Recent events in physics of quiasi one dimensional conductors related to physics of solitons.

Routes to a role of microscopic topological defects in general strongly correlated electronic systems.

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Planning :

I. Ferroelectric Mott-Hubbard phase and charge disproportionation in quasi 1d organic conductors

II. Solitons dynamics in overlap tunnelling junctions of incommensurate Charge Density Waves

III. Combined topological excitations of correlated electronic states : confinement and dimensional crossover

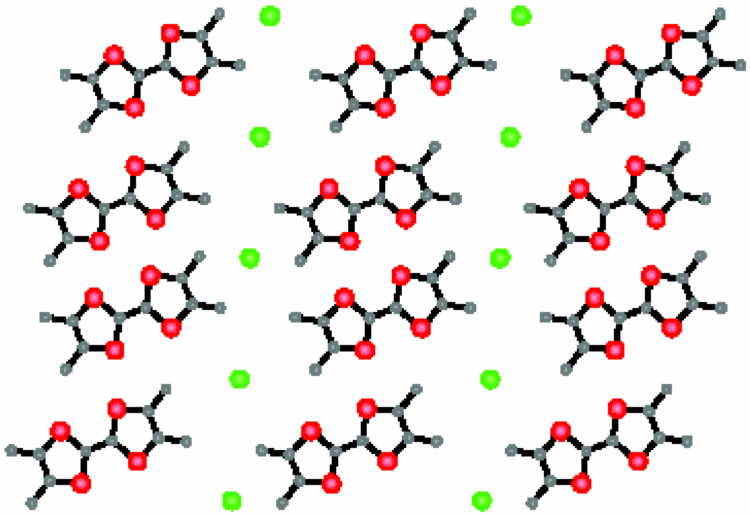
PART I

FERROELECTRIC MOTT-HUBBARD PHASE and CHARGE DISPROPORTIONATION in QUASI 1D ORGANIC CONDUCTORS

as a rout to physics of solitons

Felix Nad	Moscow and Grenoble
Pierre Monceau	Grenoble and Saclay
J.M. Fabre & C. Carcel	Montpellier
S. Brazovski	Orsay and Moscow

$(TMTCF)_2X$ C=S- Se, T- S

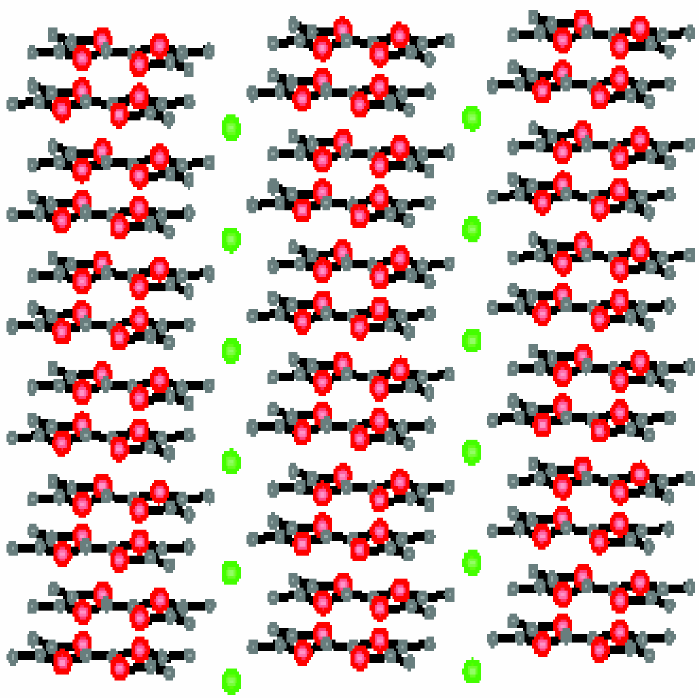


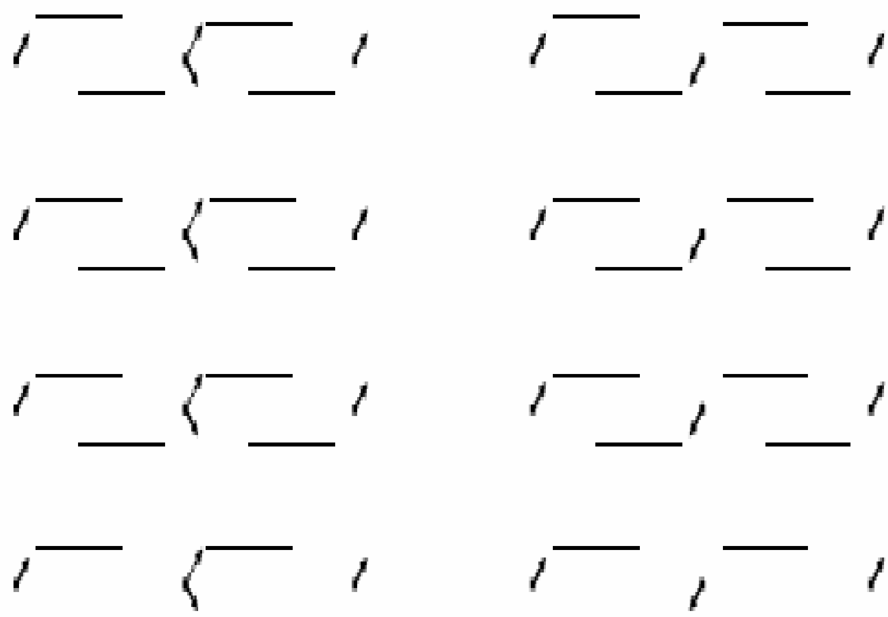
TMTSF/TMTTF molecules, their stacks, columns of counterions X

LEFT : top view

BOTTOM : side views

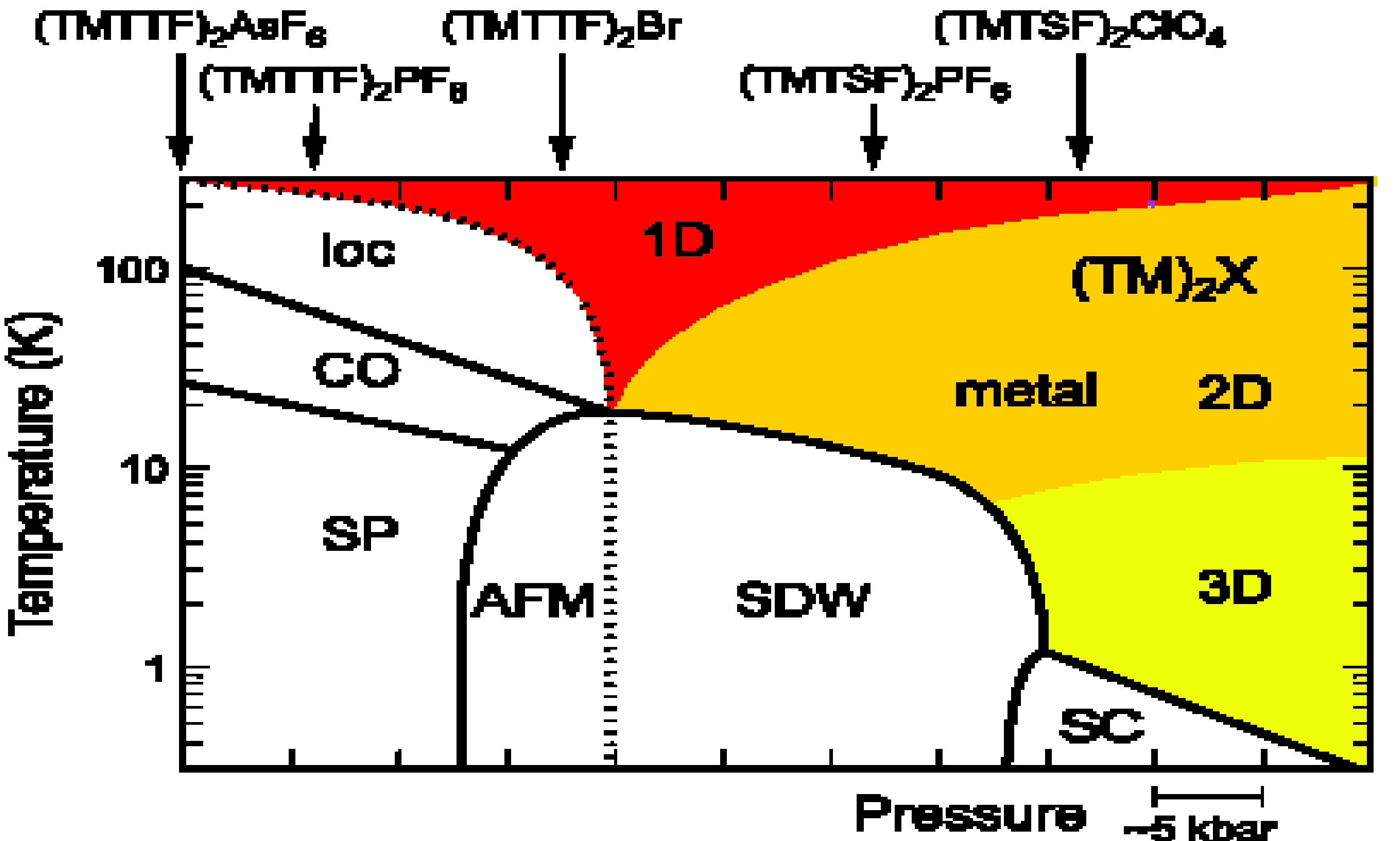
BOTTOM RIGHT : tiny structural Transitions of anion orderings

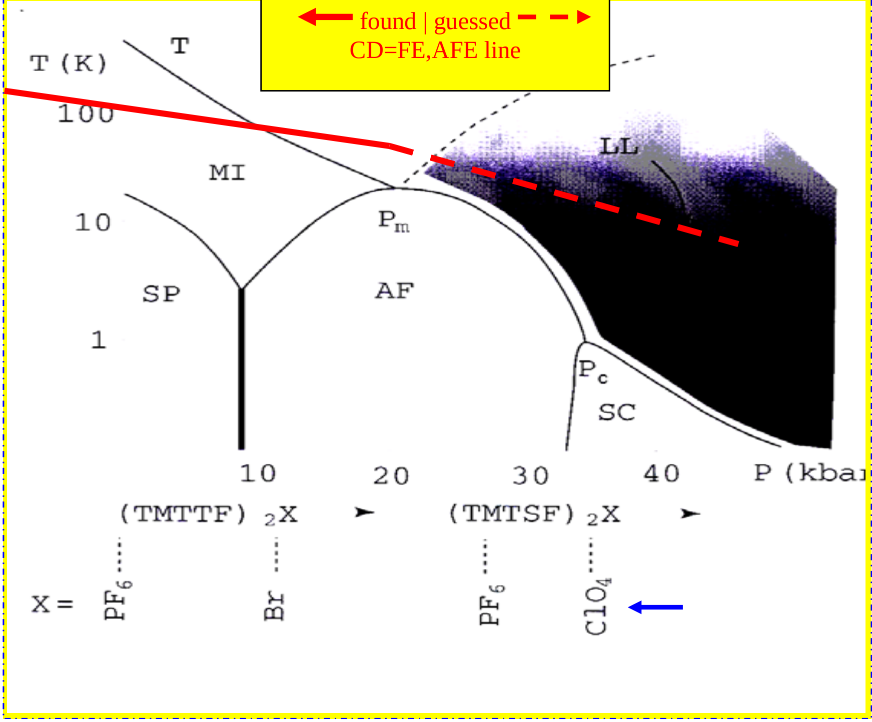




ELECTRONIC PHASES OF *(TMTCF)$_2$X* FAMILIES:

Superconductor SC, METAL versus charge localisation LOC,
Charge Ordering/Disproportionation CO, Spin-Peierls SP,
Spin Density Waves SDW, AntiFerroMagnet AFM,
add Magnetic Field Induced Spin Density Waves FISDW,
1D,2D,3D – dimension crossovers





$(TMTCF)_2X$, 1980-2002

Black and white:

SC- superconductivity

AF- AFM = SDW

SP- Spin-Peierls

LL- Luttinger liquid

MI- Mott insulator

Red line T_0 - 2000 revolution:

Structurless transitions (*Coulon et al 1985*)

= Ferroelectricity (*Nad*, *Monceau, SB, et al*)

= Charge disproportionation (*Brown et al*)

Resolving the mystery of structureless transitions: *Coulon et all, 1985*

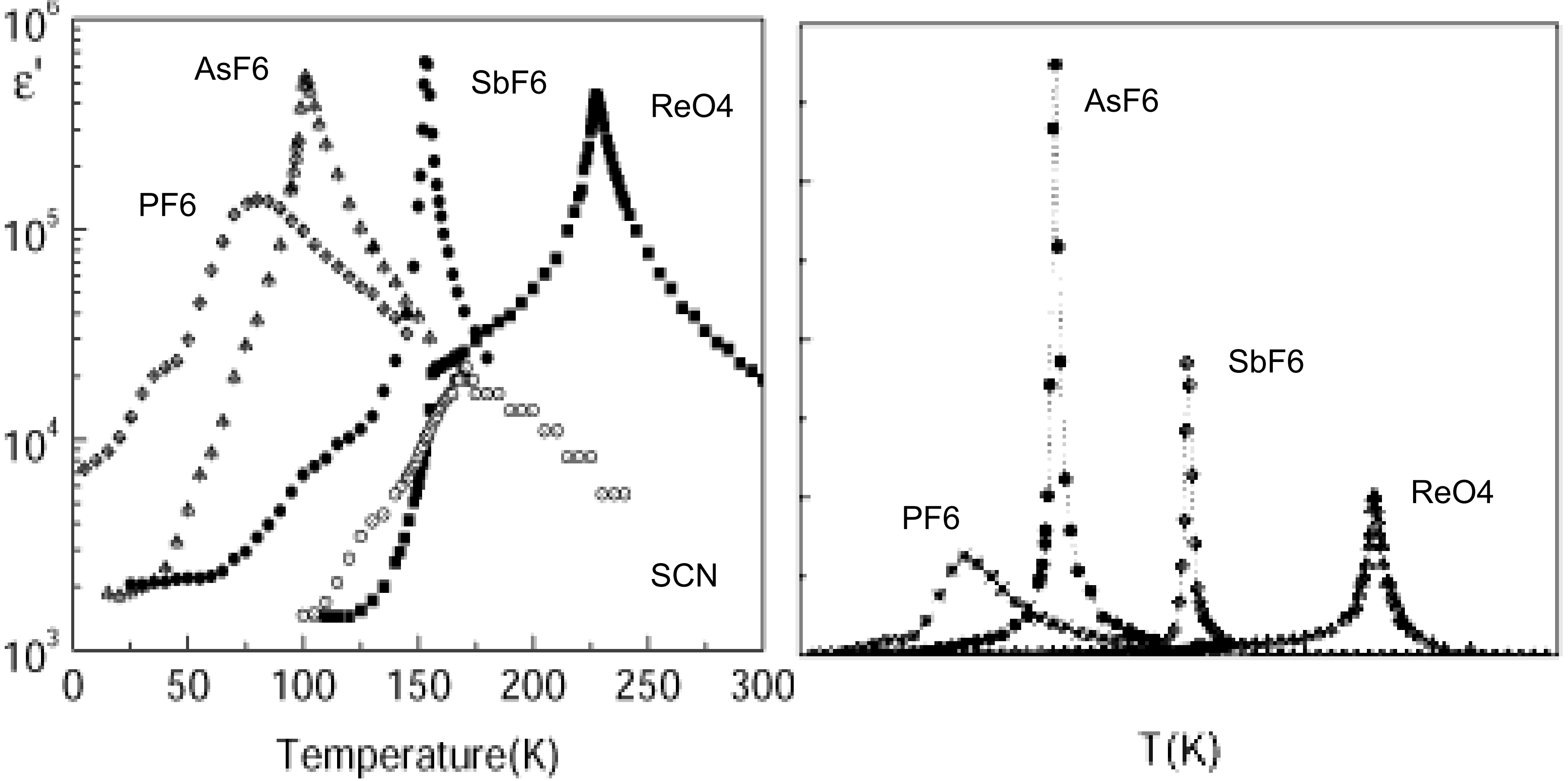
Gigantic anomaly in permitivity of $\varepsilon'(T)$ (*Nad et al, Grenoble-Moscow*)

Charge Orderin seen by NMR (*Brown - UCLA, Fujiyama -IMS*).

Views and interpretations:

FerroElectric version of Mott-Hubbard state, mixed site/bond $4K_F$ CDW, nonsimmetrically locked Wigner crystal

Facility to see Solitons: Purely 1D regime for electrons - $T_{FE} \approx 150K$ is 10 times above 3D electronic transitions.



Dielectric anomaly $\varepsilon'(T)$ in (TMTTF)2X, after Nad & Monceau

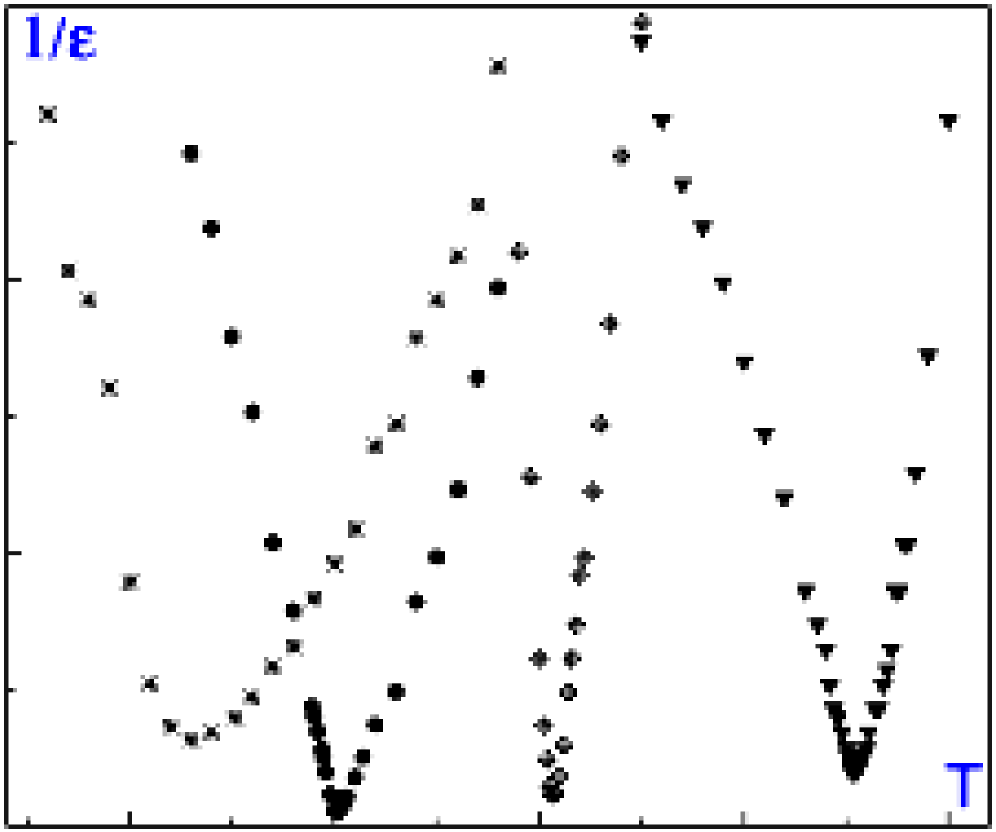
Left: at f=1MHz in *semi logarithmic scale* | Right: at f=100 kHz in *linear* scale

Anti FE case of X=SCN shows only a kink as it should be.

Smoothened anomaly in PF6 correlates with its weak frequency dispersion

- FE domain walls and hidden hysteresis ?.

Other cases - pure mono-domain “initial” FE susceptibility.



T dependence of the inverse of the real part of **ε'** at ***f=100Hz***,

$X=PF_6,AsF_6,SbF_6,ReO_4$

$1/\varepsilon' = C(T-T_0)$

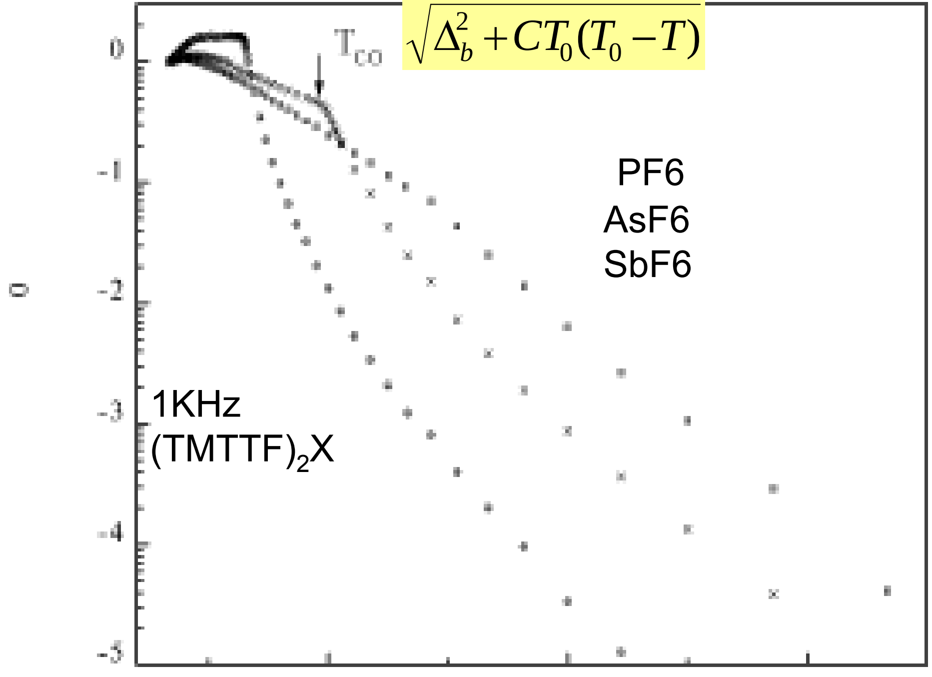
Typically $C \sim 10^4/T_0$

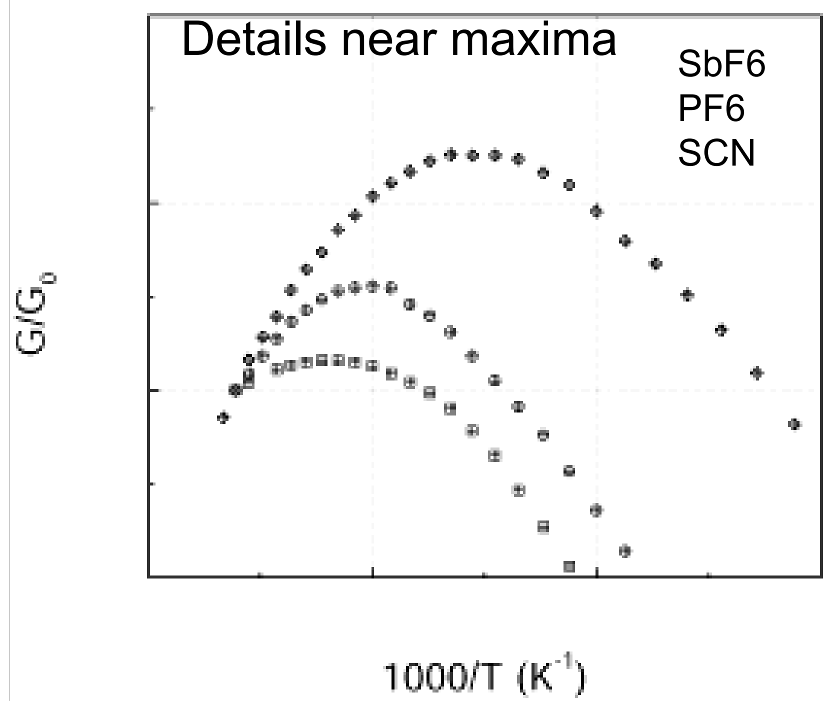
$C_< = 2C_>$ --

exact Landau theory !

Complication: PF_6

Clear cut fitting of the anomaly in $\varepsilon(T)$ to the Curie law prooves the <u>least expected</u> case of the ferroelectric phase.
Even more curiously, it is the ferroelectric version of the Mott-Hubbard state and of the Charge Disproportionation:
NMR shows a 1:1 splitting of molecular sites at $T<T_0$





Conductance G , normalized to RT, Ahrenius plot Log G(1/T).

Gaps for thermal activation Δ range within 500-2000K.

Conrarily to normal semiconductors -

no gap in spin susceptibility : χ(T) stays flat as for metal.

Clearlest example for conduction by

charged spinless solitons - holons .

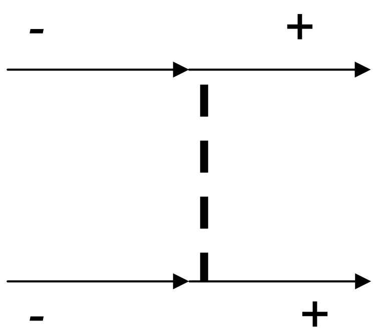
1D Mott-Hubburd state. 1 electron per site, i.e. the half filled band.

Spin degrees of freedom are split-off and gapless (free spin rotation phase θ).

Charge degrees of freedom can be gapful.

Chiral phase $\varphi=\varphi(x,t)$ for electrons near $+/-K_F$: $\Psi_{\pm} \sim \exp[\pm i\varphi/2]$

Origine: Umklapp scattering (Dzyaloshinskii & Larkin, Luther & Emery)



$U\exp[i2\varphi]$ *: amplitude of the Umklapp scattering of electrons* $(-K_F, -K_F) \rightarrow (+K_F, +K_F)$ is allowed here.

Momentum deficit $4K_F$ is just compensated by the reciprocal lattice period. Continuous chiral symmetry lifting: arbitrary translations are forbidden on the lattice.

Remnant symmetry: Allowed translations

$x \rightarrow x+2$ hence $\varphi \rightarrow \varphi+\pi$ is preserved.

$$H \sim (\hbar/4\pi\gamma)\,[v_\rho\,(\partial_x\varphi\,)^2 + (\partial_t\varphi\,)^2/v_\rho\,] - U\cos\,(2\varphi)$$

Hamiltonian degeneracy $\varphi \rightarrow \varphi+\pi$ originates current carriers:

$\pm\pi$ solitons with charges $\pm e$, energy Δ

(= holon = $4K_F$ CDW discommensuration = Wigner crystal vacancy)

Stability conditions:

$\gamma<1$: U is not renormalized to zero if already present - common case

$\gamma<1/2$: U can be spontaneously generated - new circumstances

COMBINED MOTT - HUBBARD STATE

$$H \sim [v_\rho (\partial_x \varphi)^2 + (\partial_t \varphi)^2 / v_\rho] + H_U$$

Chiral phase $\varphi = \varphi(x,t)$ for electrons near $+/- K_F$

U: amplitude of the Umklapp scattering

Dzyaloshinskii & Larkin, Luther & Emery

Other views: commensurate Wigner crystal, $4K_F$ CDW *(Pouget et al)*

2 types of dimerization $\Rightarrow$
2 interfering sources for two-fold commensurability
$\Rightarrow$ 2 contributions to the Umklapp interaction:

Site dimerization : $H_U^s = -U_s \cos 2\varphi$ (spontaneous)
Bond dimerization : $H_U^b = -U_b \sin 2\varphi$ (build-in)

At presence of both site and bond types

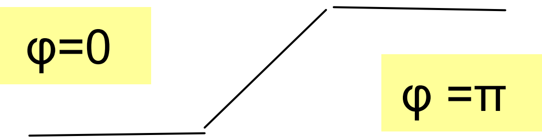
$$H_U = -U_s \cos 2\varphi - U_b \sin 2\varphi = -U \cos(2\varphi - 2\alpha)$$

$U_s \neq 0 \rightarrow \alpha \neq 0 \rightarrow$ phase φ = "mean displacement of all electrons" shifts from $\varphi = 0$ to $\varphi = \alpha$, hence the gigantic FE polarization.

From a single stack to a crystal: Macroscopic FerroElectric ground state if the same α is chosen for all stacks,
Anti-FE state if the sign of α alternates *- both cases are observed*

For a given U_s the ground state is still doubly degenerate between $\varphi = \alpha$ and $\varphi = \alpha+\pi$. $H_U = -U\cos(2\varphi - 2\alpha)$

It allows for phase π solitons, i.e. holons with the charge *e*.

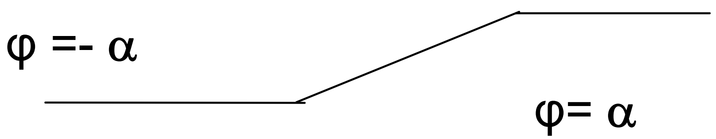


Purely on-chain solitons, exist as conducting quasiparticles both above and below the T_{FE}.

Spontaneous U_s itself can change sign between different FE domains.

Then electronic system must also adjust its ground state from α to $-\alpha$.

Hence the domain boundary $U_s \leftrightarrow -U_s$ requires for the phase soliton of the increment $\delta = -2\alpha$ which will concentrate the *non integer* charge $q = -2\alpha/\pi$ per chain.



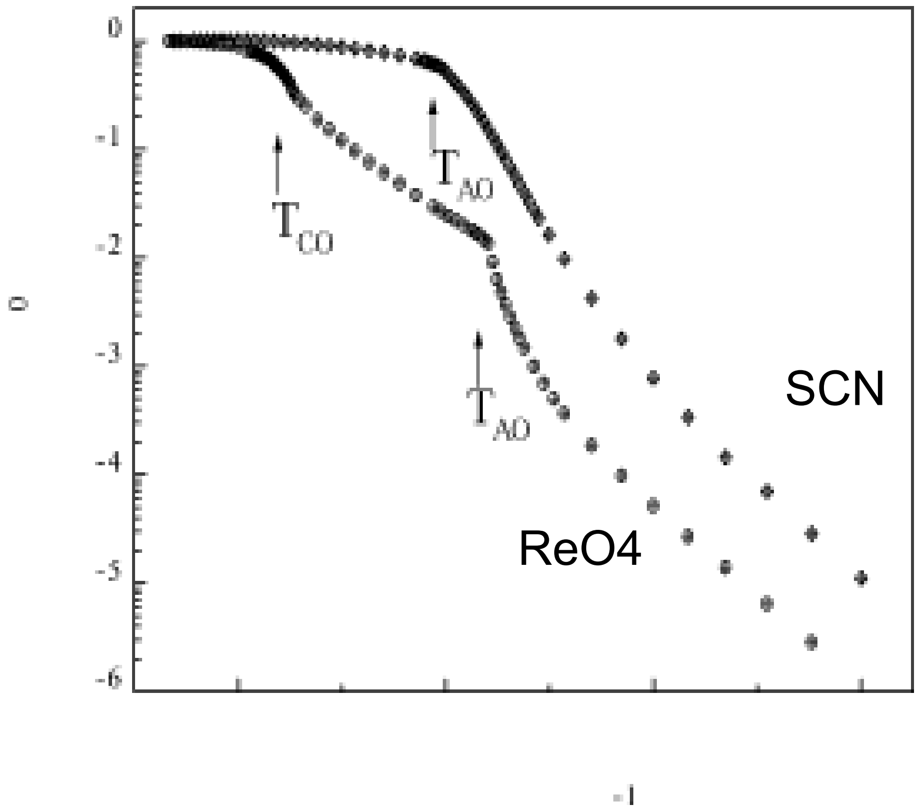
alpha- solitons are walls between domains of opposite FE polarizations

They are on-chain conducting particles only above T_{FE}.
Below T_{FE} they aggregate into macroscopic walls.
They do not conduct any more,
but determine the FE depolarization dynamics.

Effects of subsequent transitions.

Combined solitons. Spin-Charge reconfinement.

Another present from the Nature:
tetramerization in $(TMTTF)_2ReO_4$ at $\mathbf{T_{AO}<T_0}$



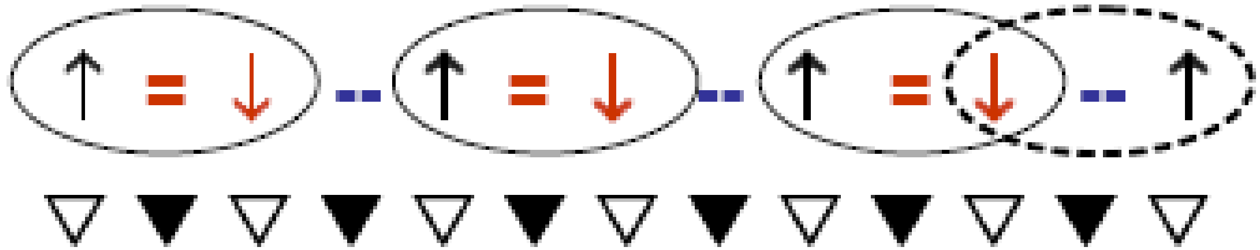
Spin-charge reconfinement below $\mathbf{T_{AO}}$ of tetramerisation. Enhanced gap Δ comes from topologically coupled **π**- solitons in both sectors of the charge and the spin. The last is weakly localized.

What does it mean ?

Spin degrees of freedom enter the game:

$$\Psi_{\pm\sigma} \sim \exp[\pm i(\varphi + \sigma\theta / 2)]$$

θ - spin phase, θ′/ π = smooth spin density



Schematic illustrations for effects of the tetramerization

Inequivalence of bonds **=** , **--** between good sites ▽

endorses ordering of spin singlets.

Also it prohibits translations by one ▽ ▼ ▽ distance

which were explored by the $\delta\varphi=\pi$ soliton.

But its combination with the defected unpaired spin

($\delta\theta=\pi$ soliton which shifts the sequence of singlets)

is still allowed as the selfmapping –

connction of equivalent ground states

Further symmetry lifting of tetramerization mixes charge and spin:
additional energy **$V\cos(\varphi-\beta)\cos\theta$** – on top of **$\sim V\cos(2\varphi)$**

φ and θ -- chiral phases counting the charge and the spin

φ'/π and θ'/π = smooth charge and spin densities

$\cos\theta$ sign instructs the CDW to make spin singlets over sorter bonds

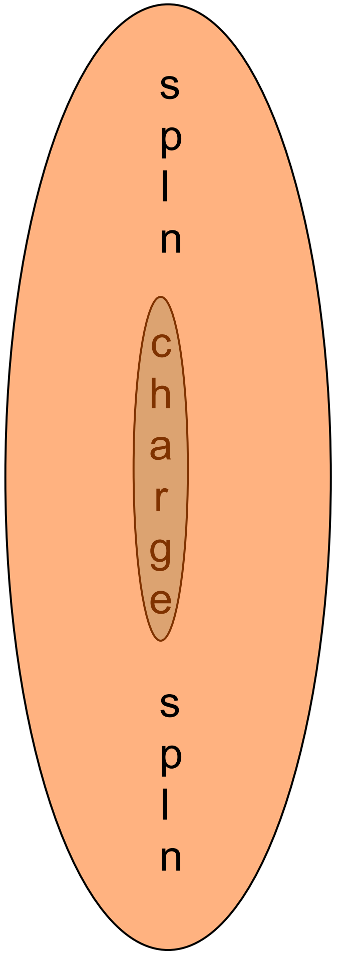
Major effects of V-term :

Opens spin gap $\mathbf{2\Delta_\sigma}$:

triplet pair of $\delta\boldsymbol{\theta}=\pi$ solitons at $\varphi=$*cnst*

- Prohibits $\delta\varphi=\pi$ solitons – now bound in pairs by spin strings
- Allows for combined spin-charge topologically bound solitons:

$\{\delta\varphi=\pi+\delta\boldsymbol{\theta}=\pi\}$ – leaves the **V** term invariant

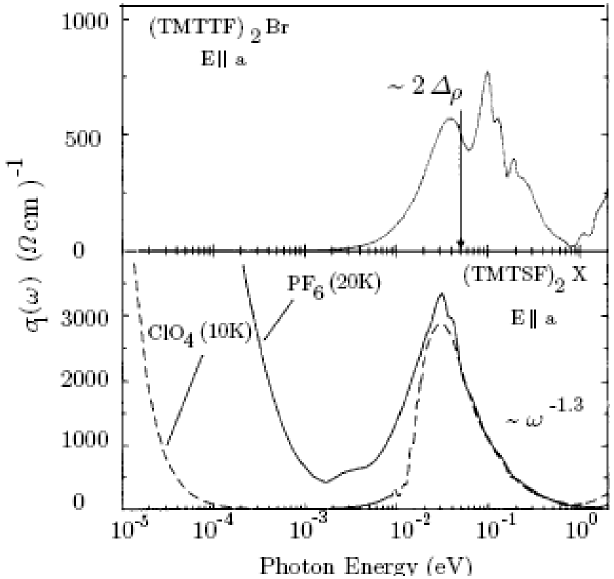


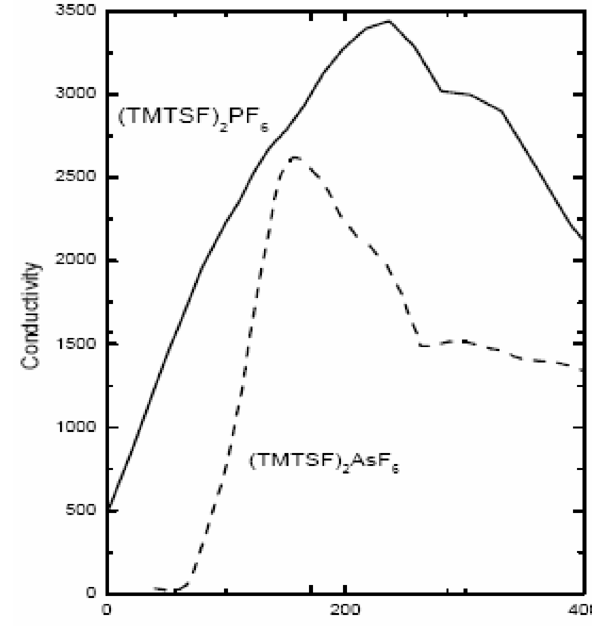
Quantum numbers of the compound particle --

charge **e** , spin ½ but differently localized:

charge **e** , $\delta\varphi=\pi$ sharply within $\hbar v_F/\Delta_\rho$

spin ½ , $\delta\boldsymbol{\theta}=\pi$ loosely within $\hbar v_F/\Delta_\sigma$





Optical Conductivity $\sigma(\omega)$ = absorption

2Δ = 2-particle gap (photoconductivity) – kinks= π- solitons

E_g - optical absorption edge (exciton = bound kink+antikink)

Regime change just at the borderline CD instability γ =1/2

Fermi gas side ½< γ <1: E_g=2Δ - no bound states

$4K_F$ CDW side γ <1/2:

E_g<2Δ - collective mode at $E_g= \omega_t= \pi\,\gamma\,\Delta <2\,\Delta$.

Region $\omega_t < \omega<2\Delta$ support quantum breathers – bound states of solitons.

PART II

Solitons in dynamics

Direct conversion of an electron into a soliton.

Solitons and dislocations in overlap tunnelling junctions of incommensurate Charge Density Waves.

Yu.I.Latyshev[1], P.Monceau[2], S.Brazovskii[3], A.I.Orlov[1], Th.Fournier[2]
[1]*Moscow*, [2]*Grenoble*, [3]*Orsay*

Observation of Charge Density Wave Solitons in Overlapping Tunnel Junctions Phys. Rev. Lett., **95**, 266402 (2005)

Subgap collective tunneling and its staircase structure in charge density waves Phys. Rev. Lett., **96**, 116402 (2006).

Yu.I. Latyshev, P. Monceau, S.B., *et al,* : *ECRYS-05 proceedings*
Interlayer tunneling spectroscopy of layered CDW materials

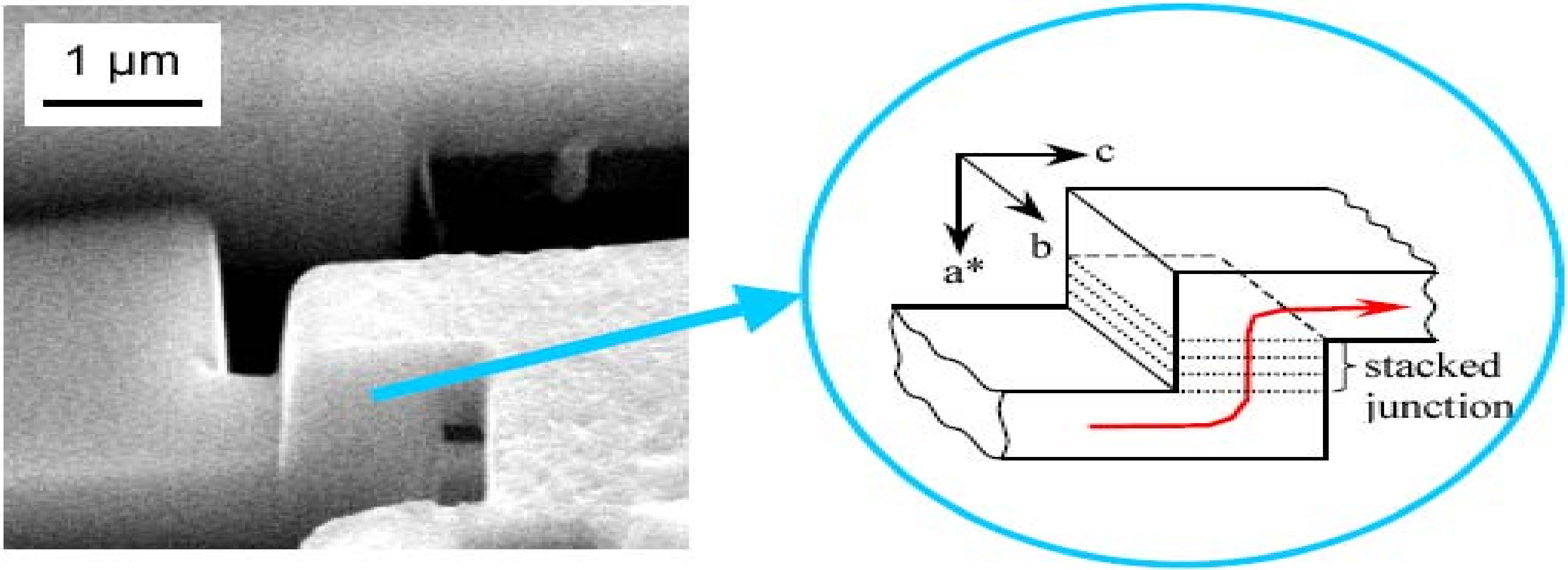
S.B.,Yu.I. Latyshev, S.I. Matveenko and P. Monceau *ECRYS-05 proceedings*
Recent views on solitons in Density Waves

S. I. Matveenko and S. B. *ECRYS-05 proceedings*
Subgap tunneling through channels of polarons and bipolarons in chain conductors
Theory of subgap interchain tunneling in quasi 1D conductors

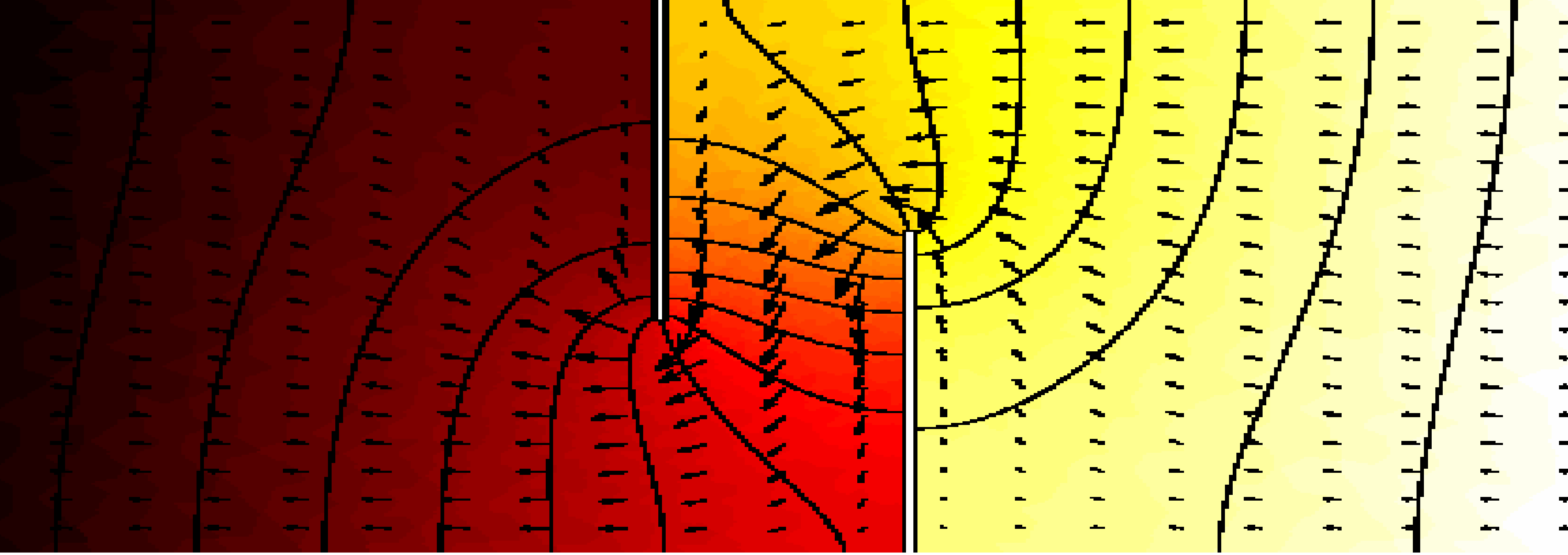
Yurii Latyshev technology of mesa structures:
fabrication by focused ion beams.

All elements – leads, the junction –
are pieces of the same single crystal whisker

Figure : Scanning electron microscopy picture of $NbSe_3$ stacked structure and its scheme.



Overlap junction forms a tunneling bridge of 200A width,
It contains 20-30 weakly coupled conducting plains
of a layered material.



Distribution of potentials in linear regime of normal conductance (values in colours, equipotential lines in black) and currents (arrows) for moderate conductivity anisotropy (A=100).
Thickness (vertical) axis is rescaled as anisotropy $A^{1/2}$=10 times.

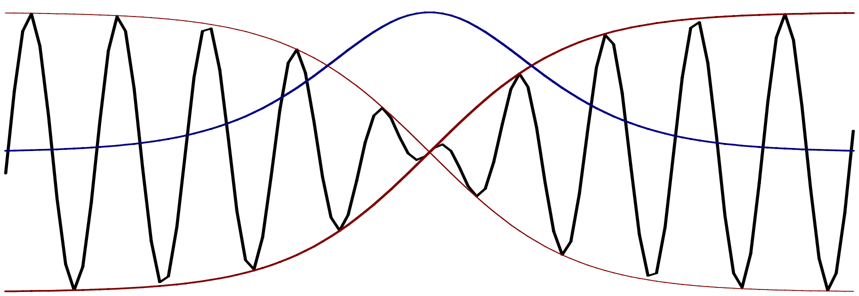
Analytic solution for junction vicinity:
Complex coordinate **z** as a function of the complex potential **S**:

$$z = Z(S,Q) = \frac{1}{\pi}\left(-\frac{\sinh S}{\sinh Q} + iS\right)$$

This creature appears in tunneling :

Amplitude soliton with energy $\approx 2/3\Delta$, total charge 0, spin ½

This is the CDW realisation of the SPINON



Oscillating electronic density,

Overlap soliton A(x),

Midgap state =spin distribution

Incommensurtae CDW : $A\cos(Qx+\varphi)$ $Q=2K_f$

Order parameter $\Delta \sim A\exp(i\varphi)$

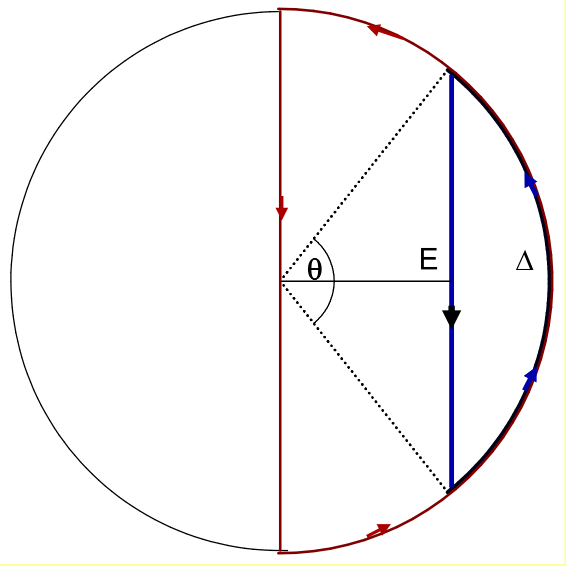
Electronic states $\Psi = \Psi_+\exp(iK_f x+i\varphi) + \Psi_-\exp(-iK_f x-i\varphi)$

$$\begin{vmatrix} k-E & \Delta^* \\ \Delta & -k-E \end{vmatrix} \begin{pmatrix} \Psi_+ \\ \Psi_- \end{pmatrix} = 0 \quad , \quad k = K - K_f = -i\partial_x$$

Peierls-Frohlich, chiral Gross-Neveu models.

The spectra are related to the nonlinear Schreodinger equation for Δ:

Fateev, Novikov, Its, Krichever; Matveenko and SB



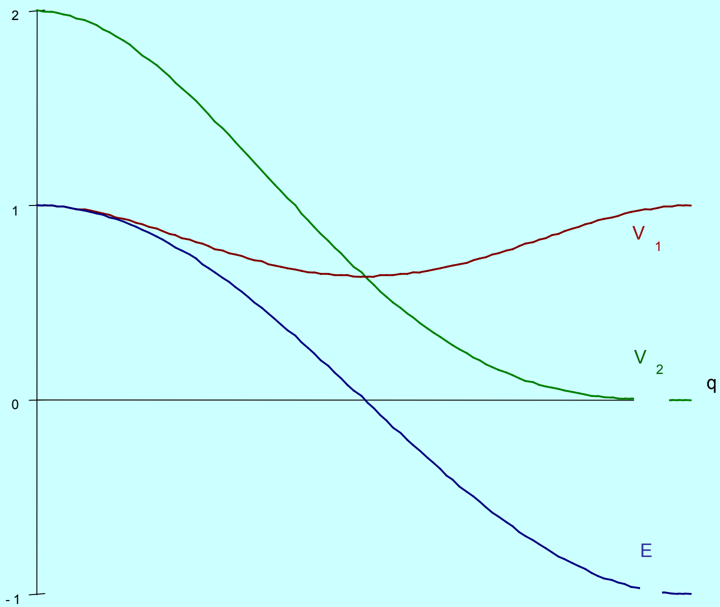
Soliton trajectories in the complex plane of the order parameter.

Red line: stable amplitude soliton.

Blue line: intermediate chordus soliton within chiral angle θ (black radial lines).

The value θ=100° is chosen which corresponds to the optimal configuration for the interchain tunnelling

S.Matveenko and S.B.



Selftrapping branches $V_n(\theta)$ for chordus solitons

for fillings n =1 and n=2,

Energy $E_0(\theta)$ of localized split-off state as functions of the chiral angle θ.

Part III
Topological Excitations of Correlated Electronic States: the rout from D=1 to higher dimensions

<u>Expectations</u> - Understanding of :

Spin-Charge separation and reconfinement

Forms of holons and spinons beyond 1D

Transfer of experimental information

Key words: solitons, instantons, complex topological defects

Solitons in 2000's, WHY?

New conducting polymers,

New events in organic conductors,

New accesses to Charge Density Waves,

New interests in strongly correlated systems as semiconductors

Elementary excitations in electronic systems with spontaneous symmetry breaking - The STRATEGY :

Symmetries: Superconductors,
Antiferromagnetic semiconductors or Mott Insulator,
Spin/ Charge Density Waves (commensurate or not)

Secure starting level: one- dimensional systems.

Solitons in the ground state and as elementary excitations.
Conversion of electrons to various solitons;
Separated or even anomalous charge, spin, currents.

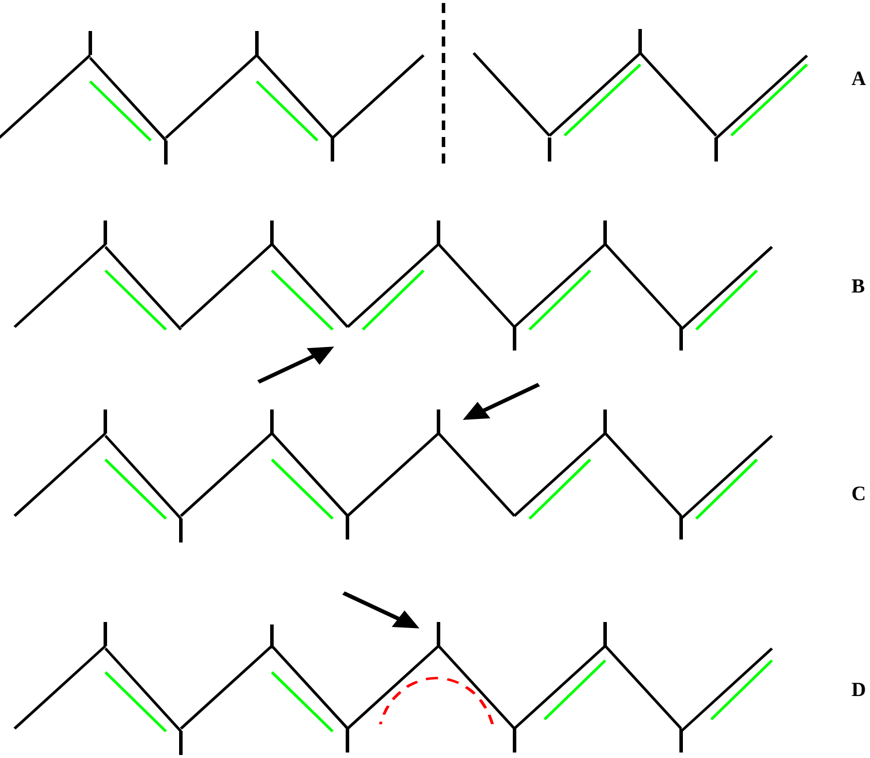
Quasi one- dimensional route:

Confinement of solitons and dimensional crossover.
Spin-charge recombination due to 3D confinement.
Solitons acquire tails.

Arbitrary systems:

Solitons acquire feathers.
Combined symmetry of spin-charge transformations,
Topological constraints and coupling,
Spin- or Charge- roton like excitations with
charge- or spin- kinks localized in the core.

Topological defects on the trans-(CH)x chain

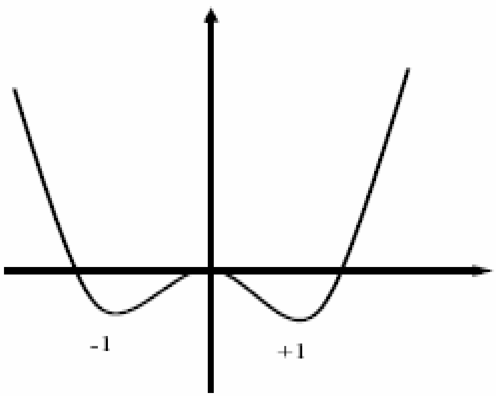


q=e,
s=0

q=-e, s=0

q=0, s=1/2

Symmetry breaking - bond dimerization.
Two equivalent ground states.
Soliton= kink between them

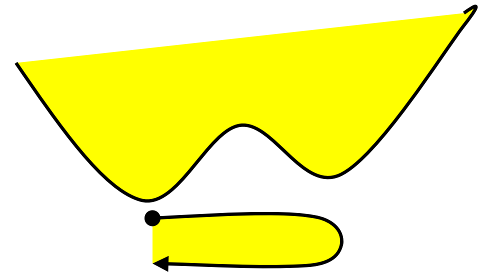


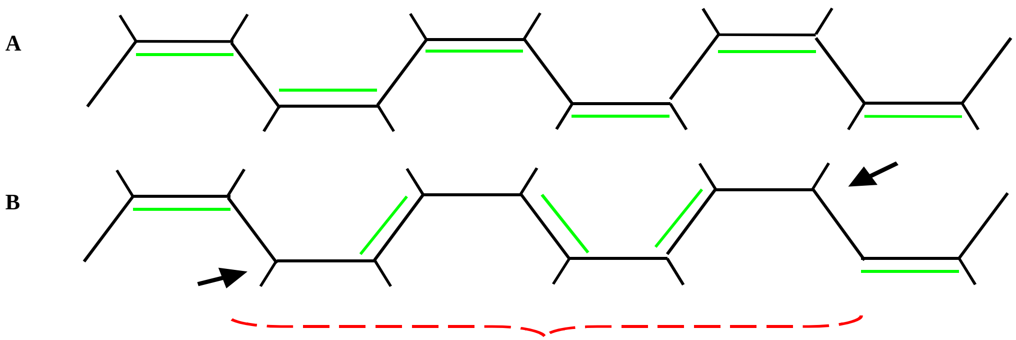
S.B., 1978; A.J. Heeger, R.J.Schrieffer, 1979; Takayama et al, 1980

Fatal effect upon kinks: lifting of degeneracy, hence confinement.
Trivial but spectacular example: global lifting of symmetry.

Nature present -- cis-isomer of $(CH)_x$:
build-in slight inequivalence of bonds
hence lifting of ground state degeneracy,
hence confinement of solitons

Cis-$(CH)_x$:
Nonsymmetric dependence
of GS energy on dimerisation





Only a short excursion
= confined pair of kinks=
to the false GS is allowed

Confinement of kinks pairs into
2e charged (bipolaron) or neutral (exciton) compex.
Symmetry determined picture of optical differences for
trans- and cis- isomers *S. B. and N. Kirova, 1981*
Photoconductivity trans-$(CH)_x$ versus photoluminescence cis-$(CH)_x$
also new optical features due to hybridization of midgap states

Can the solitons cross the boarder to the higher D world ?

Are they allowed to bring their anomalies like spin-charge separation or midgap states?

Password : *confinement.*

As topological objects connecting degenerate vacuums, solitons acquire an infinite energy unless they reduce or compensate their topological charges.

Various scenarios :

- Compensation by the gapless mode *S.B. 1980, 2000's*
- Aggregation into domain walls versus their melting by thermal deconfinement or long rage Coulomb forces
  S.B. & T.Bohr 1983, S. Teber 2001
- Coupling to structural defects in polymers.
- Binding to kink-antikink pairs, origin of bipolarons.
  S.B. & N.Kirova, 1981- 90's
- *Today's speciality :*
  Topological binding to gapless degrees of freedom

FINITE TEMPERATURE, ENSEMBLES OF SOLITONS,
PHASE TRANSITIONS OF CONFINEMENT AND AGGREGATION.
DISCRETE SYMMETRY only.

Fatal effect upon kinks: lifting of degeneracy, hence confinement.

Nontrivial but still spectacular:

local lifting in the state with long range order.

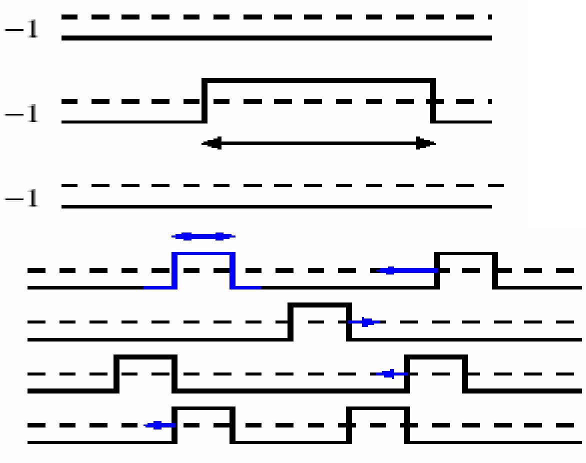
Interchain coupling of the order parameter.

$$H_I = -\sum_{\langle\alpha,\beta\rangle}\int dx V_\perp \Delta_\alpha(x)\Delta_\beta(x)$$

Two competing effects:

Binding of kinks into pairs at $T<T_c$;

Aggregation into macroscopic domain walls at $T<T_0<T_c$.



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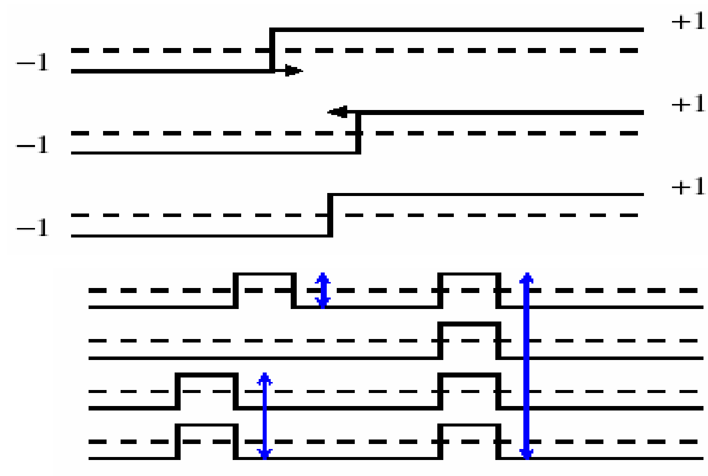

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Solution for a statistical model *T.Bohr and S.B. 1983, S.Teber et al 2000’s*

MIXED DISCRETE AND CONTENEOUS SYMMETRIES

Why did we see the single solitons in tunneling? :

combination of a discrete and continuous symmetries

Solitons are stable energetically but not topologically

Recall a general theory: Mineev & Volovik, Monastyrskii, Toulouse, etc.

Special significance: allowance for a direct transformation of one electron into one soliton.

(Only 2→2 *were allowed for kinks in discrete symmetries)*

Incommensurate CDW Order Parameter **~A(x)COS[Qx+φ]**

Δ= A exp[iφ] ; **A** - amplitude , φ - phase

Ground State with an odd number of particles:

In 1D - *Amplitude Soliton* AS Δ**(x=-∞)** ⇔ **-** Δ**(x=∞)**

via **A** ⇔**-A** at arbitrary φ=cnst

Favorable in energy in comparison with an electron, but:

Prohibited to be created dynamically in 1D

Prohibited to exist even stationary at D>1

RESOLUTION – Combined Symmetry :

Phase tails of the amplitude soliton AS:

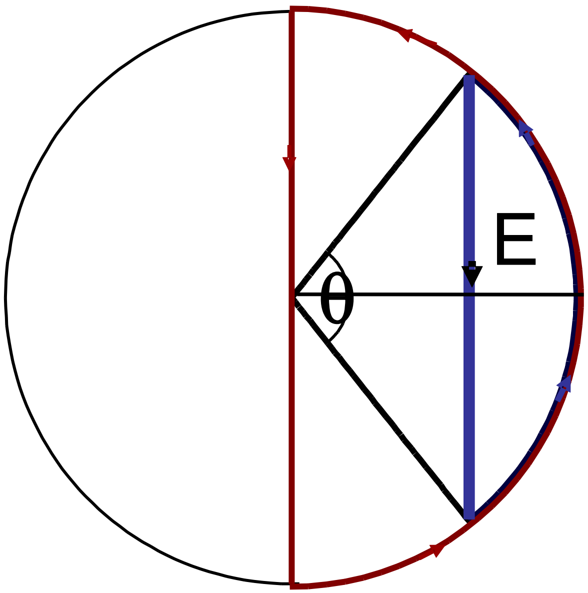
Prohibited in **D>1** (including **1+1**) environment (confinement !)

Allowed in **D>1** if acquires phase tails with the total increment

$\delta\varphi=\pi$ **{**A → -A**,** φ → φ **+π}** :

Self-mapping of the order parameter **Δ= A exp[iφ]**

Result: allowed particle with the AS core carrying the spin **1/2** plus the phase twisting wings carrying the charges **e/2**



Soliton trajectories in the complex plane of the order parameter Aexp(iϕ) .

Red vertical line: stable amplitude soliton.

Blue line: intermediate chordus soliton within chiral angle θ (black radial lines).

θ=100° is chosen - optimal configuration for interchain tunnelling *Matveenko & SB*

Arc lines: adaptational phase tails

π-rotation accumulated in the phase tails is generalized as a pair of **half- integer** vortices (D=2) or of such a vortex ring (D=3)

Half filled band with repulsion. SDW rout to the doped Mott-Hubbard insulator.

$$H_{1D} \sim (\partial\varphi)^2 - U\cos(2\varphi)\} + (\partial\theta)^2$$

U - Umklapp amplitude

(*Dzyaloshinskii & Larkin ; Luther & Emery*).

φ - chiral phase of charge displacements

θ - chiral phase of spin rotations.

Degeneracy of the ground state:

$\varphi \rightarrow \varphi+\pi$ = translation by one site

Excitations in 1D :

holon as a π soliton in φ, spin sound in θ

Higher D : A hole in the AFM environment.

Staggered magnetization $\equiv$ *AFM=SDW order parameter:*

$$\mathbf{O_{SDW} \sim \cos\varphi \exp\{\pm i(Qx+\theta)\}}$$

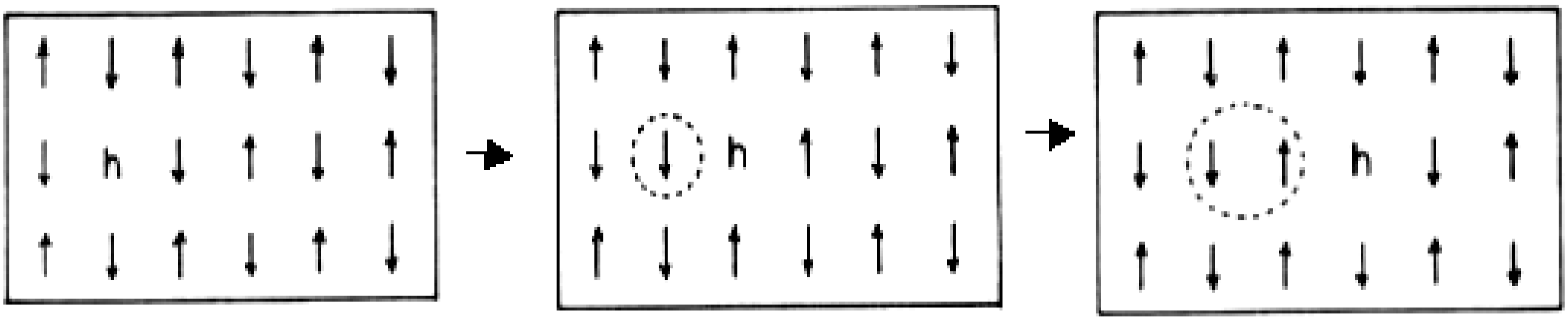
To survive in D>1 :

The π soliton in φ $\cos\varphi \rightarrow -\cos\varphi$
enforces a π rotation in θ to preserve O_{SDW}

Propagating hole as an amplitude soliton.

Its motion permutes AFM sublattices ↑,↓ creating a string of the reversed order parameter: staggered magnetization. It blocks the direct propagation.

Nagaev et al , Brinkman and Rice

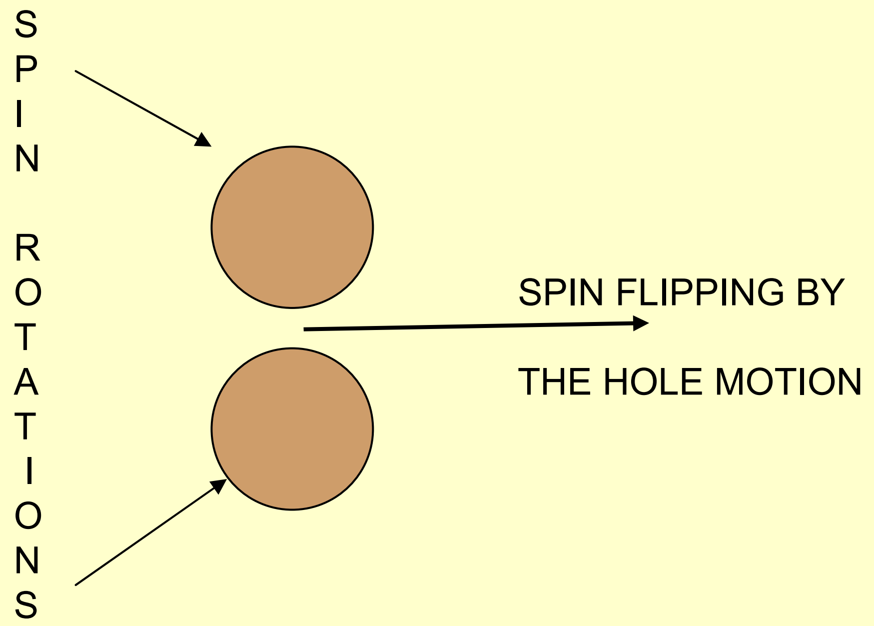


Adding the semi-vorticity to the string end heals the permutation thus allowing for propagation of the combined particle.

Resulting Elementary Excitations:

half integer vortex ring of staggered magnetization =

½ roton with the holon confined at its core.



Alternative view:

Nucleus of the stripe phase or

the minimal element of its melt.

ATTRACTING ELECTRONS

SPIN-GAP cases: Incommensurate CDW or Superconductor

$H_{1D} \sim (\partial\theta)^2 - V\cos(2\theta)\} + (\partial\varphi)^2$

V - from the backward exchange scattering of electrons

In **1D** : Spinon as a soliton $\theta \rightarrow \theta+\pi$ hence **s=1/2**

+ Gapless charge sound in φ.

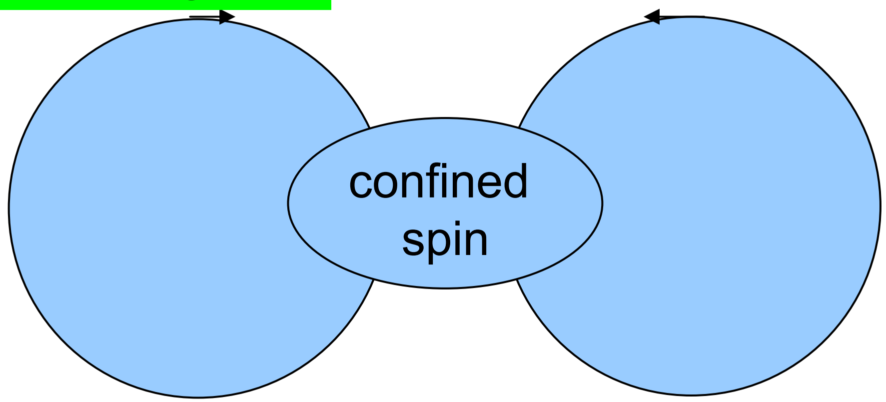
CDW order parameter $\sim \psi^{\dagger}_{+\uparrow}\,\psi_{-\uparrow} + \psi^{\dagger}_{+\downarrow}\,\psi_{-\downarrow} \sim \exp[i\varphi]\cos\theta$

At higher D : allowed mixed configuration

$\theta \rightarrow \theta+\pi$, **s=1/2** $\qquad$ $\varphi \rightarrow \varphi+\pi$, **e=1**

↑spin soliton ↑ $\qquad$ ↑charged wings↑

Spinon as a soliton +
semi-integer dislocation loop =
π - vortex of φ $\equiv$ confined spin +
semi dislocation loop

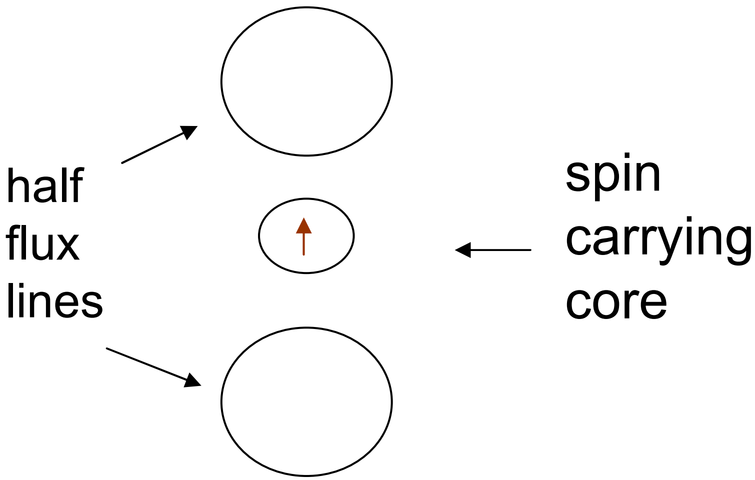


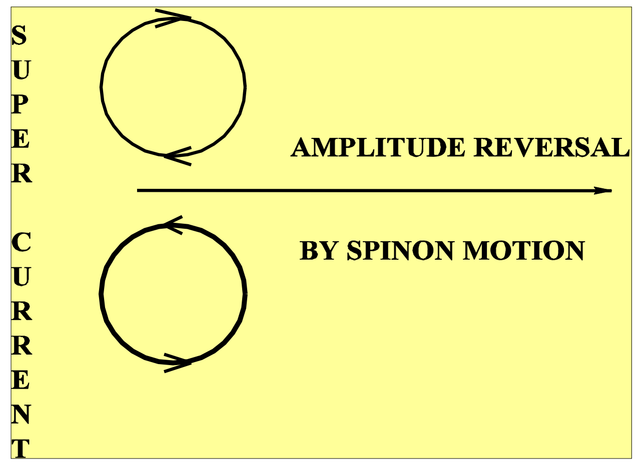
Singlet Superconductivity: D=1 → D>1

$\eta_{SC} \sim \psi_{+\uparrow}\,\psi_{-\downarrow} + \psi_{+\downarrow}\,\psi_{-\uparrow} \sim \exp[i\chi]\cos\theta$

$\theta \to \theta+\pi$ s=1/2 $\chi \to \chi+\pi$

core spin soliton wings of supercurents





Quasi 1d view : spinon as a π- Josephson junction in the superconducting wire (*applications: Yakovenko; ^{3}He- Varocuaux*)

2D view : pair of π- vortices shares the common core bearing unpaired spin.

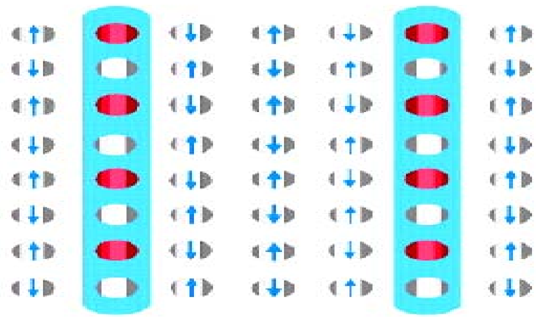
3D view : half-flux vortex stabilized by the confined spin.

Best view: nucleus of melted FFLO phase in spin-polarized SC

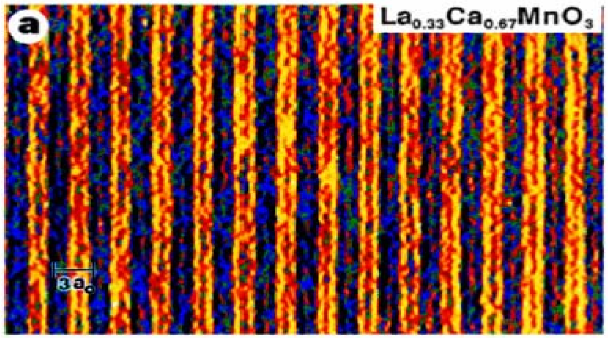
Inverse rout: from stripes to solitons

1D → quasi 1D → 2D,3D route to dopping of AFM insulator.
Aggregation of holes (extracted electrons) into stripes.

Left: scheme derived from neutron scattering experiments.
Right: direct visualization via electron diffraction microscope.



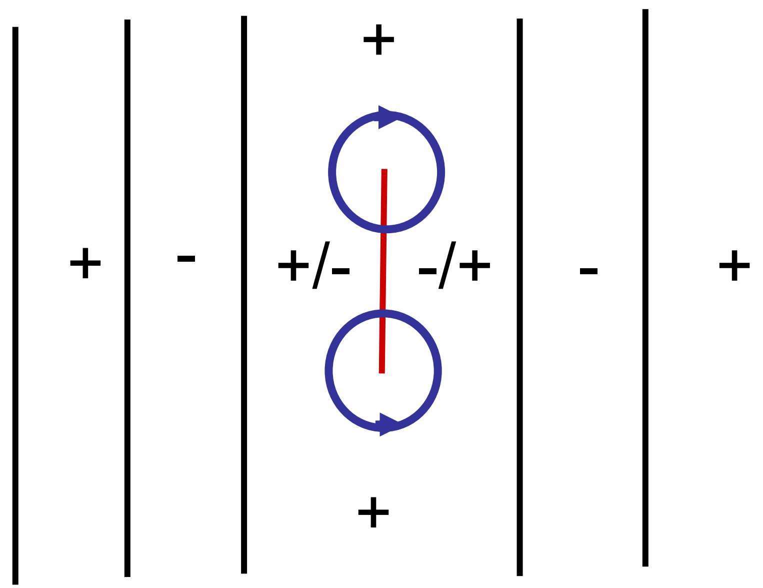
J.Orenstein et al Science 288, 468 (2000)



S.Mori et al Nature 392, 473 (1998)

Equivalence for spin-gap cases:
Fulde-Ferell-Larkin-Ovchinnikov FFLO phase in superconductors
Solitonic lattices in CDWs above the magnetic breakdown
Solitonic lattices in spin-Peierls GeCuO in HMF - Grenoble

Kink-roton complexes as nucleuses of melted macro structures: FFLO phase for superconductors or strips for doped AFMs.



A defect embedded into the regular stripe structure (black lines).

+/- are the alternating signs of the order parameter amplitude.

Termination points of a finite segment (red color) of the zero line must be encircled by semi-vortices of the □ rotation (blue circles)

to resolve the signs conflict.

The minimal segment corresponds to the spin carrying kink

SUMMARY

- Existence of solitons is proved experimentally in single- or bi-electronic processes of 1D regimes in quasi 1D materials.
- They feature self-traping of electrons into midgap states and separation of spin and charge into spinons and holons, sometimes with their reconfinement at essentially different scales.
- Topologically unstable configurations are of particular importance allowing for direct transformation of electrons into solitons.
- Continuously broken symmetries allow for solitons to enter D>1 world of long range ordered states: SC, ICDW, SDW.
- They take forms of amplitude kinks topologically bound to semi-vortices of gapless modes – half integer rotons
- These combined particles substitute for electrons certainly in quasi-1D systems – valid for both charge- and spin- gaped cases
- The description is extrapolatable to strongly correlated isotropic cases. Here it meets the picture of fragmented stripe phases

Some obligatory references in theory:

Brinkman & Rice
Dzyaloshinskii & Larkin
Finkelstein & Wiegman
Fukuyama & Tanaka
Kirova
Kusmartsev
Luther & Emery
Matveenko
Mineev & Volovik
Nagaev
Schrieffer
Schultz
Shriman and Sigia
Varoquaux
Zaanen and Husseinov
etc., etc.