Magnetothermopower of Organic Superconductor κ-$(ET)_2Cu(NCS)_2$: possible charge density wave scenario

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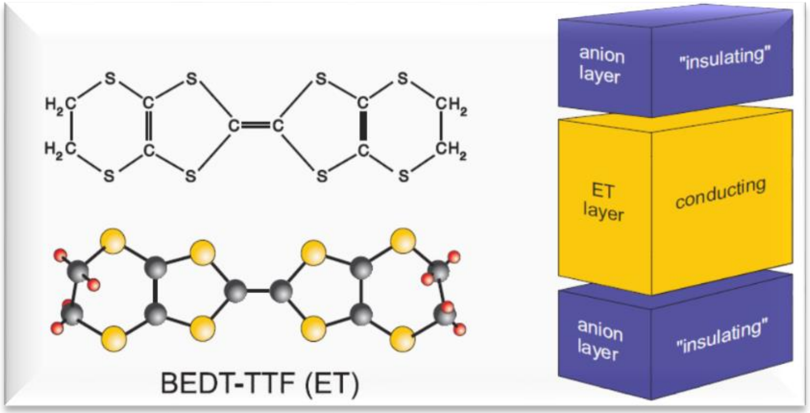
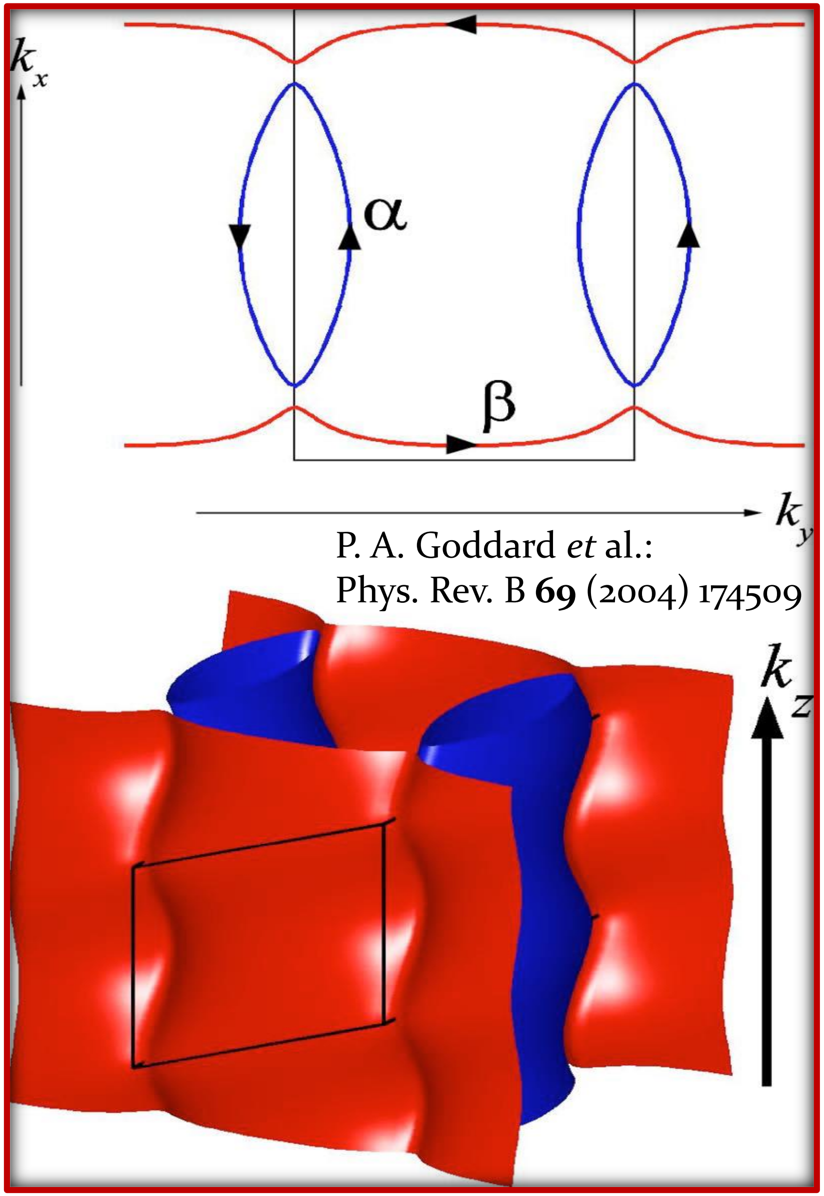
Organic Superconductor κ-$(ET)_2Cu(NCS)_2$

- *The most popular and best characterized material out of all the organic charge-transfer salts!*
- *simple Fermi surface, which consists of two elliptical Q2D pockets and a pair of warpedQ1D sheets*
- *high superconducting transition temperature Tc = 10.4 K*
- *a number of similarities with the high-Tc cuprate YBCO*



Fermi surface of κ-$(ET)_2Cu(NCS)_2$



P. A. Goddard *et* al.:
Phys. Rev. B **69** (2004) 174509

WHY MAGNETOTHERMOPOWER?

$$S_{ik} = \frac{E_i}{\nabla_k T} = \rho_{il}\,\alpha_{lk}$$

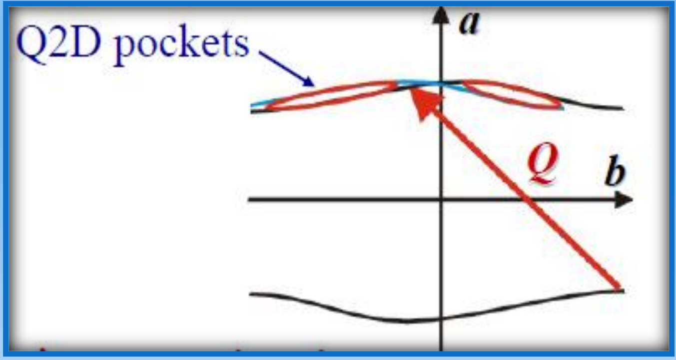
- ♦ sensitive to the electron energy spectrum
- ♦ possibilities of studying the electronic structure of the organic conductors
- ♦ the sign of the transport carriers
- ♦ the relation between the anisotropy of the electronic bands and superconducting state

- **New ordered states** - change in the electron-hole asymmetry

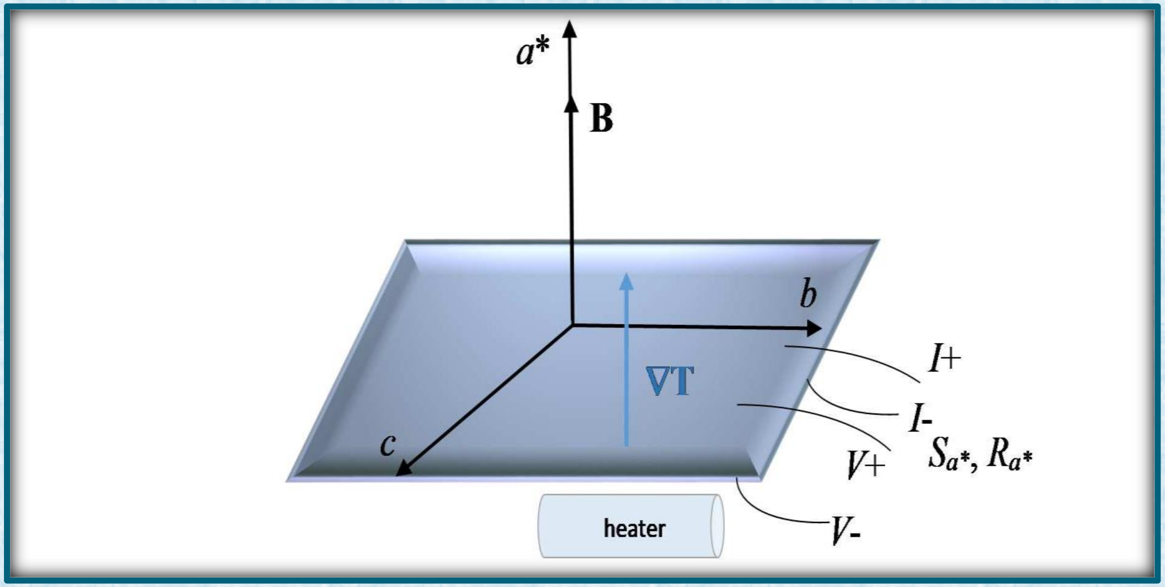
In quantizing magnetic fields:

- the structure of the energy spectrum and the relaxation mechanisms of charge carriers
- electron-electron and phonon interactions in organic metals
- the acoustic energy absorption at high frequencies

Imperfect nesting
(higher order hopping)



Experimental setup



- *Single crystals of κ-$(ET)_2Cu(NCS)_2$ were synthesized by the electrocrystallization technique*
- *^{3}He system with field up to 32 T at the NHMFL, Tallahassee*

The experimental geometry for the interlayer magnetoresistance and magnetothermopower (Seebeck effect) measurements in the organic superconductor κ-$(ET)_2Cu(NCS)_2$ as a function of the magnetic field. The applied magnetic field and temperature gradient are along the less conducting axis a of the superconductor, perpendicular to the Q2D conducting bc plane.

MAGNET LAB
NATIONAL HIGH MAGNETIC FIELD LABORATORY
FLORIDA STATE UNIVERSITY - LOS ALAMOS NATIONAL LABORATORY - UNIVERSITY OF FLORIDA

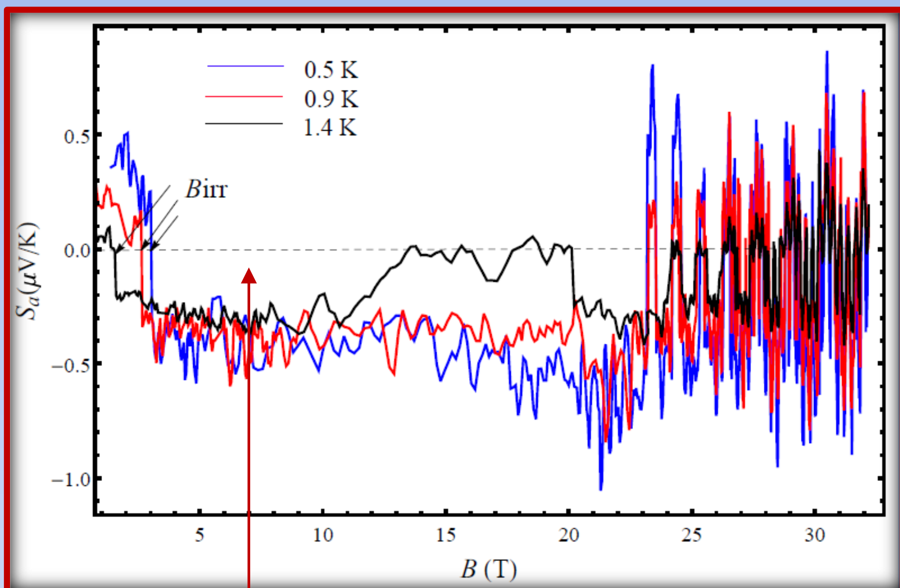
Magnetothermopower

$$\tau_{\text{osc}} = \frac{\tau_0 \Delta_{\text{osc}}}{1 + \Delta_{\text{osc}}}$$

$$\Delta_{\text{osc}} = \left(\frac{e\hbar B}{m_c(\theta)\varepsilon}\right)^{1/2} \sum_e \left|\frac{\partial^2 S_e}{\partial p_B^2}\right|^{-1/2} \sum_{k=1}^{\infty} a_k \frac{(-1)^k}{k^{1/2}} R_{\text{T}}(k\Lambda) R_{\text{S}}(k) \cos\left[\frac{k S_e}{e\hbar B} \pm \frac{\pi}{4}\right]$$

$$\sigma_{zz}^{\text{osc}} \sim \Delta_{\text{osc}}$$

$$\alpha_{zz}^{\text{osc}} \sim \frac{\partial \Delta_{\text{osc}}}{\partial \ldots}$$



• There is a specific feature in a form of a dip followed by an upturn in the magnetothermopower of κ–(ET)2Cu(NCS)2, similar to the one in the Seebeck coefficient of the high-*Tc* cuprate YBCO

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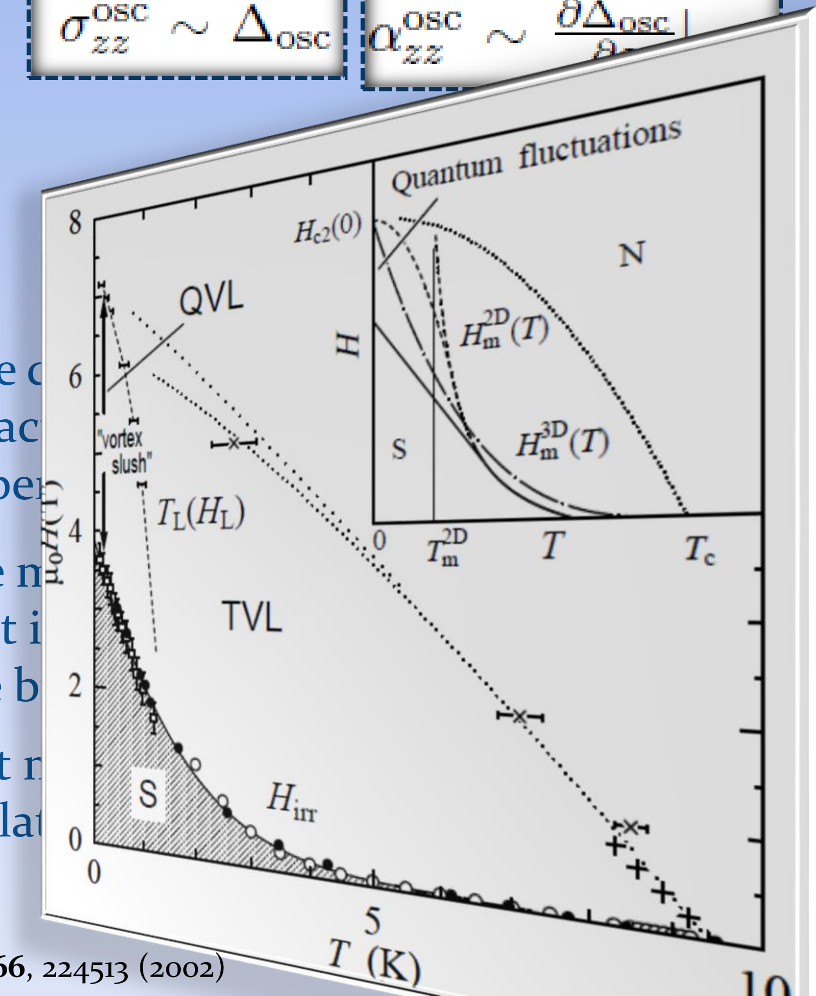
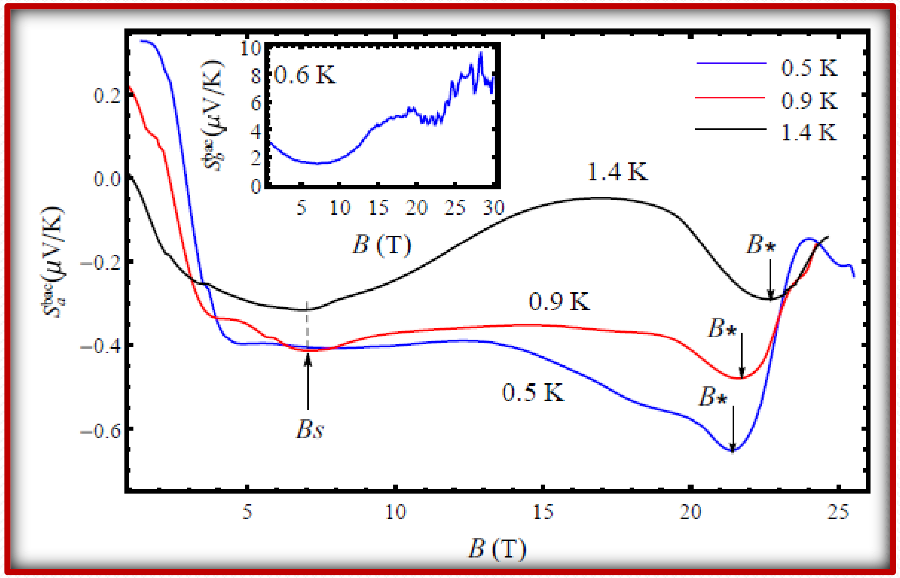


T. Sasaki *et al.*, Phys. Rev. B **66**, 224513 (2002)

Background magnetothermopower



- The inset shows the interlayer magnetothermopower the organic conductor α-$(ET)_2KHg(SCN)_4$ at low temperature of 0.6 K

! striking similarity in the transport properties of YBCO and κ–$(ET)_2Cu(NCS)_2$

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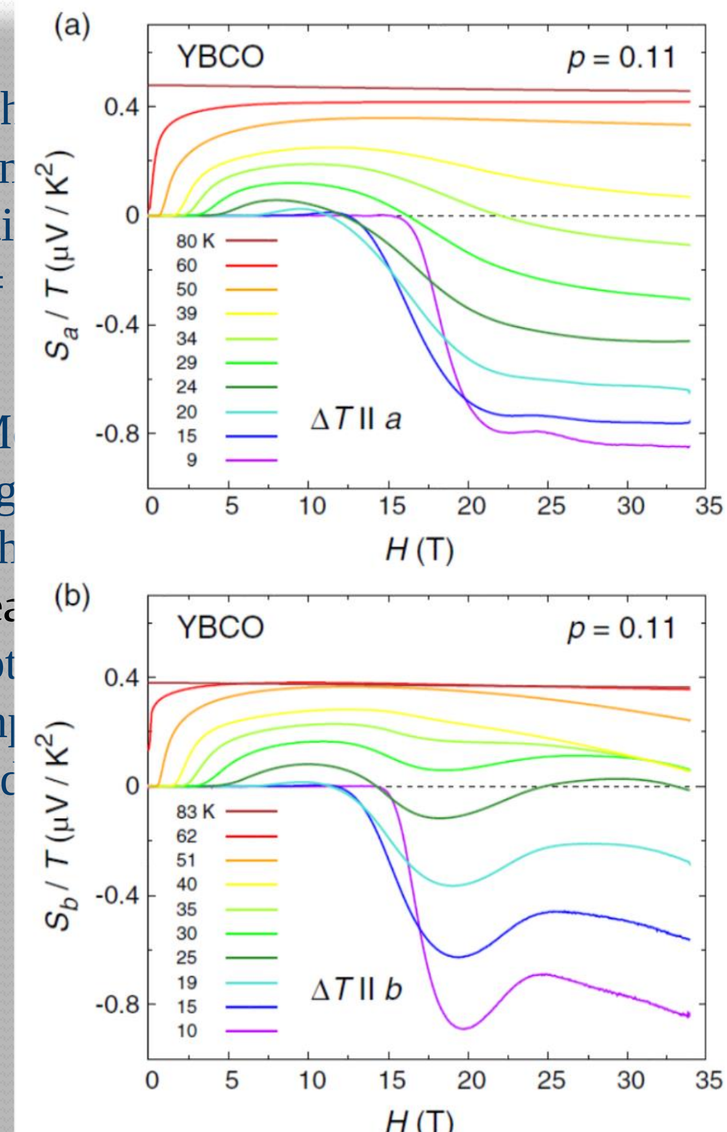
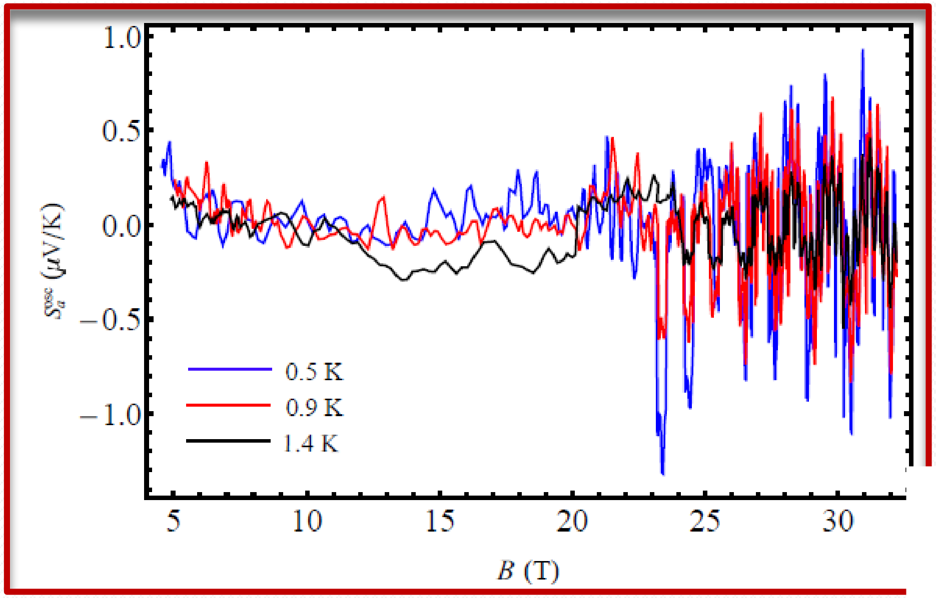
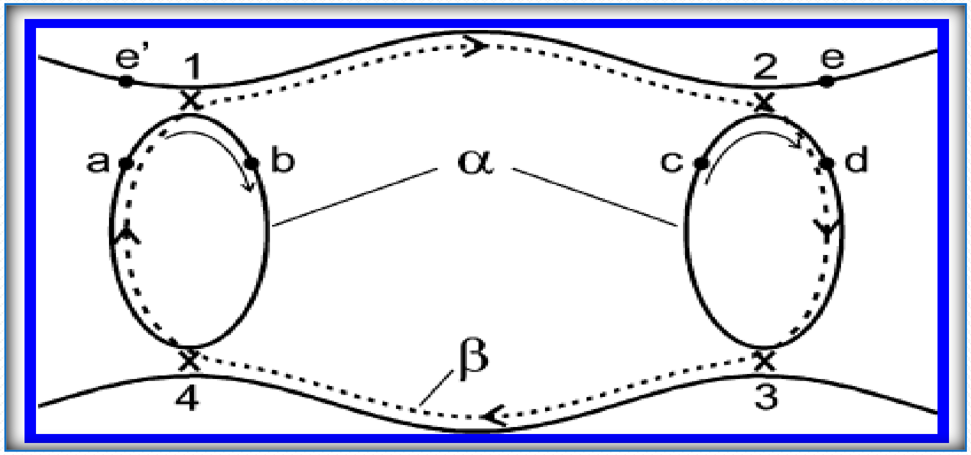
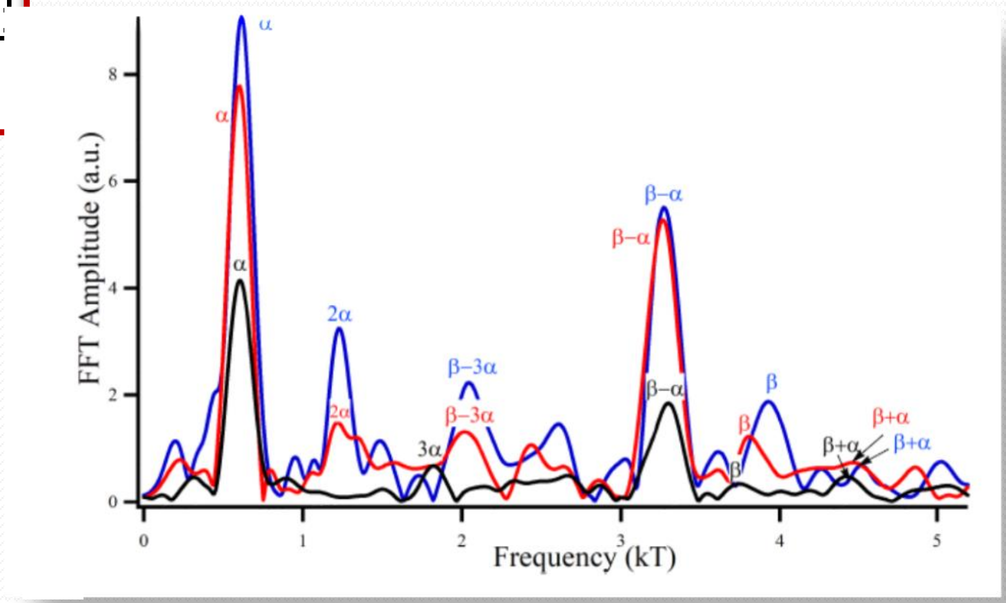


Magnetothermopower quantum oscillations

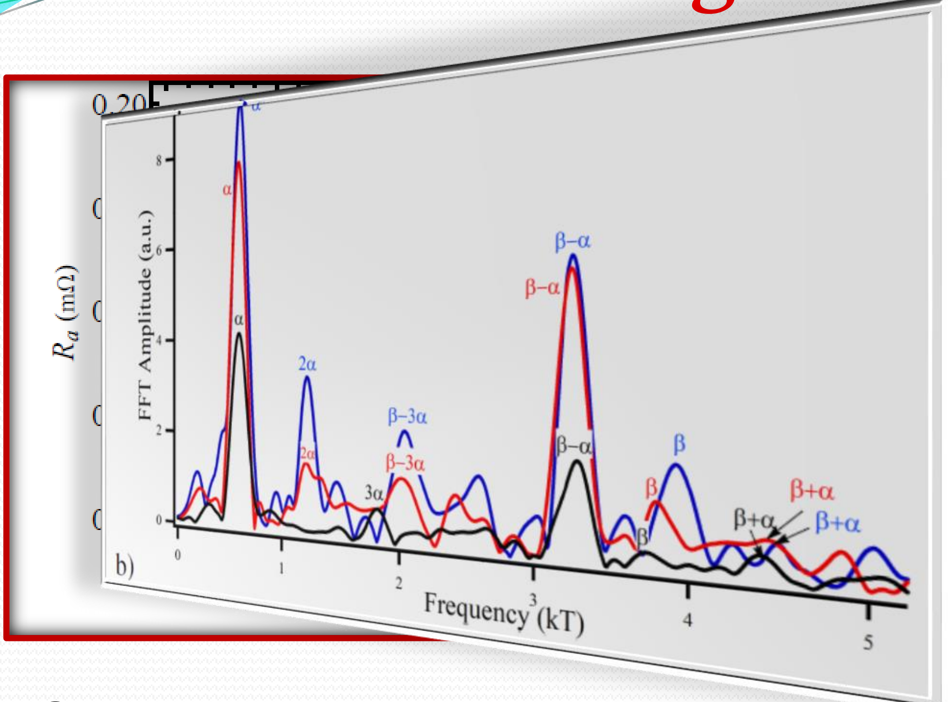






- The FFT spectrum of thermopower reveals a plethora of frequencies. The first two peaks in the low frequency region are due to the fundamental oscillations, $F\alpha$ and its heavily damped (especially at T = 1.4 K) second harmonic $F2\alpha$.

Magnetoresistance



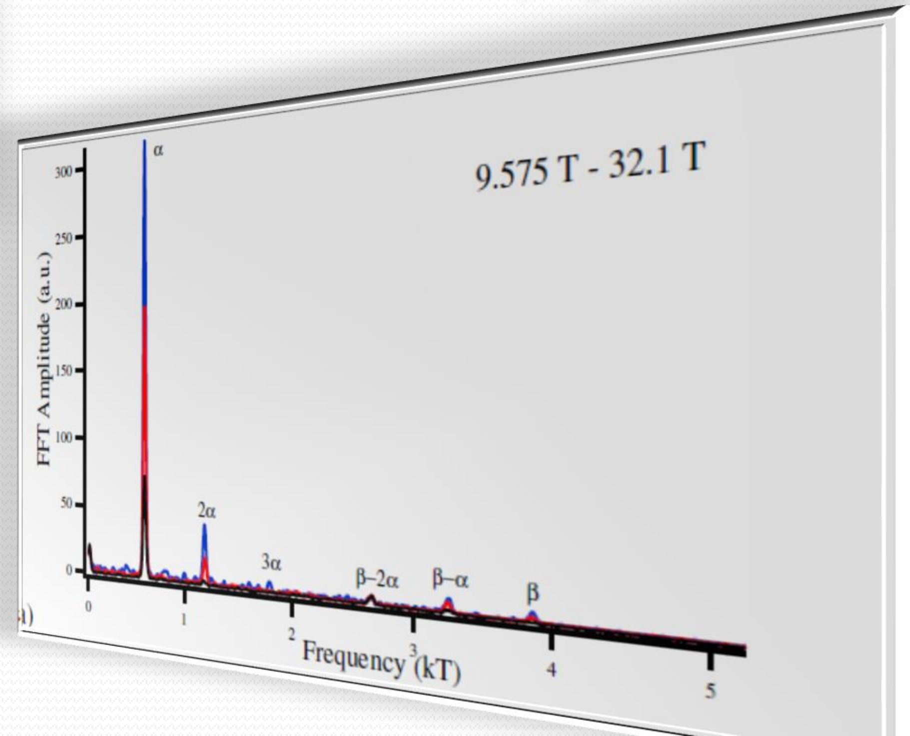
The interlayer magnetoresistance of κ-(ET)2Cu(NCS)2 , Ra (B), measured in magnetic field up to 32 T and three different temperatures: T = 0.5 K, 0.9 K and 1.4 K.

The existence of possible CDW modulations as a primary cause for the observed features can be attributed not to the nesting instability on the Q1D part of FS (at least not totally to that mechanism) but rather to the interlayer effects in this material

$S = \rho\alpha$, with the thermoelectric tensor expressed by the Mott formula

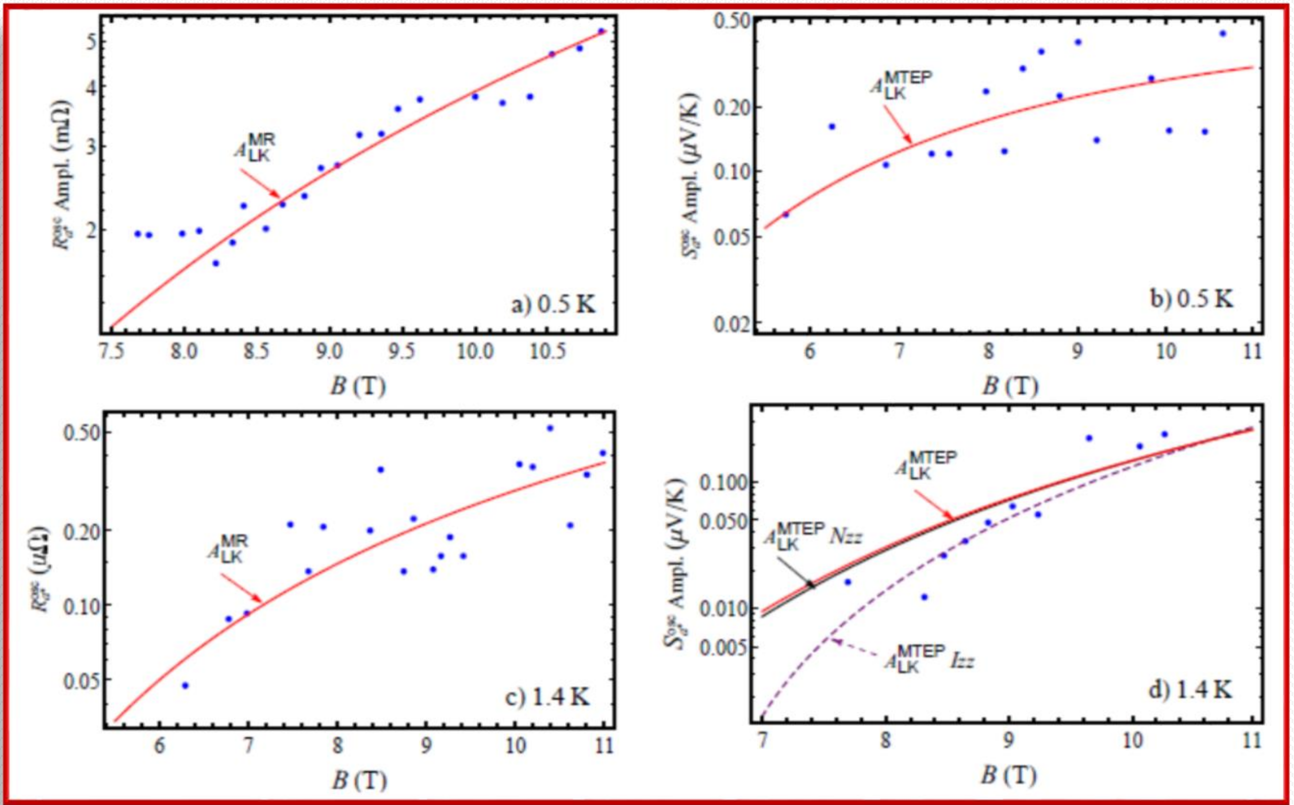
$$\alpha = \frac{\pi^2 k_B^2 T}{3e} \frac{d\sigma(\varepsilon)}{d\varepsilon}\bigg|_{\varepsilon=\varepsilon_F}$$

There is a 'hump' in the interlayer magnetoresistance of κ-$(ET)_2Cu(NCS)_2$ between the superconducting and normal state



FFT spectrum of magnetoresistance reveals existence of $F\beta$ and another forbidden frequency $F\beta - F2\alpha$ in addition to $F\beta - F\alpha$ while $F\beta + F\alpha$ frequency is absent

Quantum oscillation amplitude



The amplitude A_{LK} of the first harmonic of the oscillations in the single band is given by $A^{MR}{}_{LK} \sim R_T R_D R_S$ for MR and $A^{MTEP}{}_{LK} \sim B^{-1/2} R_T R_D R_S$ for MTEP. $R_T = (14.69 m^* T/B)/\sinh(14.69\, m^* T/B)$ - the temperature factor, $R_D = \exp(-m_b T_D/B)$ - the Dingle factor, $R_S = \cos(g m_b/2m_e)$ is the spin factor.

Above 1 K, an additional damping of the oscillation amplitude in the normal state is seen in MTEP below 10 T but not in MR. The dHvA oscillations also do not show additional amplitude damping in normal and vortex state.

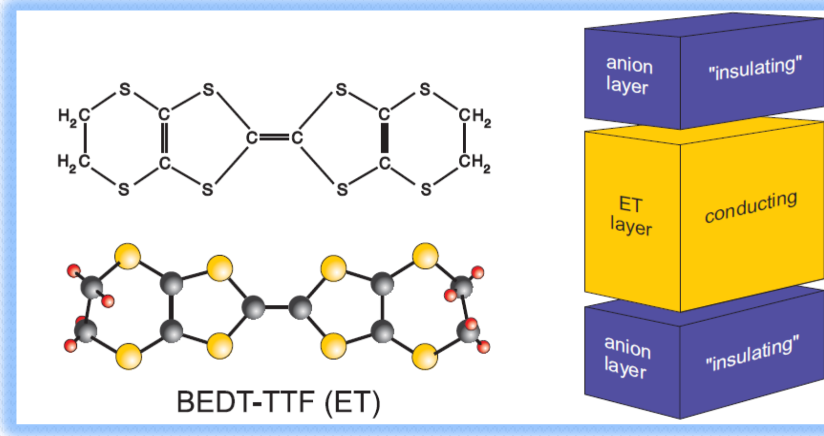
V. M. Gvozdikov, Phys. Rev. B **70**, 085113 (2004)
V. M. Gvozdikov, Low Temp. Phys. **37**, 1209 (2011)

The black curve is fitting of the amplitude with taking into account the kinetic layer-stacking factor for coherent electron motion across the layers $N_{zz} = 0.1 B J_1(2\pi t/h\omega_c)$, $A^{MTEP}{}_{LK} N_{zz}$, which is responsible for the SdH amplitude and oscillates in inverse magnetic field due to the warping of the FS.

The purple curve is fitting of the thermopower amplitude by taking into account the oscillating thermodynamic layer-stacking factor $I_{zz} = J_0(4\pi t/h\omega_c)$, $A^{MTEP}{}_{LK} I_{zz}$, which modulates the dHvA oscillations.

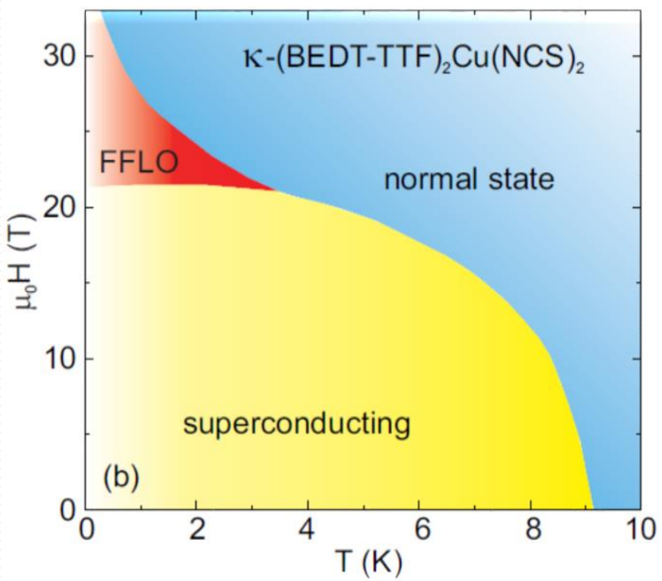
Summary

• The superconductivity in the organic superconductor κ-$(ET)_2Cu(NCS)_2$ is mediated by a charge density wave order rather than antiferromagnetic fluctuations



• The two field-induced successive phase transitions, consisting of two similarly ordered states each restricted to a finite magnetic field window are in fact charge density wave ordered states arising as a result of the layer-stacking mechanism in the interlayer direction

• The interlayer effects and not the nesting are important in the formation and existence of a possible CDW order as a predecessor of the superconducting state in this organic superconductor



• The mechanism of layer-stacking in the interlayer direction might has a profound effect on the lattice parameters of the material leading to certain structural changes in this direction