Coulombian disorder in Charge Density Wave

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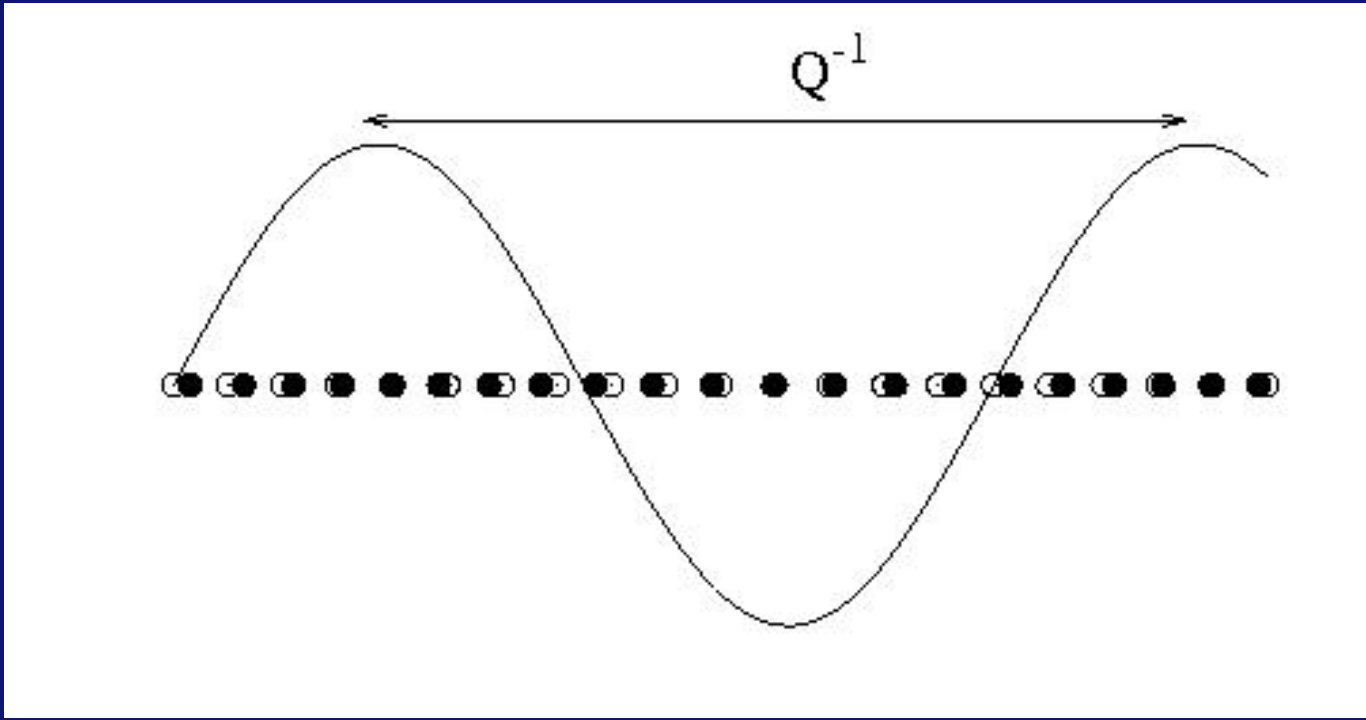
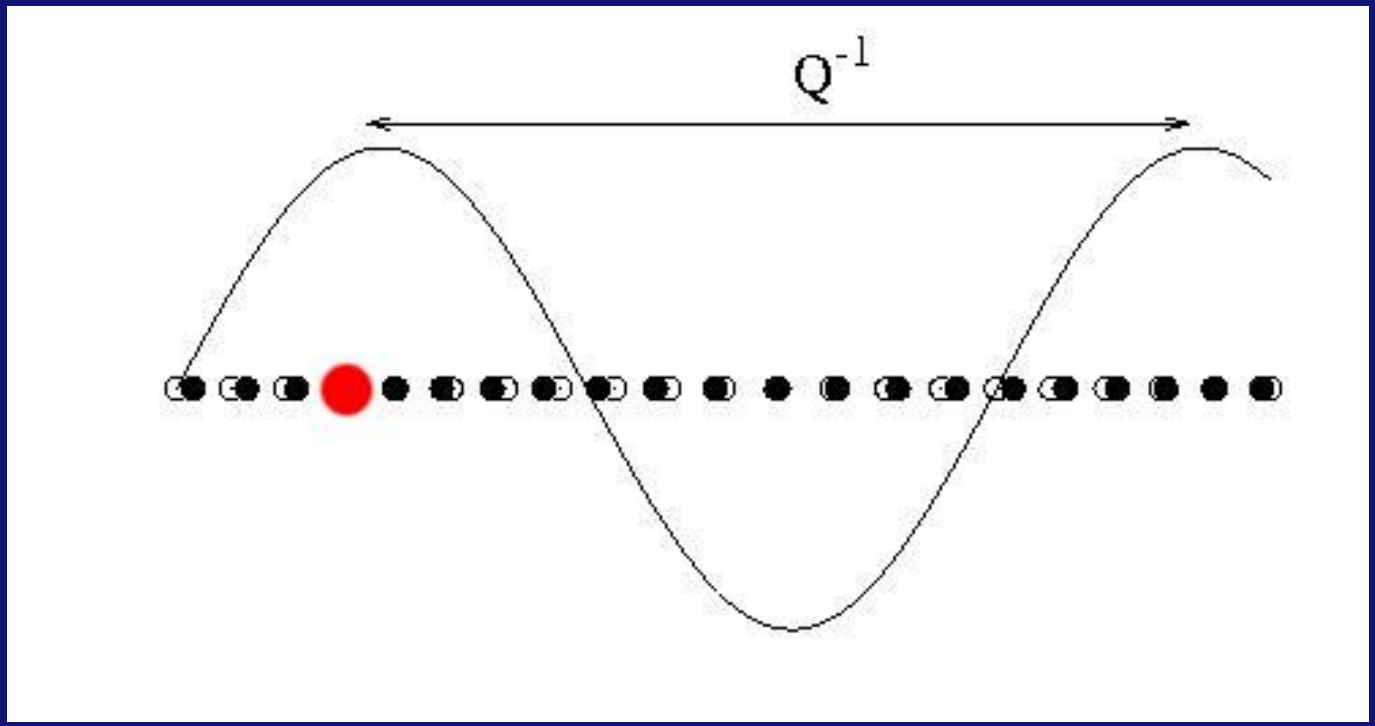
Charge Density Wave (CDW)

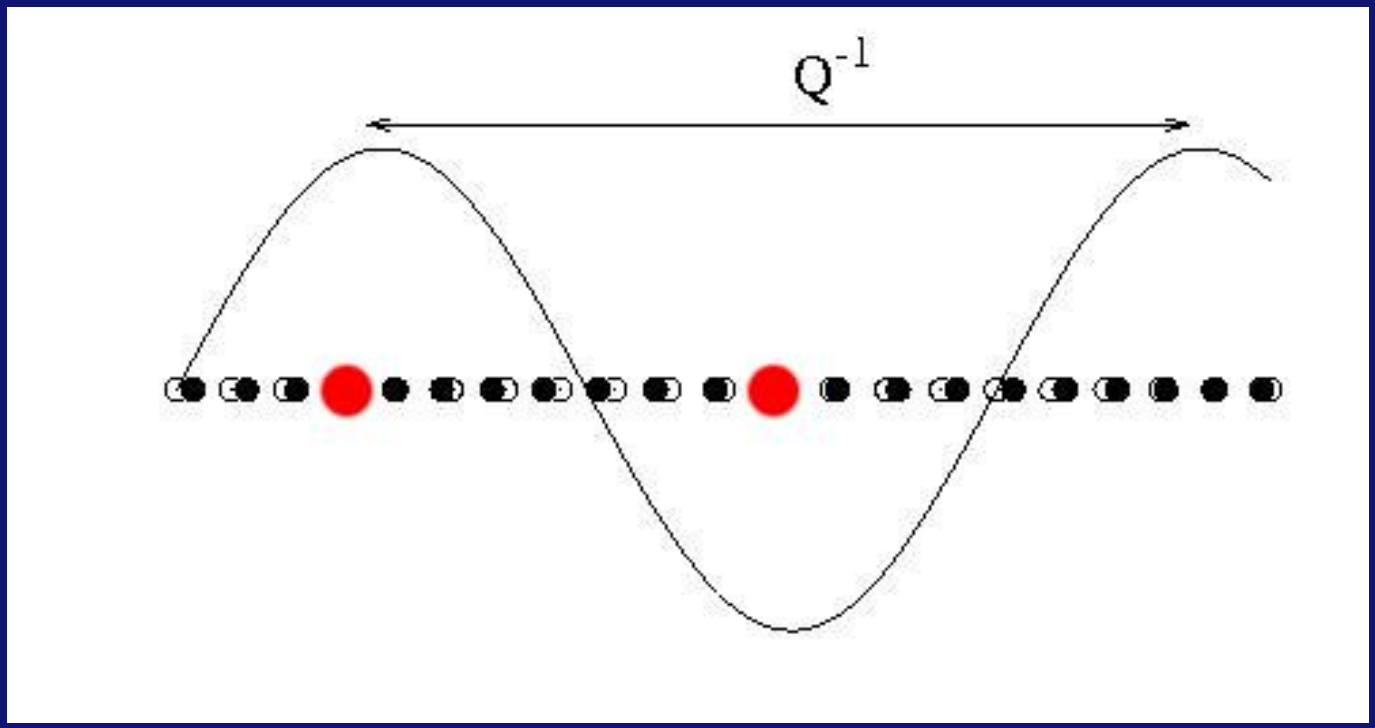


Electron Density $\rho(\mathbf{r}) = \rho_0 + \rho_1 \cos(\mathbf{Q}\mathbf{x} + \phi)$

Density Decomposition



Density Decomposition



Electron Density $\rho(\mathbf{r}) = \rho_0 + \frac{\rho_0}{\mathbf{Q}}\partial_x\phi(\mathbf{r}) + \rho_1 \cos\left(\mathbf{Qx} + \phi(\mathbf{r})\right)$

Short Range model

$$H = \int d\mathbf{r} \frac{\mathbf{c}}{\mathbf{2}} \left(\nabla \phi(\mathbf{r})\right)^{\mathbf{2}} - \mathbf{V}(\mathbf{r})\rho(\mathbf{r})$$

Forward Scattering $\quad H_{\text{dis.}} = -\frac{\rho_0}{Q} \int_r V(\mathbf{r}) \partial_{\mathbf{x}} \phi(\mathbf{r})$

Backward Scattering $\quad H_{\text{dis.}} = -\rho_1 \int_r V(\mathbf{r}) \cos\left(\mathbf{Q}\mathbf{x} + \phi(\mathbf{r})\right)$

Statistical Tilt Symmetry

$$\phi(q) = \tilde{\phi}(q) + \frac{\rho_0}{Q} \frac{i q_x}{q^2} V(q),$$

Weak disorder ($d = 3$)

$$B(r) = \int_q \overline{\langle \phi(q)\phi(-q)\rangle}[1 - \cos qr] = B^{\mathsf{FS}}(r) + B^{\mathsf{BS}}(r)$$

$B^{\mathsf{FS}}(r)$ saturates

Random force model (Larkin)

$B(\mathbf{r}) \sim \mathbf{r}$ Replica Symmetry

Bragg glass phase (Nattermann, Giamarchi, Le Doussal)

$B(\mathbf{r}) \sim \log(\mathbf{r})$ Replica Symmetry Breaking

Coulomb Interaction 1

$$H_{\text{el.}} = \frac{1}{2} \int \frac{d^3q}{(2\pi)^3} G^{-1}(q) \|\phi(q)\|^2$$

$$G^{-1}(q) = \frac{n_c \hbar v_F v_\perp^2}{2\pi v_x^2} \left[\frac{q_x^2}{\mathbf{q}^2 \xi_0^2} + \mathbf{q}_\perp^2 \right]$$

$d = 3$: Random force model (Efetov, Larkin)

$$B(\mathbf{r}) \sim \log(\mathbf{r})$$

$d = 3$: Replica Symmetry Breaking (Rosso, Giamarchi)

$$B(\mathbf{r}) \sim \log(\log(\mathbf{r}))$$

Upper critical dimension: $d_c = 4 \rightarrow d_c = 3$

Coulomb Interaction 2

$$H_{\text{dis.}} = \int d\mathbf{r}d\mathbf{r}' \frac{\rho(\mathbf{r})\rho_{\text{imp.}}(\mathbf{r}')}{\|\mathbf{r}-\mathbf{r}'\|}$$

Backward Scattering

$$H_{\text{dis.}} = -\rho_1 \int_r \cos\left(Qx + \phi(\mathbf{r})\right) \frac{\rho_{\text{imp.}}(\mathbf{r}')}{\|\mathbf{r}-\mathbf{r}'\|}$$

Forward Scattering

$$H_{\text{dis.}} = -\frac{\rho_0}{Q} \int_r \partial_x \phi(\mathbf{r}) \frac{\rho_{\text{imp.}}(\mathbf{r}')}{\|\mathbf{r}-\mathbf{r}'\|}$$

Backward Scattering

Backward disorder is still short ranged

$$B^{\mathsf{BS}}(\mathbf{r}) \sim \log(\log(\mathbf{r}))$$

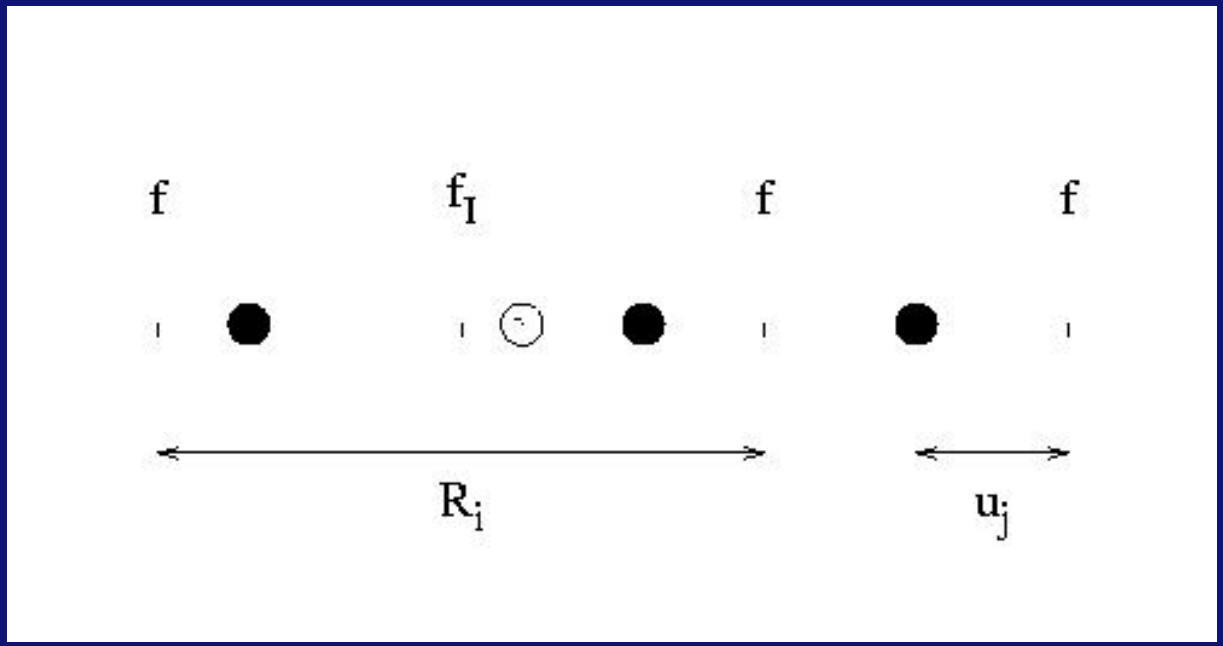
Forward Scattering

The action is still quadratic

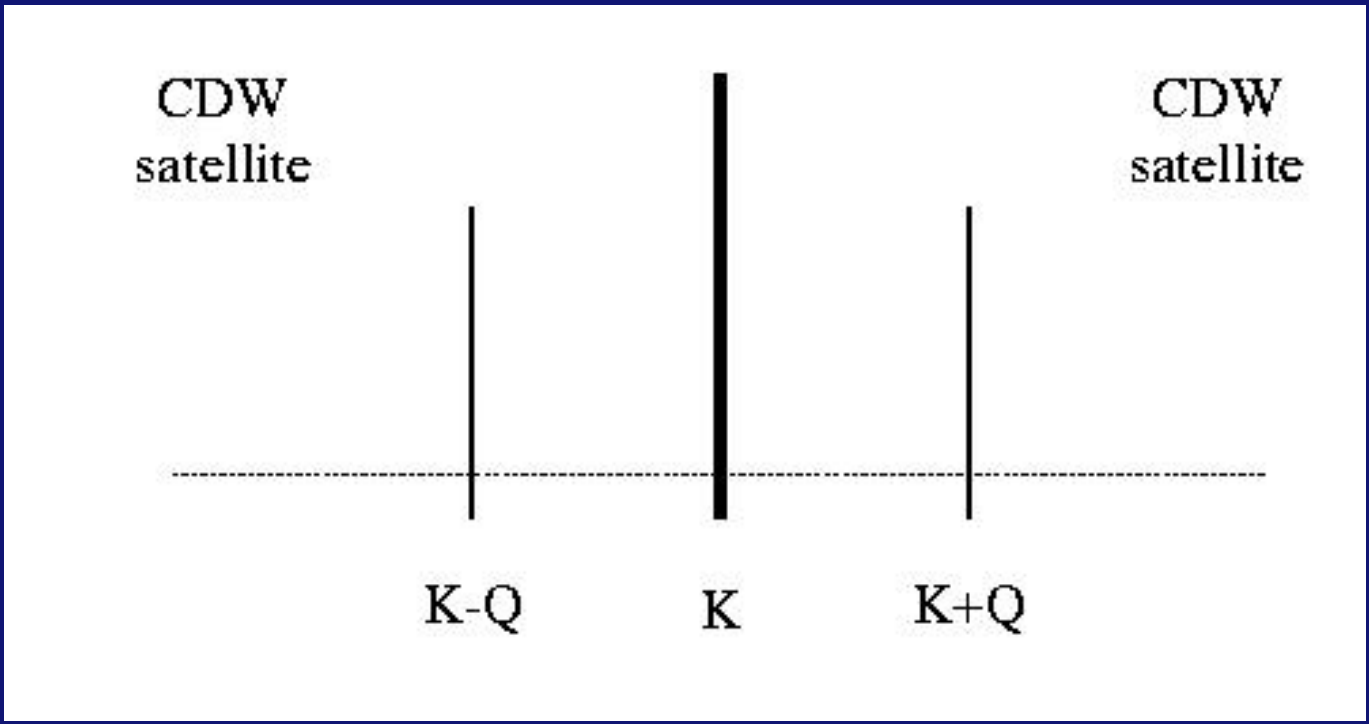
$$B^{\mathsf{FS}}(\mathbf{r}) \sim \log(\mathbf{r})$$

Intensity of the spectrum

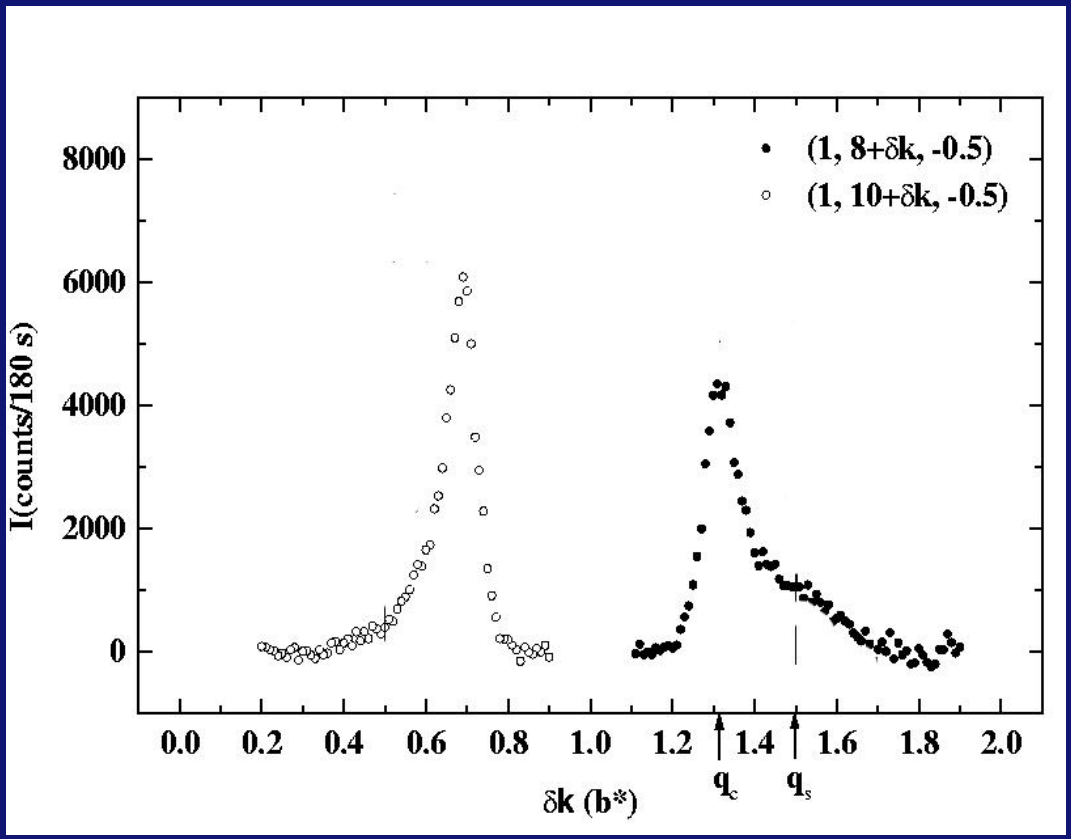
$$I(q) = \frac{1}{V} \sum_{i,j} e^{-iq\,(R_i - R_j)} \left\langle \overline{f_i f_j e^{-iq\,(u_i - u_j)}} \right\rangle$$



X-ray spectrum: two satellites



Experiments:



Ravy *et al.*, *Phys. Rev. B* **62**, R16231 (2000) Blue Bronzes:
$V^{+5} \rightarrow Mo^{+6}$

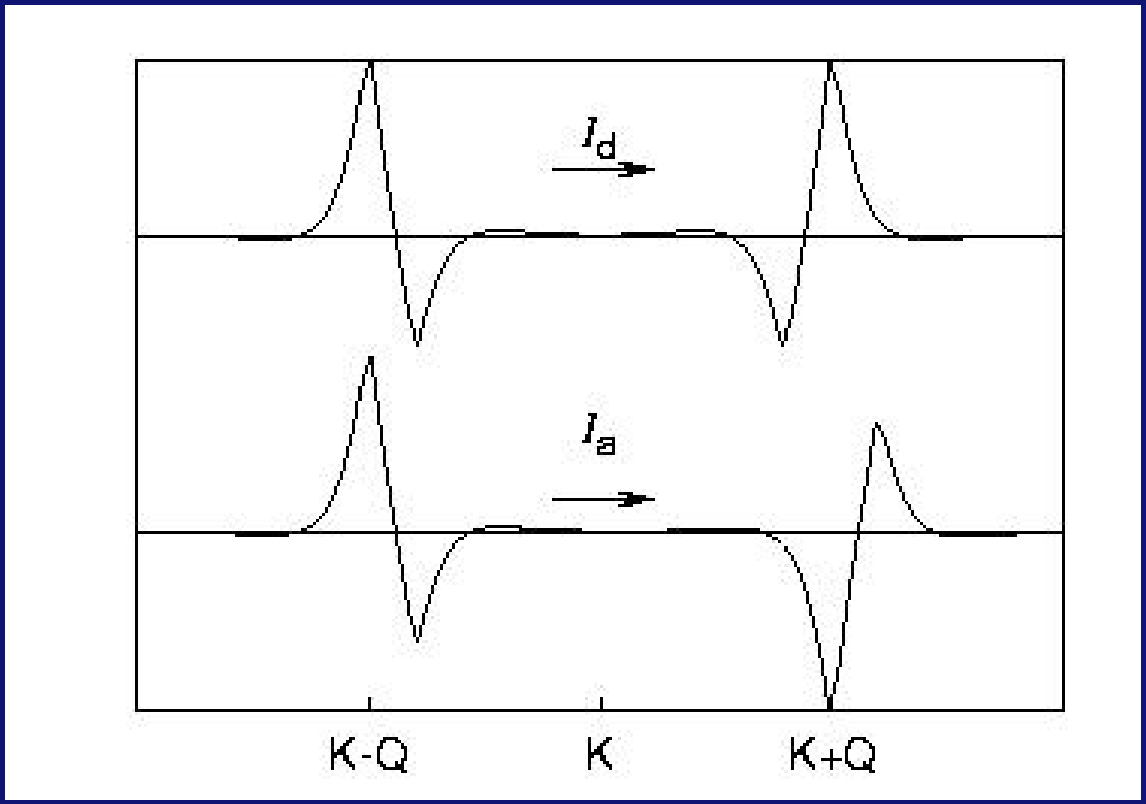
Developing $I(q) = I_{\mathsf{d}} + I_{\mathsf{a}} + \ldots$

$$
\begin{aligned}
I_{\mathsf{d}}(K+Q+k) &\sim \int d^3\mathbf{r}\, e^{-i\mathbf{k}\cdot\mathbf{r}} C_{\mathsf{d}}(\mathbf{r})\,, \\
I_{\mathsf{a}}(K+Q+k) &\sim \int d^3\mathbf{r}\, e^{-i\mathbf{k}\cdot\mathbf{r}} C_{\mathsf{a}}(\mathbf{r})
\end{aligned}
$$

with

$$
\begin{aligned}
C_{\mathsf{d}}(\mathbf{r}) &= \left\langle \overline{e^{i(\phi(\mathbf{r}/2)-\phi(-\mathbf{r}/2))}} \right\rangle\,, \\
&= C_{\mathsf{d}}^{\mathsf{F.S}}(\mathbf{r}) C_{\mathsf{d}}^{\mathsf{B.S}}(\mathbf{r})\,, \\
C_{\mathsf{a}}(\mathbf{r}) &= \chi(\mathbf{r}) C_{\mathsf{d}}(\mathbf{r}) \\
\chi(r) &\sim \frac{1}{r}
\end{aligned}
$$

Symmetry Properties



Results

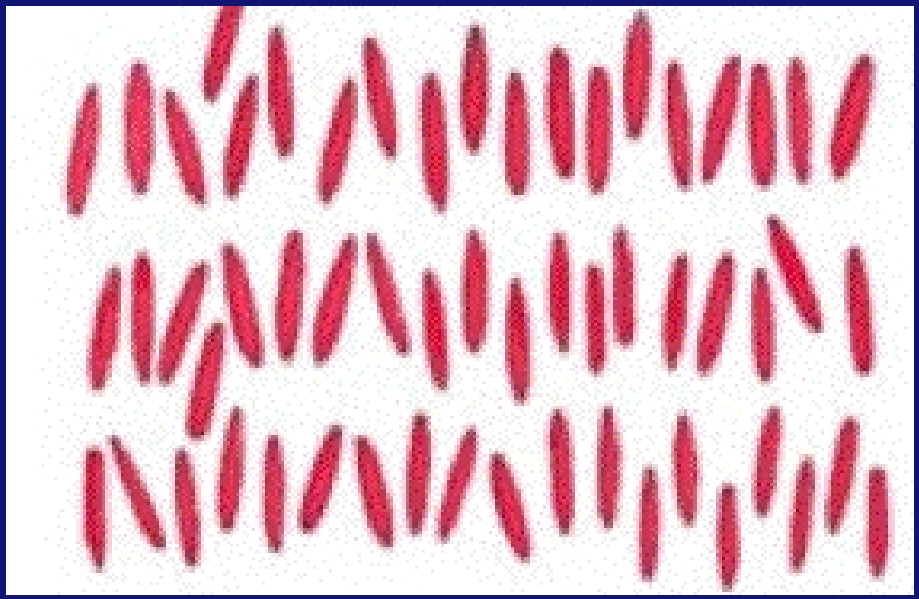
disorder	elasticity	
	Short range	Long range
Short range	$I_d(q) \sim q^{\eta-3}$	$I_d(q) \sim q^{-3}$
Long range	Unphysical	$I_d(q_x) \sim \|q_x\|^{\kappa-2}$ $I_d(q_\perp) \sim \|q_\perp\|^{2(\kappa-2)}$

- $\eta \sim 1$ is the Bragg Glass exponent
- κ is not universal

  $\kappa = \frac{DQ^2 v_x}{16\pi\xi\rho_0^2 v_\perp}$

- for $K_{0.3}MoO_3$, κ in the range $[0.16 - 0.8]$.

Smectic-A



$$H_{\text{el.}} = \int d\mathbf{q} \left[\frac{\mathbf{B}}{\mathbf{2}} \mathbf{q_x^2} + \frac{\mathbf{k_{11}}}{\mathbf{2}} \mathbf{q_\perp^4} \right] \|\mathbf{u_q}\|^{\mathbf{2}}$$

Same peaks, but replace D with $K_B T$

Conclusions:

- Non-local elasticity changes statics and dynamics of CDW
- Long range disorder affect only the forward scattering term
- Coulombian disorder does not affect dynamics
- Smectic-like behaviour in statics