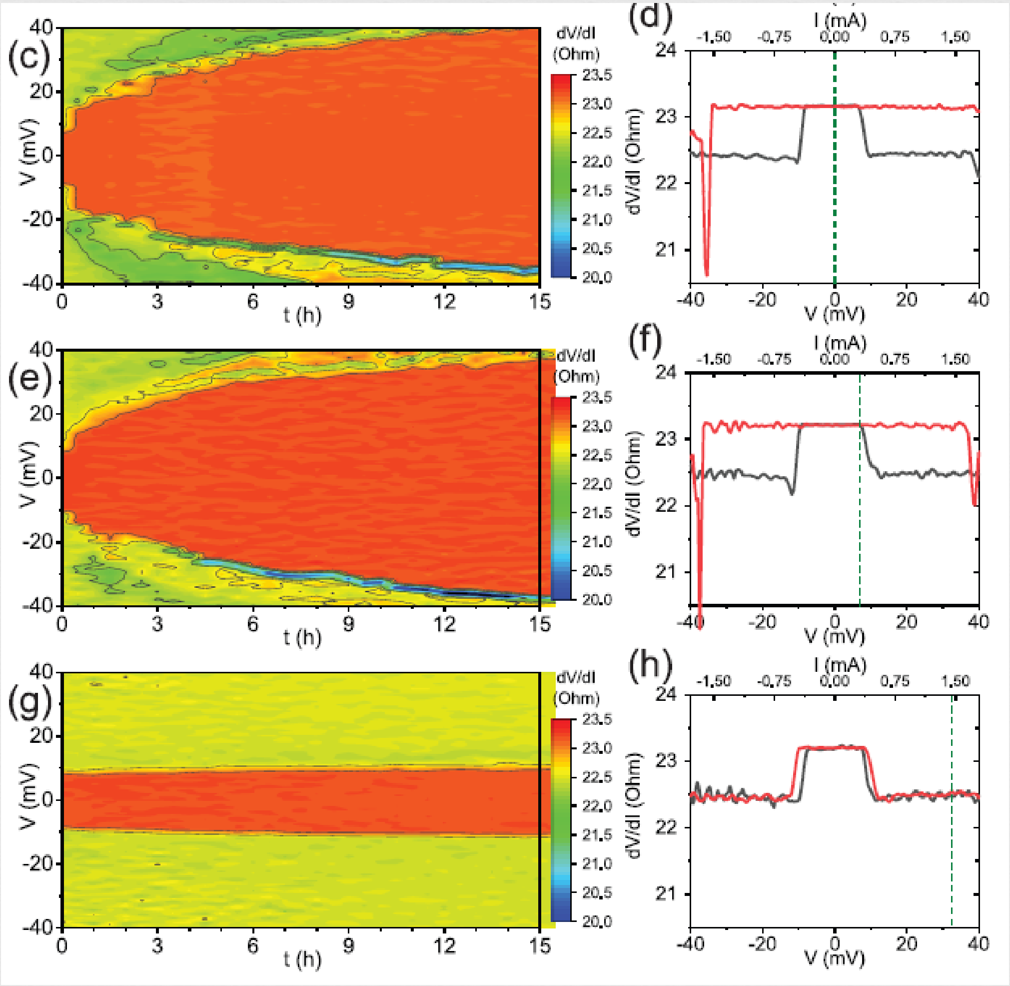
Chao Tang, *Europhys. Lett.*, **35** (8), 597 (1996)

Exposure at different current state ($TbTe_3$)

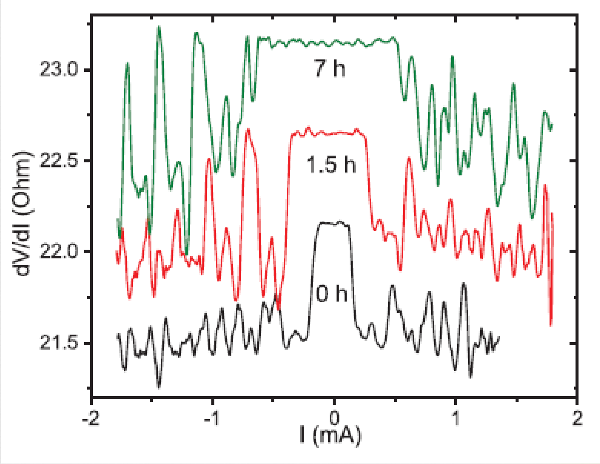
$I=0$

$I<I_{th}$

$I>I_{th}$



Shapiro steps structure improved under exposure

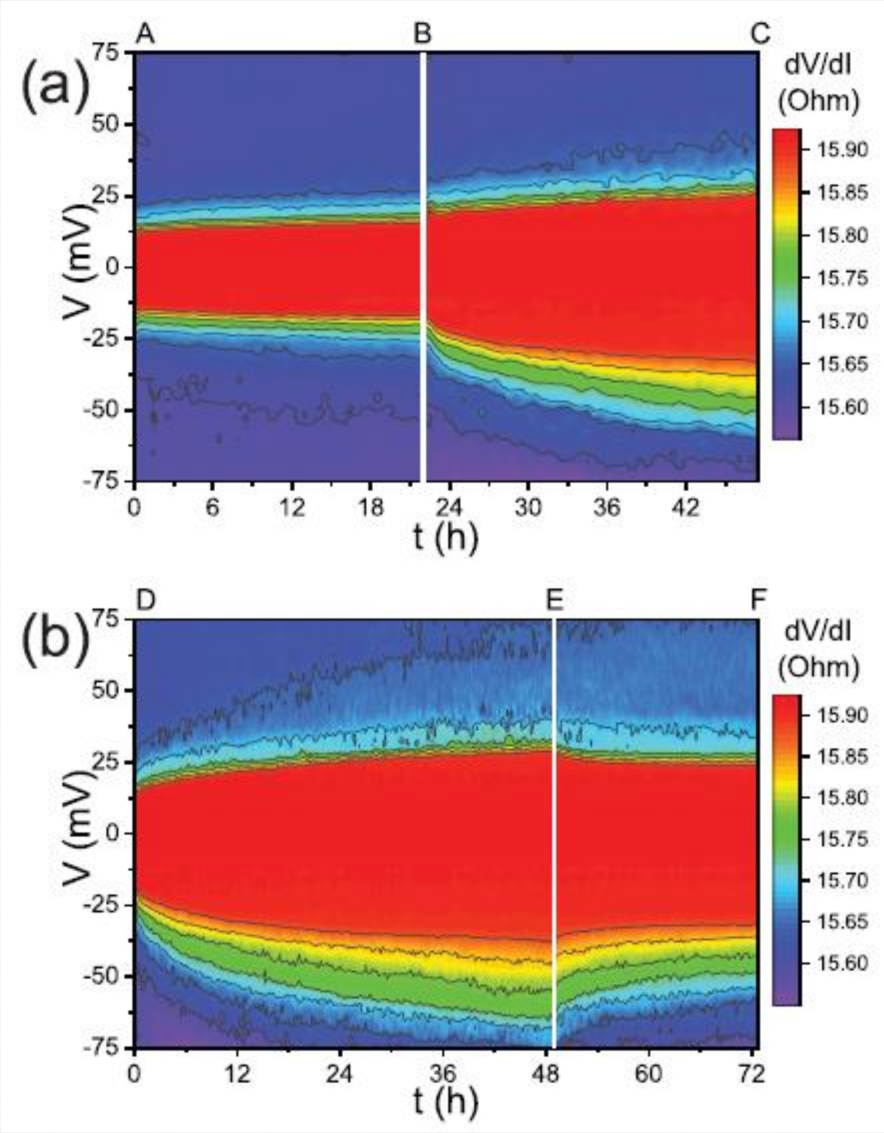


Time-effect is practically absent in the sliding state of CDW -

- something happens with the CDW sub-system.

Appl. Phys. Lett. ***118****, 253102 (2021)*

280 K


A
B
C
(a)
dV/dI
(Ohm)
15.90
15.85
15.80
15.75
15.70
15.65
15.60
75
50
25
0
-25
-50
-75
V (mV)
0
6
12
18
24
30
36
42
t (h)
D
E
F
(b)
dV/dI
(Ohm)
15.90
15.85
15.80
15.75
15.70
15.65
15.60
75
50
25
0
-25
-50
-75
V (mV)
0
12
24
36
48
60
72
t (h)

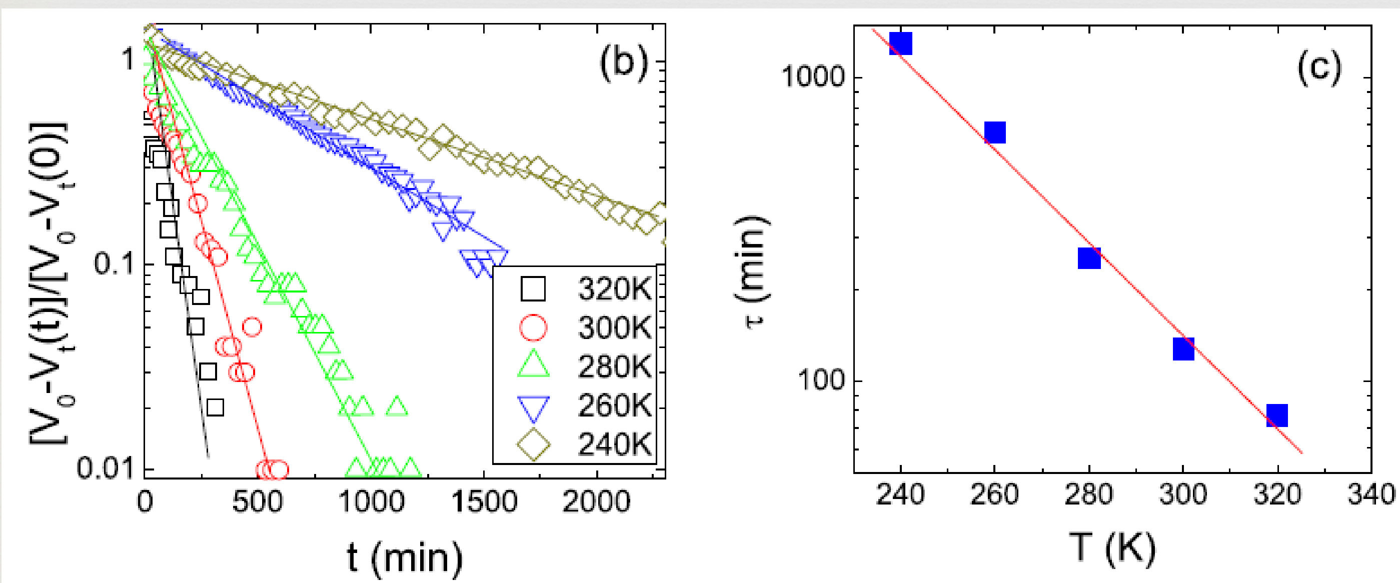
being at a given thermodynamic parameters
+
without external perturbations

} **the system tends to its ground state**

Growth of E_t with time ⟶ relaxation to the ground state

Characteristic time parameters of such relaxation

Assuming exponential relaxation



$$\tau \sim \exp\left(-\frac{T}{T_0}\right)$$

$$T_0 \approx 30\ \mathrm{K}$$

V_0 is saturating (**?**) value of the threshold voltage

Mobile impurities? ⟶ No

PHYSICAL REVIEW B VOLUME 53, NUMBER 23 15 JUNE 1996-I

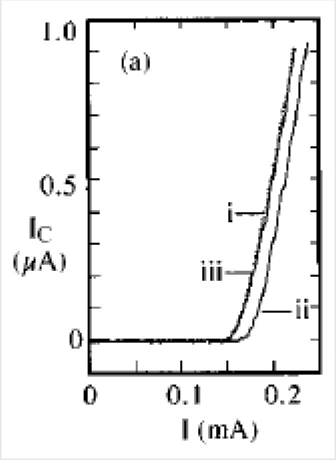
Dislocations and the motion of weakly pinned charge-density waves: Experiments on niobium triselenide containing mobile indium impurities

J. C. Gill
H. H. Wills Physics Laboratory, Tyndall Avenue, Bristol BS8 ITL, United Kingdom

(Received 31 October 1995; revised manuscript received 29 January 1996)

The In increases E_T by an amount δE_T,
which is greatest when the CDW is at rest, and can be reduced almost to zero by its continuous motion.

$TbTe_3$ – no reduction to zero. Only stop of increase.



Increase of E_t – less than 30% ⟶ In $TbTe_3$ – 1000%

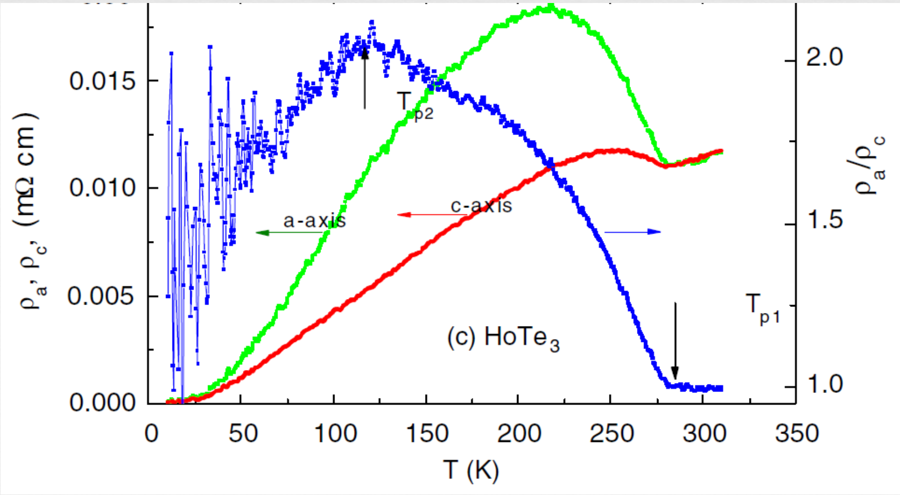
time taken for δE_T to adjust to a change in the state of the CDW (of the order of 1s at 115 K)

In $TbTe_3$ – 10^5 s at 240 K

No peak effect in $NbSe_3$

$HoTe_3$

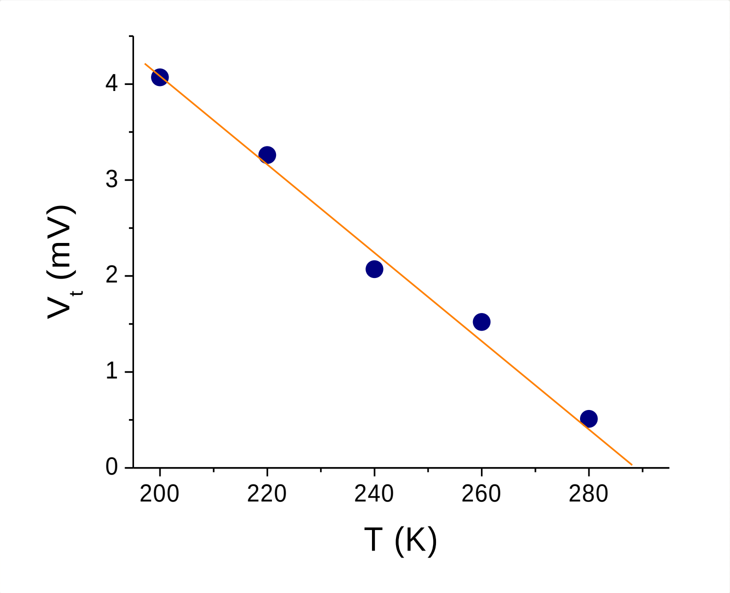
Two CDW transitions: T_{CDW1}=285 K and T_{CDW2}=110 K



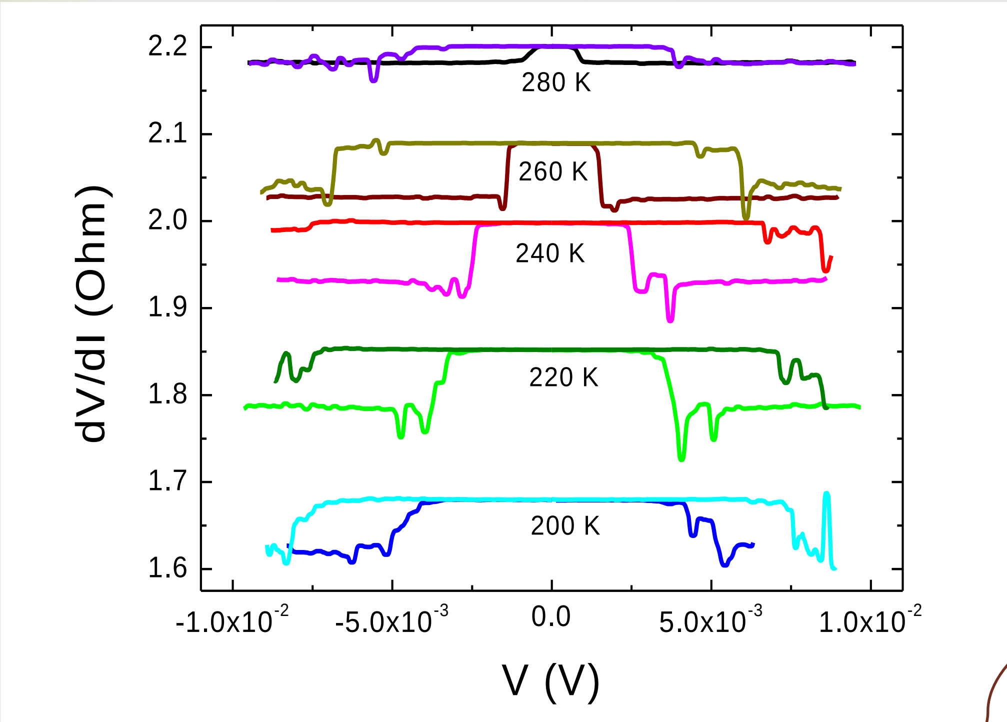
Never warmed above room temperature

Exposed at 280 K, 260 K, 240 K, 220 K and 200 K

before exposition Et(T)



Studying this effect in $HoTe_3$ for exposure time up to 200 hours

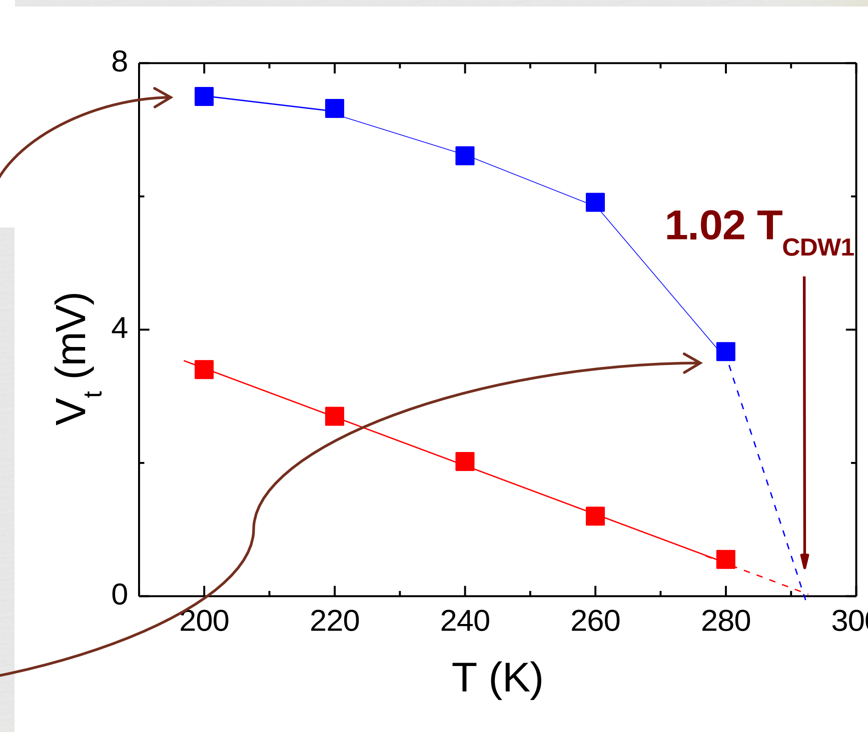


Initial and final differential IVs

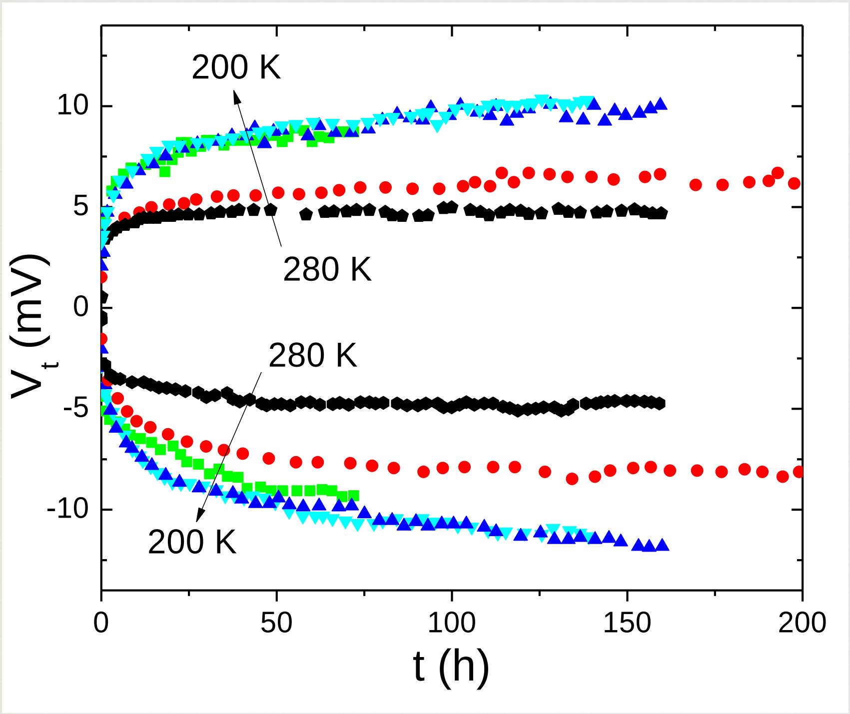
~2 times

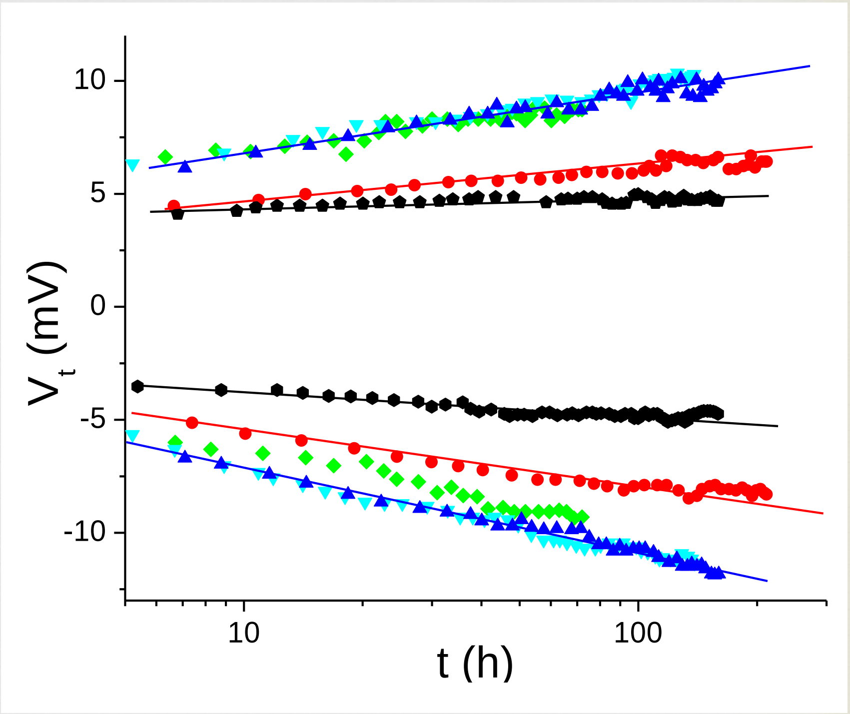
Initial and final $E_t(T)$

~10 times



TIME PARAMETERS





No saturation even after 150 hours

Linear dependence $E_t(\lg(t))$

GLASSY STATE

CONCLUSION

1. Demonstrating all features of the CDW sliding in quasi-1D systems, the CDW sliding in 2D compounds of RTe3 family reveals specific features which are differ from 1D case: linear dependence of Et(T); very low velocity of the CDW.
2. Most intriguing feature is time evolution of the threshold electric field. Something happens, but what?
3. Detail structure studying need to be done to understand that.

Thank you very much for attention