Charge Order in $NbSe_2$

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Outline

- Introduction
  - 1D CDWs
  - 2D CDWs
  - $NbSe_2$
- Weak Coupling
- Strong Coupling
  - gap
  - pseudogap
- Conclusions

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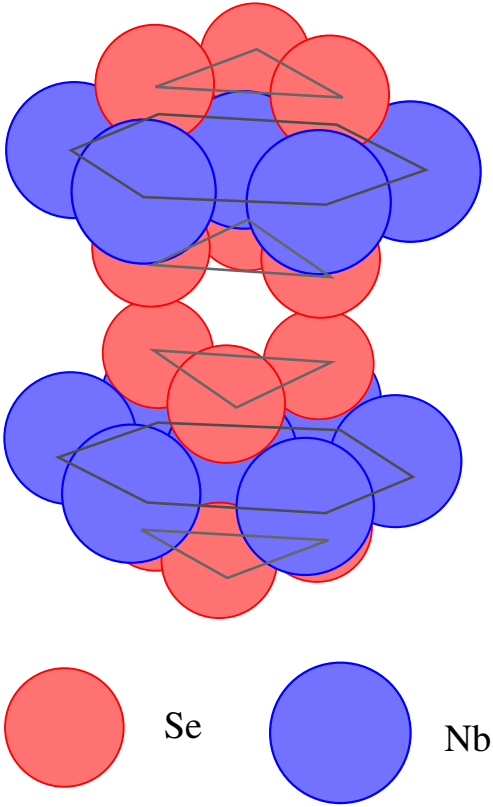
Niobium Diselenide



Prototype layered CDW Material

Mysteries:

- CDW gap in 1 band only
- wide 'Kohn anomaly'
- particle/hole gap asymmetry
- gap offset
- pseudogap

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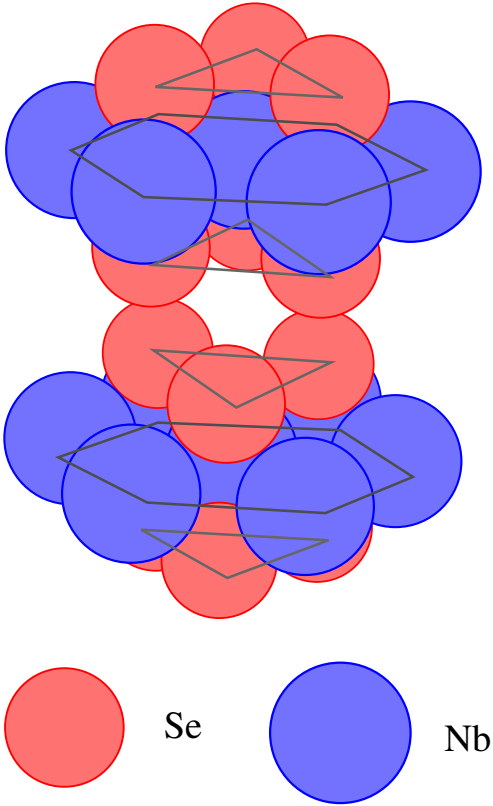

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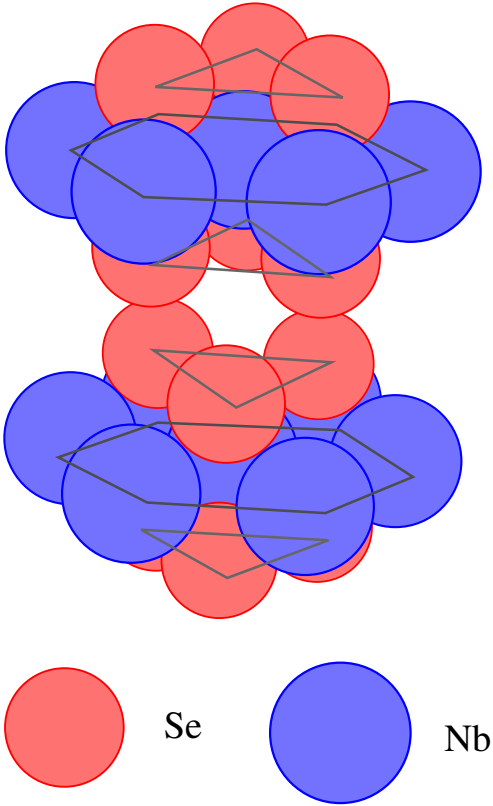

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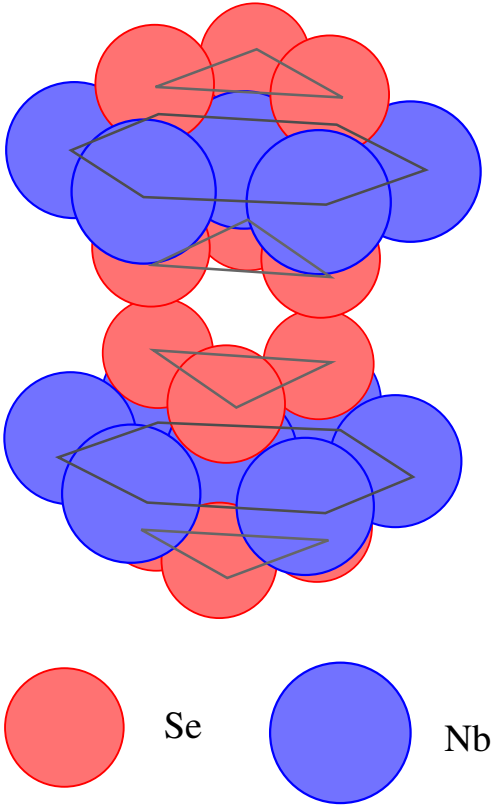

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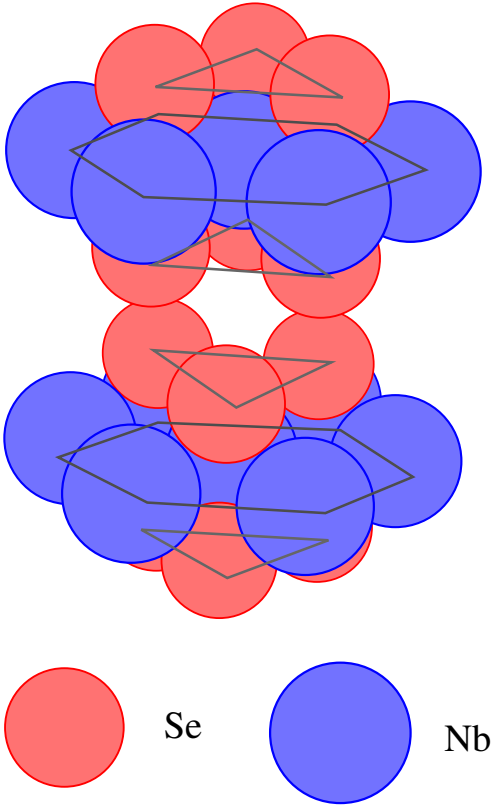

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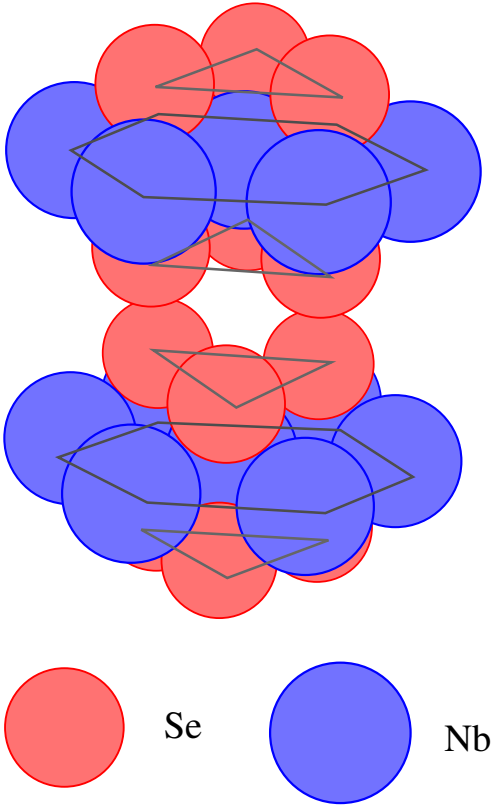

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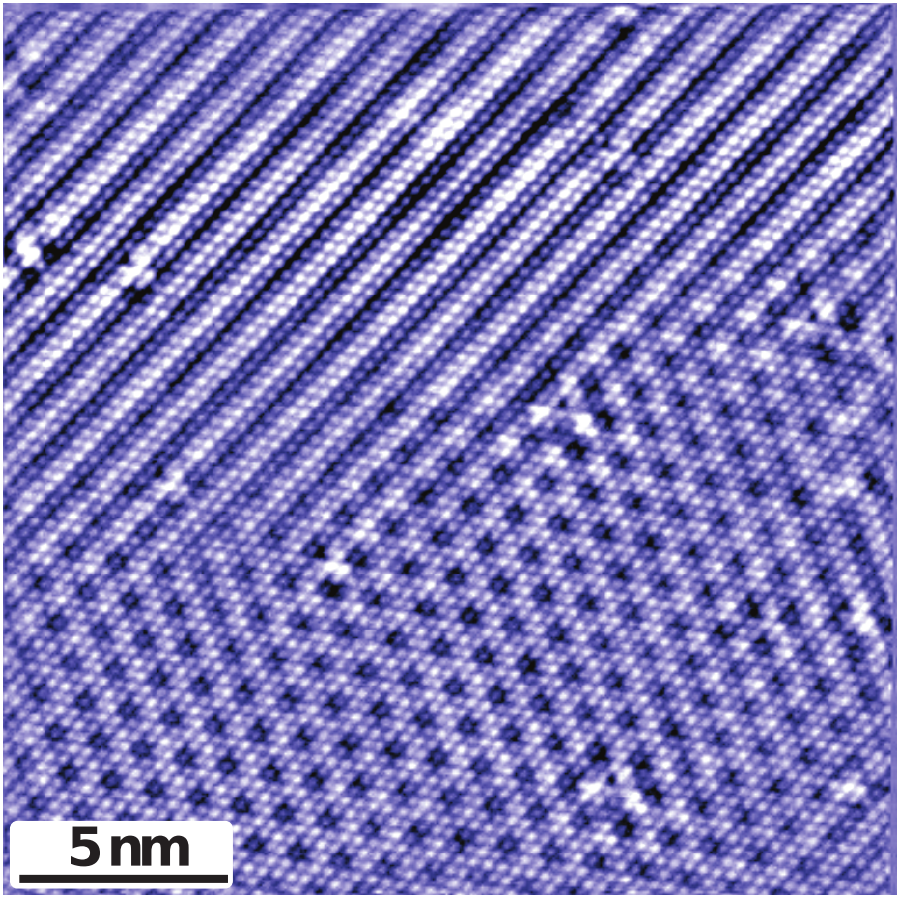
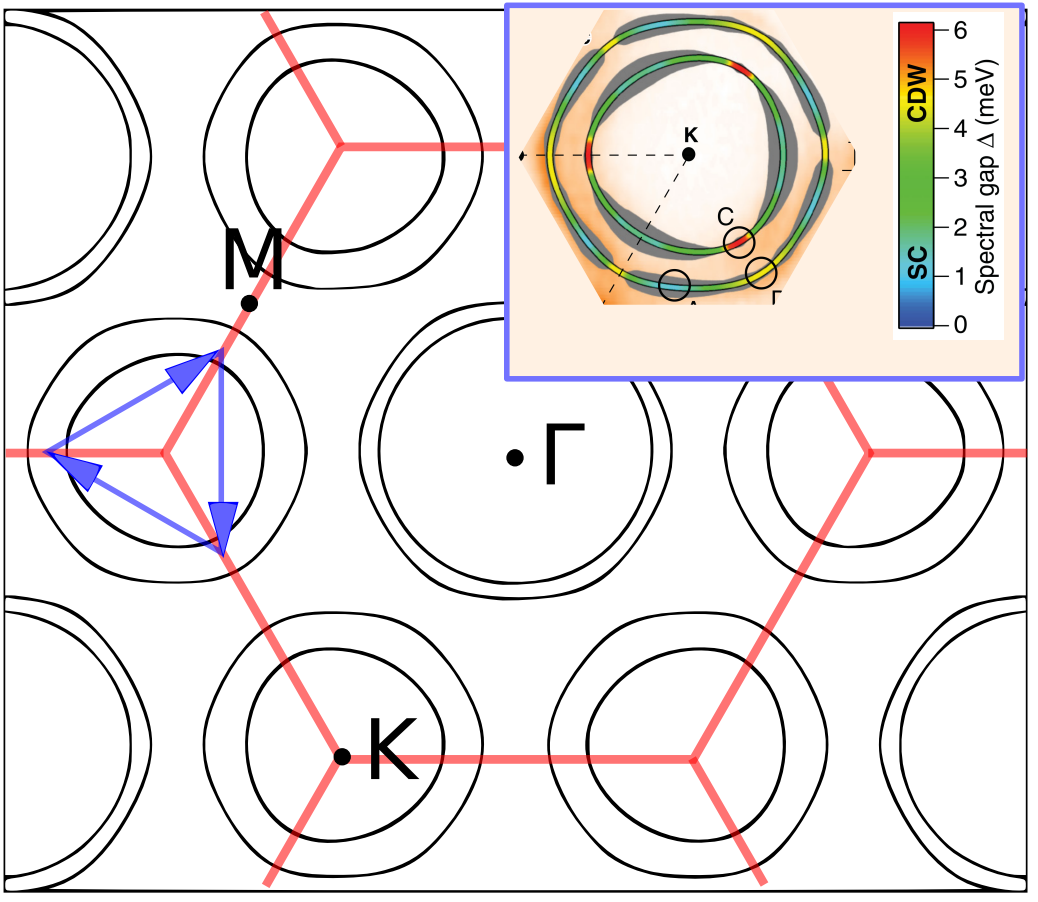
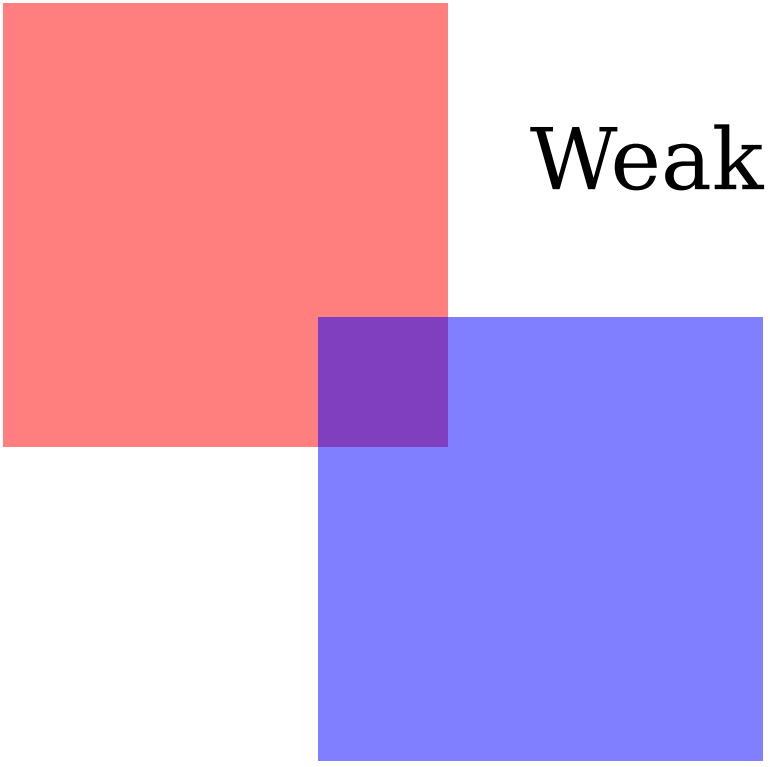


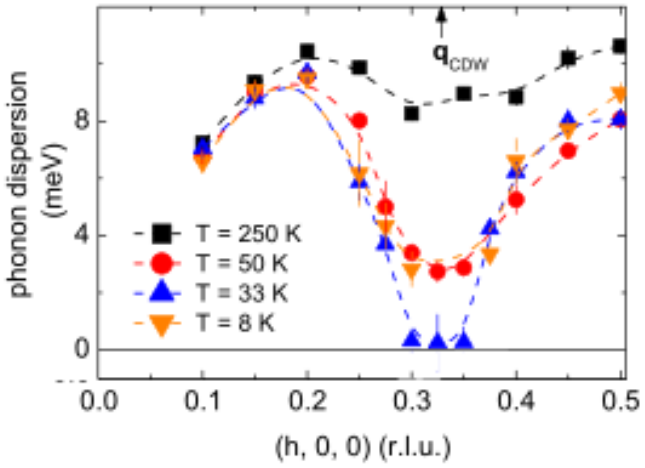
A. Soumyanarayanan *et al.* PNAS 110(5):1623-1627 (2013)

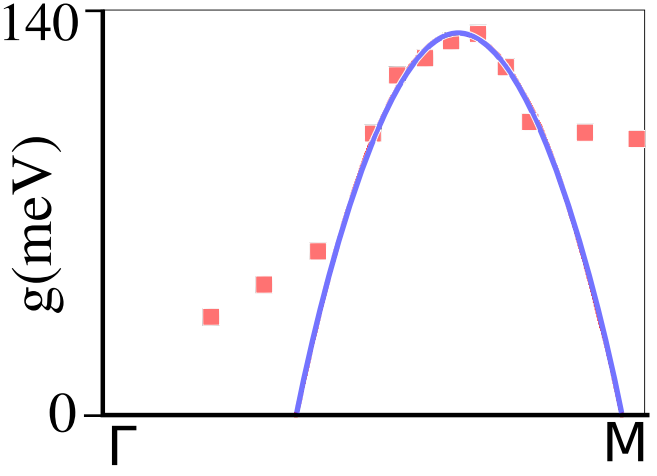


D. J. Rahn *et al.* PRB 85, 224532 (2012)

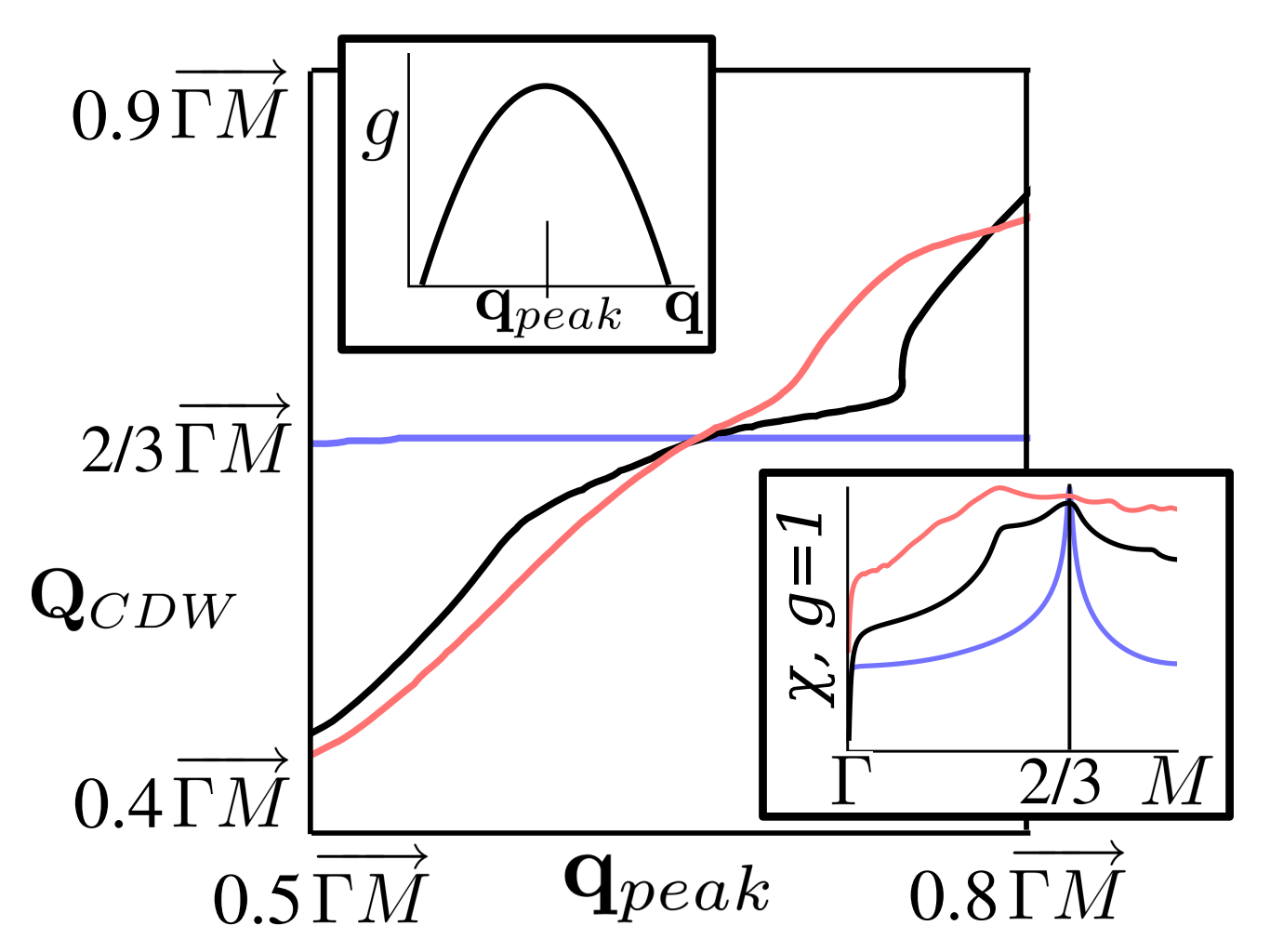


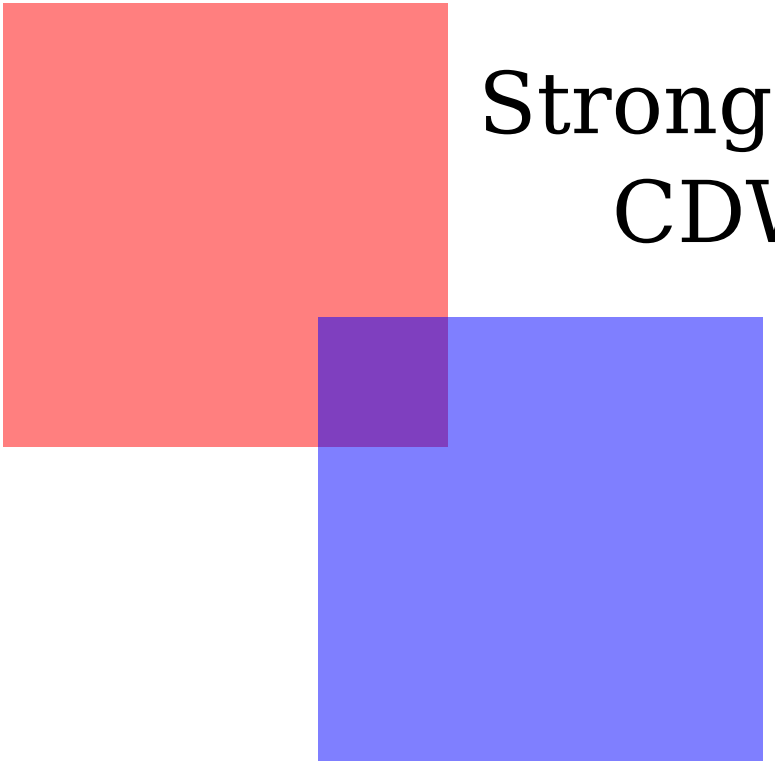
Weak Coupling





F. Weber *et al.* PRL 107, 107403 (2011)


$0.9\overrightarrow{\Gamma M}$
$2/3\overrightarrow{\Gamma M}$
$0.4\overrightarrow{\Gamma M}$
$\mathbf{Q}_{CDW}$
$0.5\overrightarrow{\Gamma M}$
$\mathbf{q}_{peak}$
$0.8\overrightarrow{\Gamma M}$
g
$\mathbf{q}_{peak}$
$\mathbf{q}$
$\chi,\ g=1$
Γ
$2/3$
M



Strong Coupling: CDW Gap

$$H|A_\lambda\rangle = E_\lambda S|A_\lambda\rangle$$

$$\mathbf{g}^{\lambda,\lambda'}_{\mathbf{k},\mathbf{k}'} \propto \mathbf{v}^{\lambda}_{\mathbf{k}} \left[A^\dagger_{\mathbf{k}} S_{\mathbf{k}} A_{\mathbf{k}'}\right]^{\lambda\lambda'} - \left[A^\dagger_{\mathbf{k}} S_{\mathbf{k}'} A_{\mathbf{k}'}\right]^{\lambda\lambda'} \mathbf{v}^{\lambda'}_{\mathbf{k}'}$$

C. M. Varma *et al.* PRB 19, 6130-6141 (1978)

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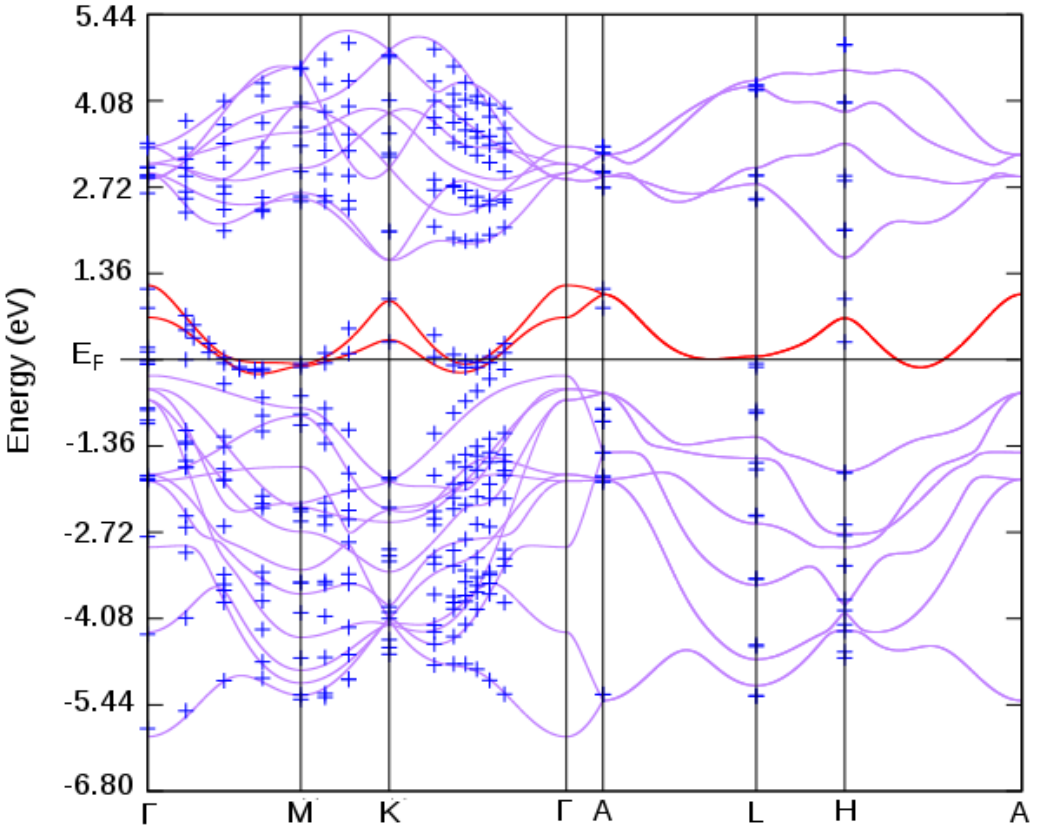
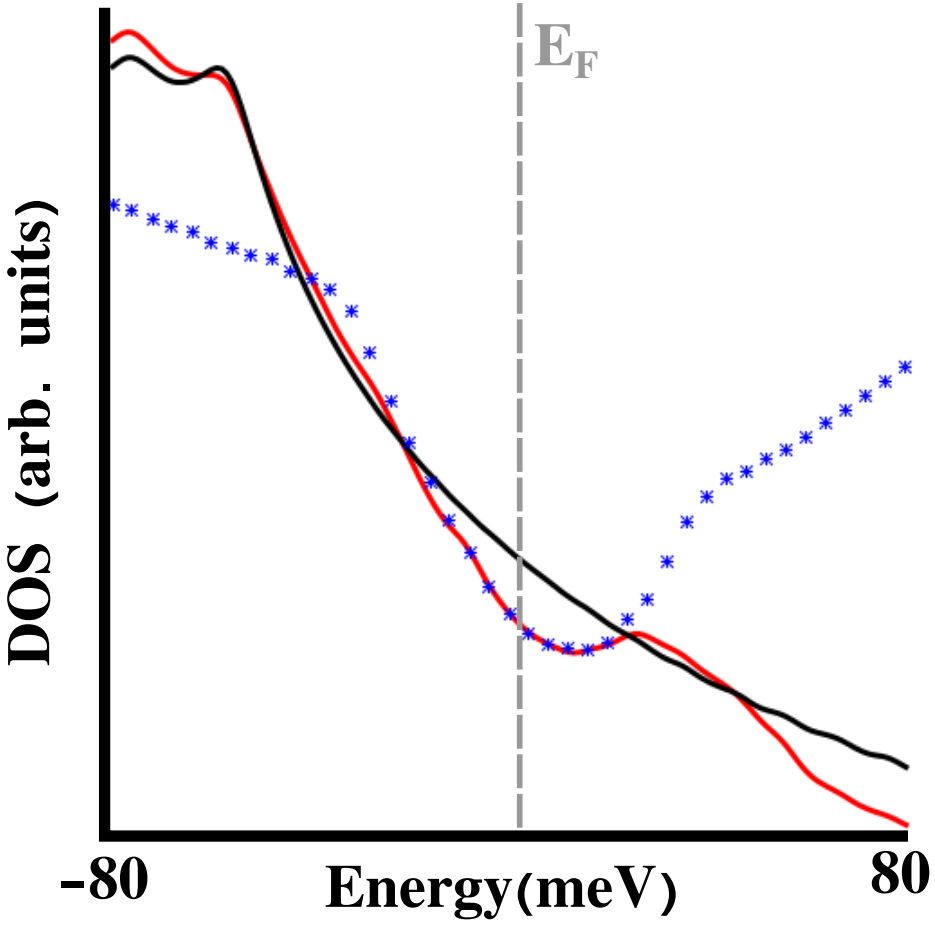
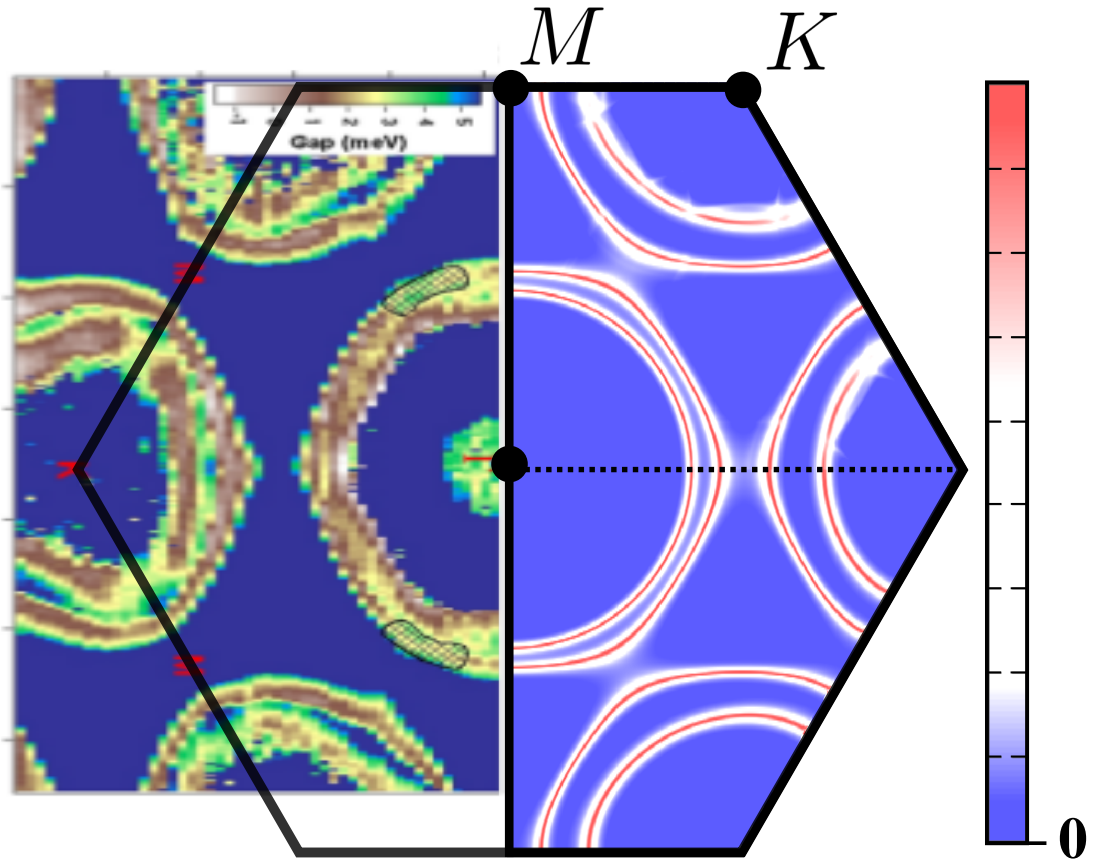
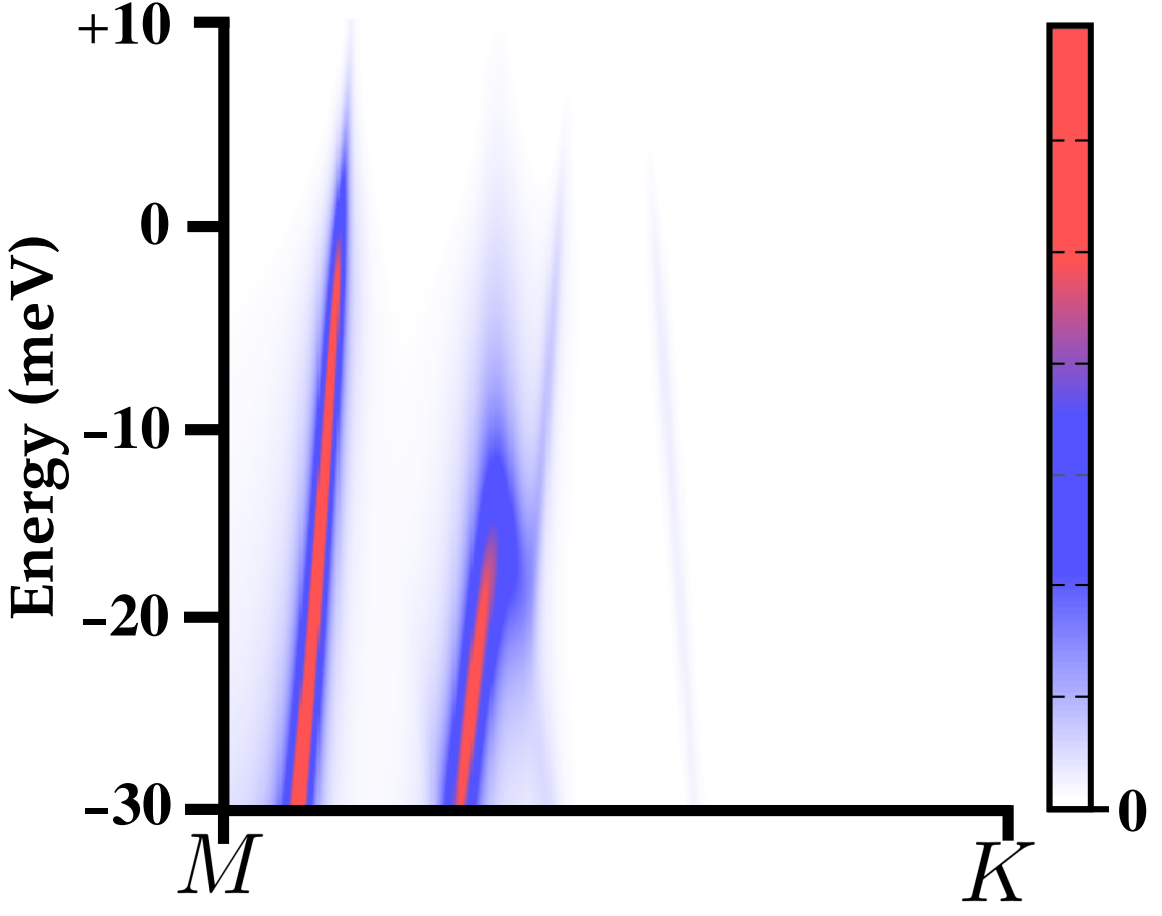


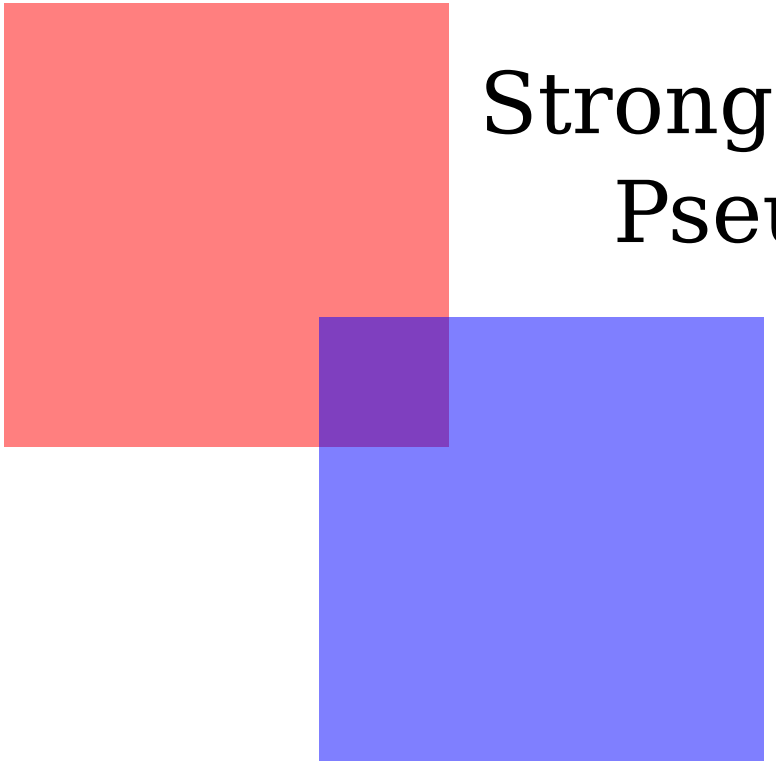


Soumyanarayanan *et al.*, PNAS 110, 1623-1627 (2013)

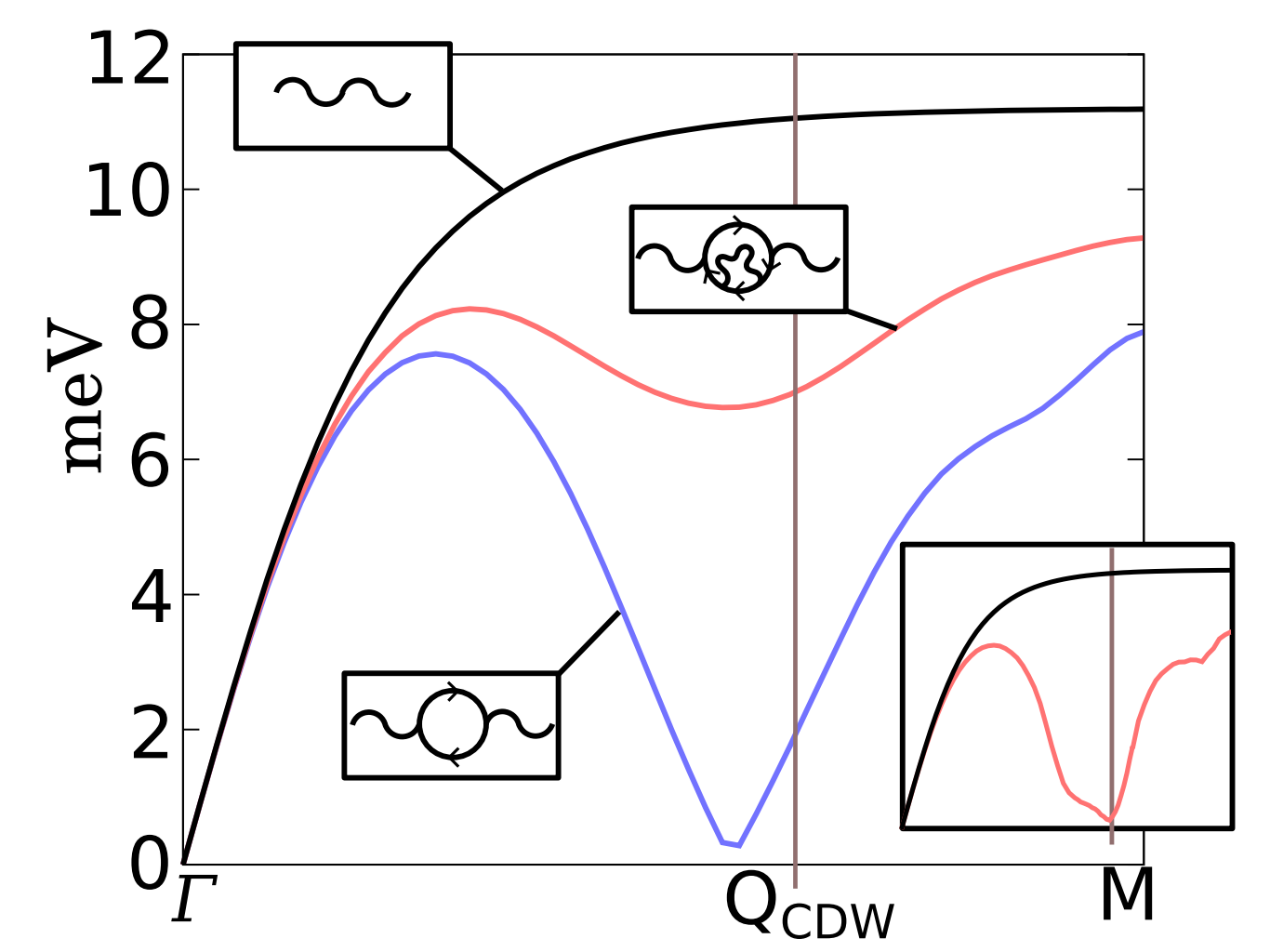


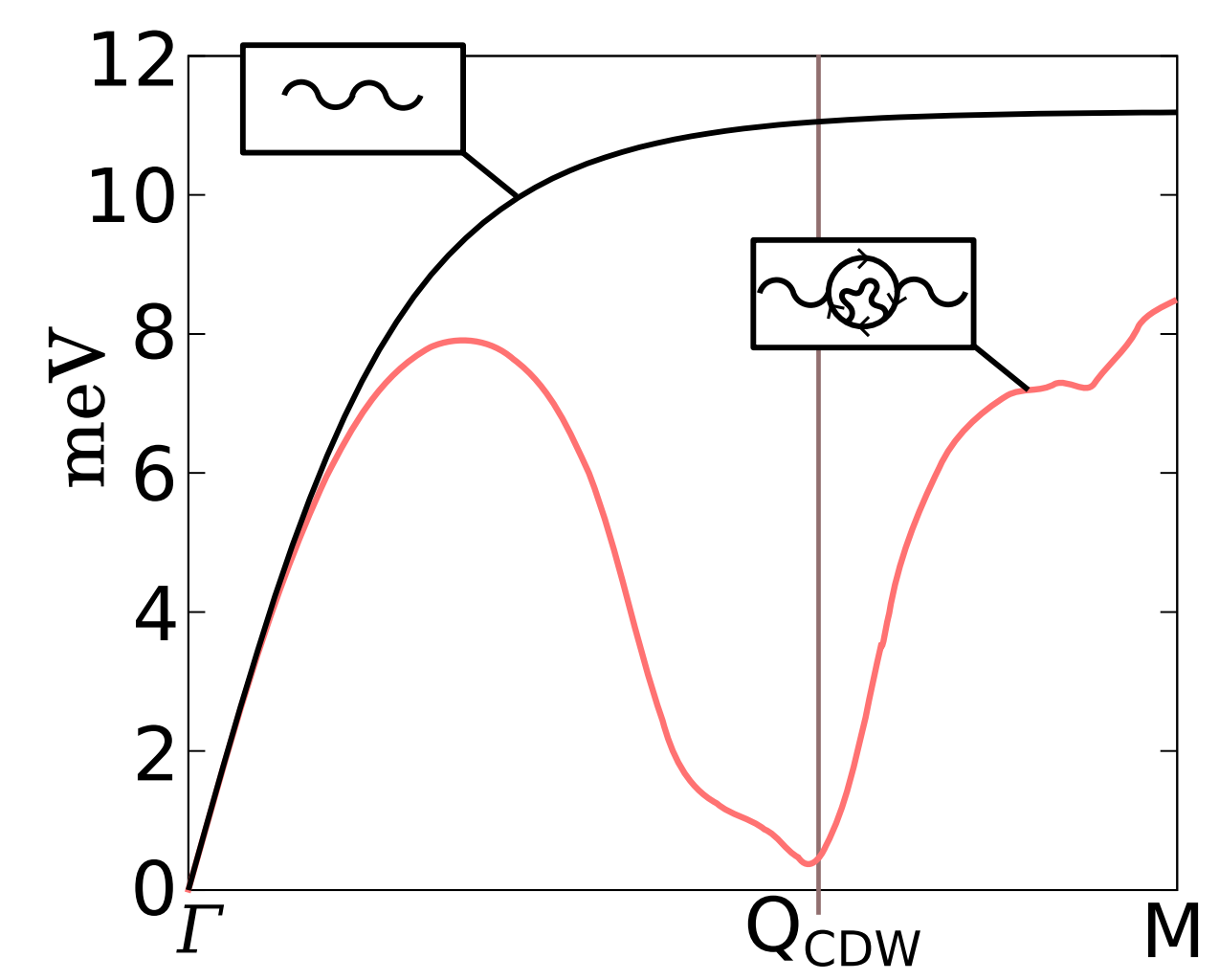
Borisenko *et al.*, PRL 102, 166402 (2002)


+10
0
-10
-20
-30
Energy (meV)
M
K
0



Strong Coupling: Pseudogap


12
10
8
6
4
2
0
meV
Γ
Q_CDW
M


12
10
8
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Conclusions

- Peierls Mechanism not the natural starting point in D>1
- $g_{kk'}^{\lambda\lambda'}$ needed
- First consistent theoretical explanation of $NbSe_2$ experimental results

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Thanks For Listening

F. Flicker and Jasper van Wezel, "*Charge Order from Orbital Dependent Coupling Evidenced by* $NbSe_2$", **Nature Communications 6, 7034 (2015)**

Y. Feng, J. van Wezel, J. Wang, F. Flicker, D. M. Silevitch, P. B. Littlewood, and T. F. Rosenbaum, "*Quantum Criticality and the Charge Density Wave Phase Transition in* $NbSe_2$", **Nature Physics 11, 865 (2015)**

F. Flicker and Jasper van Wezel, "*Charge Ordering Geometries in Uniaxially Strained* $NbSe_2$", **Physical Review B 92, 201103 (Rapid Communications) (2015)**

F. Flicker and Jasper van Wezel, "*Charge Order in Monolayer* $NbSe_2$", in preparation