Quantum Density Waves

S.Tanda*, T.Matsuura, M.Tsubota, G.Kumagai, J.Ishioka, T.Toshima#, T.Tsuneta$, K.Inagaki&,Nobukane,Fukuda K.Ichimura,Kondo group~,Sakoda, Nakatsugawa(NIMS),

Dept.Appl.Phys.,Hokkaido University, Sapporo, # Toyama colledge of Technology, $ Nara Univ. of Education, & Asahikawa med.Univ. ,Japan ~Univ. of Tokyo

2022 Aug 11 Ecrys

Ecrystal Organizers raised me and my colleague as scientists for long time of 35 years.

We appreciate
Serguei(76), Natacha(75), Pierre(80).

（Even so, you guys are old, of course you are young at heart.）

But I miss a little…..

Outline

1. Introduction: Quantum Density Waves

2. Quantum Phenomena: Macroscopic Quantum Coherence in Real Space Topology

  2-1.Topological Crystals : Ring,Mobius,Hopf-link crystals

  2-2. CDW: Macroscopic quamtum coherence 1

  ★ Aharonov-Bohm effects in Real-space loop

  ★ Shapiro steps of loop CDW circulating current

  ★ Reinterpretation of Memory effect

  2-3.Chiral CDW, Monolayer, Monostring

3. Quantum Anomaly in K-Space Topology

Aharonov Bohm Effect in Functional-space

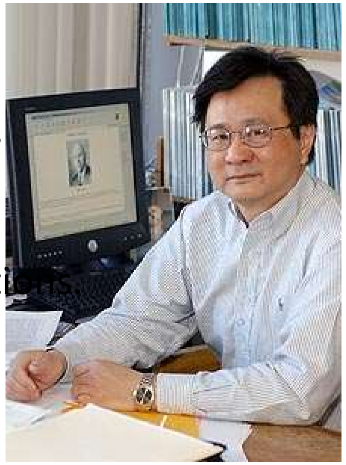
Bardeen conjecture

He visited Sambongi Lab. in Hokkaido Univ.
two times, 40 years ago.(1982 and 1983)
At those time I was under-graduate student. And he ask us two questions.

1. **Is CDW sliding a quantum tunneling process?**
2. **Can Monolayers and Monostrings be CDWs？**

N. P. Ong also visited Hokkaido University in 1983.
He then looked at our X-ray equipment and asked how large a bulk sample(1T-TaS2) would be needed to observe CDW satellite reflections.

I remember answering 1mm thick.
But now it 's the world of 0.1nm.

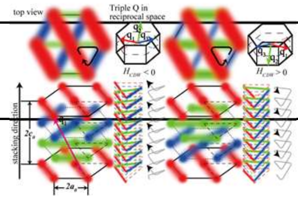


He is co-discoverer of a mode of electron motion in one-dimensional metals called sliding charge-density-waves with Pierre.

I send our this monolayer paper, Pierre, Dragan, and Ong

Ong send this paper to P.A.Lee ➡ 1T-TaS2 as a quantum spin liquid PNAS

Superconductor and CDW: Macroscopic Coherence

Superconductors ~110year	CDW ~60 year
Gauge Symmetry, Meisssner (Diamag)	Translational Symmetry, Frolich super.
Tc=285K	Tc=600K MX_2, MX_3
Josephson Effect Shapiro steps	Narrow Band Noise Shapiro steps,
SQUID Quantum Coherence	Ring CDW, Topological AB Effec 
BKT transition in thin film	Monolayer CDW: 1T - TaS2 Kosterlitz line
Vortex	Soliton lattice , discommensuration
Stripe, （CuO2layer FeTe）	Stripes: 1T-TaS_2 ,2H-$TaSe_2$
Chiral superconductor	Chiral CDW 
?	Time Crystals ?
?	Quantum Anomaly?

Quantum Density Waves : New Grand State

Charge Density Waves: MX3
Spin Density Waves :Cr
Mass Density Waves :I@CNT

Quantum Density Waves

- ★ Nano CDW, MQT
- ★ AB effect :interference
- ★ Quantum Anomaly
- ★
- ★

$NbSe_3$ (MX3) :CDW and Superconductors Researches in Hokkaido Univ. 45 Years

Discovery of quasi 1D $NbSe_3$: Sambongi, Yamaya ,Tsutsumi (1977)

Memory Effect of CDW in $NbSe_3$: Ido Oda, Okajima (1986)

Ring Crystals in $NbSe_3$: Kawamoto, Okajima, Tanda, Yamaya (1999)

Möbius Crystals in $NbSe_3$ Tanda Tsuneta Inagaki Okajima Yamaya

Nature 417 397 (2002)

Hopf-link crystals Matsuura, Yamanaka, Hatakenaka, Matsuyama, Tanda

Topological AB quantum Effects in MX3: PRB (2006)

PRB(2009,2010,2011-) Tsuboa, Matsuura, Kumagai Inagaki,Tanda

Chiral CDW in $TiSe_2$: Ishioka, Oda, Ichimura, Tanda PRL(2010),PRB(2011)

Monolayer CDW 1T-TaS2,TaSe2 npj quant.mat.(2017)

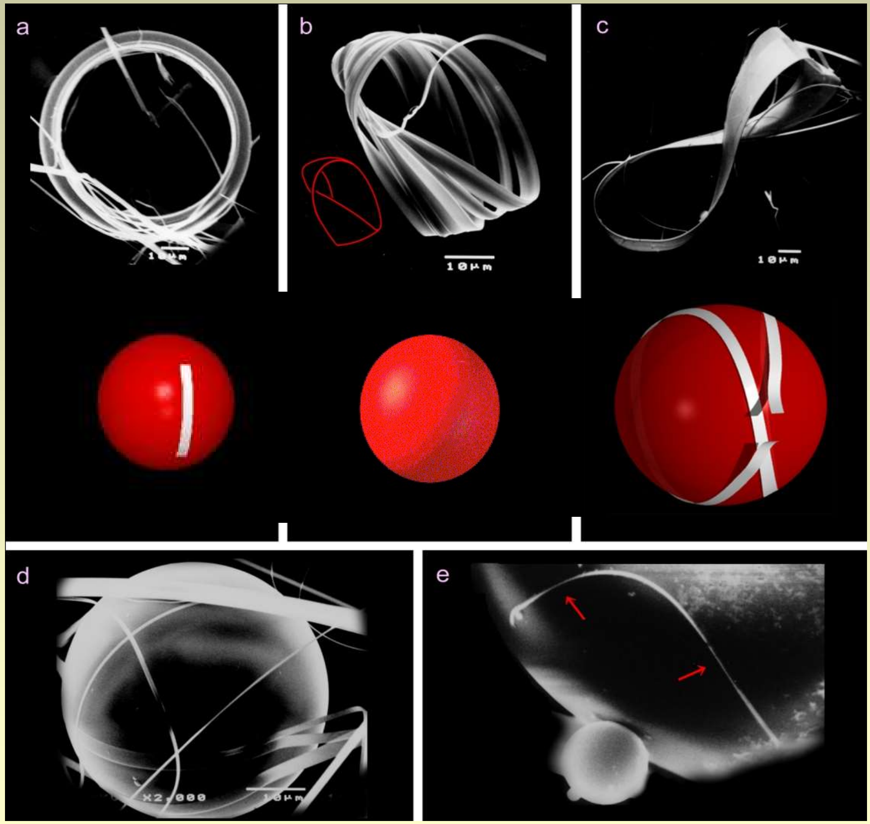
Origin of Stripe Sci. Rep.(2020)

Monostring CDW NbS3,NbSe3,

K-spaceTopology Control;Nature Mat.20,1093 (2021)

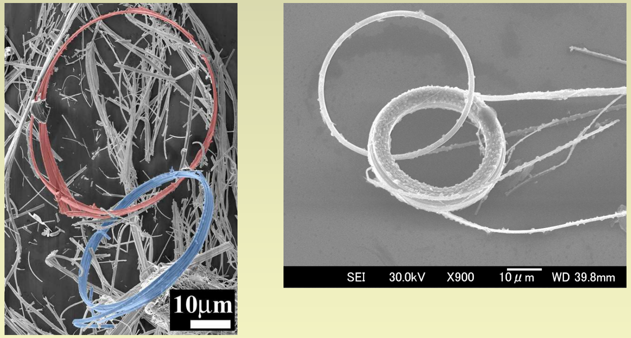
Topological crystals

Ring (L = 0) Möbius (L = 1/2) Figure-8 (L = 1)



Nature 417,397 (2002)

Hopf-link Crystals



T.Matsuura et.al. Journal of Crystal Growth 297, 157(2006)

Can we introduce the concept of topology into crystals ?

Originally, What's Crystal ?

↓

Bragg reflection !

Definition of International Union of Crystallography (1991)

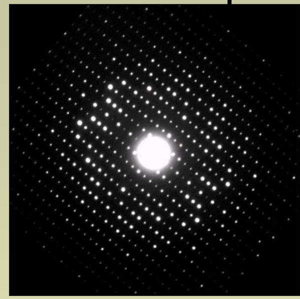
Definition of Crystals

Crystals show Bragg reflection

Snow crystal

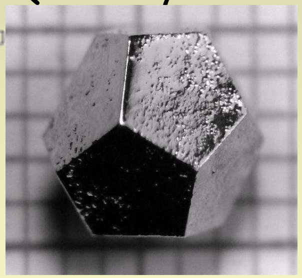
Bragg reflection of electron beam/X-ray

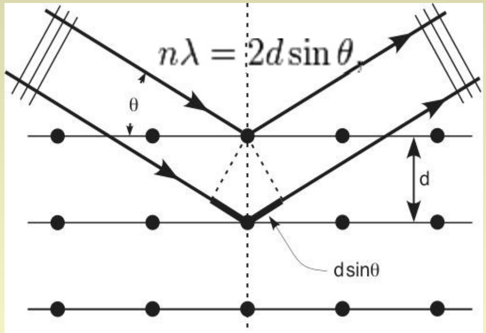
Reciprocal space



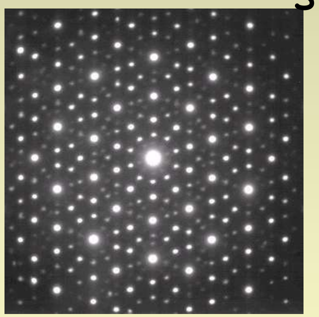
Mathematically, Fourier transform from real space (lattice) to *k*-space (Bragg spots)

Quasicrystal



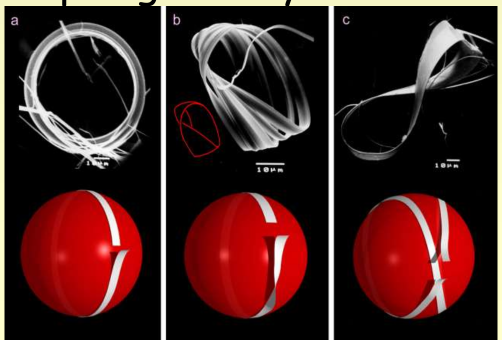


spots



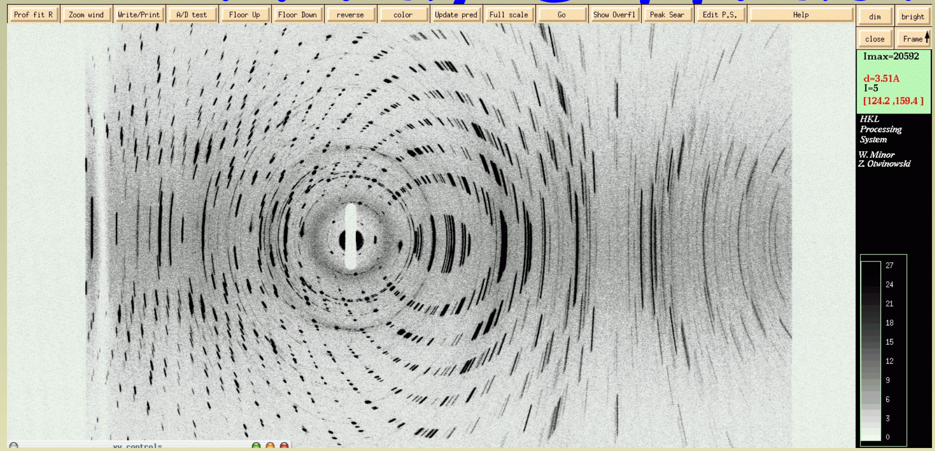
Crystals and quasicrystals show sharp Bragg spots

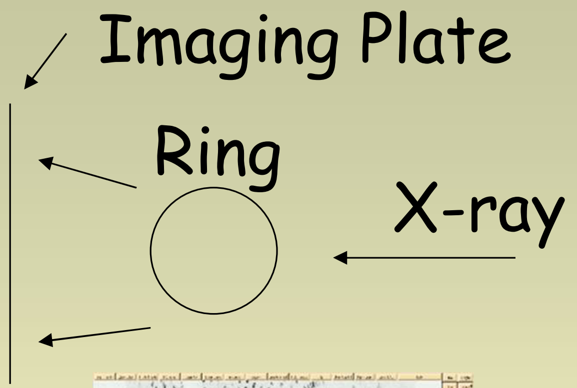
Topological crystal

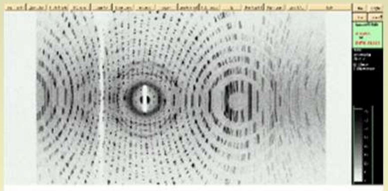


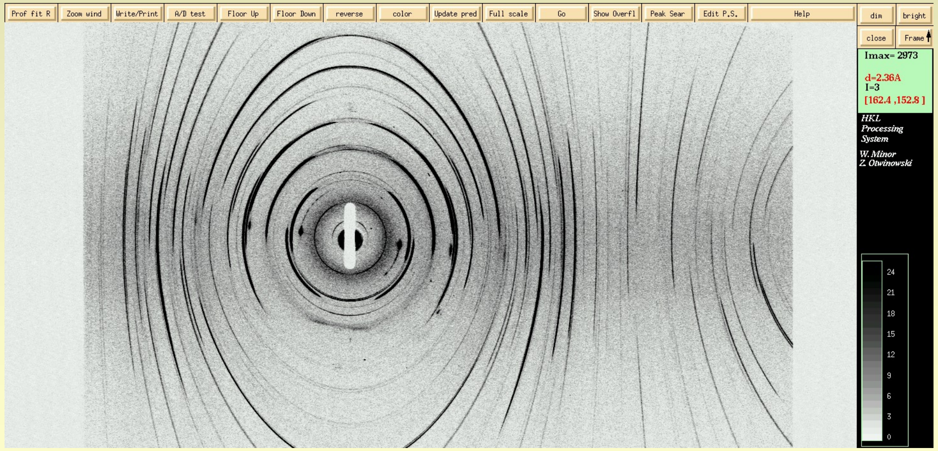
?

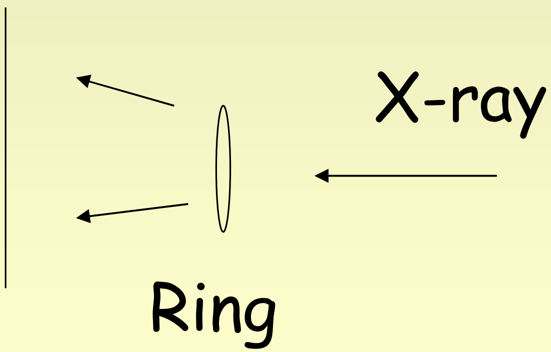
X-ray Diffraction: Ring









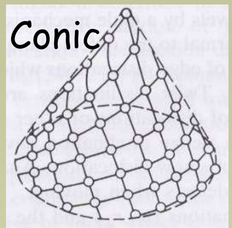


Bragg Ring

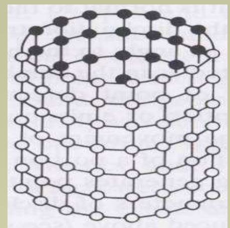
Line is homogeneous

Single Crystal !!

Classification of Topological Crystals



ω= 1/2π
ω^*= 0π



ω= 2π
ω^*= 0π

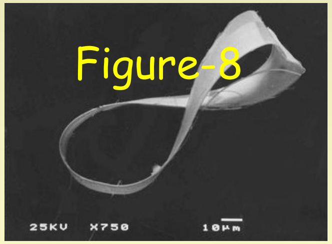
ω: Wedge Disclinations
ω^* : Twist

ω^*, ω is independent,respectively, due to the topological defect theory of the crystals, as yet. (by Frank)

Topological Crystals ⟷ New Definition ! / Knot Theory ⟷ **L_k= ($\omega+\omega^*$)/ 2π-1 Linking Number**

ω= 2π
ω^*= 0π
L_k = 0

ω= 2π
ω^*= 1π
L_k = 1/2



ω= 2π
ω^*= 2π
L_k = 1

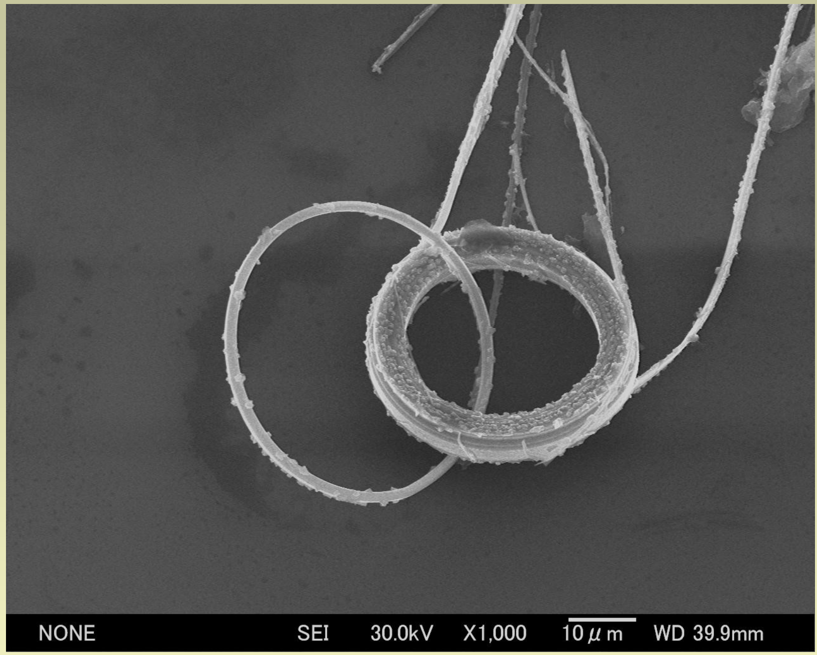
Global Wedge + Global Twisting

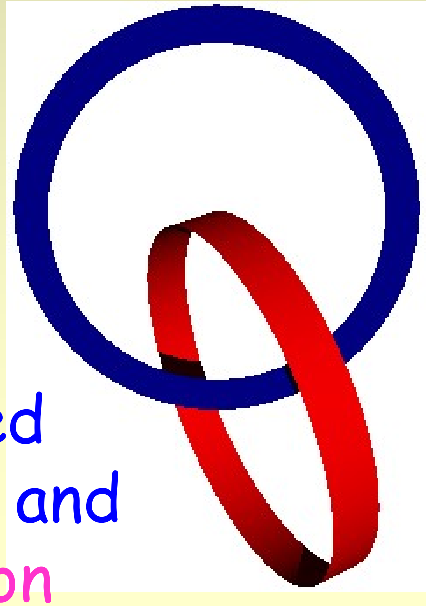
↓

Knots Crystals !!

$$\frac{1}{2\pi}\int_{crystal} f\left(\omega,\omega^*\right) dV = L_k$$

Discover Hopf-Link Crystals



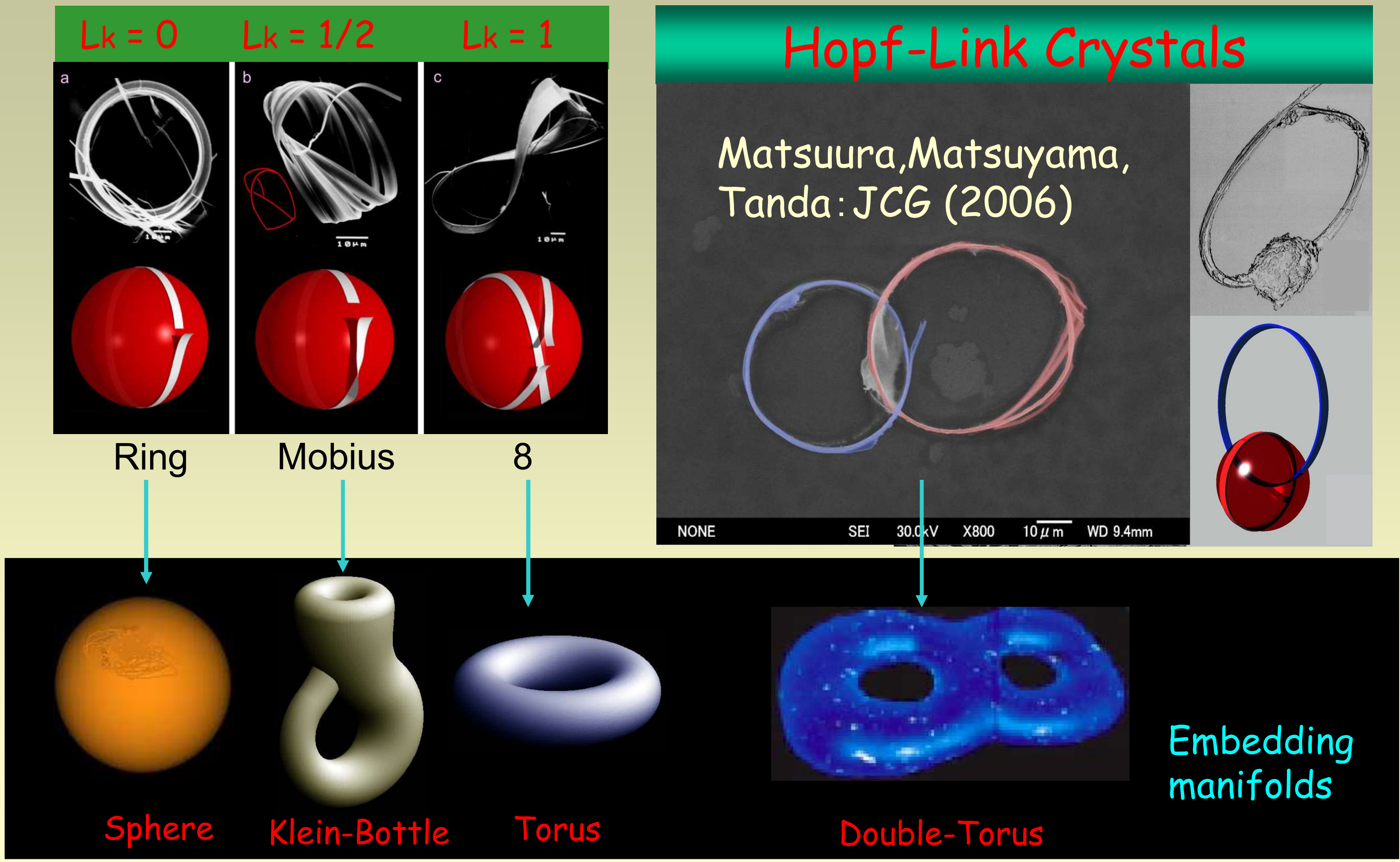


Topologically linked crystals

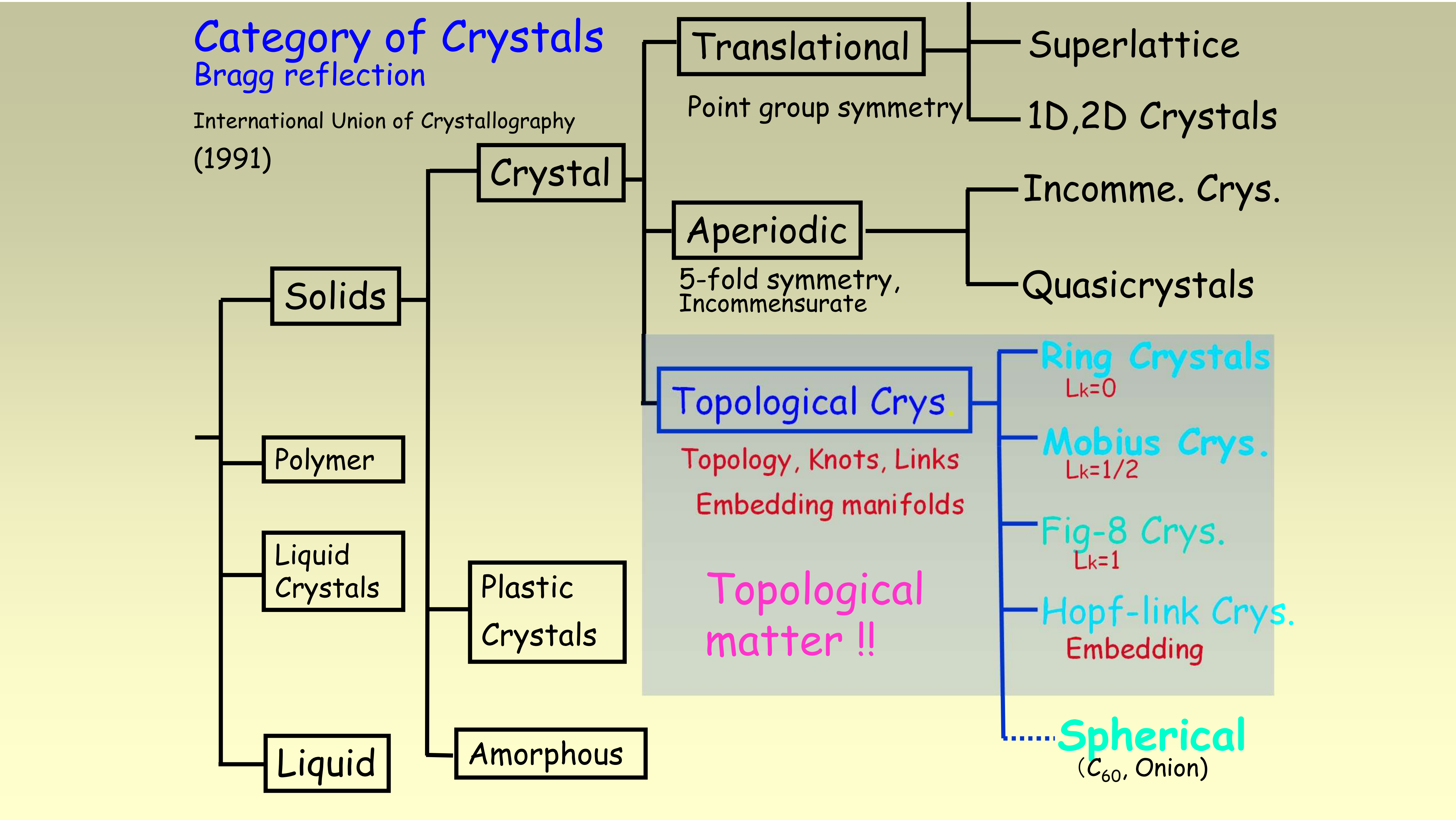
T.Matsuura, M.Yamanaka, N. Hatakenaka,T. Matsuyama, and S. Tanda, Journal of Crystal Growth 297, 157 (2006).

Hopf-link crystals cannot be categorized by the linking number of Knots crystals and usual point groups → New Classification

Classification By Embedding manifolds

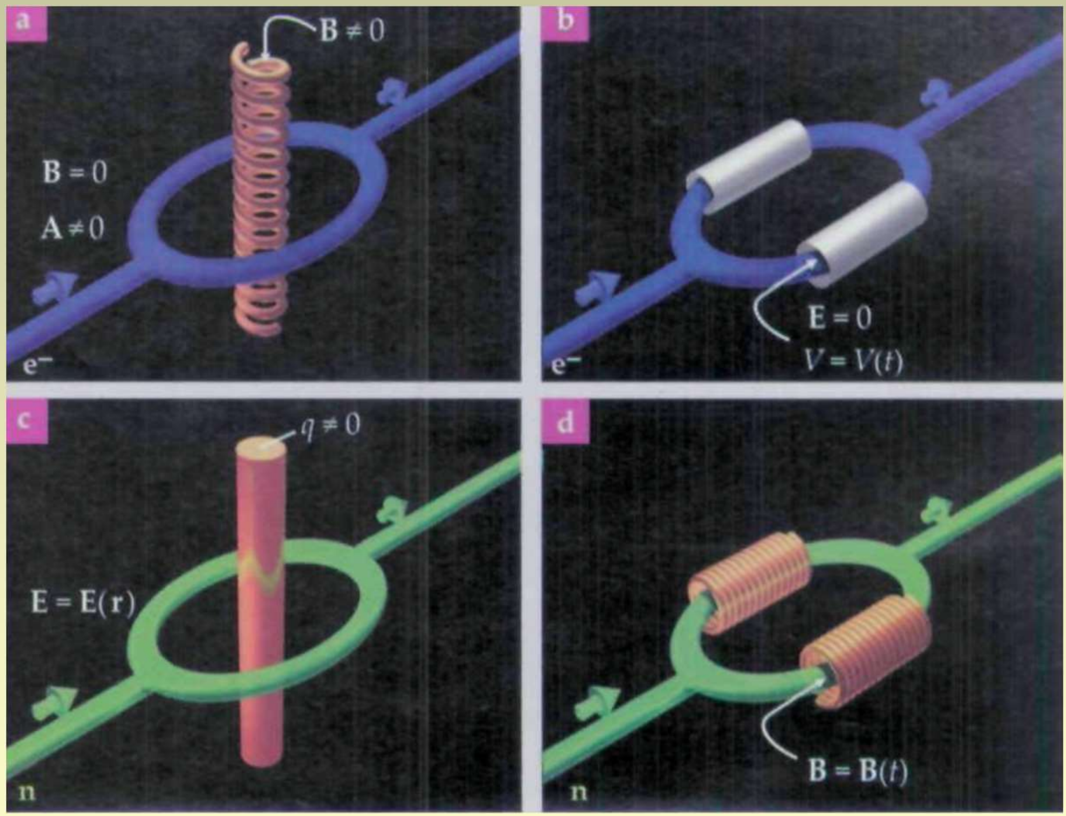


We propose New Classification with Embedding manifolds



Category of Crystals
Bragg reflection
International Union of Crystallography
(1991)
Crystal
Translational
Point group symmetry
Superlattice
1D,2D Crystals
Aperiodic
5-fold symmetry, Incommensurate
Incomme. Crys.
Quasicrystals
Solids
Polymer
Liquid Crystals
Liquid
Plastic Crystals
Amorphous
Topological Crys.
Topology, Knots, Links
Embedding manifolds
Topological matter !!
Ring Crystals
Lk=0
Mobius Crys.
Lk=1/2
Fig-8 Crys.
Lk=1
Hopf-link Crys.
Embedding
Spherical
(C60, Onion)

AB Effect of CDW in the Loop



We need a hole to investigate interference of wave function.

Quanta by Real space topology

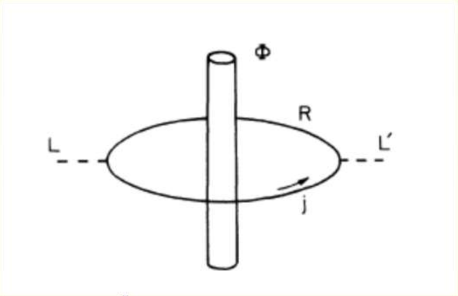
1. **AB Effect of CDW in the Loop**
2. **Circulating current of CDW By Shapiro Steps in the Loop**
3. **Memory Effect: Ido Steps**

Instanton AB effect

- Prediction by Bogachek et al. (1990)

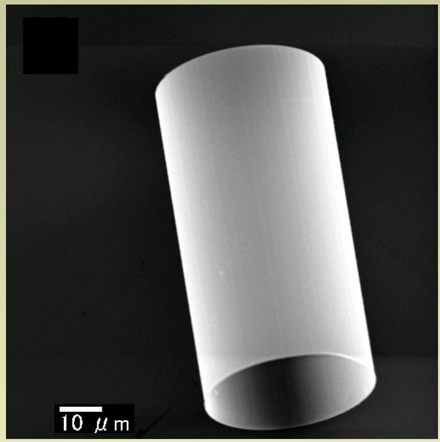
$$F_\phi = -\frac{1}{\beta}\ln\int D\phi \exp\left[-\int_0^L dx \int_0^\beta d\tau\, L_E(\phi)\right]$$

$$L_E(\phi) = N_0[(1/2)\dot{\phi}^2 + (c_0^2/2)(\phi')^2] - (N_0\omega_0^2/M^2)(1-\cos M\phi) - (ie/\pi c)A\dot{\phi}\ .$$

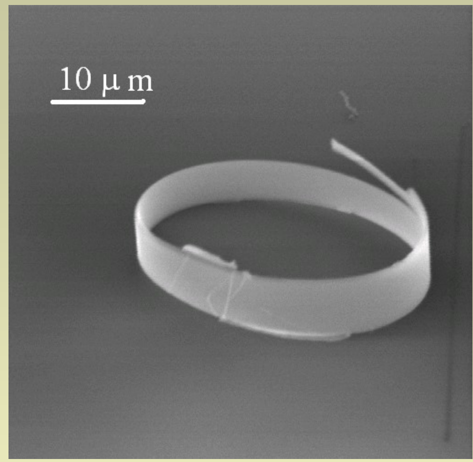


- However, we have found no theorists who support their formulation.
- As an experimentalist, I conduct the following study…

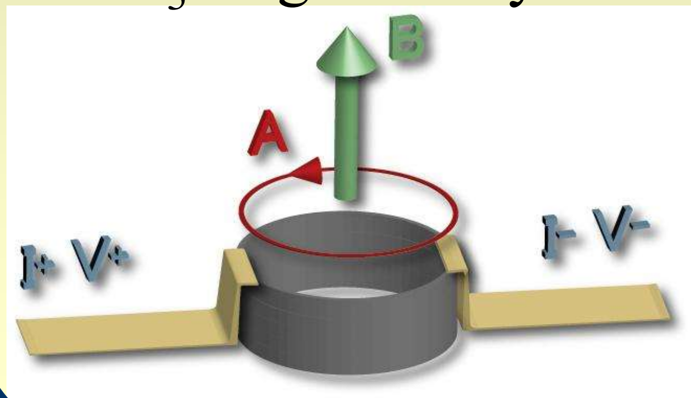
Experimental Setup

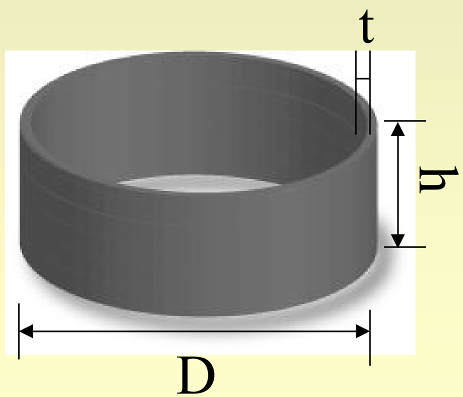


FIB cut



TaS_3 ring/tube crystal



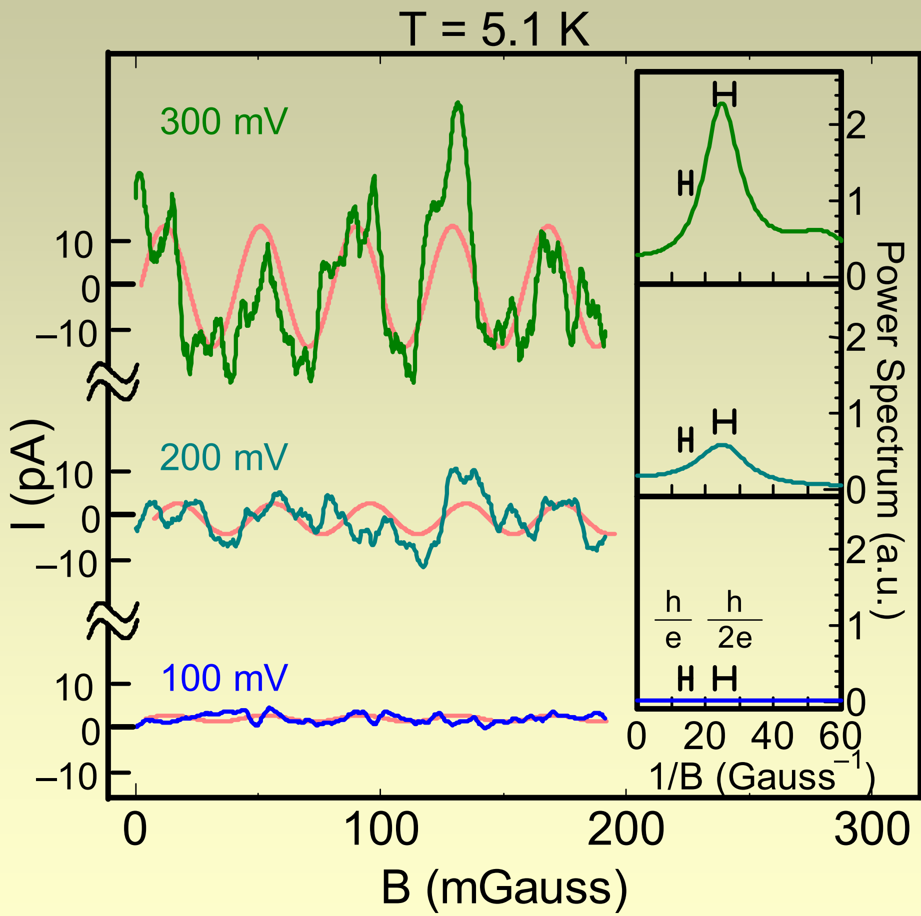


$t \approx 0.1 \mu m$

$h \approx 1 \mu m$

$D \approx 27 \mu m$

Result



Periodic oscillations were observed.

Estimation of unit charge

$$\Delta B = \frac{\Phi}{S} = \frac{h}{e^*} \cdot \frac{1}{\pi r^2}$$

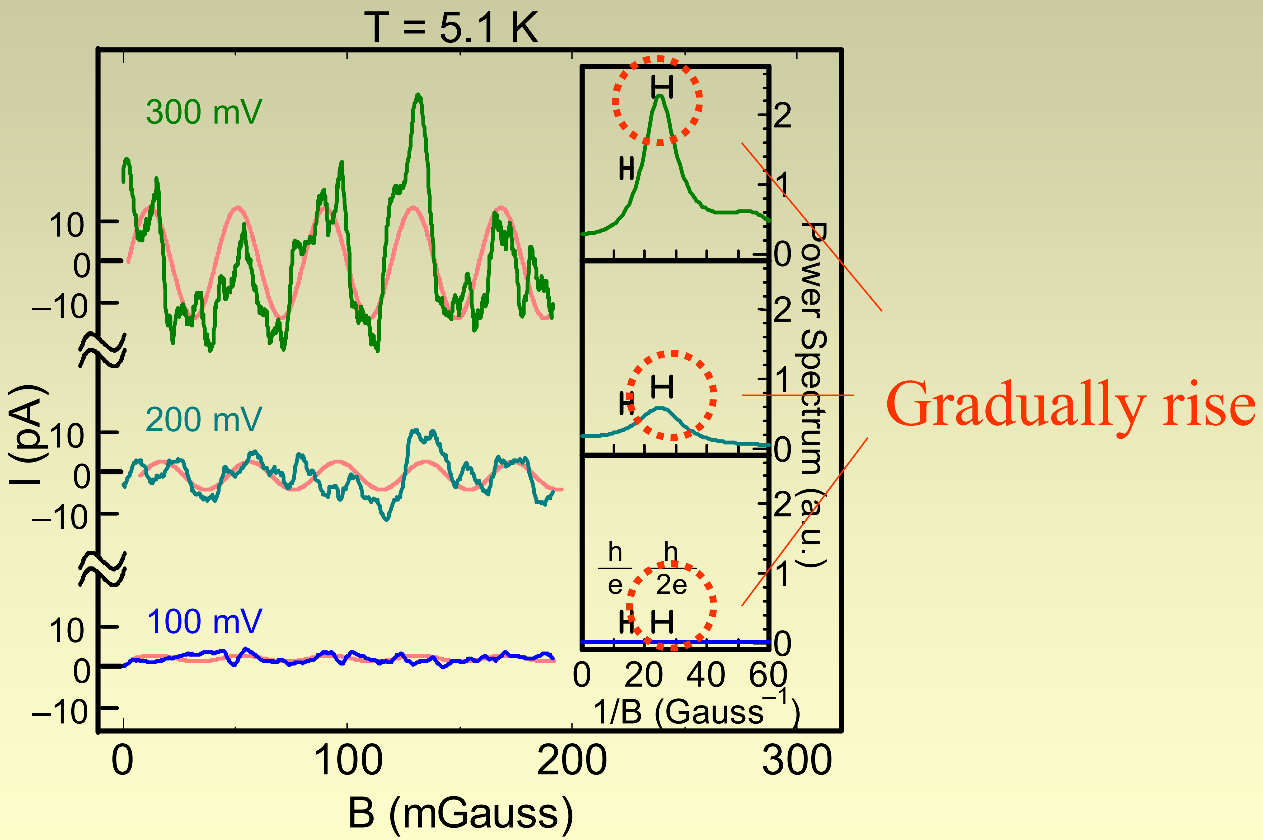
ΔB: The period of the oscillation

S: The area of the ring crystal

Sample	Diameter	Area m^2	Period	Charge
A	27 μm	5.6×10^{-10}	39.7 mGauss	3.0×10^{-19} C
B	17 μm	2.3×10^{-10}	95.2 mGauss	3.1×10^{-19} C

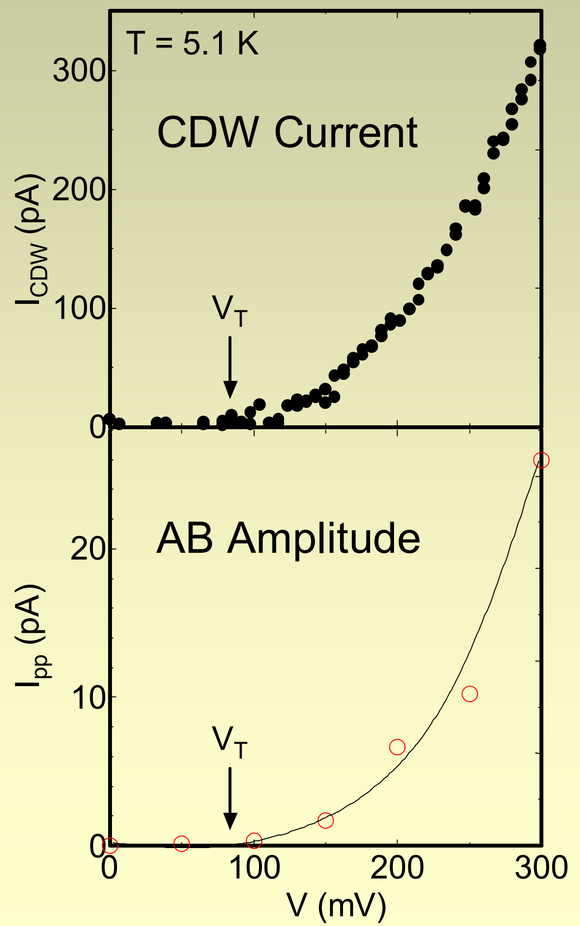
Unit charge corresponds to 2e (=3.2×10^{-19} C)

h/2e Oscillations



Other peaks (h/e, h/4e,,) were not observed.

AB Amplitude



Two curves behave similarly

The amplitude of the interference is related with sliding CDW.

Perioicity

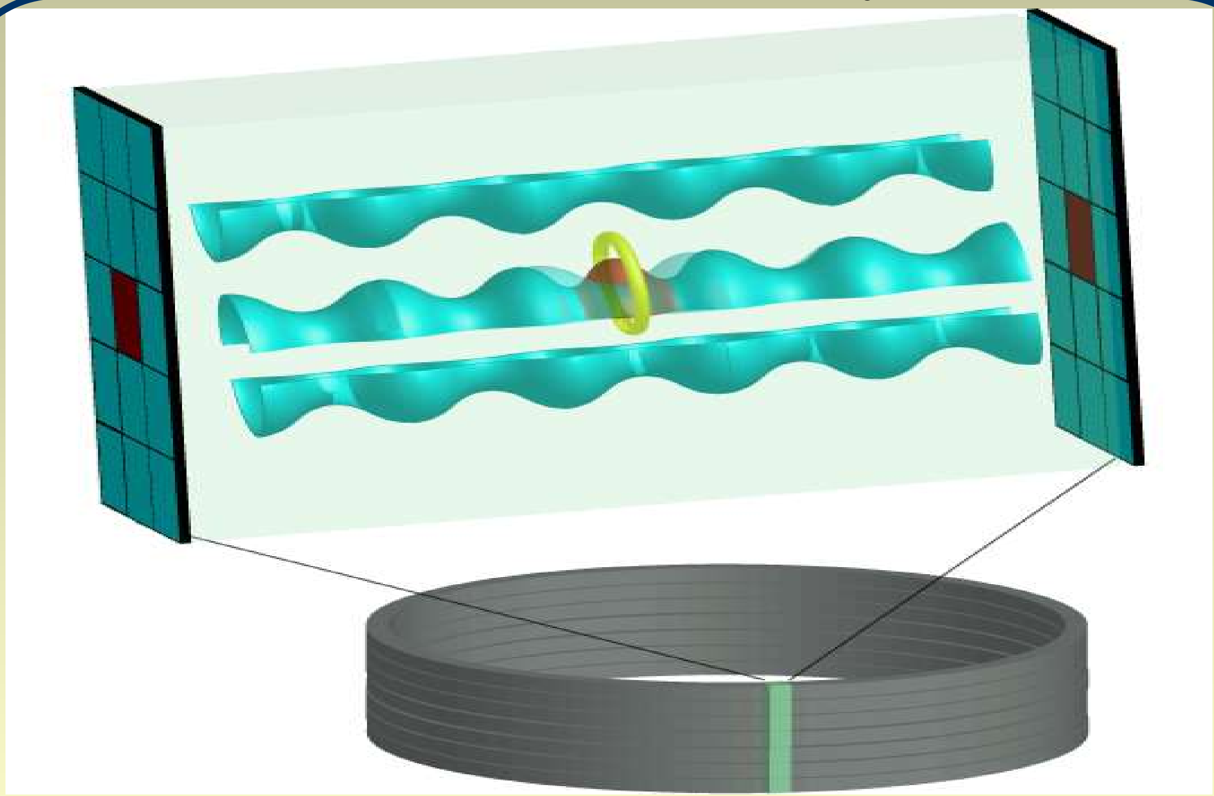
$$\frac{h}{2e}$$

Sliding regime

$$\frac{AB\ amplitude}{CDW\ current} \approx 0.1$$

We propose the CDW Dislocation loop model

Edge dislocation loop : soliton



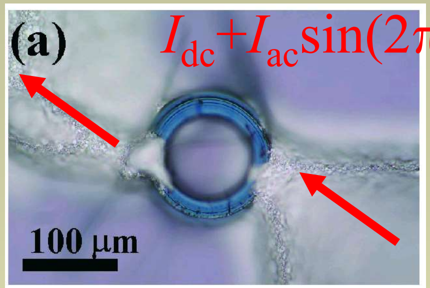
The dislocation loop of CDW cannot escape from a CDW chain, and provides 2e charge.

M. Tsubota, K. Inagaki, S. Tanda, Physica B: Condensed Matter
Vol. 404, pp416-418, (2009)

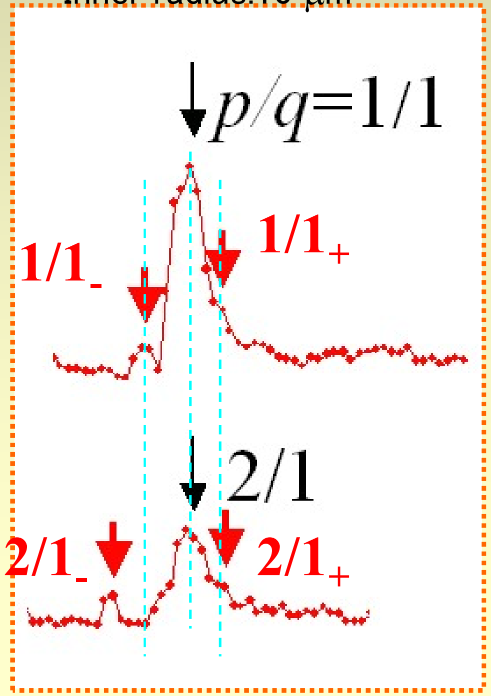
Quanta by Real space topology

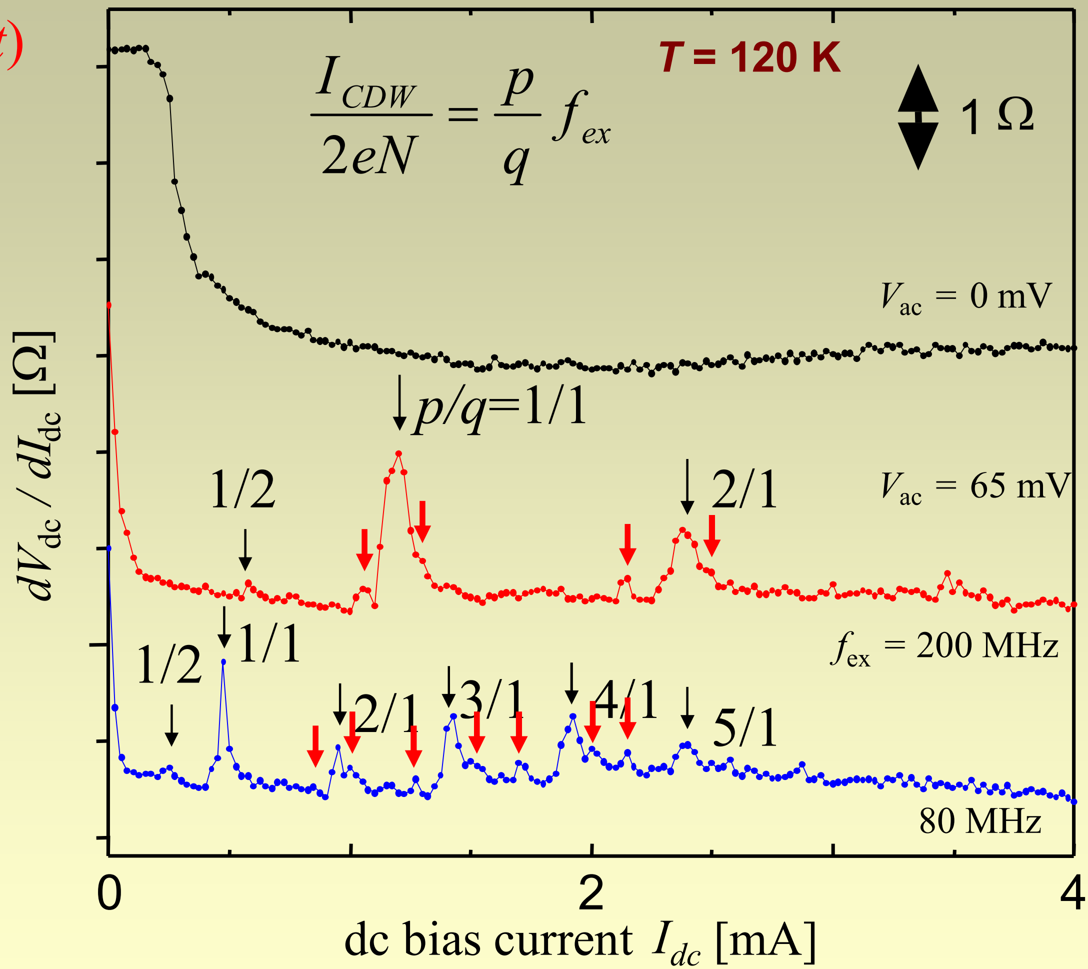
1. **AB Effect of CDW in the Loop**
2. **Circulating current of CDW**
   By Shapiro Steps in the Loop
3. **Memory Effect: Ido Steps**

★★ Shapiro peaks in CDW loops



$NbSe_3$ ring
Outer radius: 120 μm
Inner radius:10 μm

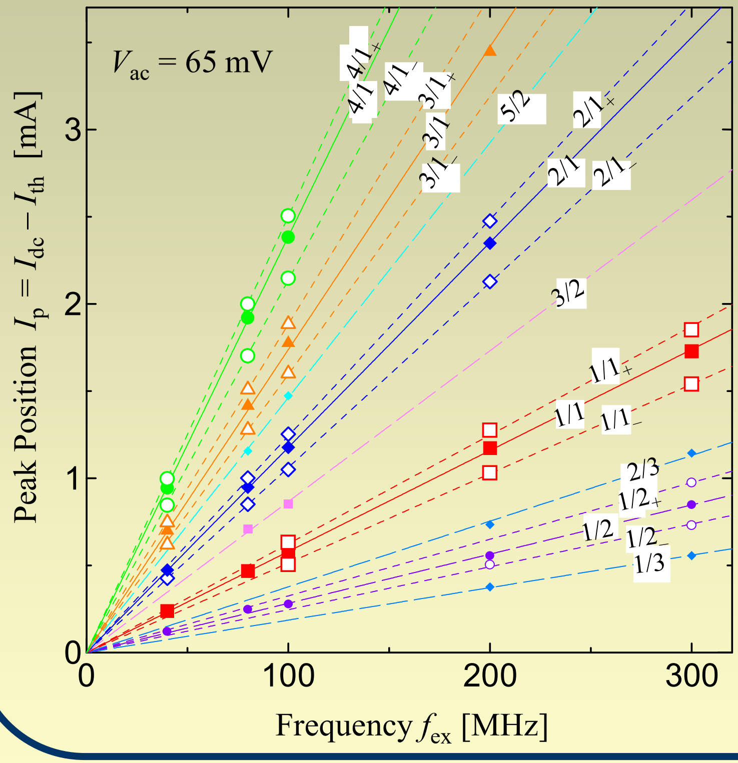




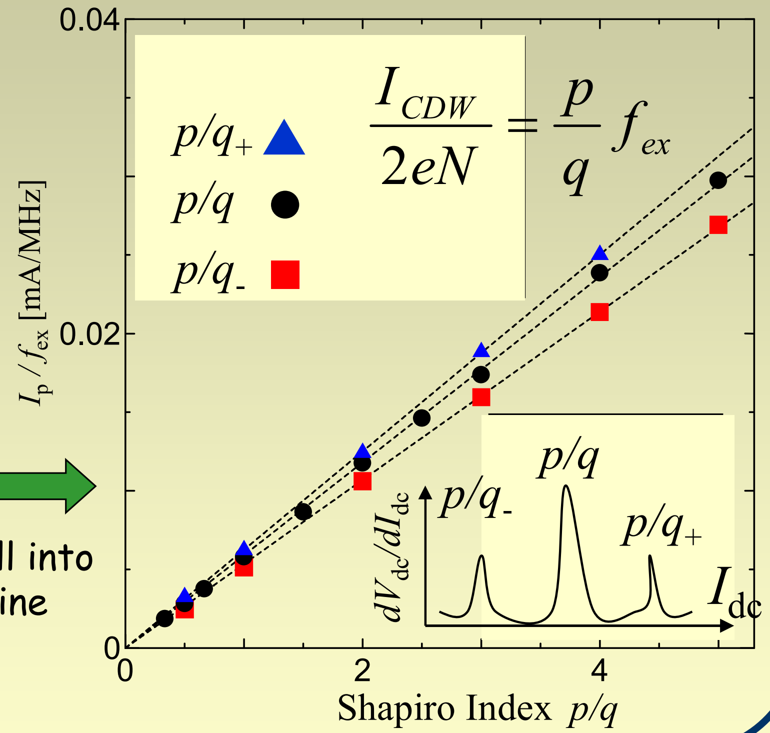
Subpeaks at both sides of Shapiro peaks are observed!

Analysis of peak positions

f_{ex} = 40, 80, 100, 200, 300 MHz

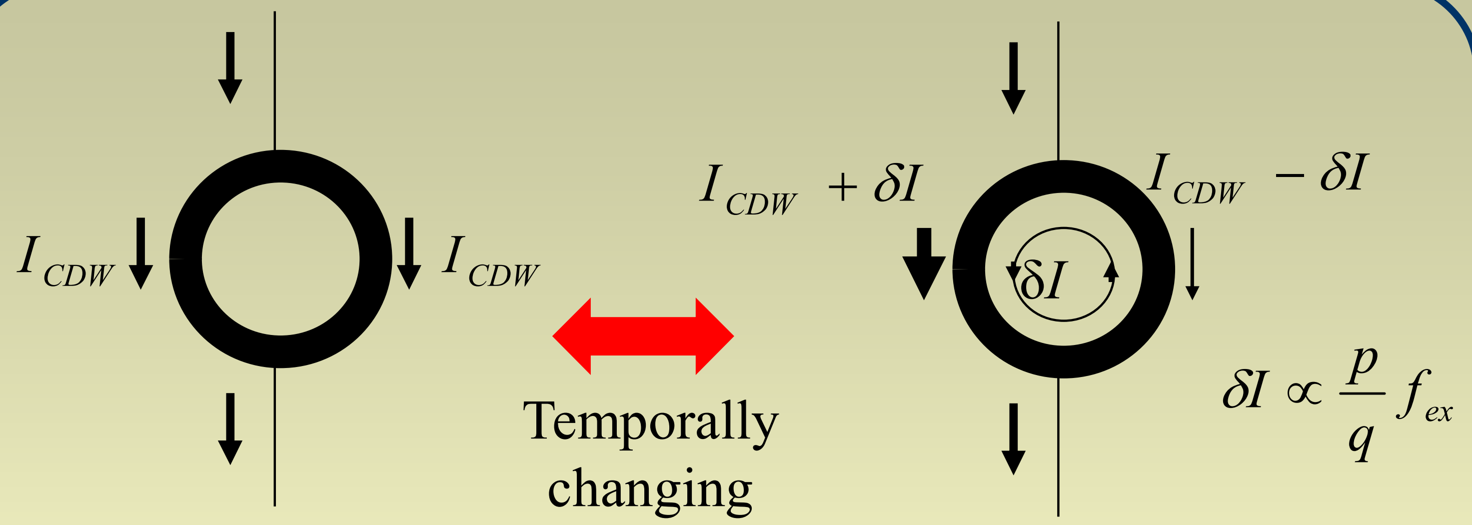


Fall into 3 line



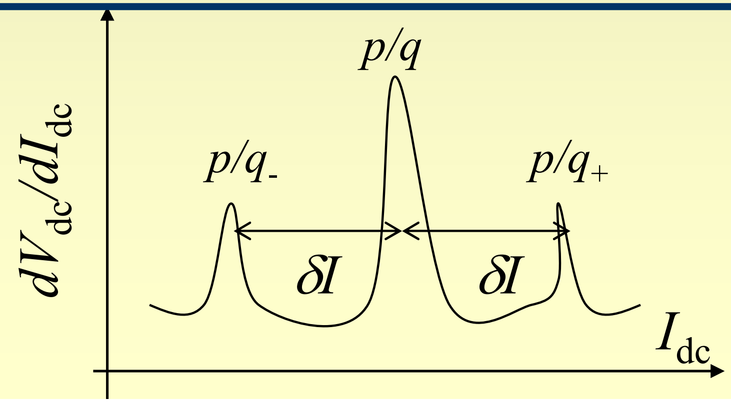
Discovery of Beat peak only in the loop CDW !!

Circulating current



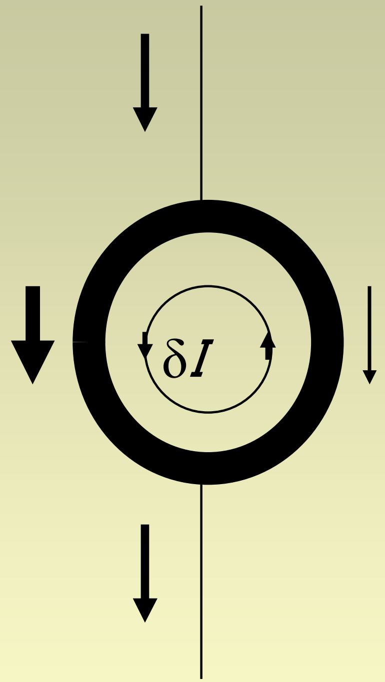
$$\frac{I_{CDW}}{2eN} = \frac{p}{q} f_{ex}$$

$$\frac{I_{CDW} \pm \delta I}{2eN} = \frac{p}{q} f_{ex}$$



Additional current must exist in the loop CDW

Damping time of Circulating current



If CDW is circulating, the damping time can be estimated by

Circumference: 10^{-4} m

Phason velocity: 10^{4} m/s

Circumference / Phason velocity = 10^{-8} s

>> $NbSe_3$ Phason damping time: 10^{-11} s

Richard and Chen, Solid State Commun. **86** 485 (1993)

Elongation of damping time !!

→ Precursor of Fröhlich supercurrent

T. Matsuura, K. Inagaki, and S.Tanda, Phys.Rev.B 79, 014304 (2009).

Quanta by Real space topology

1. AB Effect of CDW Loop
2. Circulating current of CDW
   By Shapiro Steps in the Loop
3. Memory Effect: Ido Steps

Pulse-duration Quantization Memory Effect: Quantum Time Density Wave

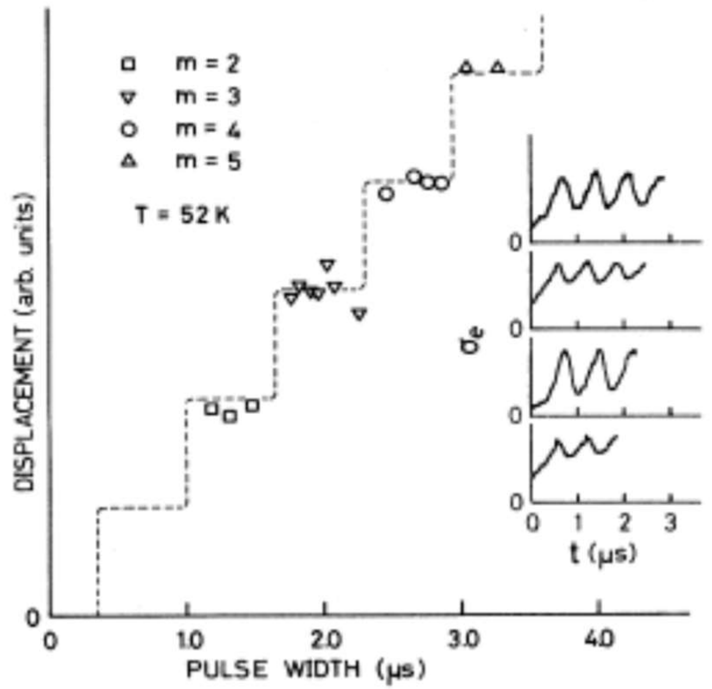


FIG. 2. Displacement of the CDW within a pulsed field as a function of the pulse width (arbitrary unit). The dotted line is a guide for the eye. Inset: Dependence of the extra conductivity due to sliding CDW on the pulse width.

Y. Okajima and M. Ido, Phys. Rev. B 40, 7553 (1989)

They suggested that phase slip events near strong pinning centers organize their timing upon application of a repetitive drive sequence.

regardless of pulse height
or pulse width

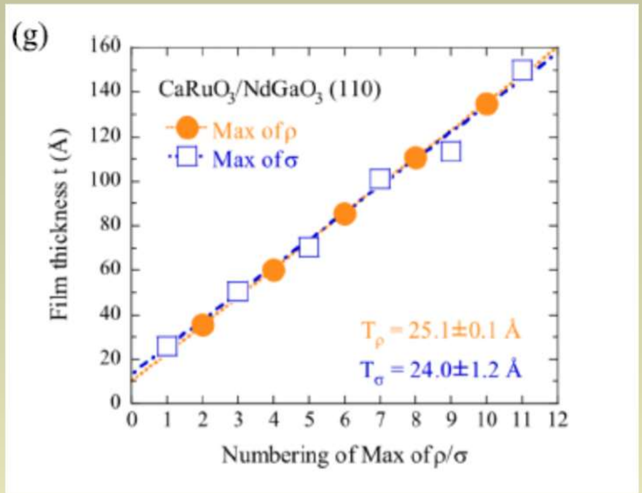
pulse first becomes
fractional

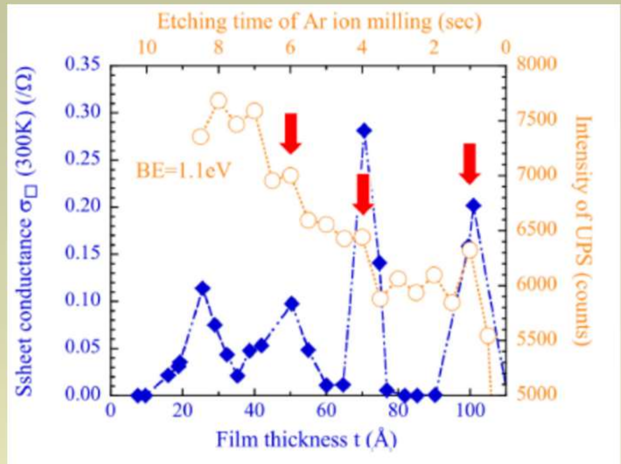
↓

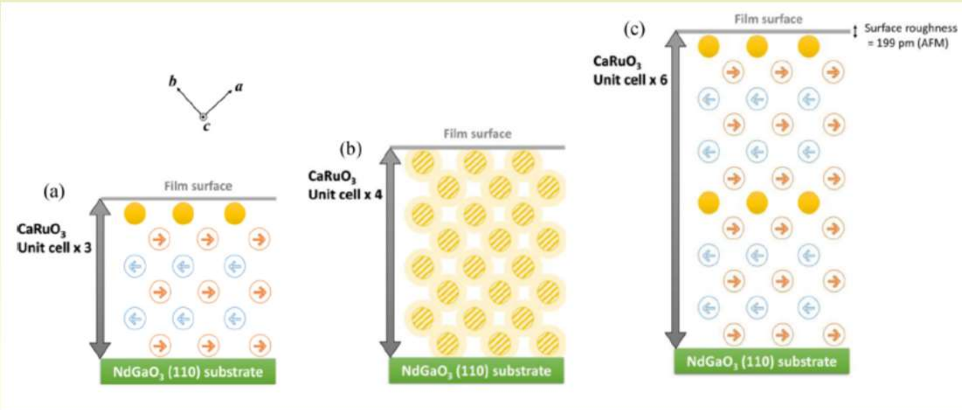
pulse duration is quantized such as an integral multiple of the CDW wavelength

↓

Time-controlled Quantum DW

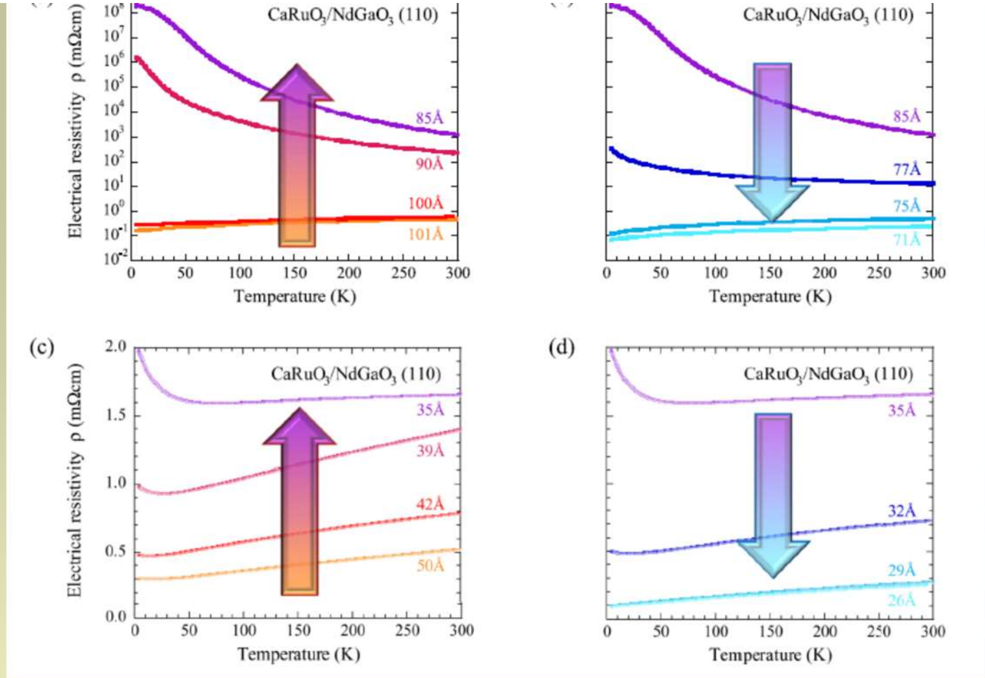


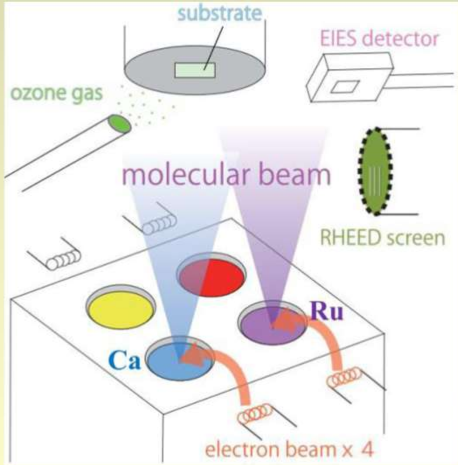


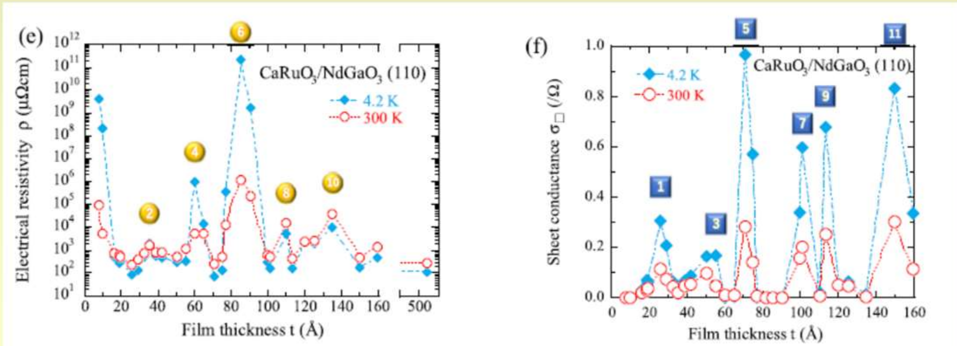


Space controlled Quantum DW

Space controlled Quantum DW







Extraordinary alternating metal-insulator transitions in CaRuO3 ultrathin films at integer multiples of 25 Å of thickness PRB 104, 195420 (2021)
M. Sakoda ,1,* H. Nobukane ,2,3 S. Shimoda,4 and S. Tanda1,3

1.Aharonov-Bohm effects in Real-space loop

CDW Dynamics is Quantum

2. Can Monolayer and Monostring be CDWs？

Dose the BKT phase exist in CDW system ?

YES → **Under what condition ?**

NO ↓

New Topological Phase ?

Line defects

Plane defects

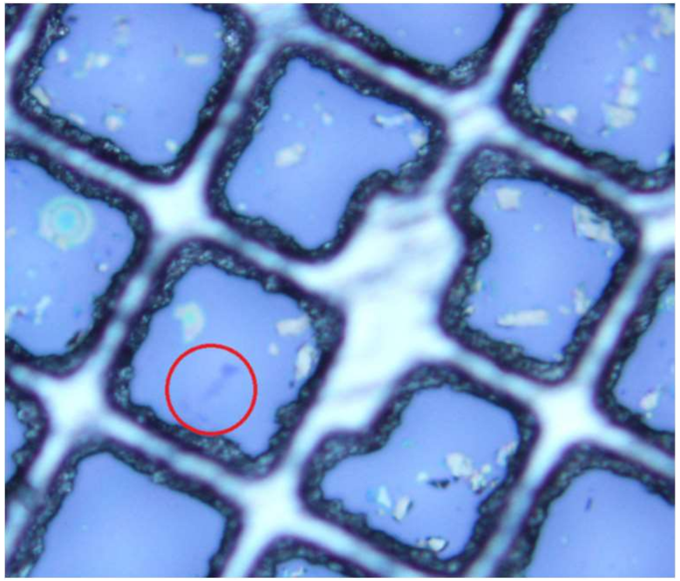
Texure

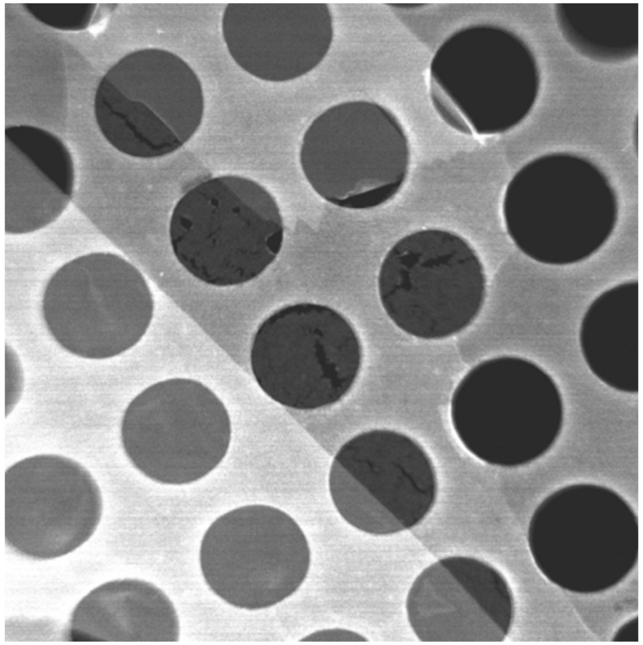
The important things is evidence of existence of CDW !

Direct Observation

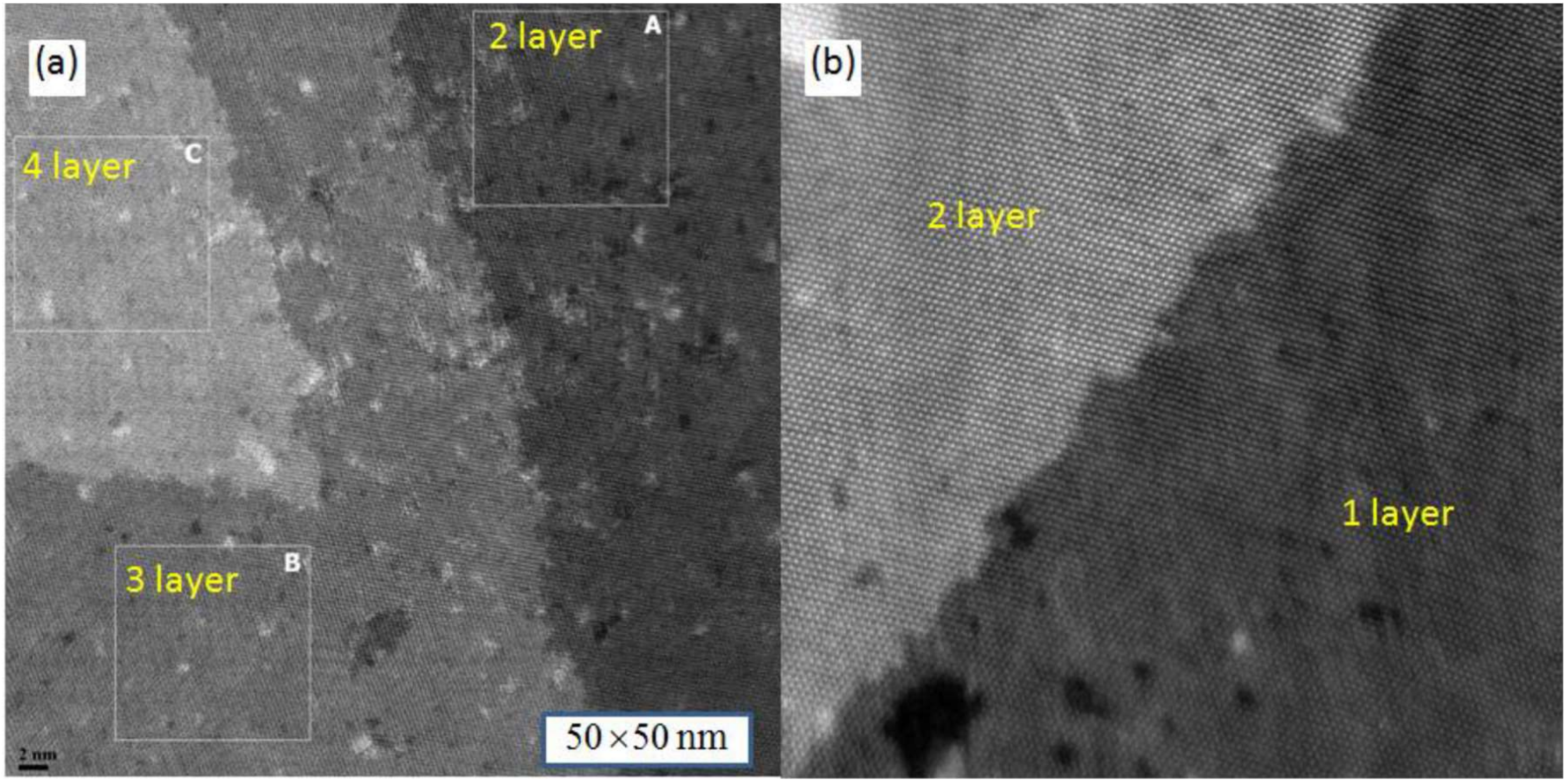
Without a substrate

Exforliate



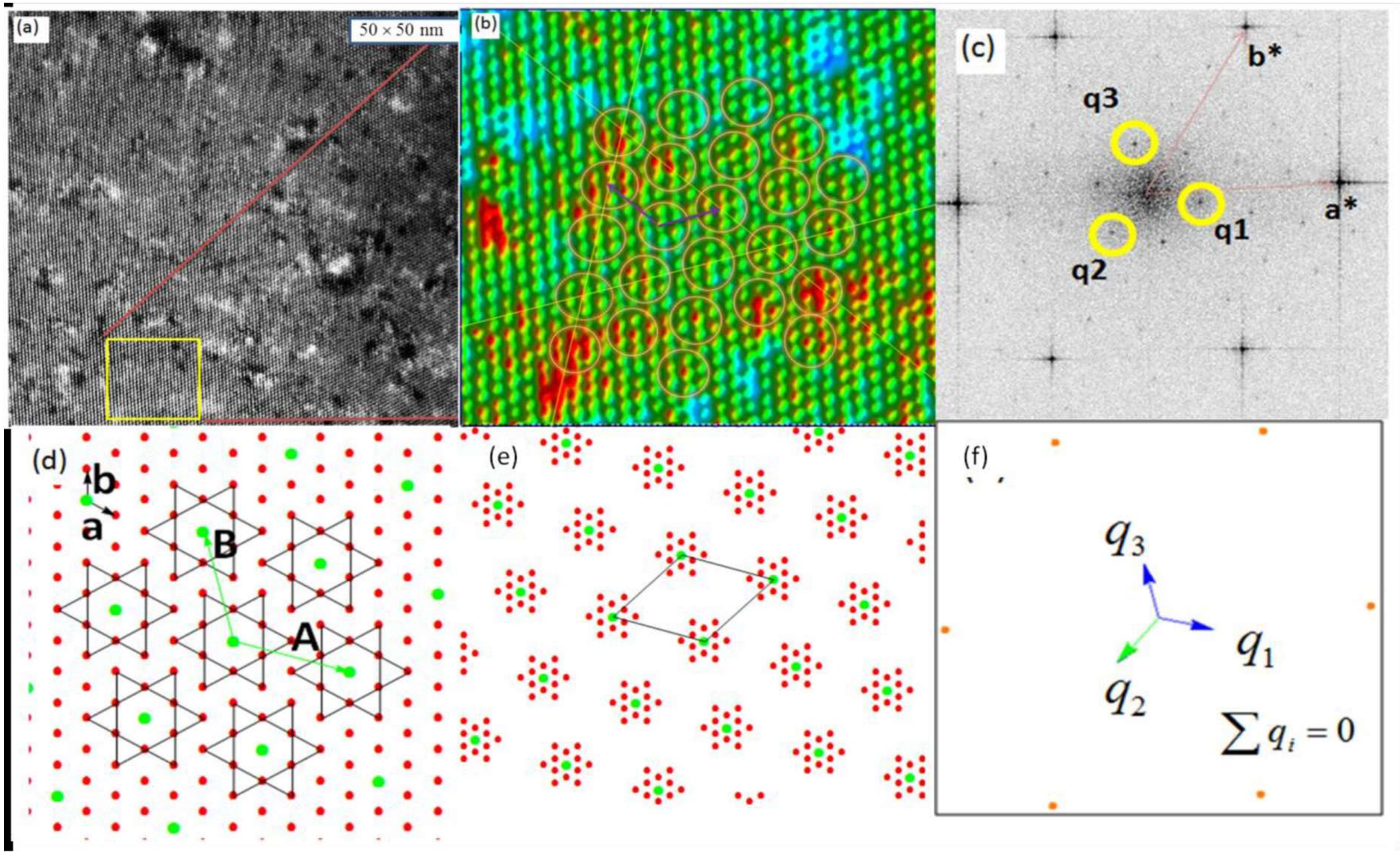


Low Bias vortage Scanning Transmission Electron microscope



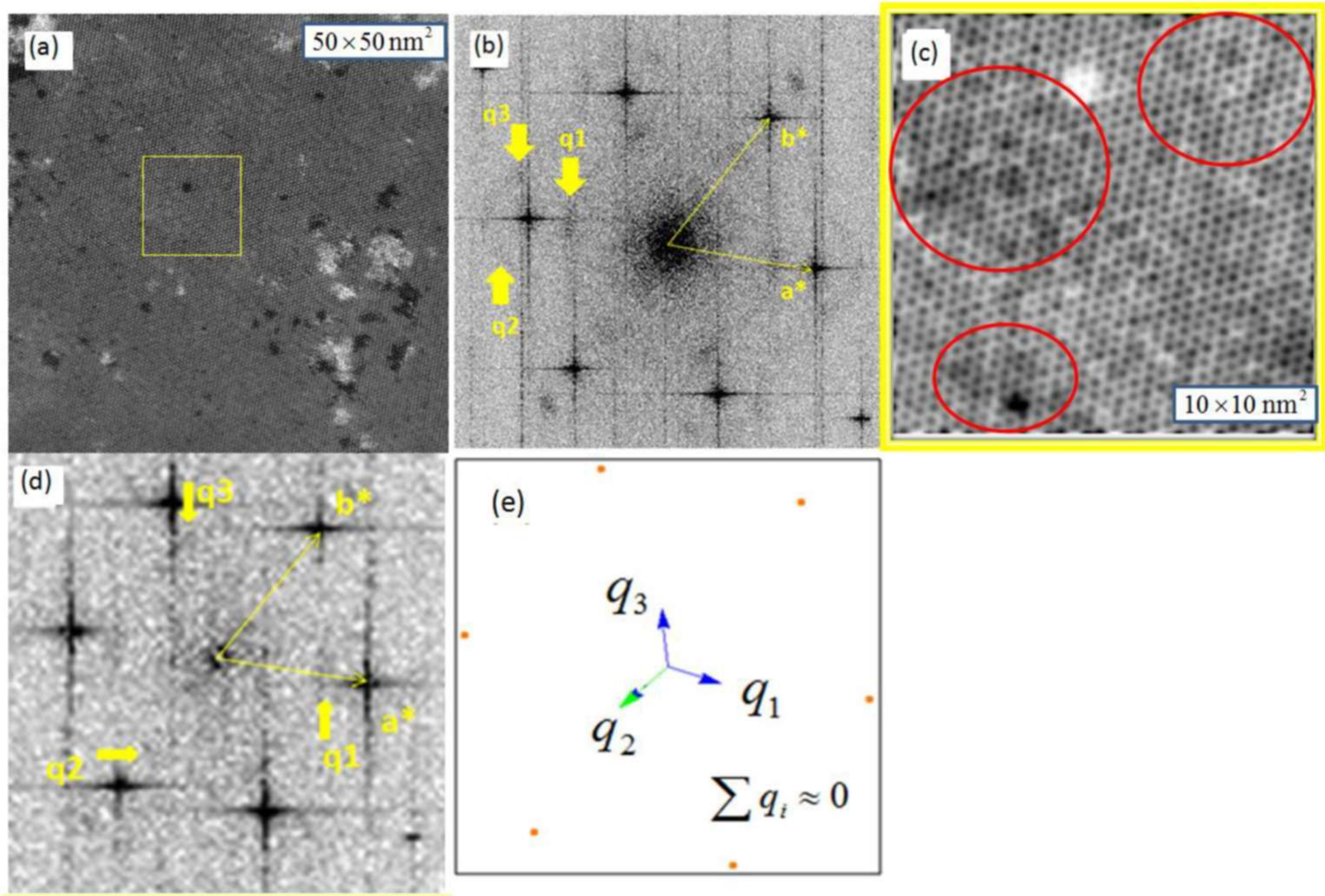
The magnitude of the brightness corresponds to the number of layers

Trilayer 1T-TaS2 ➡ Commensurate CDW emerge at room temperatute, Surprisingly !.



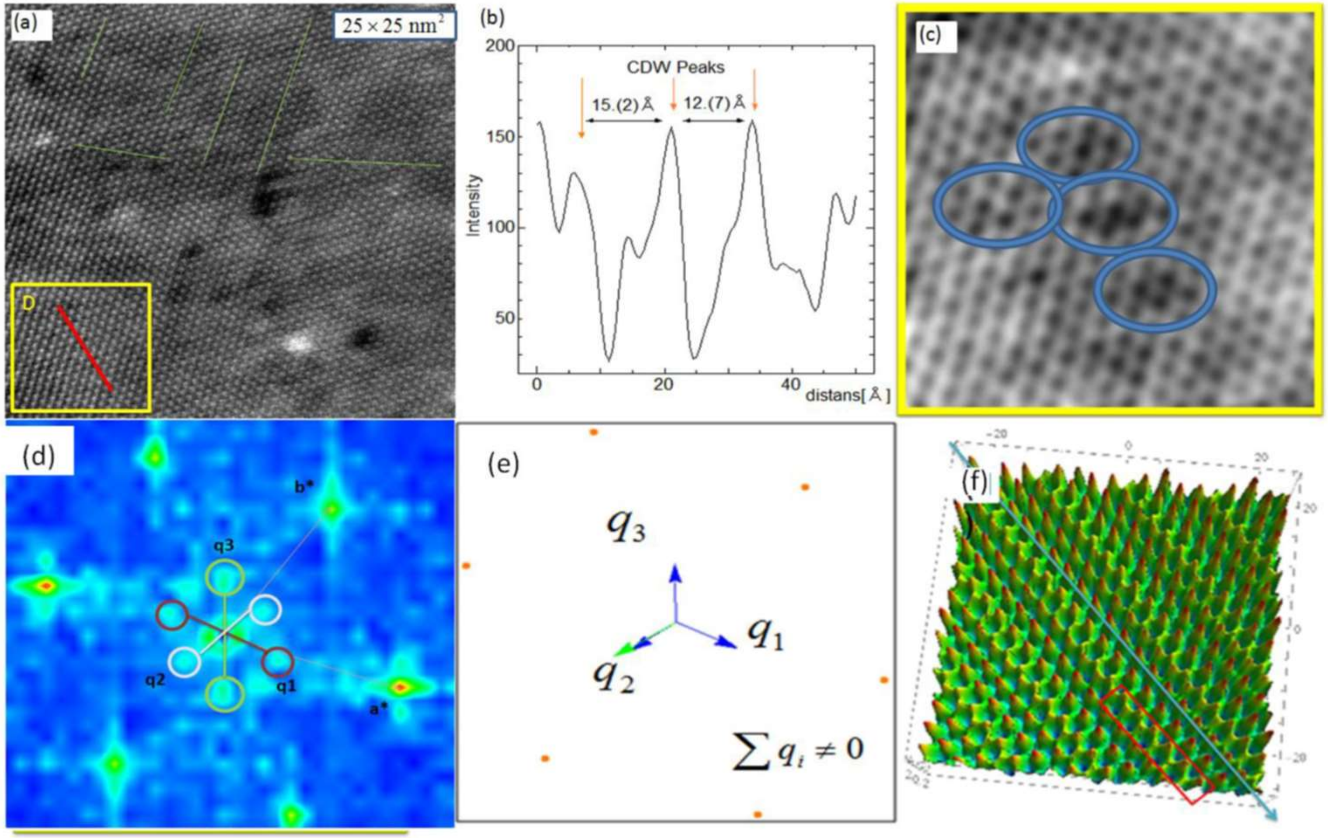
Surprisingly, super-lattices of C-CDW are seen throughout the entire sample and are particularly obvious in the yellow frame in the lower left of this image

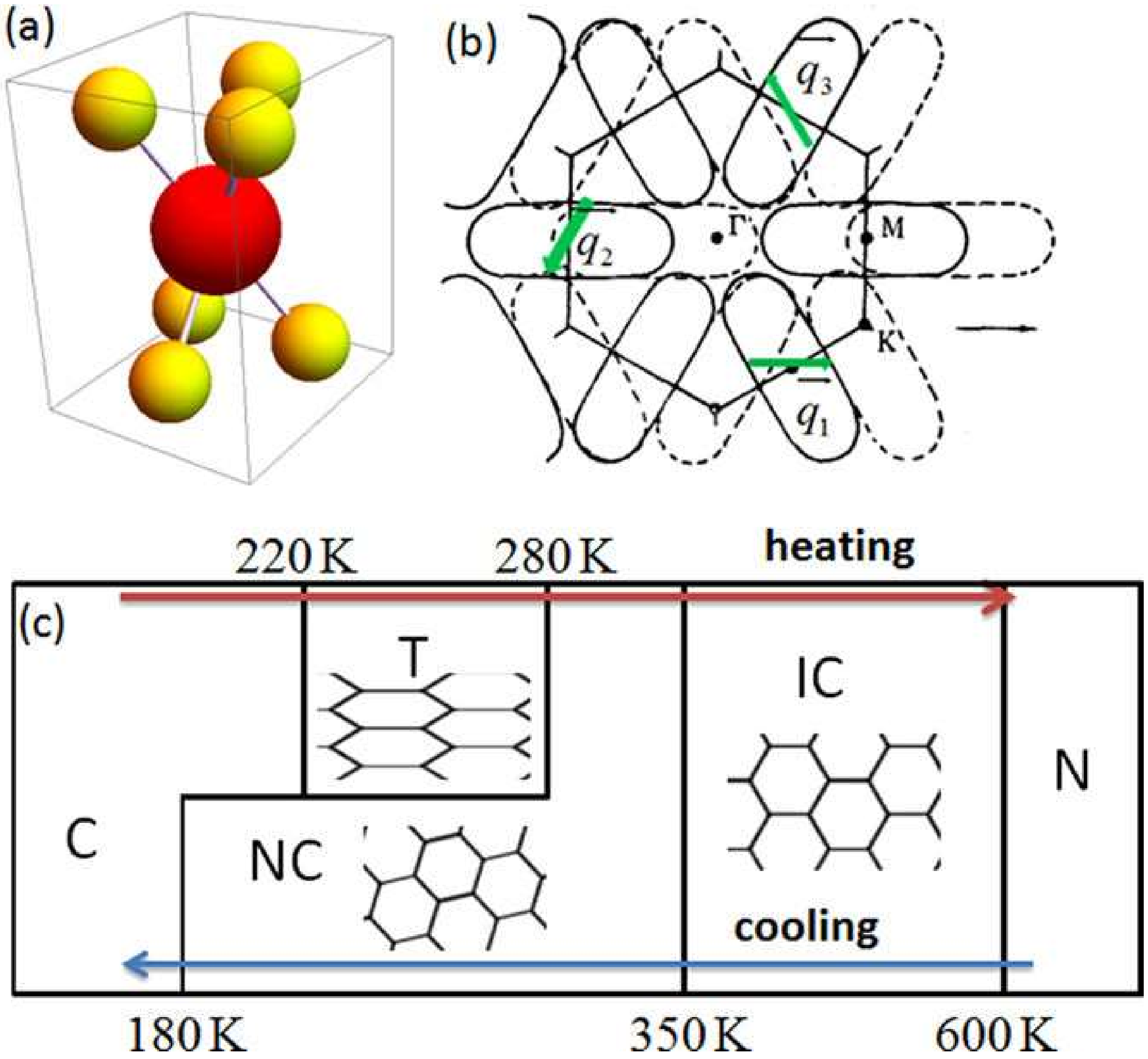
Bi-layer 1T-TaS2



The sum of **q** vectors is approximately **0**

Mono-layer 1T-TaS_2

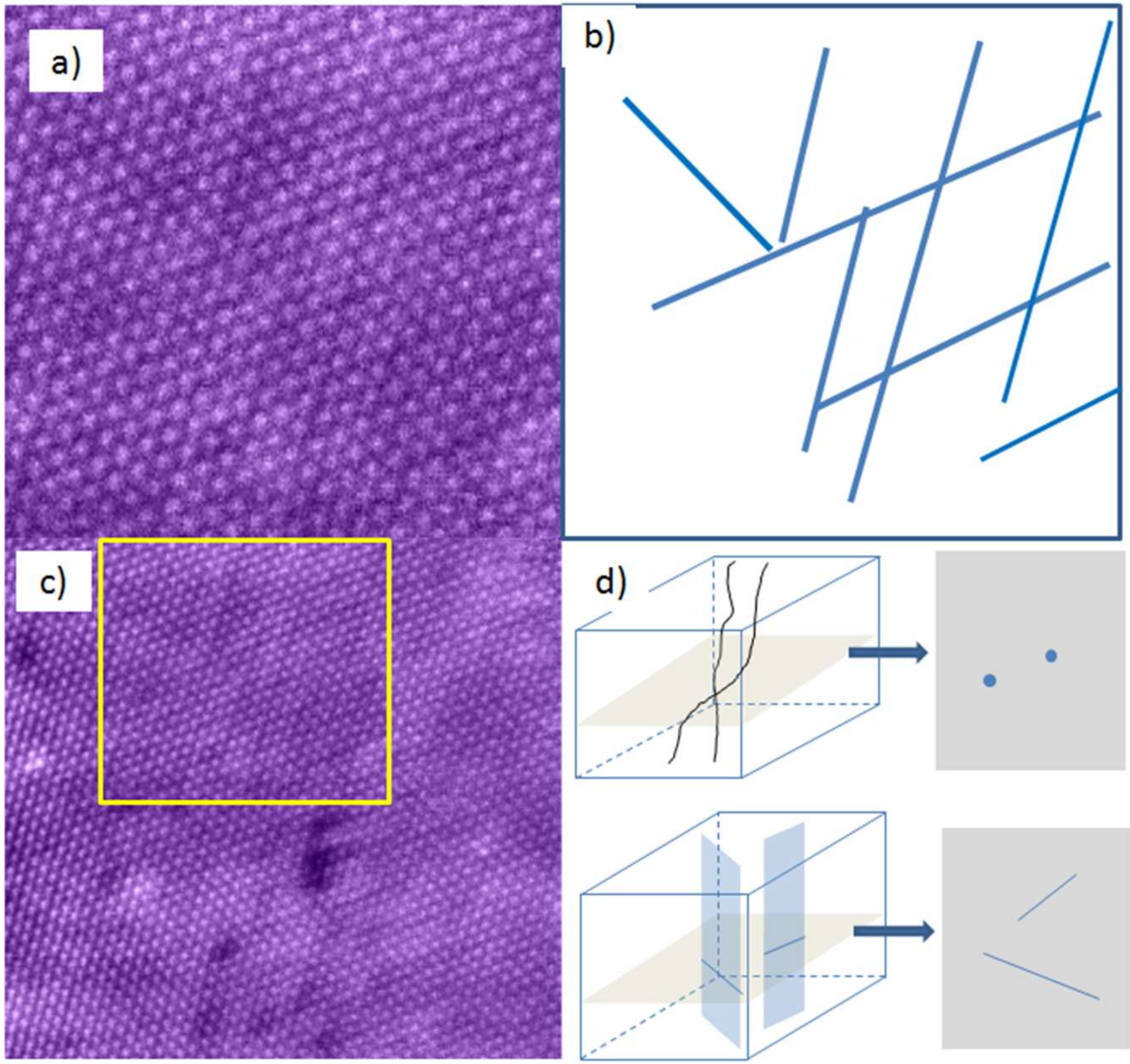




Synthetic Metals, 11 (1985) 85-100. J. Phys. Soc. Jpn, 53 2 (1984) 476-479.

	Experimental Results		Bulk Data (Previous Works)	
(a)	Tri-layer		Commensurate phase	
q	$\mid \mathbf{q}_i \mid / \mid \mathbf{a}* \mid$	ψ	$\mid \mathbf{q}_i \mid / \mid \mathbf{a}* \mid$	ψ
	0.280(8)	13.3°	0.277	13.90
(b)	Bi-layer		Nearly-Commensurate phase	
	$\mid \mathbf{q}_i \mid / \mid \mathbf{a}* \mid$	ψ_i	$\mid \mathbf{q}_i \mid / \mid \mathbf{a}* \mid$	ψ_i
$\mathbf{q}_1$	0.287(2)	9.0°		
$\mathbf{q}_2$	0.277(2)	10.0°	0.283	12.7°
$\mathbf{q}_3$	0.287(1)	11.5°		
(c)	Mono-layer		T-phase (T = 270K) [15]	
	$\mid \mathbf{q}_i \mid / \mid \mathbf{a}* \mid$	ψ_i	$\mid \mathbf{q}_i \mid / \mid \mathbf{a}* \mid$	ψ_i
$\mathbf{q}_1$	0.323(0)	7.5°	0.288	15.6°
$\mathbf{q}_2$	0.276(3)	15.5°	0.303	13.4°
$\mathbf{q}_3$	0.293(8)	19.0°	0.286	11.84°

(d)	$\mathbf{q1} + \mathbf{q2} + \mathbf{q3}$	Correlation Length
higher layer	$= \mathbf{0}$	
tri-layer	$= \mathbf{0}$	70 ± 25Å
bi-layer	$\approx \mathbf{0}$	30 ± 10Å
mono-layer	$\neq \mathbf{0}$	7.5 ± 2.5Å


a)
b)
c)
d)

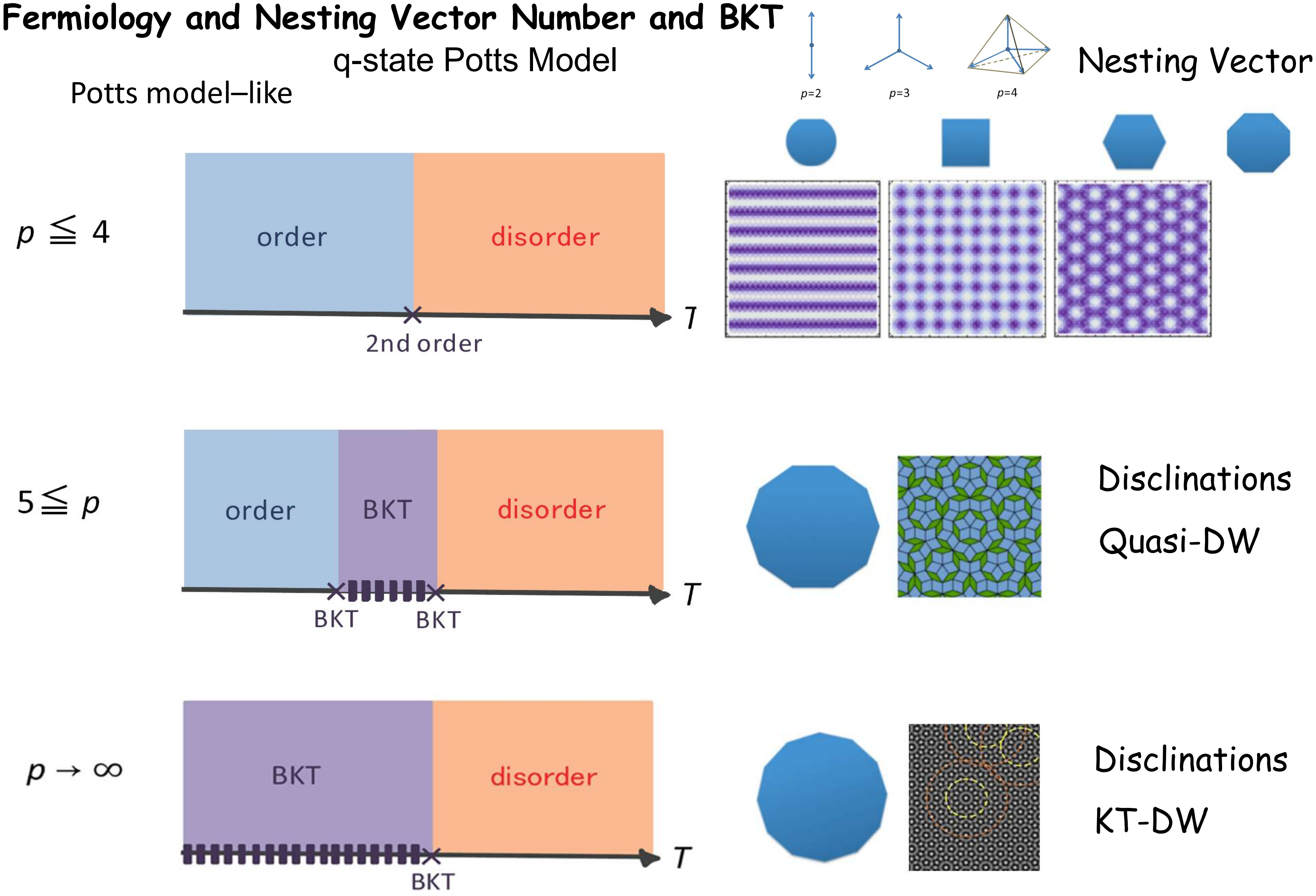
Kosterlitz line: line defects in CDW monolayer

Conference on Topology and its Applications
Kentucky, USA, 2018

I proposed to call this line defect the "Kosterlitz line".

He immediately said "OK"

Fermiology and Nesting Vector Number and BKT



Chiral charge-density waves

Phys. Rev. Lett. 105, 176401 (2010)

J. Ishioka, Y. H. Liu, K. Shimatake, T. Kurosawa, K. Ichimura, Y. Toda, M. Oda, S. Tanda

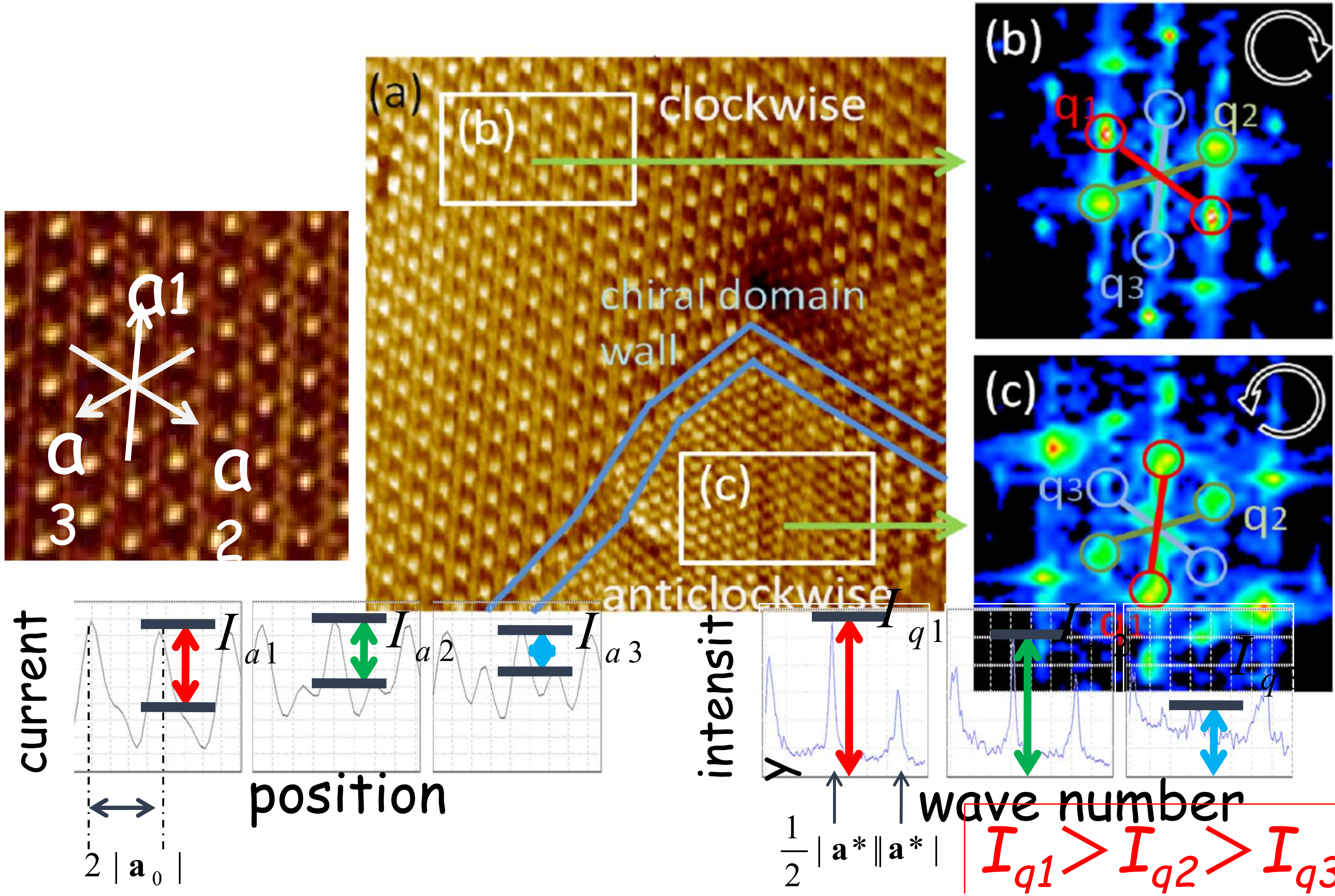
PHYSICAL REVIEW B **84**, 245125 (2011)

Charge-parity symmetry observed through Friedel oscillations in chiral charge-density waves

J. Ishioka,[1] T. Fujii,[2] K. Katono,[1] K. Ichimura,[1,3] T. Kurosawa,[4] M. Oda,[3,4] and S. Tanda[1,3]

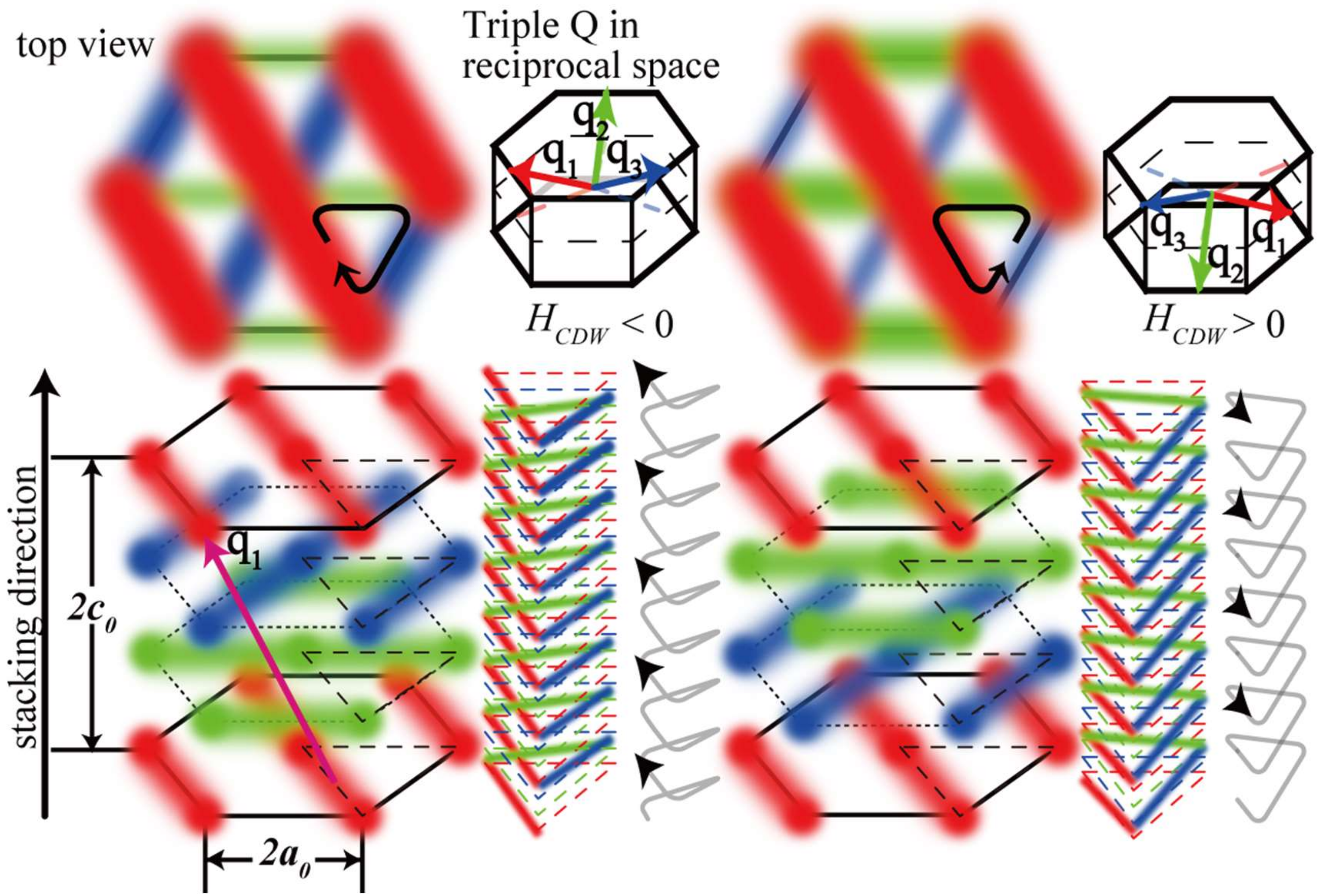
PHYSICAL REVIEW B **86**, 247102 (2012)

STM image and Fourier image on 1T-TiSe$_2$ CDW

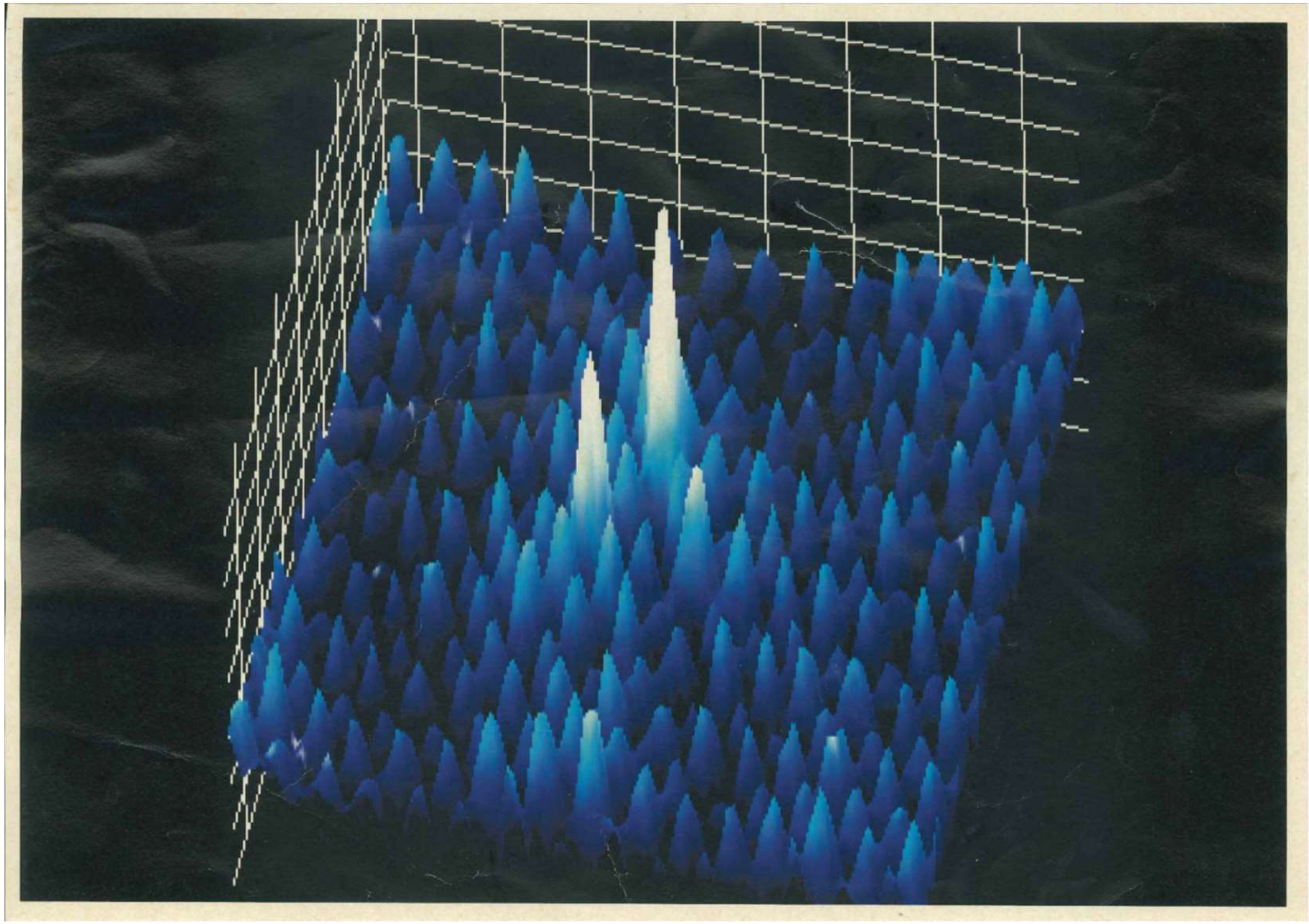


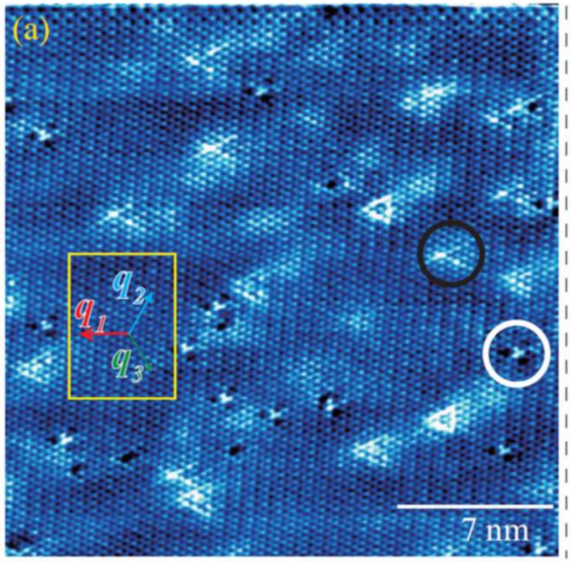
$I_{q1} > I_{q2} > I_{q3}$

Helical charge density wave model formed by triple-q

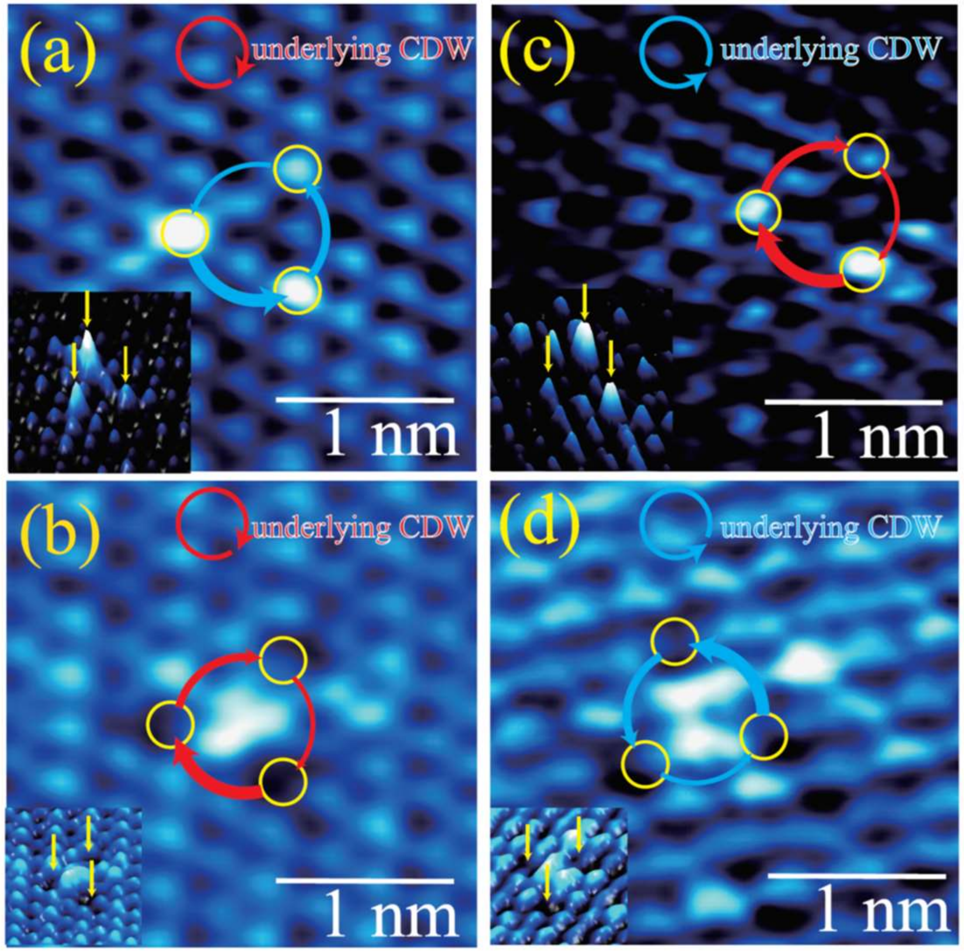


Point-like defect





(a)
q2
q1
q3
7 nm



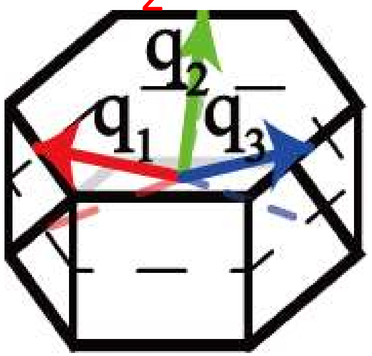
(a)
underlying CDW
1 nm
(c)
underlying CDW
1 nm
(b)
underlying CDW
1 nm
(d)
underlying CDW
1 nm

New internal degree of freedom:
CDW helicity: Nesting vector Number 6

$$H_{CDW} \equiv \mathbf{q}_1 \cdot (\mathbf{q}_2 \times \mathbf{q}_3)$$

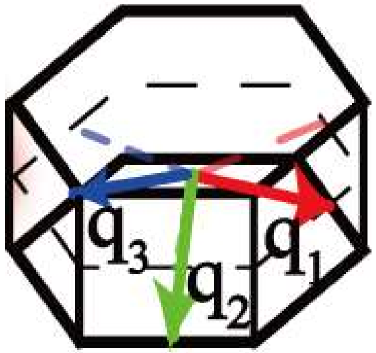
$H_{CDW} < 0$

1T-$TiSe_2$



left-handed chiral CDW

$H_{CDW} > 0$

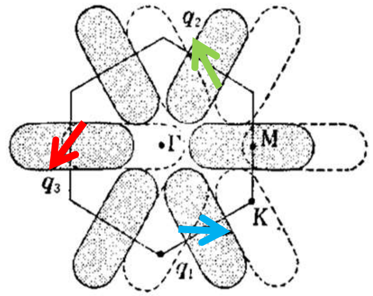


right-handed chiral CDW

$$H_{CDW} \equiv \mathbf{q}_1 \cdot (\mathbf{q}_2 \times \mathbf{q}_3) \neq 0$$

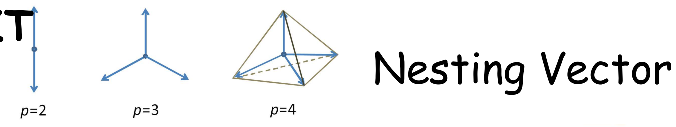
$H_{CDW} = 0$

Ex.1T-TaS_2

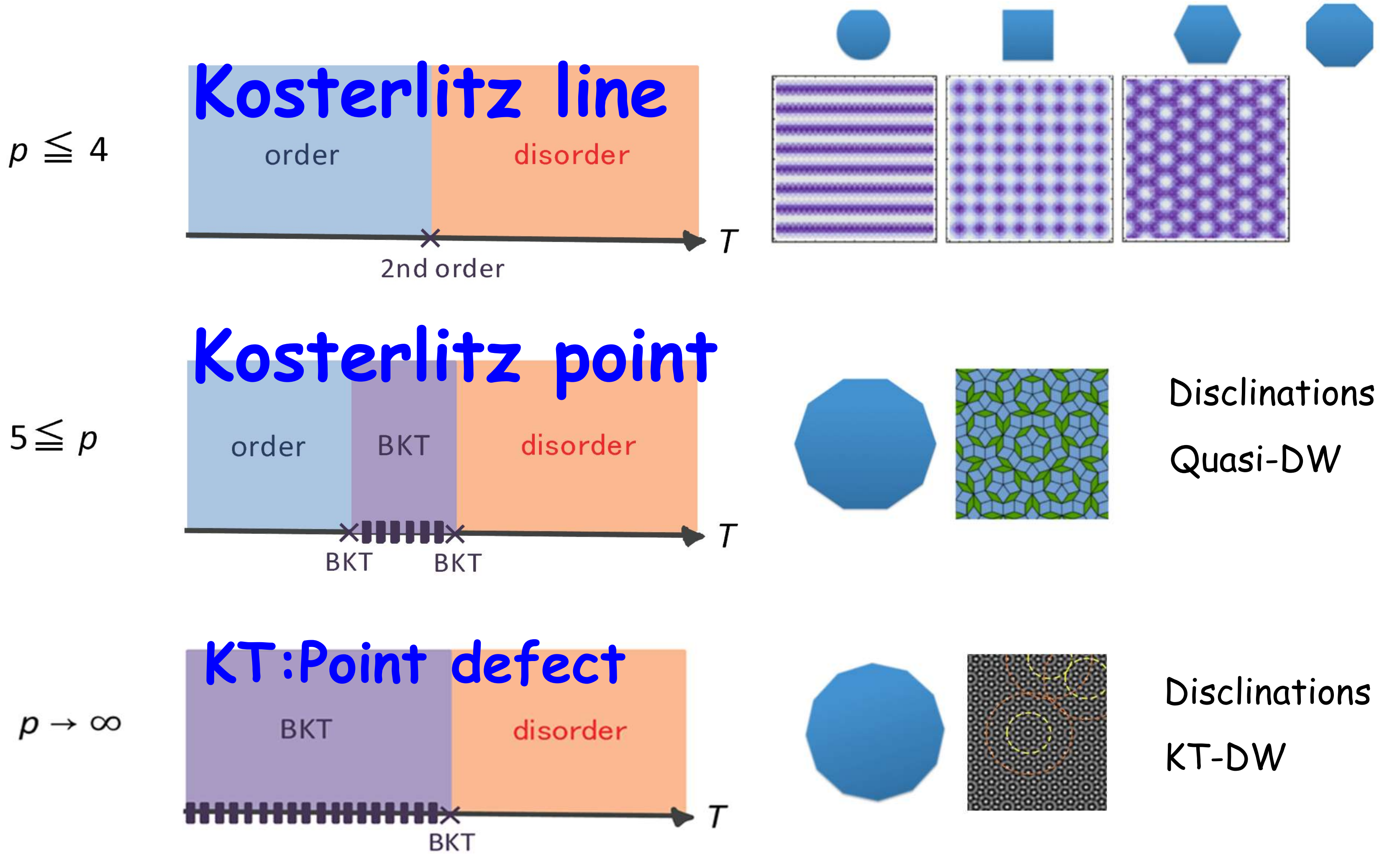


typical 2D CDW (Plane)

Fermiology and Nesting Vector Number and KT



Potts model–like



Nakanishi-Shiba model (extended McMillan model)

$$F=\sum_l \int d^2r\left[\sum_{j=1,2,3}\{\phi^*_{jl}A_j(Q_{cj}-i\nabla,T)\phi_{jl}+B|\phi_{jl}|^4+C|\phi_{jl}|^2|\phi_{j+1\,l}|^2\right.$$
$$+E\,\mathrm{Re}\,(\phi^3_{jl}\phi^*_{j+1\,l})\}+D\,\mathrm{Re}\,(\phi_{1l}\phi_{2l}\phi_{3l})]$$

→ Commensurability energy

$$+\sum_l G\int d^2r \sum_{j=1,2,3}\mathrm{Re}\,[e^{ig}\phi^*_{jl}\phi_{jl+1}+a\,e^{ig'}\phi^*_{jl}\phi_{jl+2}],$$

→ Interlayer Coupling

Bi-layer coupling nearest neighbor

Tri-layer coupling: (next nearest neighbor)

Mono-layer ?

We found that stripe is Possible without Interlayer Coupling .

Origin of Stripe and Quasi-Stripe CDW Structures in Monolayer MX_2 Compounds Nakatsugawa, S. Tanda & T.N. Ikeda, Scientific Reports 10, 1239 (2020)

↓

Kosterlitz line: line defects in CDW monolayer

Bi-layer ? Chiral layer ?

Future Work

Monolayer exibit CDW.

Non Helicity ➡ no BKT : 3 Potts model-like

Helicity ➡ BKT : 6 potts model-like My Conjecture

Bi-layer CDW is simillar to T Phase

Tri-layer CDW is C Phase at room Temp.

1T-TaS2 TaSe2

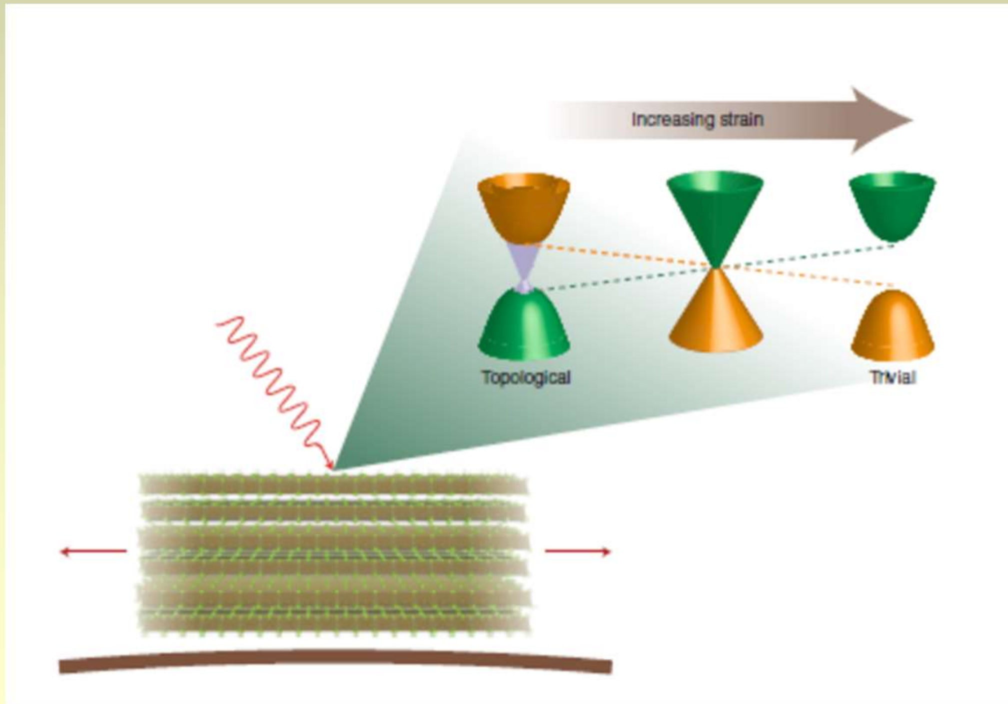
Monostring exibit CDW ?

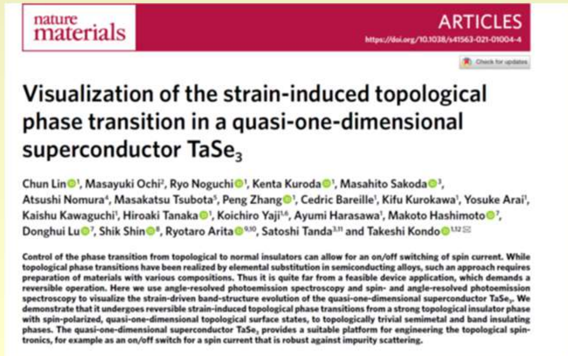
Now we try to insert MX3 in CNT

Cu doped TaSe3 is also CDW state !

EPL 2017

K-space topology control: by R-space ring





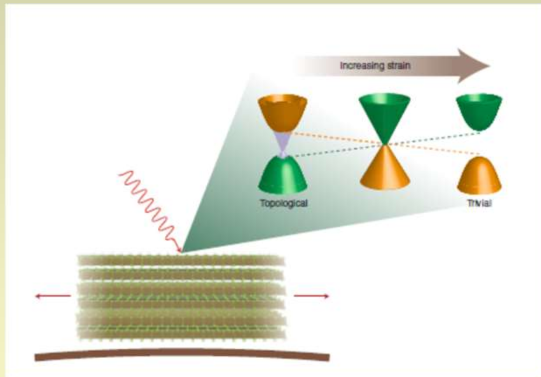
nature materials
ARTICLES
https://doi.org/10.1038/s41563-021-01004-4
Check for updates

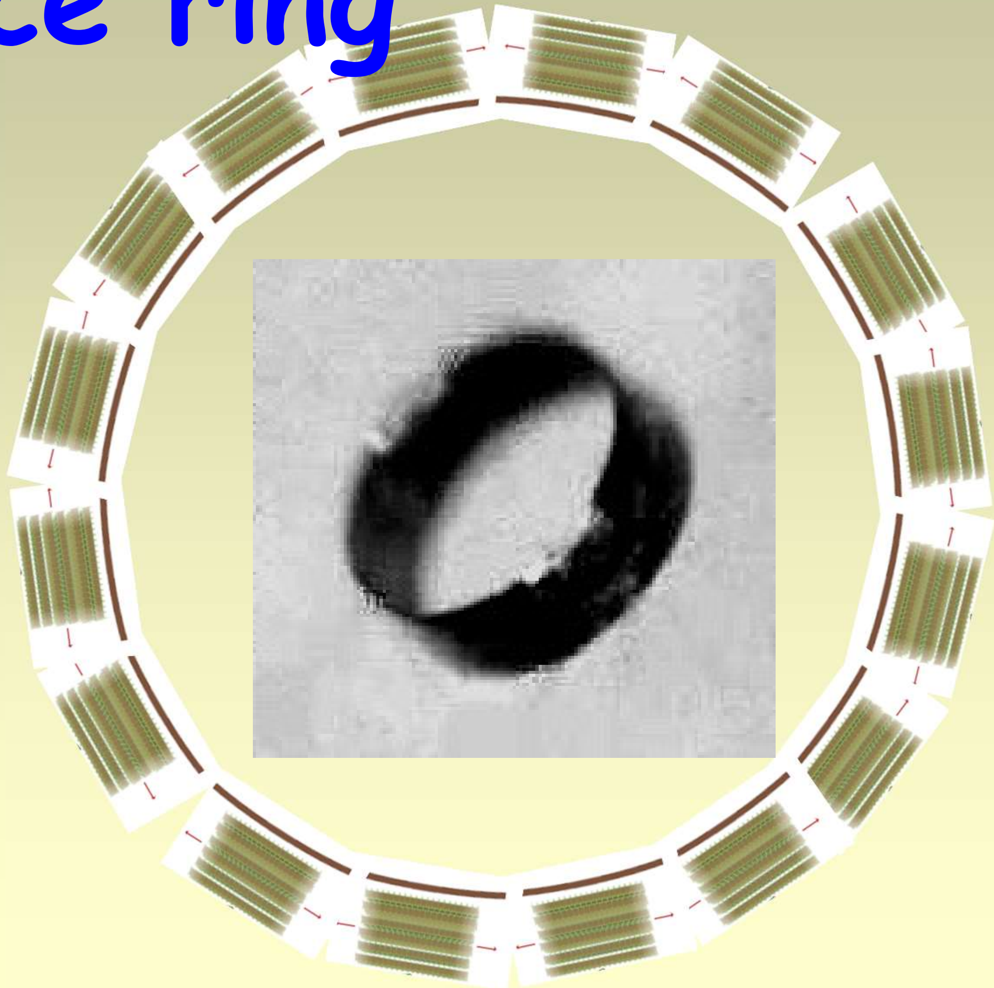
Visualization of the strain-induced topological phase transition in a quasi-one-dimensional superconductor $TaSe_3$

Chun Lin[1], Masayuki Ochi[2], Ryo Noguchi[1], Kenta Kuroda[1], Masahito Sakoda[3], Atsushi Nomura[4], Masakatsu Tsubota[5], Peng Zhang[1], Cedric Bareille[1], Kifu Kurokawa[1], Yosuke Arai[1], Kaishu Kawaguchi[1], Hiroaki Tanaka[1], Koichiro Yaji[1,6], Ayumi Harasawa[1], Makoto Hashimoto[7], Donghui Lu[7], Shik Shin[8], Ryotaro Arita[9,10], Satoshi Tanda[3,11] and Takeshi Kondo[1,12] ✉

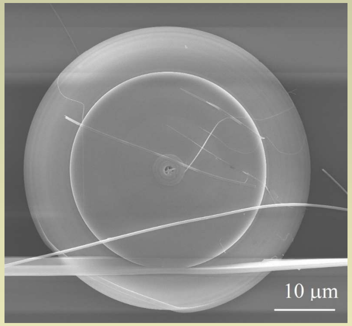
Control of the phase transition from topological to normal insulators can allow for an on/off switching of spin current. While topological phase transitions have been realized by elemental substitution in semiconducting alloys, such an approach requires preparation of materials with various compositions. Thus it is quite far from a feasible device application, which demands a reversible operation. Here we use angle-resolved photoemission spectroscopy and spin- and angle-resolved photoemission spectroscopy to visualize the strain-driven band-structure evolution of the quasi-one-dimensional superconductor $TaSe_3$. We demonstrate that it undergoes reversible strain-induced topological phase transitions from a strong topological insulator phase with spin-polarized, quasi-one-dimensional topological surface states, to topologically trivial semimetal and band insulating phases. The quasi-one-dimensional superconductor $TaSe_3$ provides a suitable platform for engineering the topological spintronics, for example as an on/off switch for a spin current that is robust against impurity scattering.

K-space topology control ← R-space ring

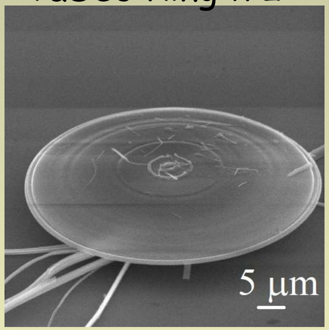


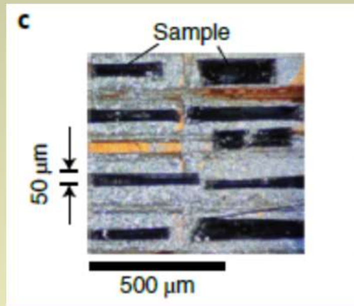


TaSe3 Ring #1

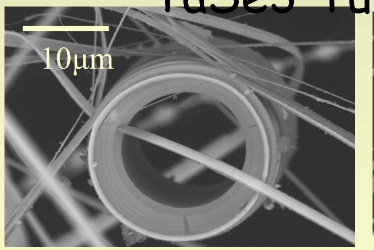


TaSe3 Ring #2

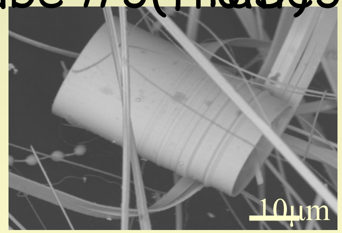




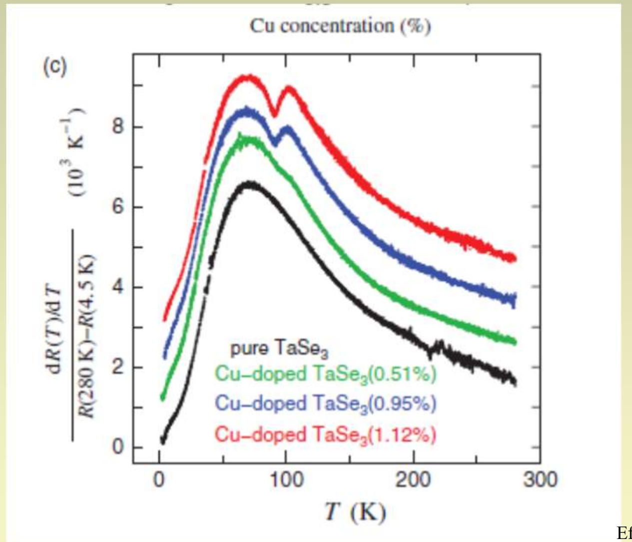
TaSe3 Tube #3(front)



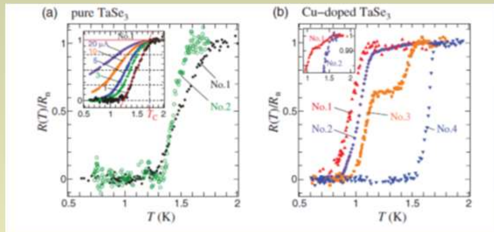
TaSe3 Tube #3 (side)

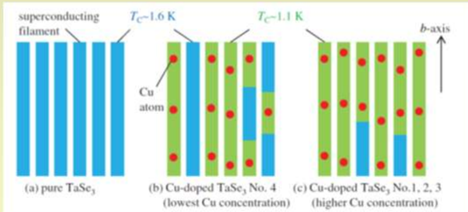


Cu dopedTaSe3 ⇒ induced CDW + Superconductors



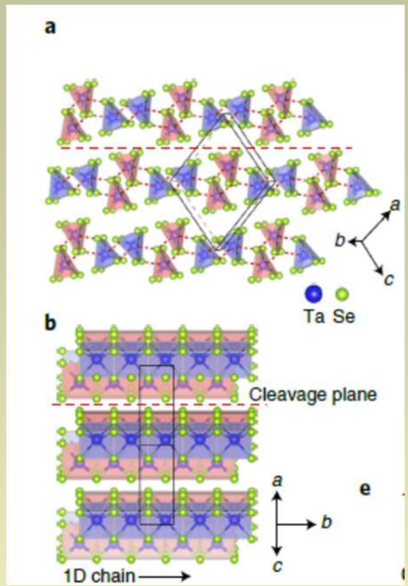
Emergence of a resistance anomaly by Cu-doping in TaSe3
A. Nomura, K. Yamaya, S. Takayanagi, K. Ichimura, T. Matsuura, S. Tanda
Europhys. Lett. 119, 17005 (2017)

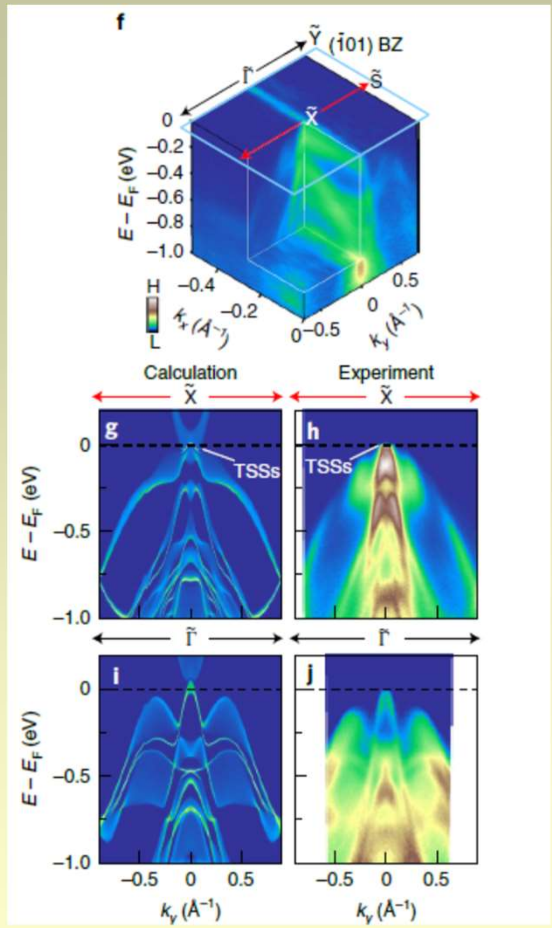


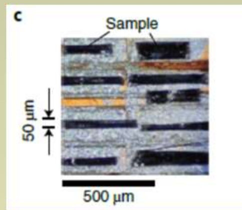


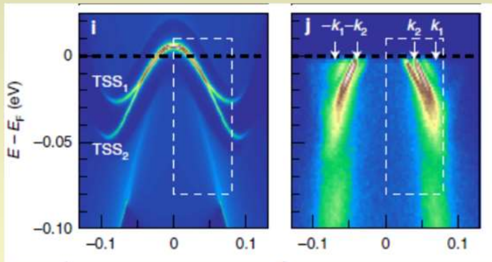
Effect of Cu doping on superconductivity in TaSe3: Relationship between superconductivity and induced charge density wave
A. Nomura, K. Yamaya, S. Takayanagi, K. Ichimura, and S. Tanda
Europhys. Lett. 124, 67001(2018)

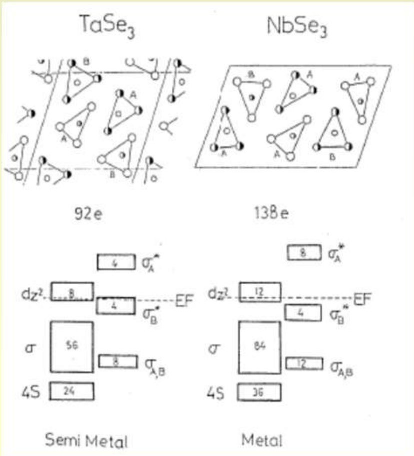
Laser Arpes to measure K-space precisely

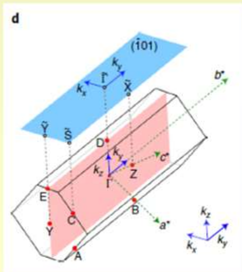




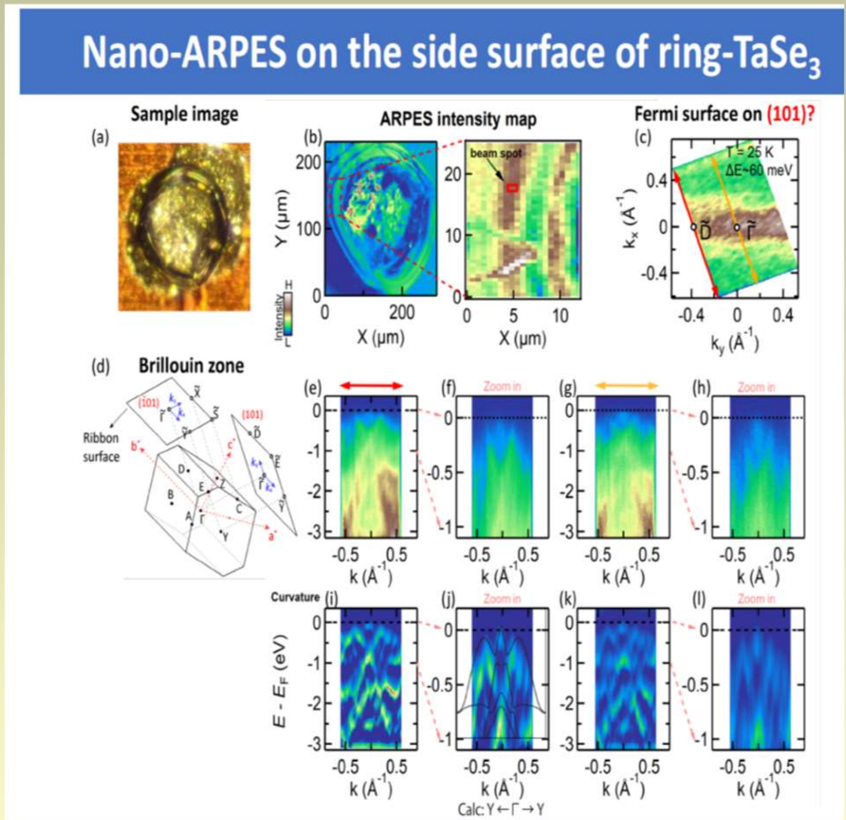




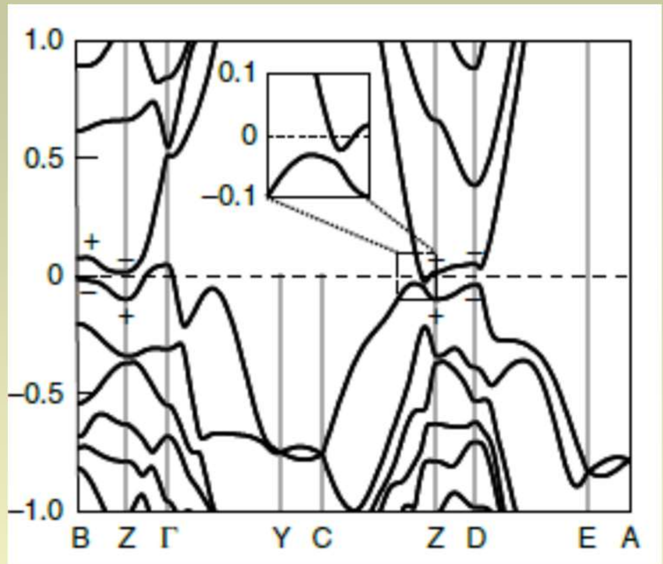




Ring Sample



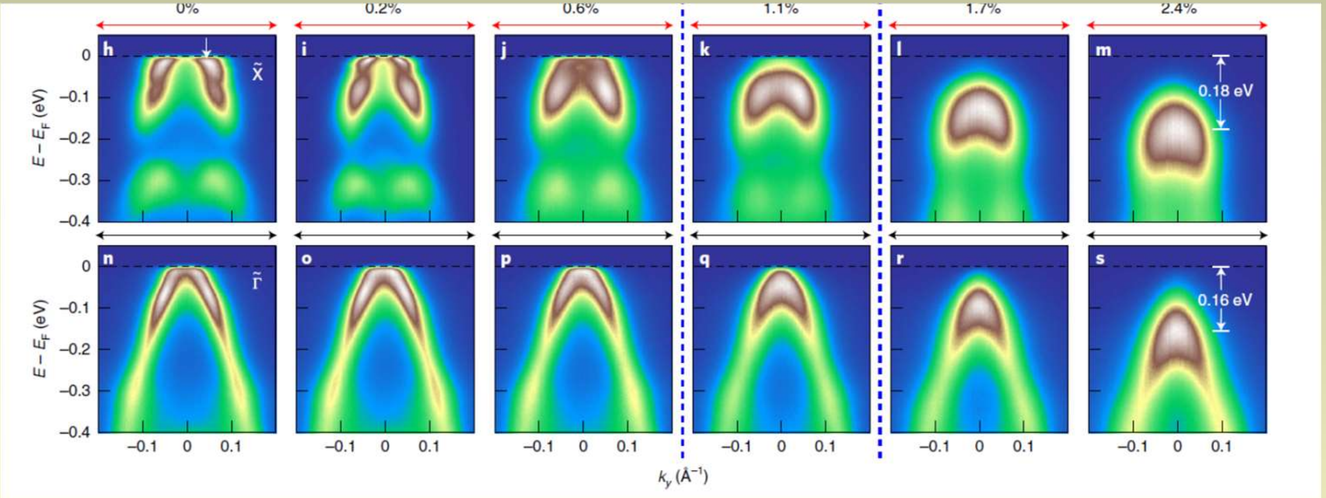
Nano-ARPES on the side surface of ring-$TaSe_3$
Sample image
ARPES intensity map
Fermi surface on (101)?
beam spot
T = 25 K
ΔE~60 meV
Brillouin zone
Ribbon surface
Curvature
Zoom in
Calc: Y ← Γ → Y

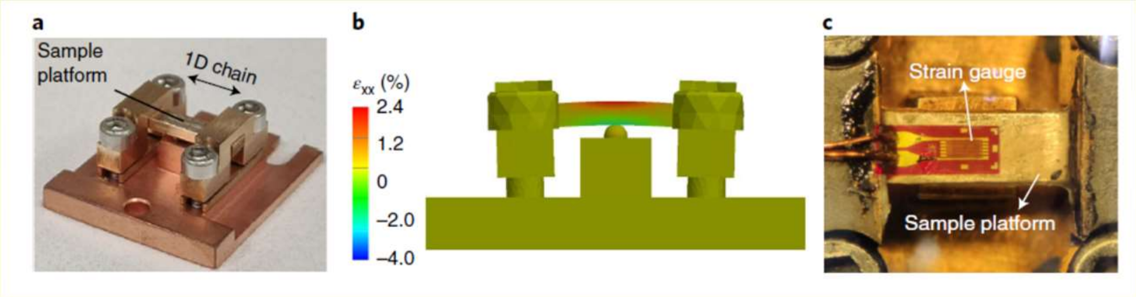


B Z Γ Y C Z D E A

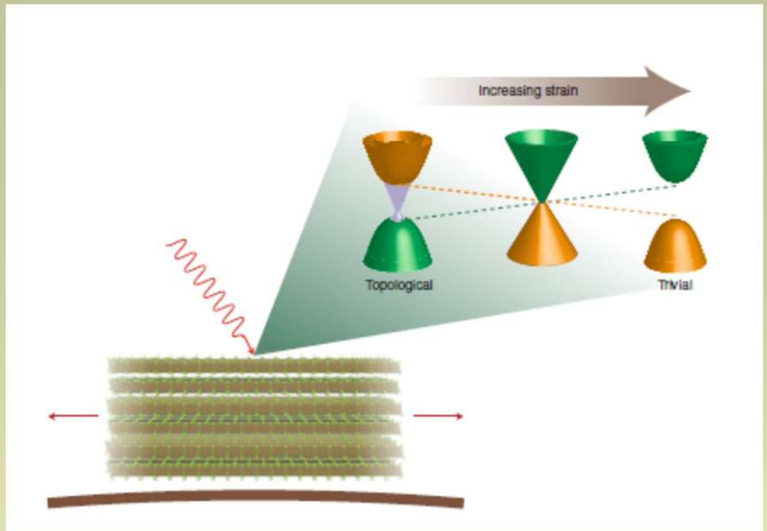
To precisely understand the Ring data

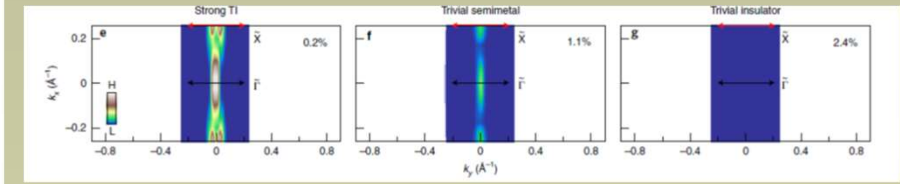
→ bending uniaxial pressure

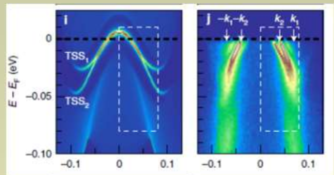


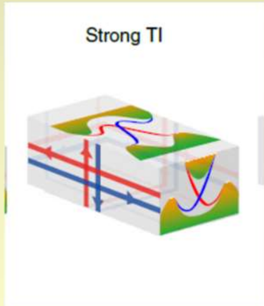


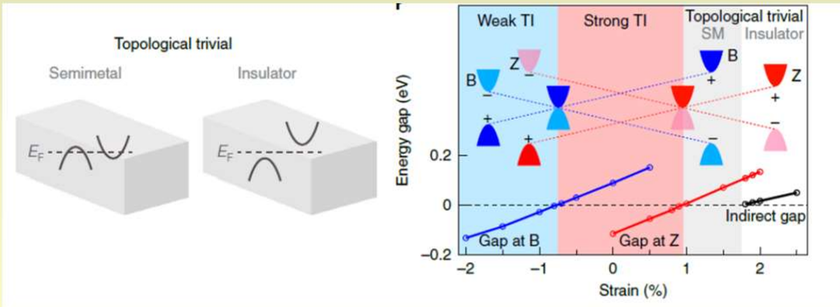
We can control Schrodinger to Dirac wave function !







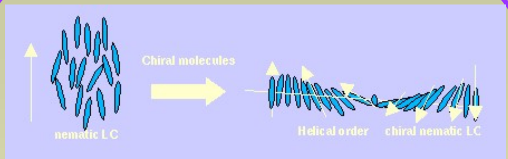




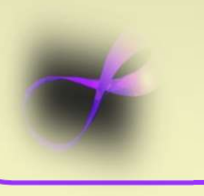
Chiral Current may induce in the strain sample and Ring samples

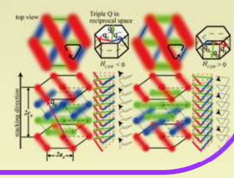
Helical instability

Real space Topology

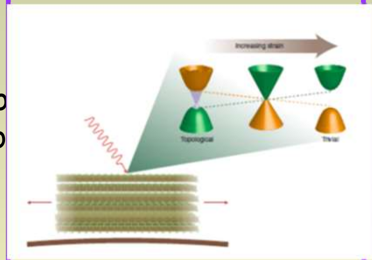


In nematic liq. Crystals, the excess of chiral molecules leads to the helicity term, $n\cdot(\nabla\times n)$ and to the chorestelic structure.



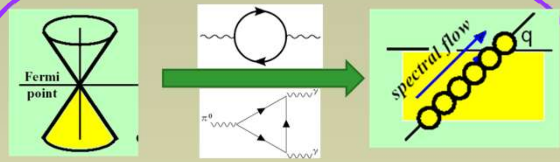


K-space topology control



Real space Topology control

K-space Topology



In Standard model, particle-hole pair (vacuum polarizers: quantum fluctuation) make helicity/chiral current in the gauge fields as quantum anomalies. Adler-Bell-Jackiw

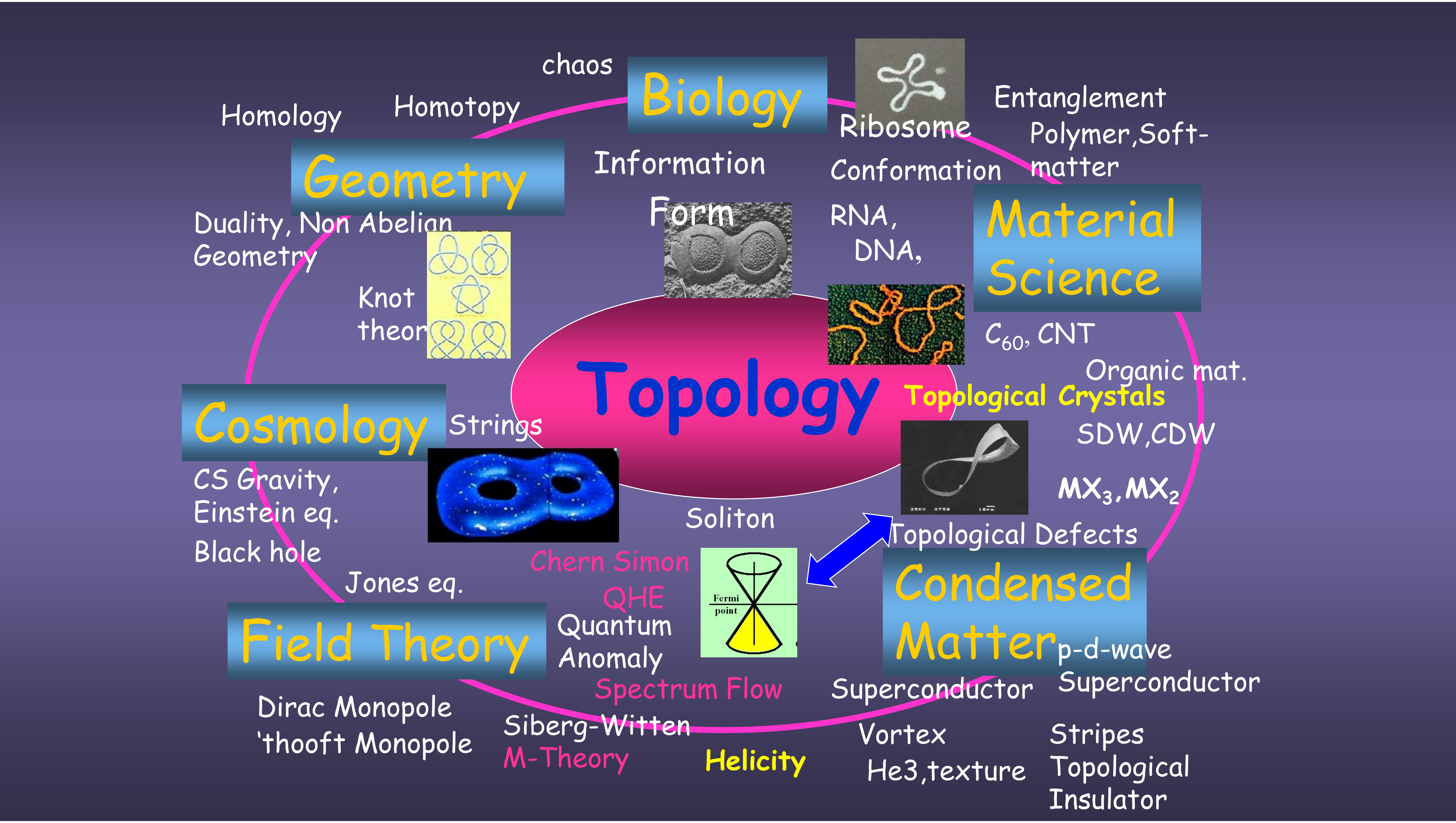
$E: Chiral\ Anomaly\ (1+1)D$

$A\cdot B: Parity\ Anomaly\ (2+1)D$

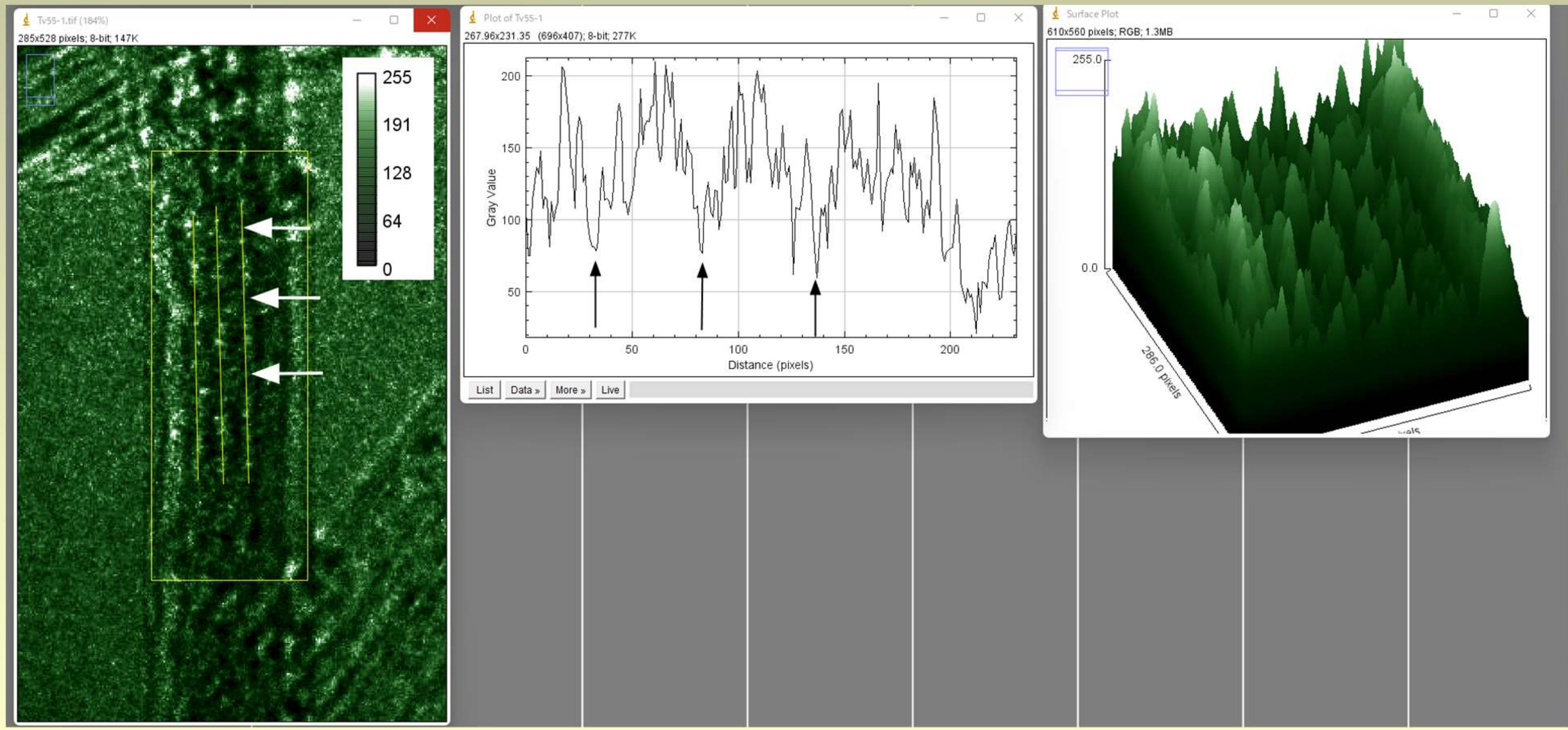
$E\cdot B: Chiral\ Anomaly\ (3+1)D$

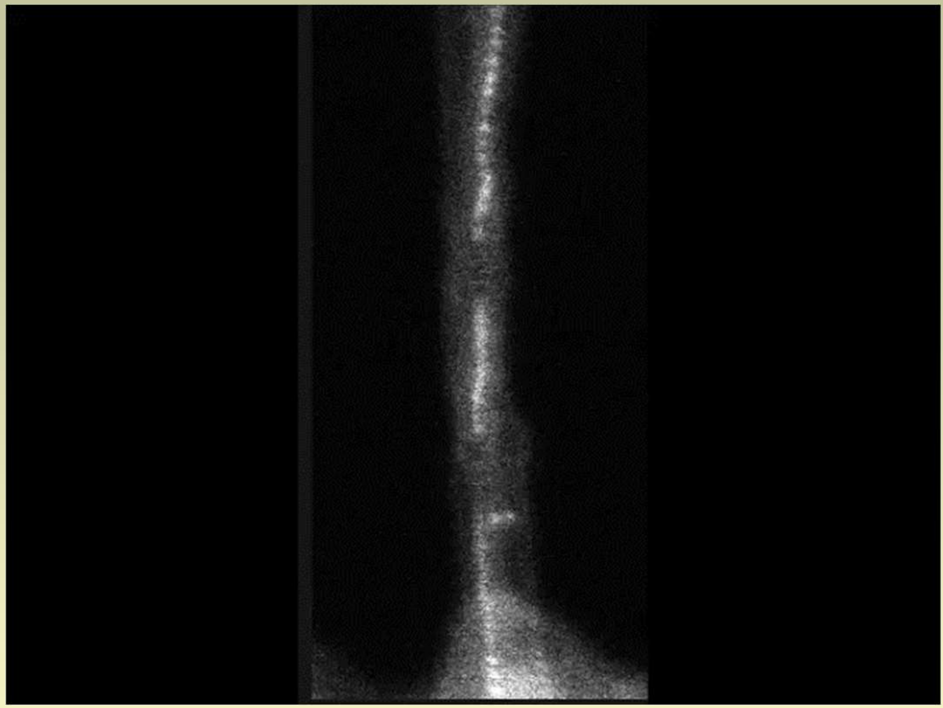
Real space Topology control becomes to K-space Topology control !

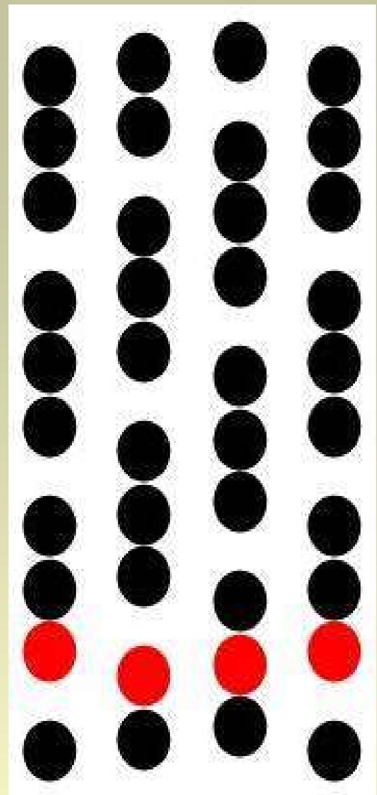
New Phenomena of Parity/Chiral anomaly in Ecrys 2025 !!

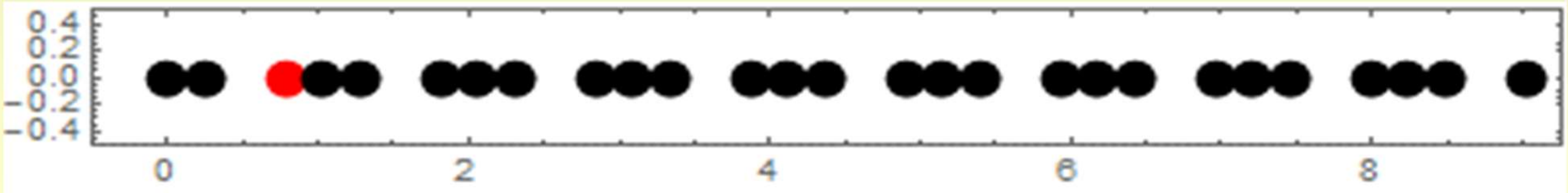

chaos
Biology
Homology
Homotopy
Ribosome
Entanglement
Polymer,Soft-matter
Geometry
Information
Conformation
Form
RNA,
DNA,
Material Science
Duality, Non Abelian Geometry
Knot theor
C_{60}, CNT
Organic mat.
Topology
Topological Crystals
Cosmology
Strings
SDW,CDW
CS Gravity,
Einstein eq.
MX_3,MX_2
Black hole
Soliton
Topological Defects
Chern Simon
QHE
Fermi point
Jones eq.
Field Theory
Quantum Anomaly
Condensed Matter
p-d-wave Superconductor
Spectrum Flow
Superconductor
Dirac Monopole
'thooft Monopole
Siberg-Witten
M-Theory
Helicity
Vortex
He3,texture
Stripes
Topological Insulator

NbSe3 in CNT   NbSe3 become CDW








0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8

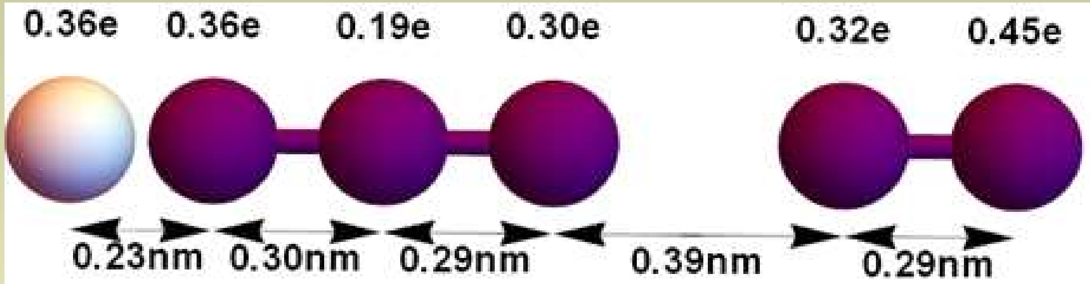
We found that mass density waves carry charges.

MDW → CDW

Initial placement

charge

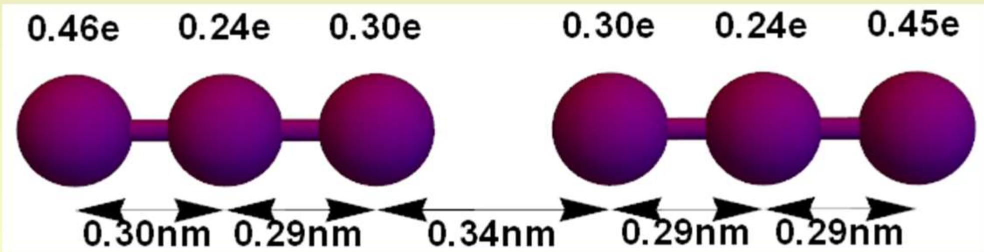
Atomic distance



final placement

charge

Atomic distance



Bardeen Conjecture is almost solved

Aharonov-Bohm effects in Real-space loop

Monolayer and Monostring exibit CDW.

Real space Topology control becomes to K-space Topology control !

Quantum Density Waves !

"Kosterlitz line" as a bonus

Time-controlled QDW

Space controlled QDW

Never follow behind!!