In operando electronic structure of quantum materials

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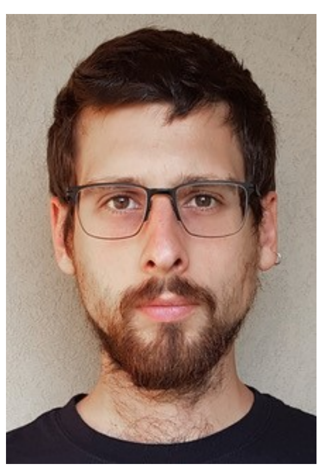

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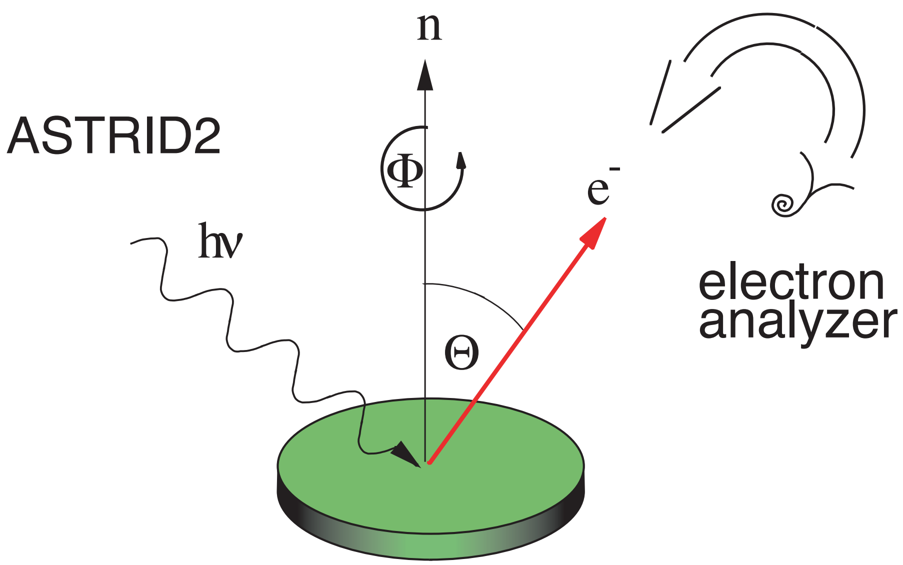
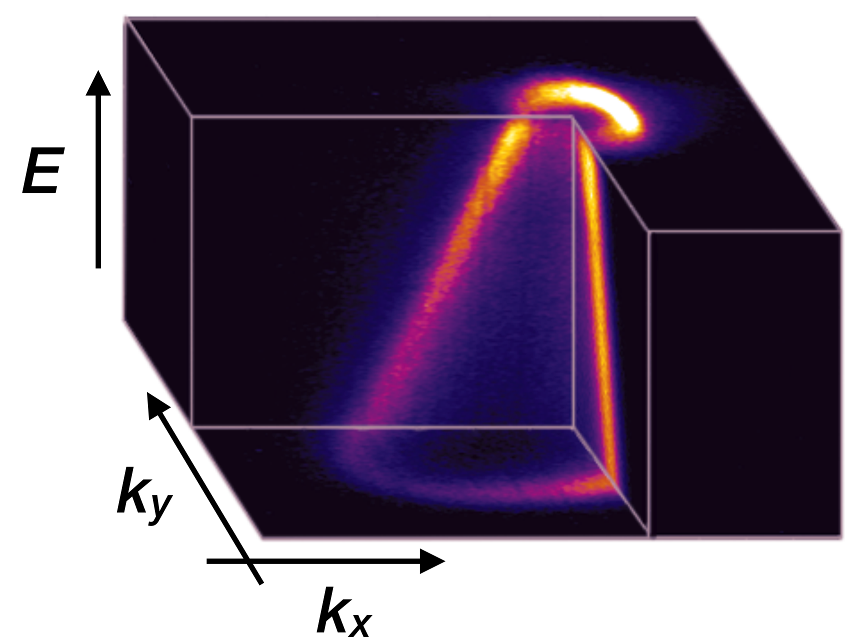
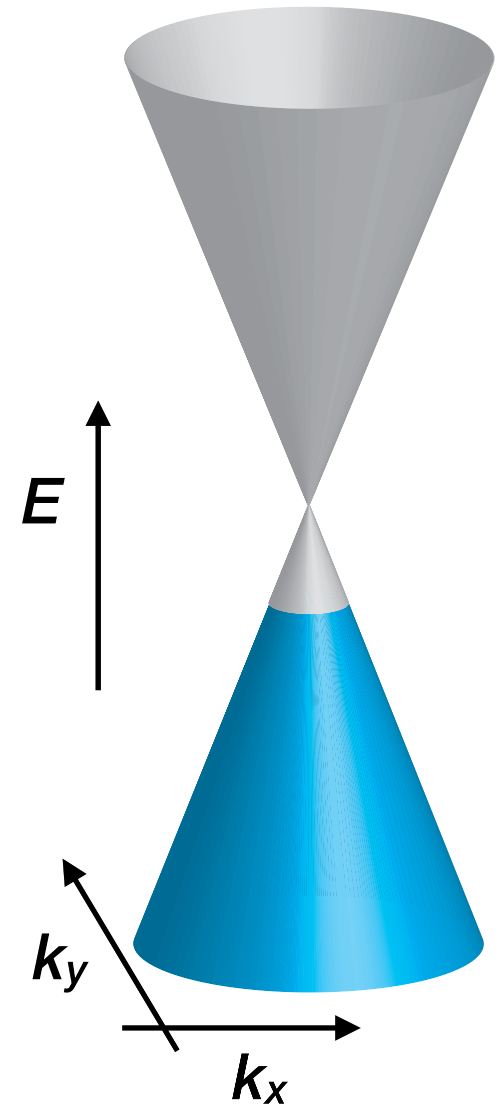
VILLUM Centre of Excellence for Dirac Materials

angle-resolved photoemission (ARPES): a direct view at the band structure



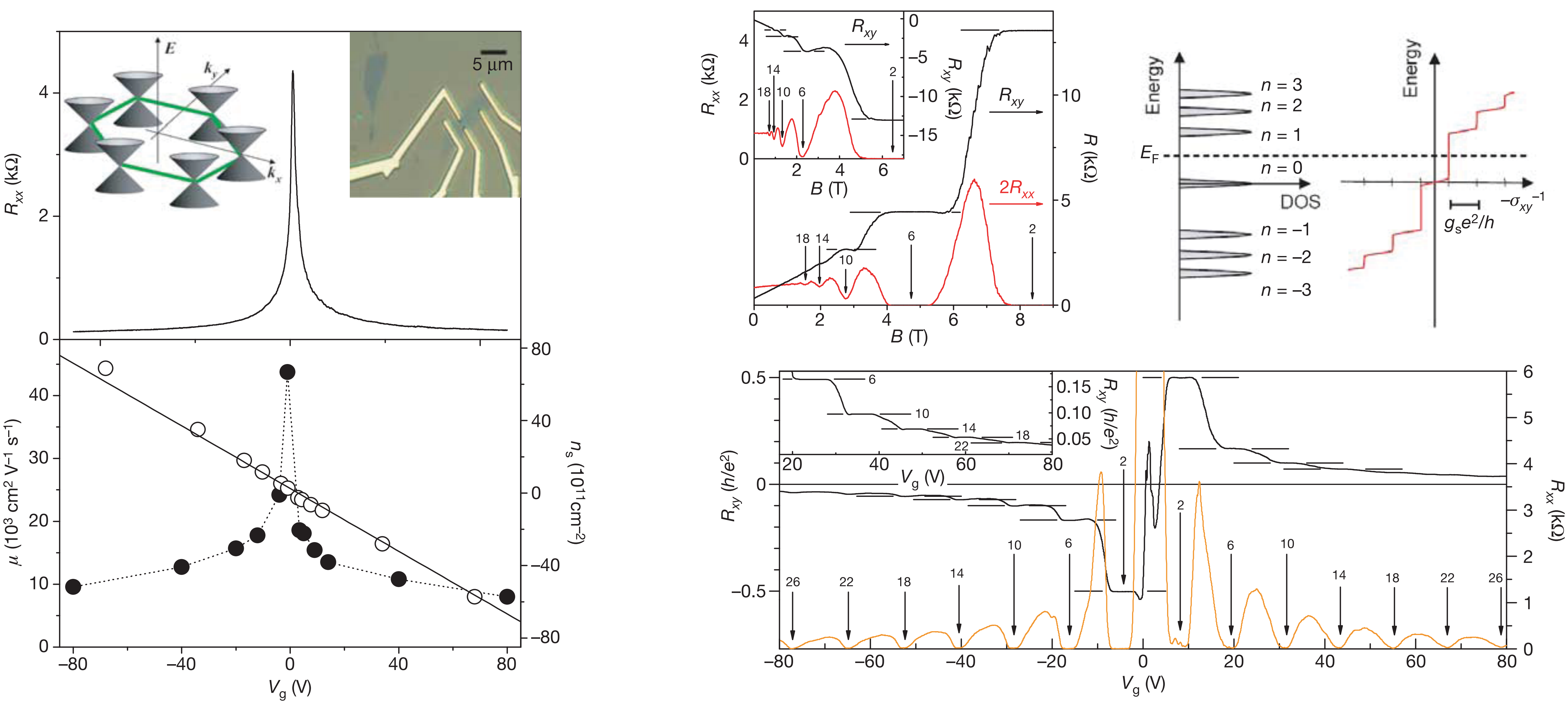




$$I \propto |M|^2 \mathscr{A}(\omega, \mathbf{k}) f(\omega, T)$$

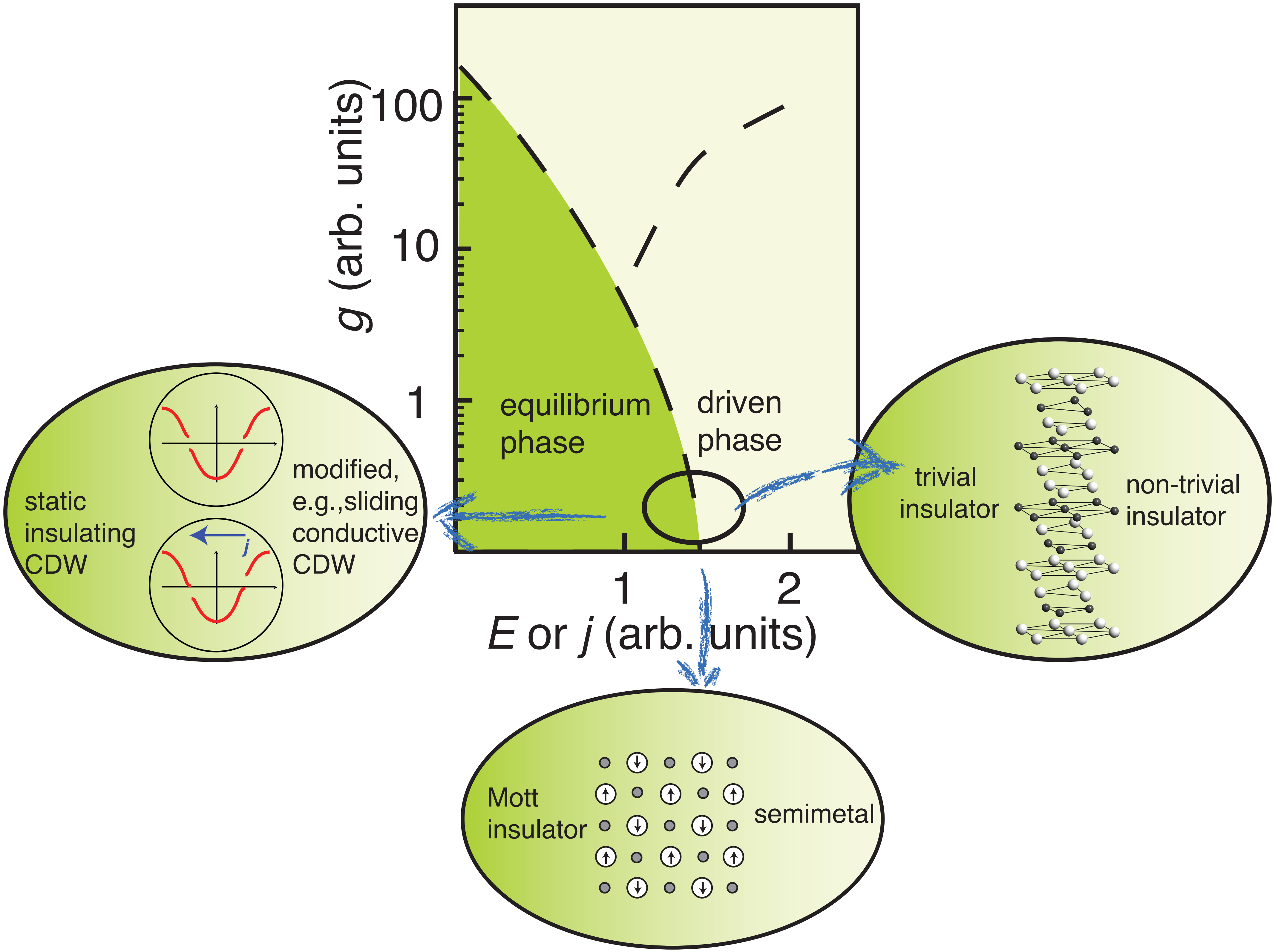
$$\mathscr{A}(\omega, \mathbf{k}) = \frac{\pi^{-1} |\Sigma''(\omega)|}{[\hbar\omega - \epsilon(\mathbf{k}) - \Sigma'(\omega)]^2 + \Sigma''^2(\omega)}$$

transport experiments (on graphene)



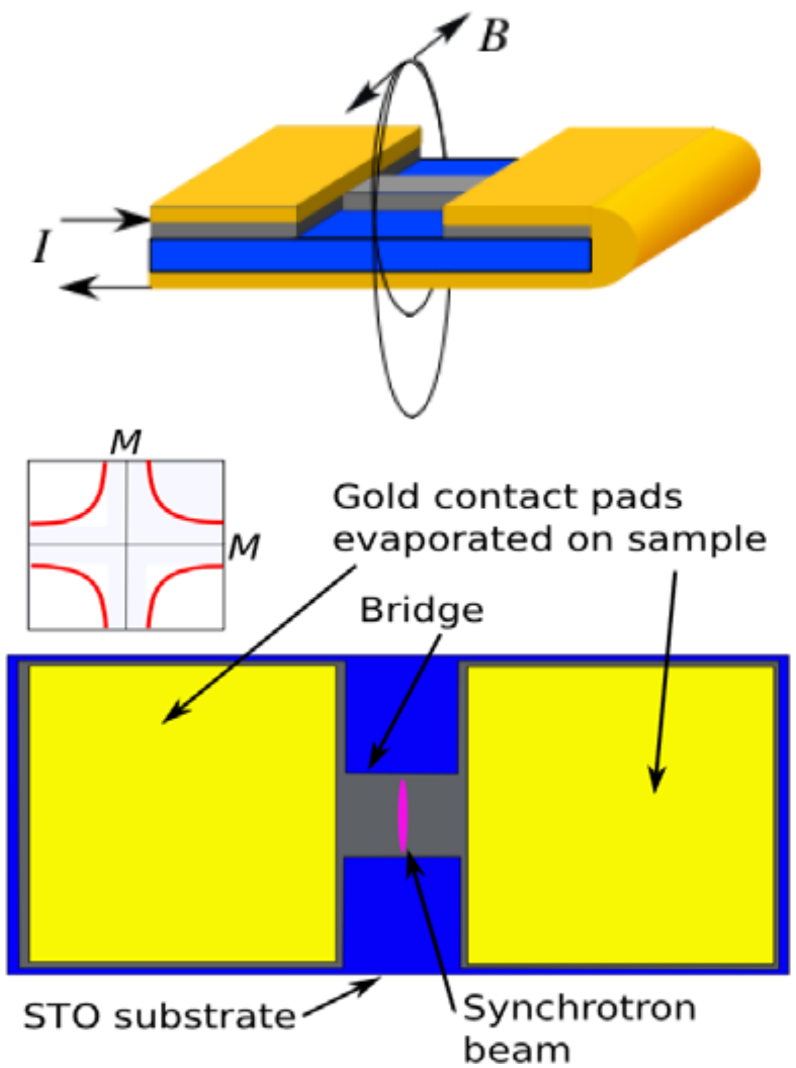
quantum Hall effect in graphene Yuanbo Zhang *et al.* Nature 2005

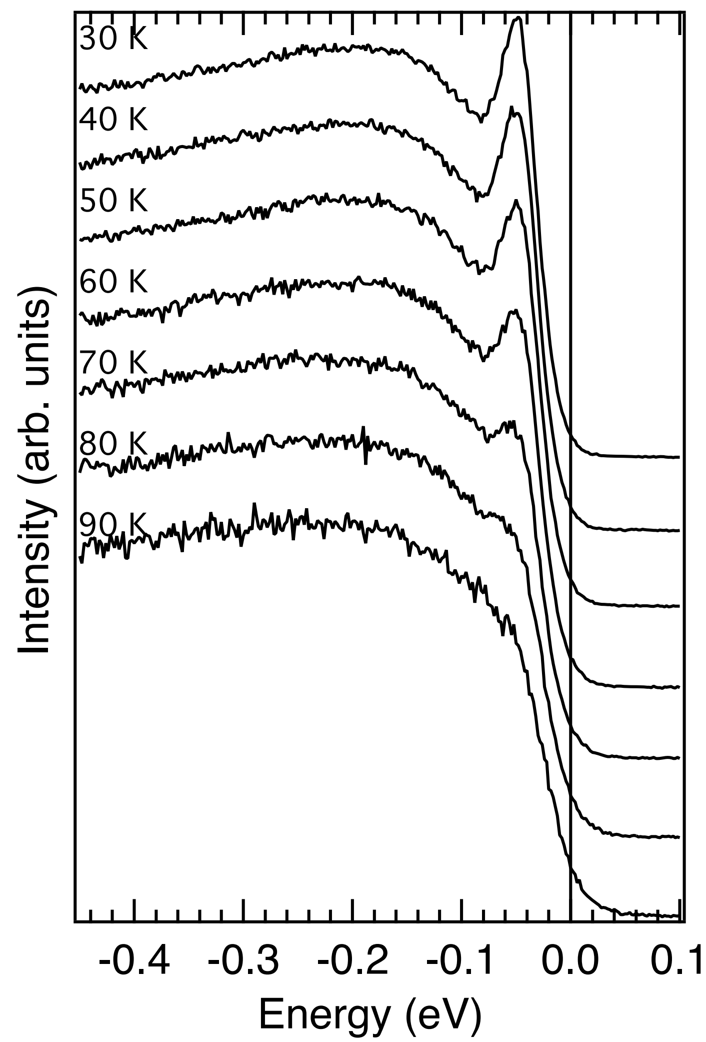
field-induced changes

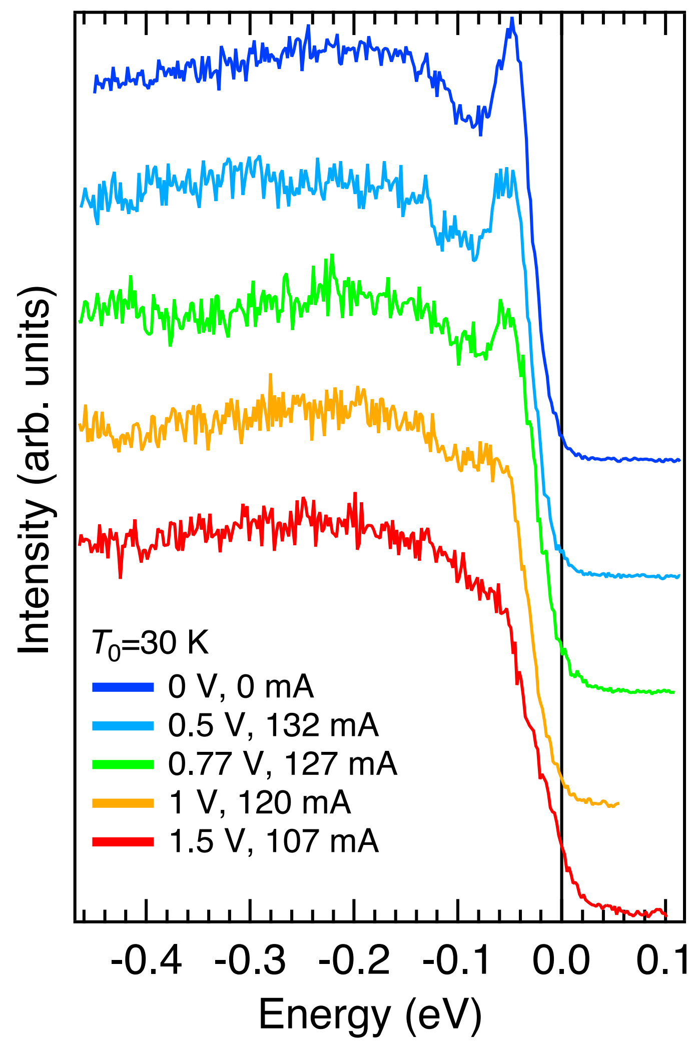


AVS Quantum Science **3**, 021101 (2021).

combining ARPES and transport



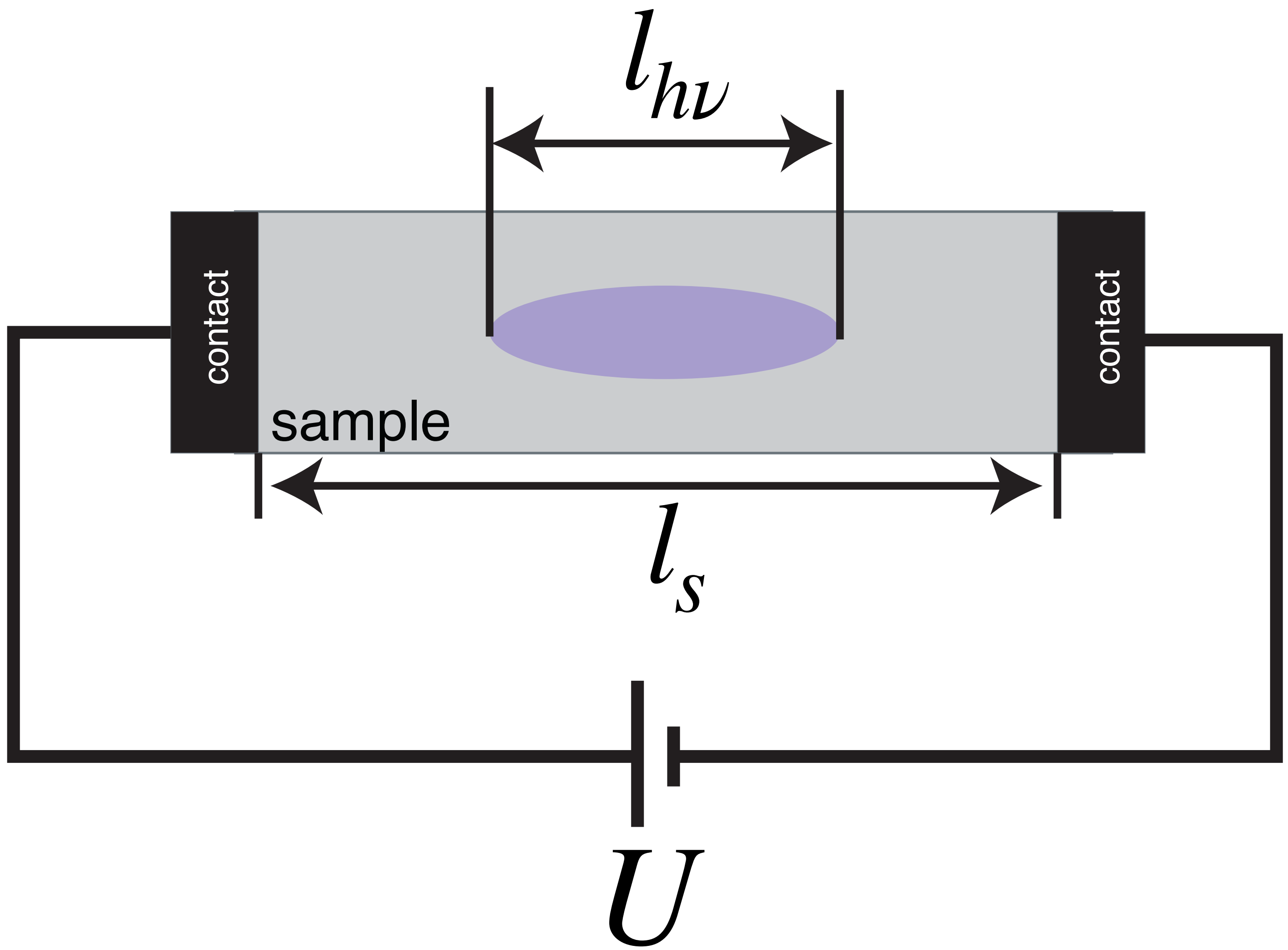




A. Kaminski *et al.,* Phys. Rev. X **6**, 031040 (2016).

see also: M. Naamneh *et al.,* arxiv1607.0290 (2016).

steady state current and ARPES

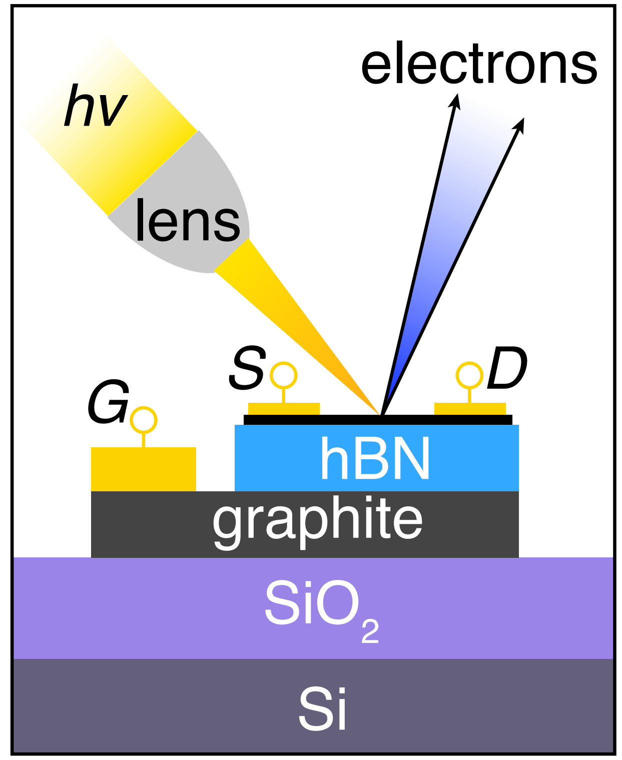


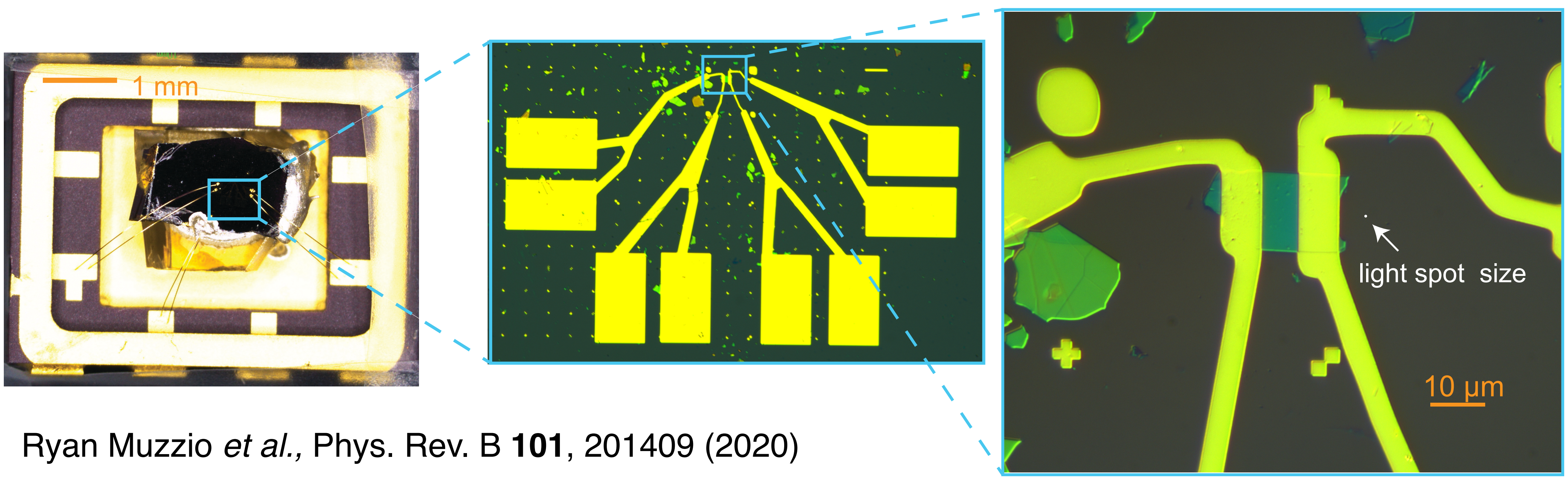
energy resolution limited to: $eU\dfrac{l_{h\nu}}{l_S} \approx 0.1\mathrm{eV}$

for typical synchrotron and field of 10^4 Vm^{-1}

part I: ARPES graphene-based devices

nanoARPES on a graphene device

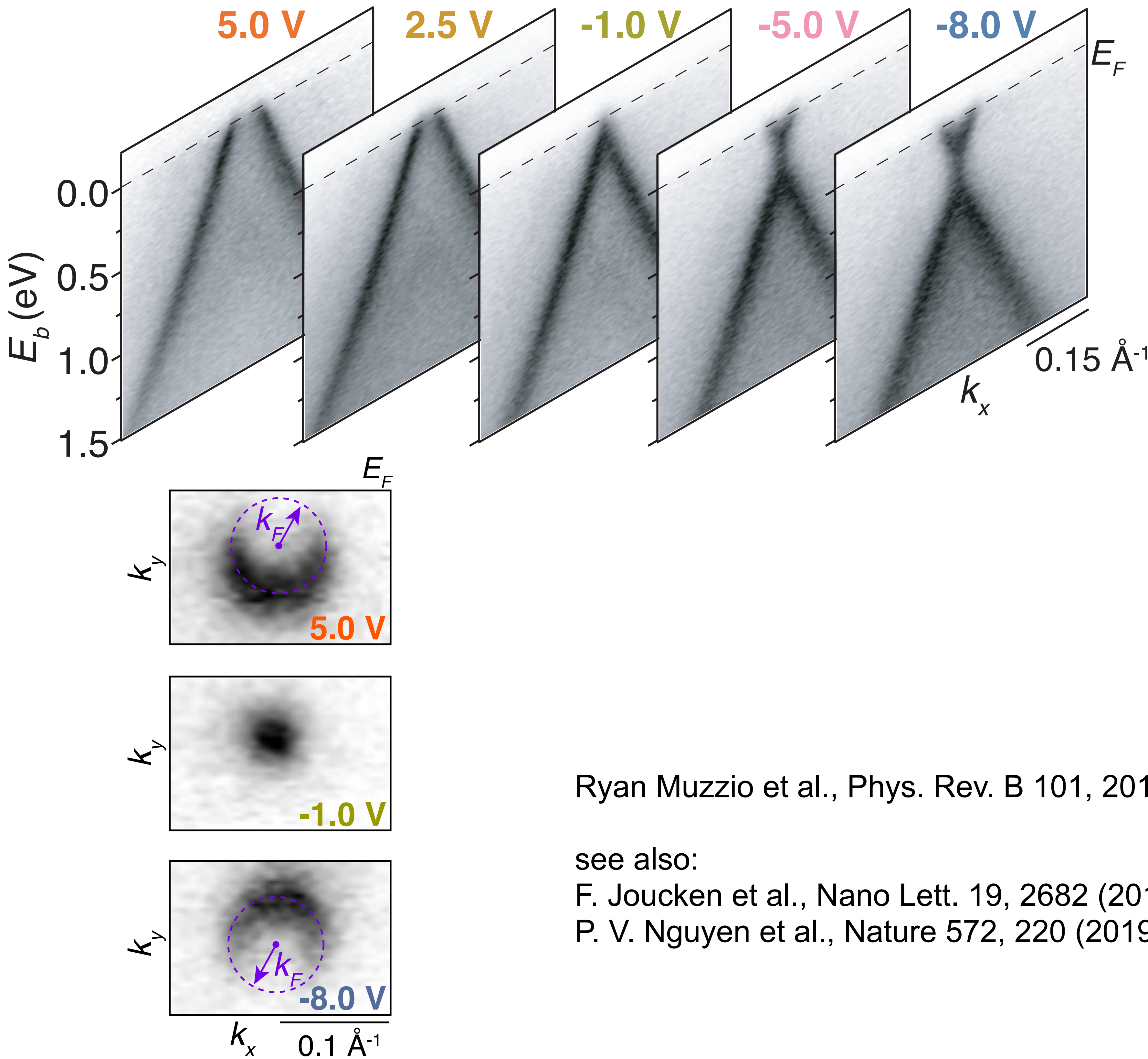




Ryan Muzzio *et al.,* Phys. Rev. B **101**, 201409 (2020)

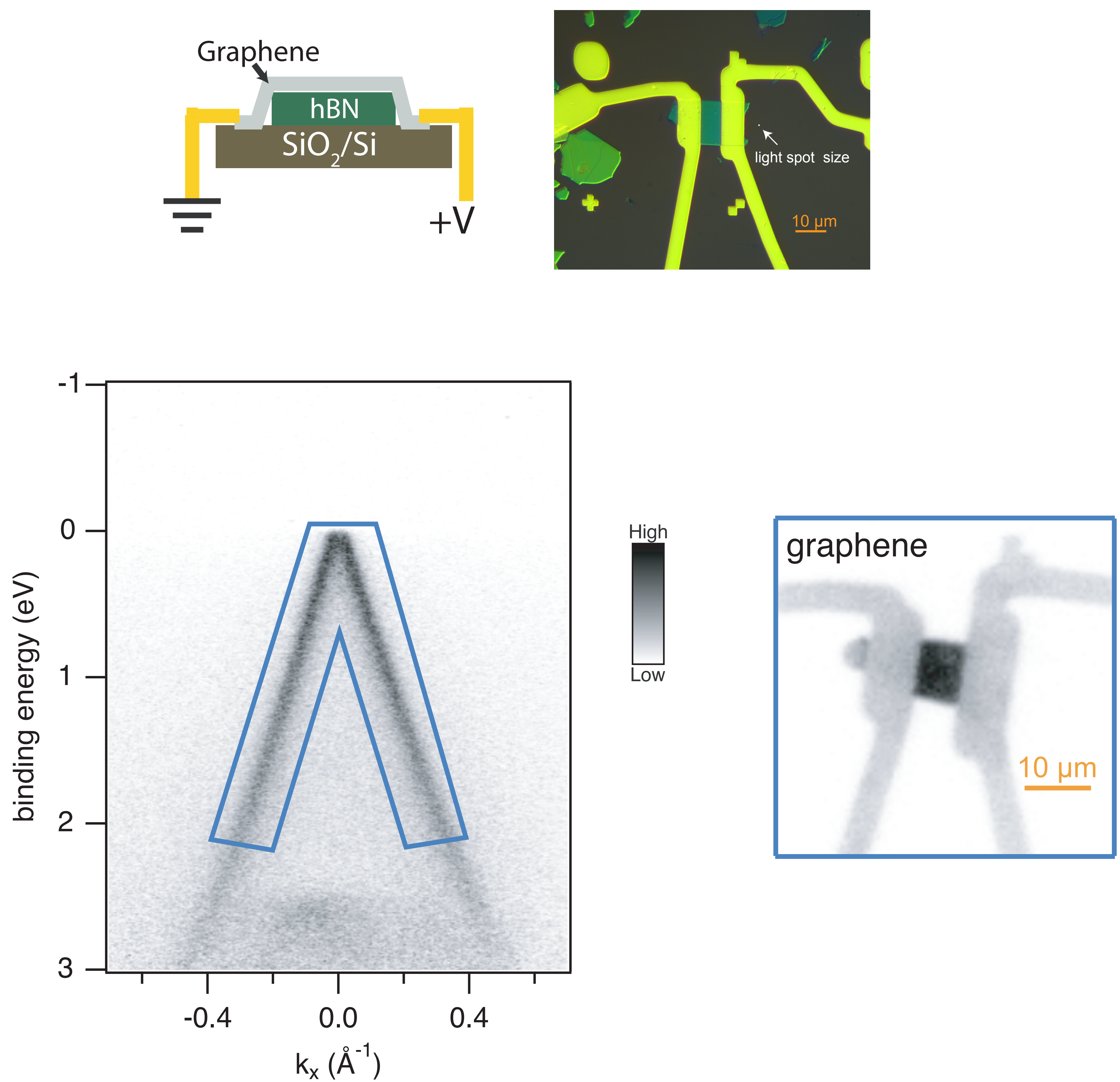
Davide Curcio *et al.,* Phys. Rev. Lett. **125**, 236403 (2020)

static gating

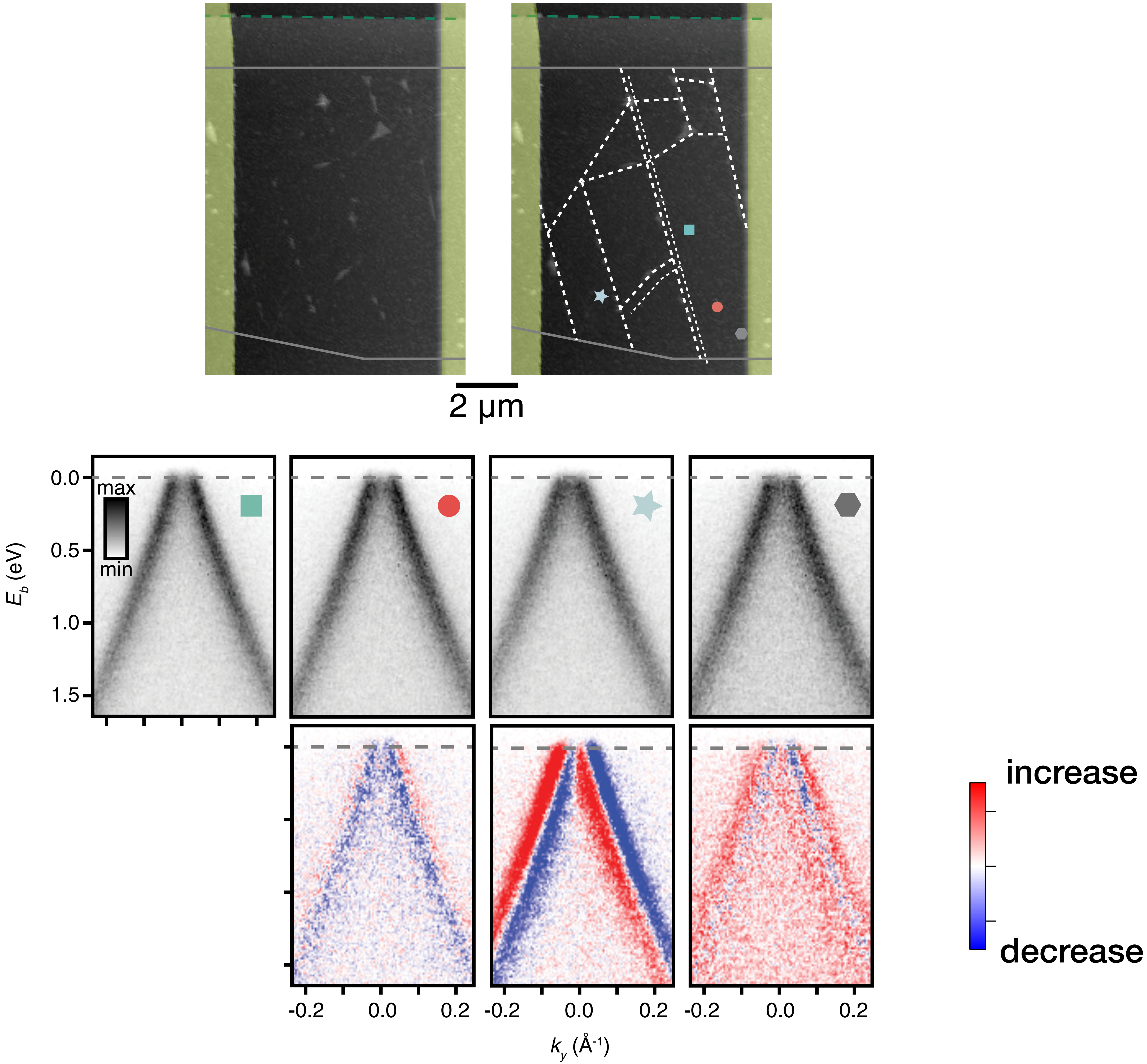


Ryan Muzzio et al., Phys. Rev. B 101, 201409 (2020)

see also:
F. Joucken et al., Nano Lett. 19, 2682 (2019).
P. V. Nguyen et al., Nature 572, 220 (2019).

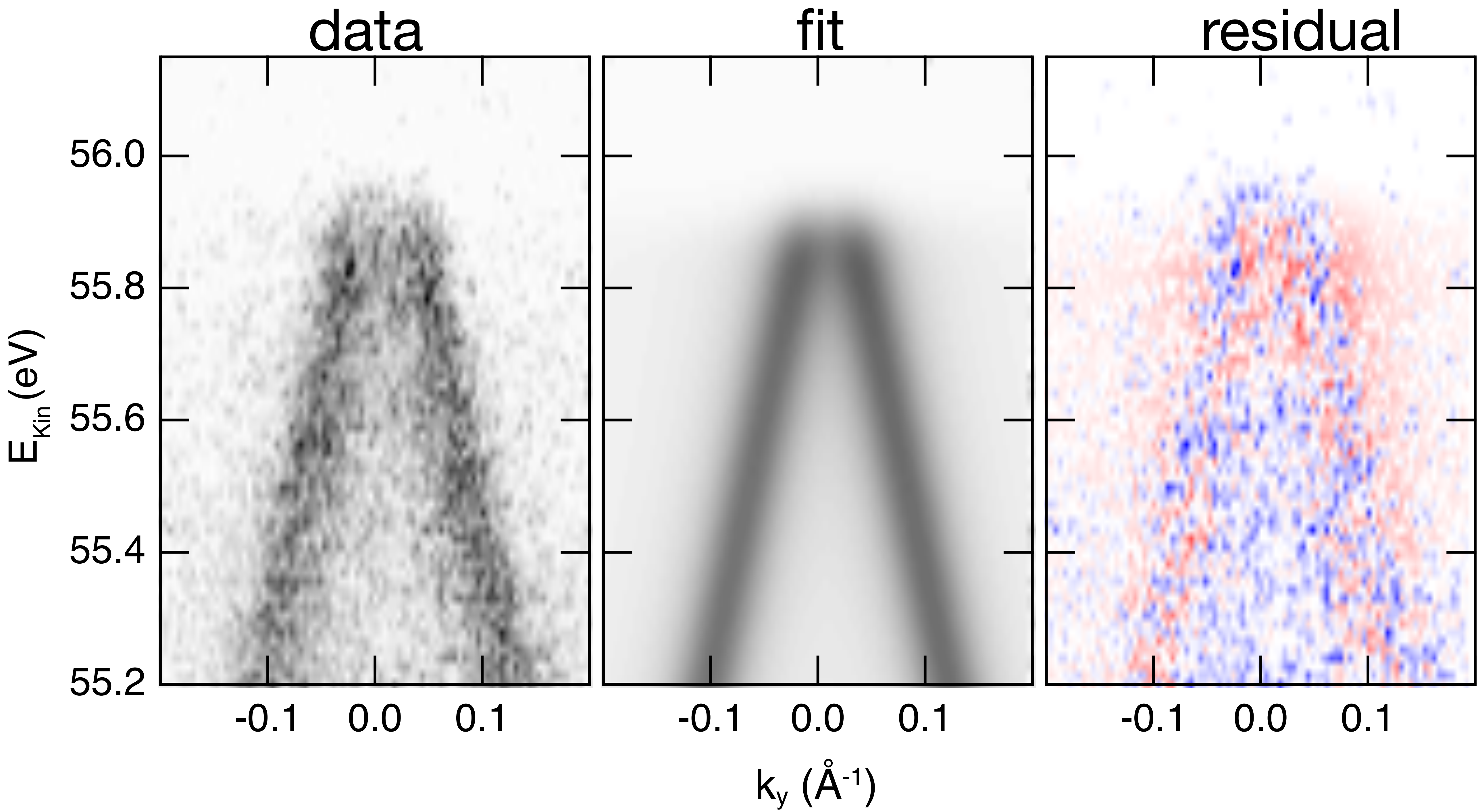


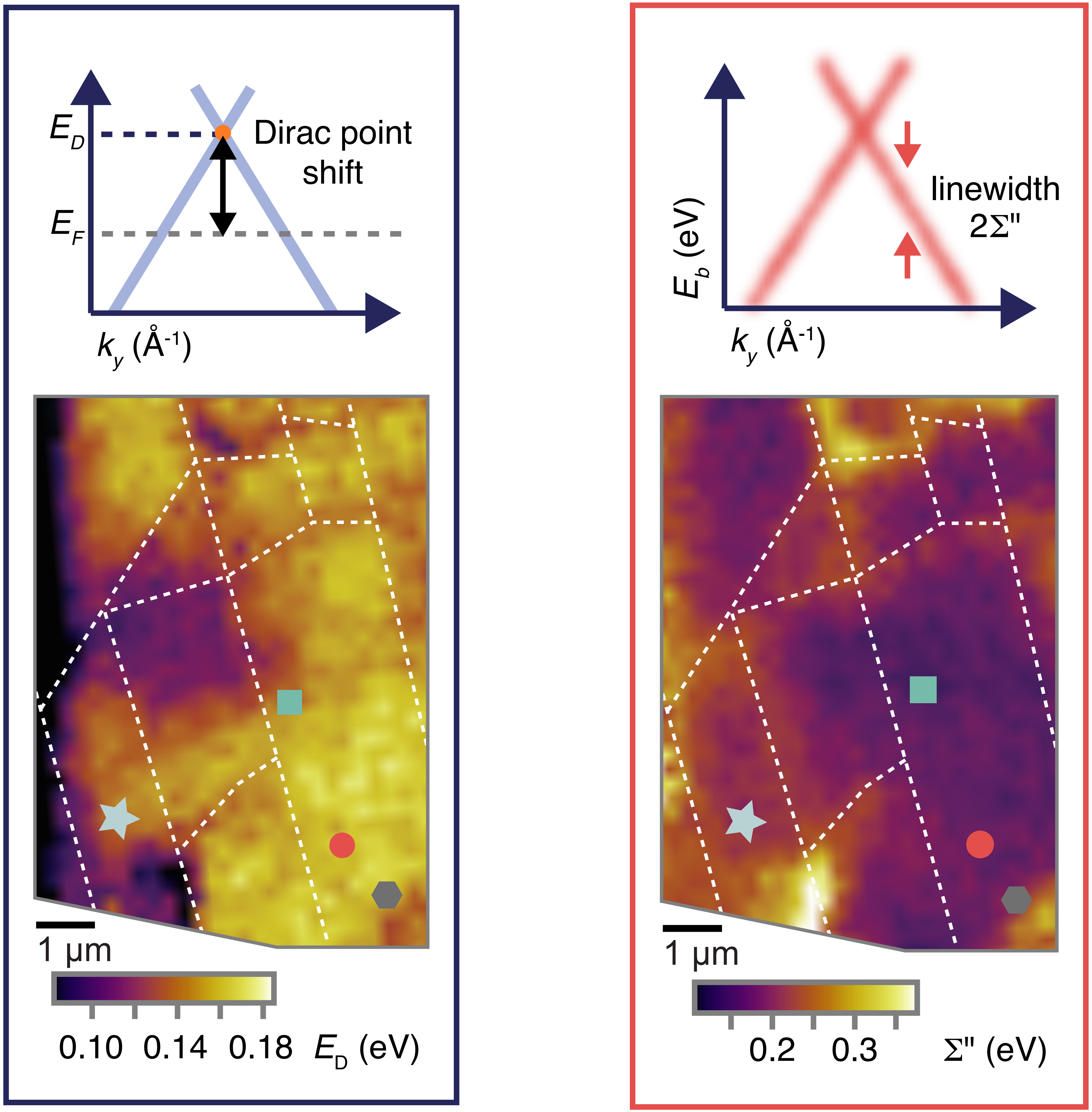
Graphene
hBN
SiO2/Si
+V
light spot size
10 µm
-1
0
1
2
3
binding energy (eV)
-0.4
0.0
0.4
kx (Å-1)
High
Low
graphene
10 µm


2 μm
0.0
0.5
1.0
1.5
max
min
E_b (eV)
-0.2
0.0
0.2
k_y (Å^{-1})
increase
decrease

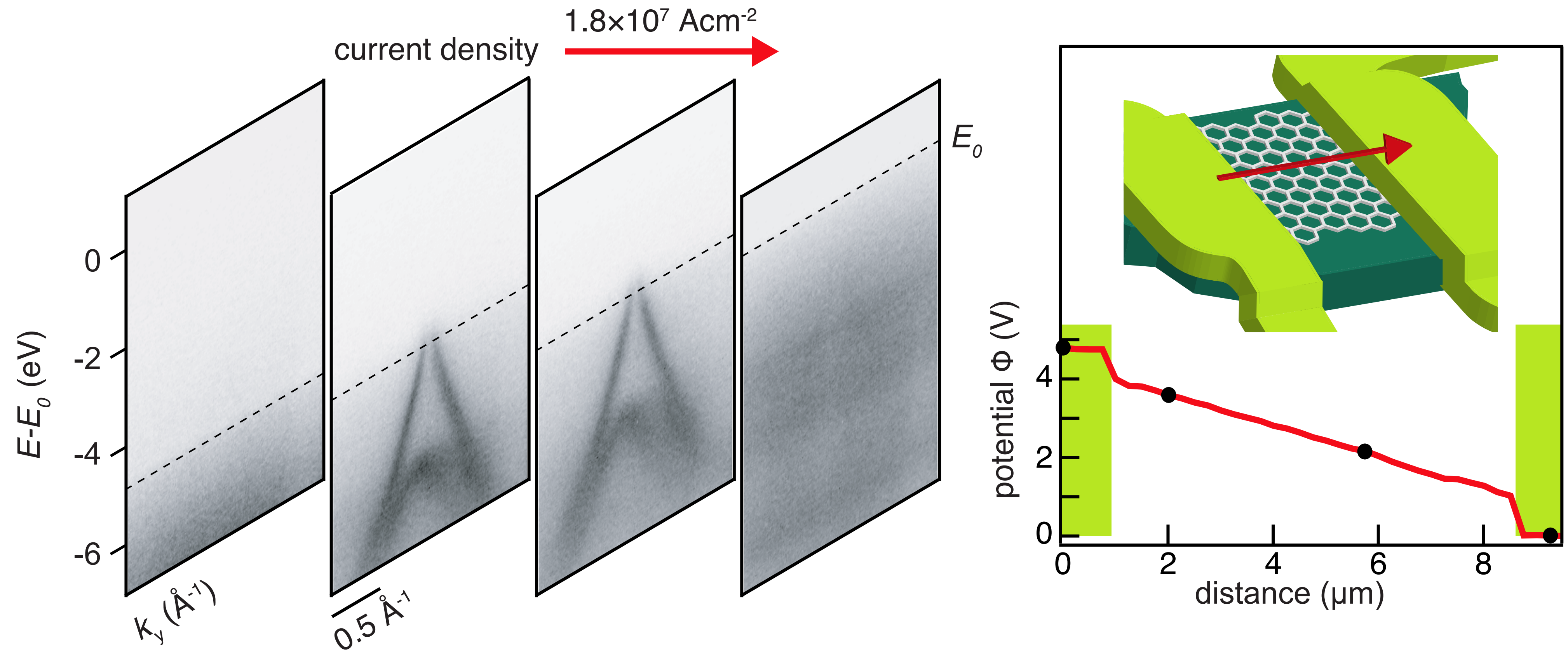
$$I \propto |M|^2 \mathscr{A}(\omega, \mathbf{k}) f(\omega, T)$$

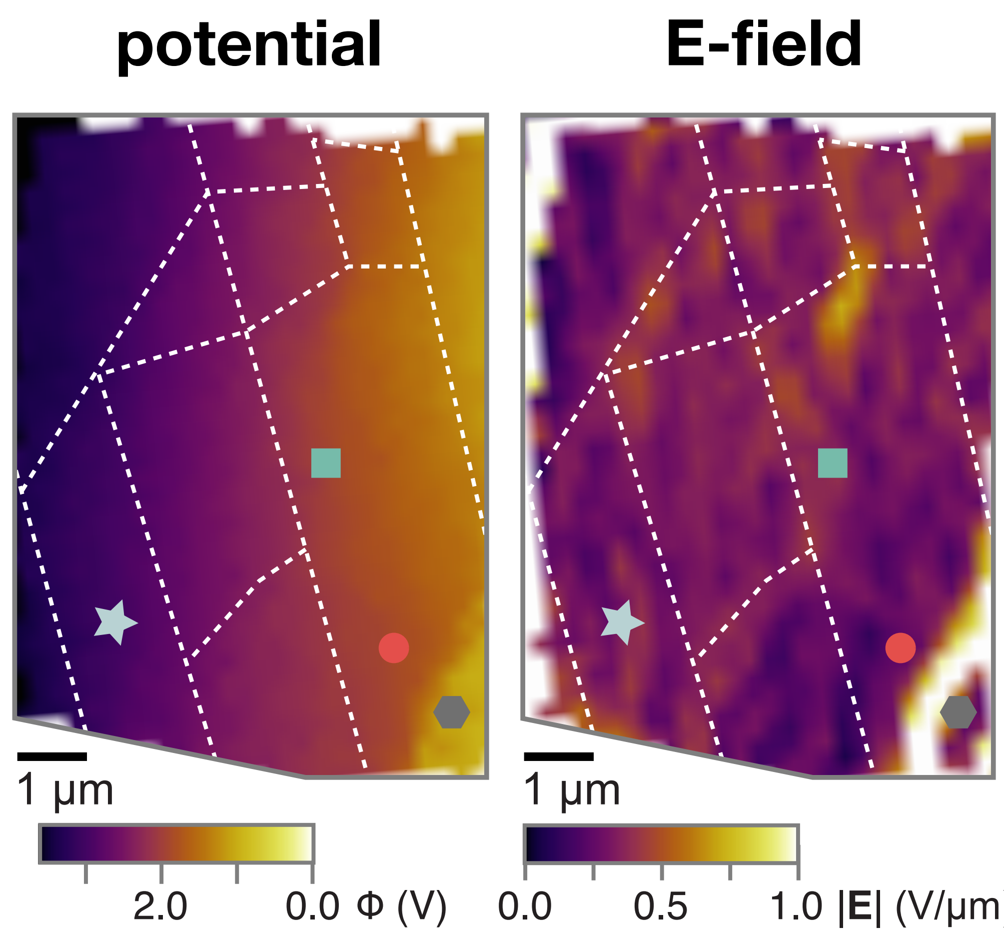
$$\mathscr{A}(\omega, \mathbf{k}) = \frac{\pi^{-1}|\Sigma''|}{[\hbar\omega - \epsilon(\mathbf{k})]^2 + \Sigma''^2}$$



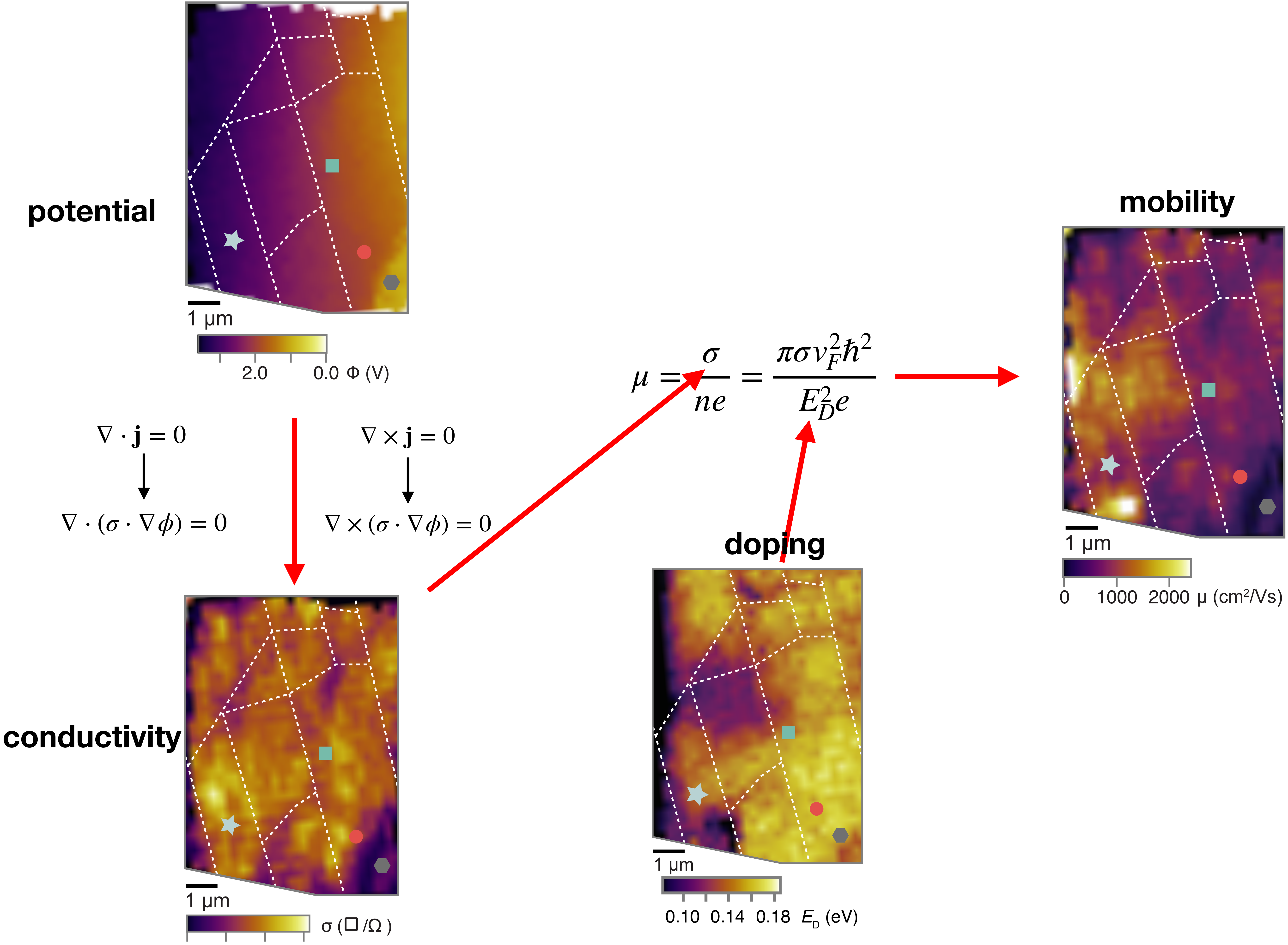


Davide Curcio *et al.,* Phys. Rev. Lett. **125**, 236403 (2020)



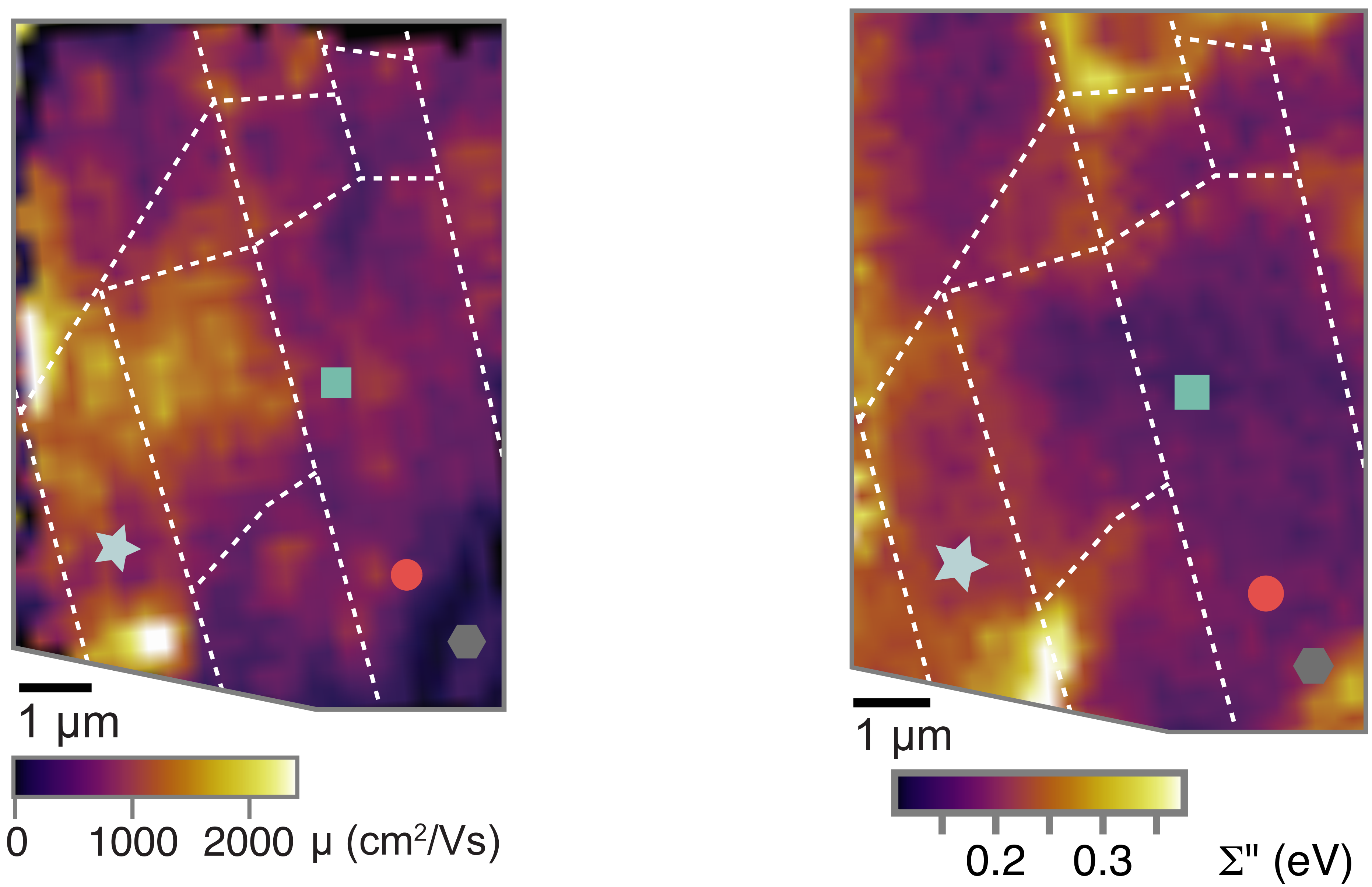


Davide Curcio *et al.*,
Phys. Rev. Lett. **125**, 236403 (2020)



Davide Curcio *et al.*, Phys. Rev. Lett. **125**, 236403 (2020)

mobility and self-energy



Davide Curcio *et al.,* Phys. Rev. Lett. **125**, 236403 (2020)

Conclusions I

- The spectral function of current-carrying devices can be explored with nanoARPES.
- This also gives the quantities such as the position-resolved conductivity (via the potential) and mobility (via potential and filling from the spectral function).

Davide Curcio *et al.,* Phys. Rev. Lett. **125**, 236403 (2020)
PH, AVS Quantum Science **3**, 021101 (2021).