

Electronic Structure and Electron Dynamics in Single-Layer Transition Metal Dichalcogenides

VASSCAA-9

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²Current address: School of Physics and Astronomy, Monash university, Australia

15/08/2018



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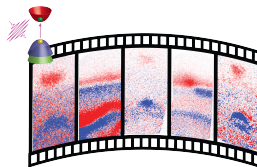
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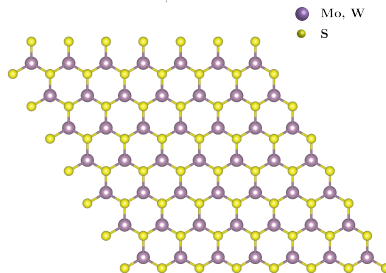


Outline

- 1 2D Materials
 - TMDC Crystal and Electronic Structure
 - 2D Material Synthesis
- 2 Experiment
 - ARPES & TR-ARPES
- 3 Results
 - Semiconducting TMDCs
 - Metallic TMDCs
- 4 Summary

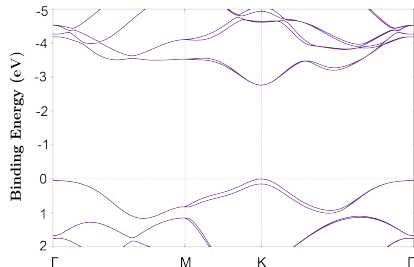
Semiconducting 1H-TMDCs

MoS_2 , WS_2

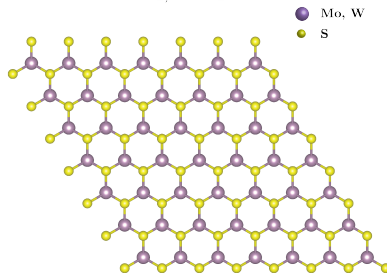


Semiconducting 1H-TMDCs

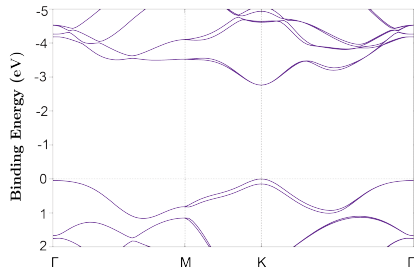
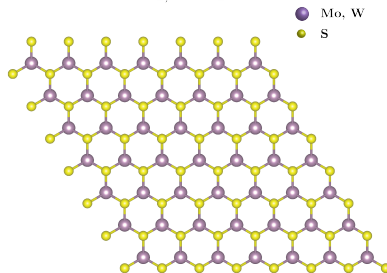
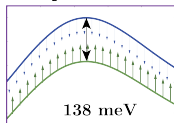
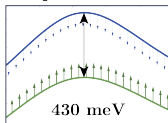
Single Layer MoS_2 band structure



MoS_2 , WS_2

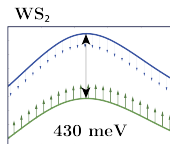
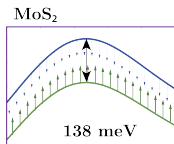
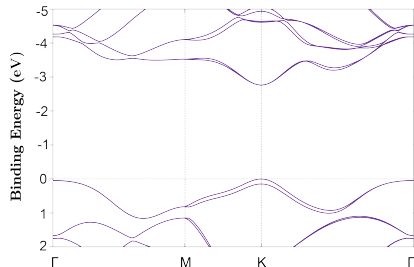


Semiconducting 1H-TMDCs

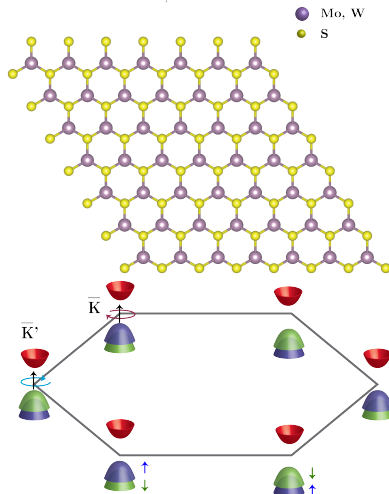
Single Layer MoS₂ band structureMoS₂, WS₂MoS₂WS₂

Semiconducting 1H-TMDCs

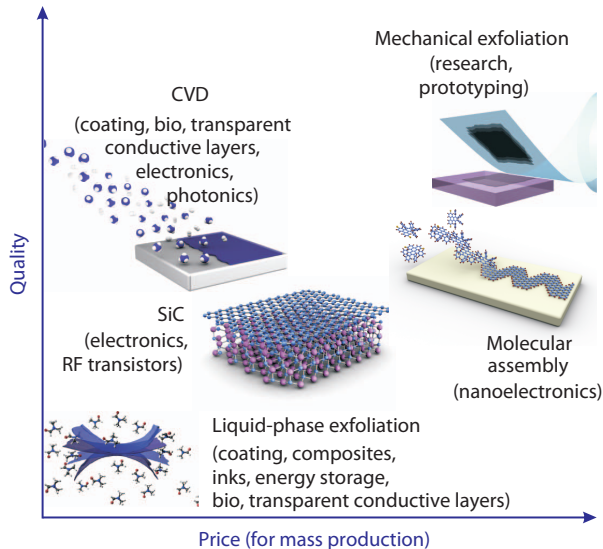
Single Layer MoS₂ band structure



MoS₂, WS₂

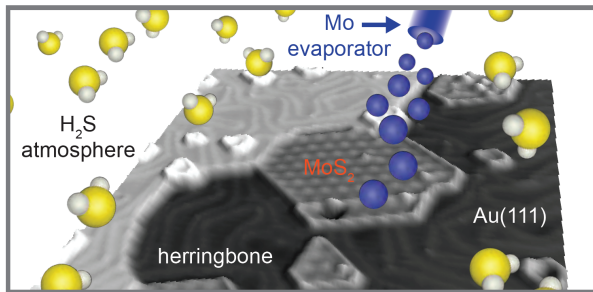


Production of 2D materials



K Novoselov et al. Nature 490:192-200, 2012

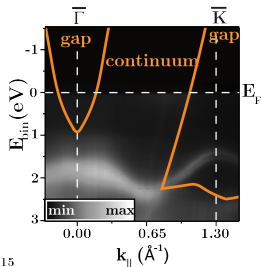
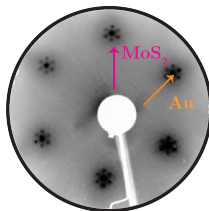
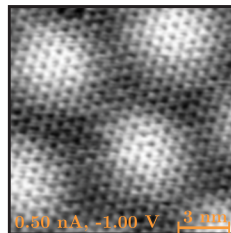
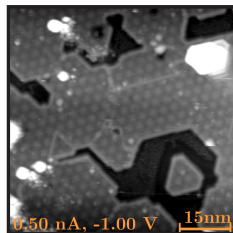
TMDC Synthesis



Signe S. Grønberg et al., *Langmuir*, 31, 2015

Further improvement of TMDC growth : H. Bana et al., *2D Mater.*, 5, 2018
L. Bignardi et al., arXiv: 1806.04928v1
J. Hall et al., *2D Mater.*, 5, 2018

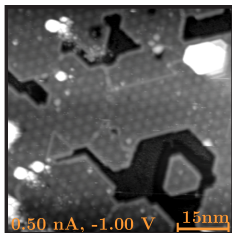
MoS₂/Au(111)



S.S. Grönberg et al., Langmuir, 31 2015

J. A. Miwa et al., Phys. Rev. Lett, 114, 2015

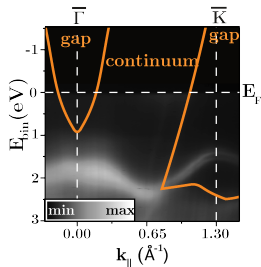
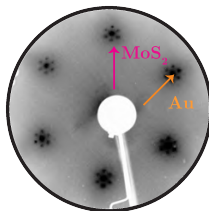
MoS₂/Au(111)



Freestanding MoS₂ - 2.8 eV

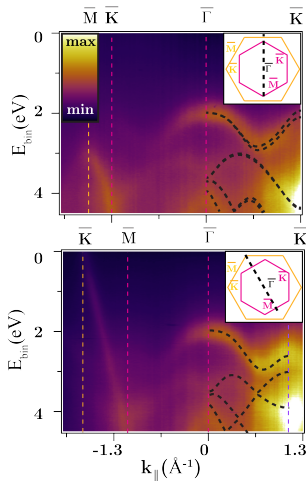
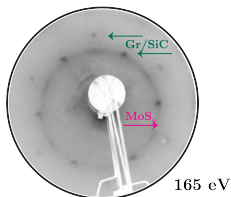
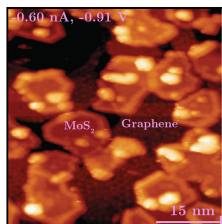
Optical (A exciton) - 1.9 eV

K doping - 1.39 eV



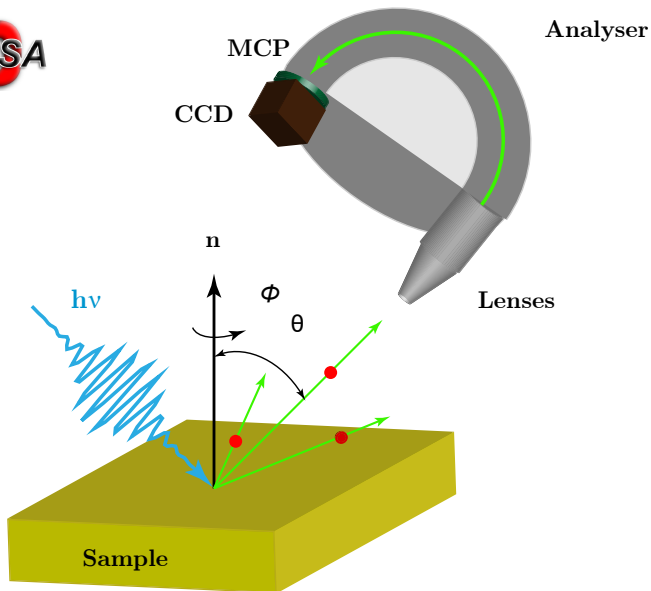
Gronborg et al., Langmuir, 31:9700-9706, 2015

MoS₂/graphene Characterisation

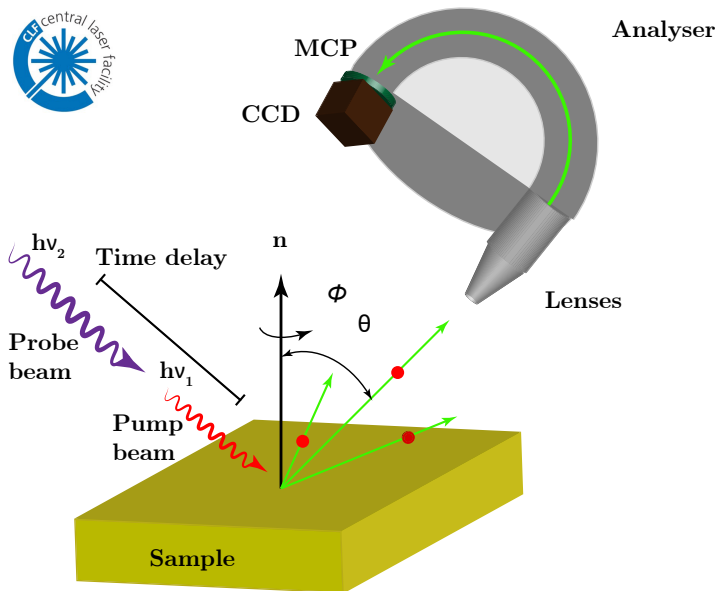


Miwa et al., ACS Nano, 9:6502-6510, 2015

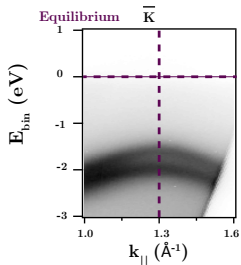
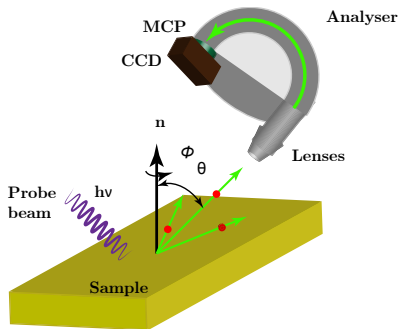
ARPES



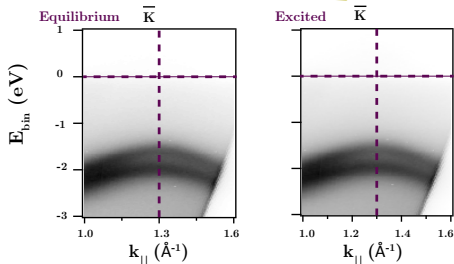
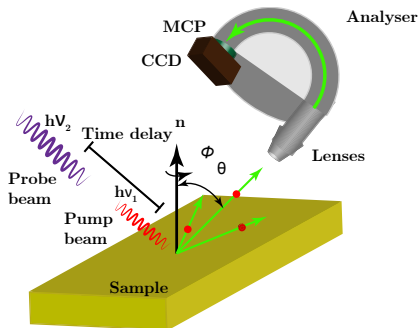
TR-ARPES



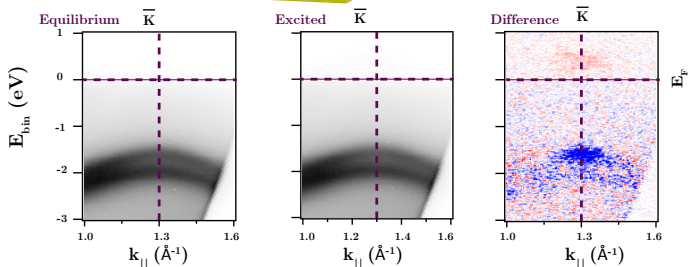
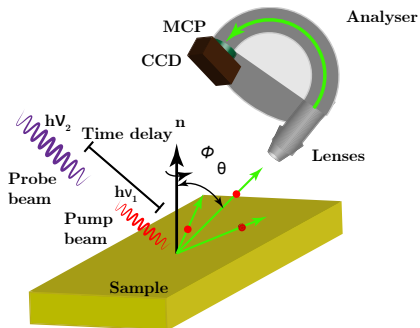
TR-ARPES



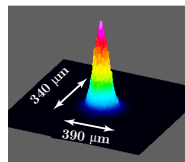
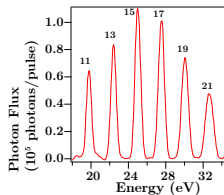
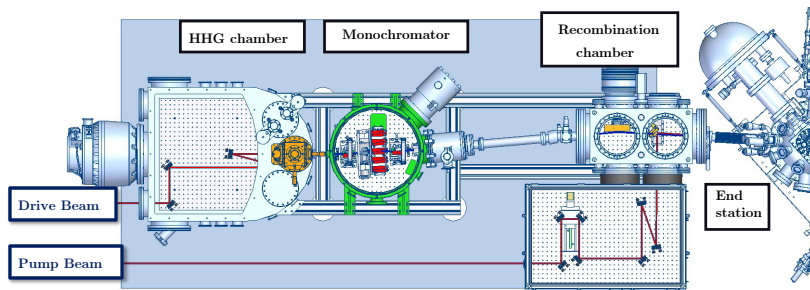
TR-ARPES



TR-ARPES

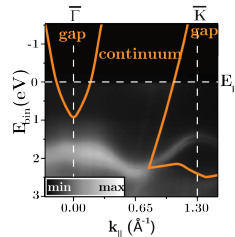
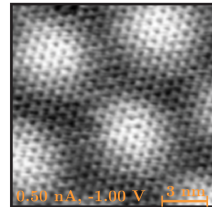
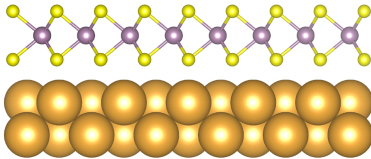


ARTEMIS



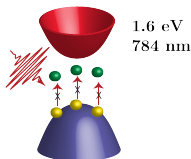
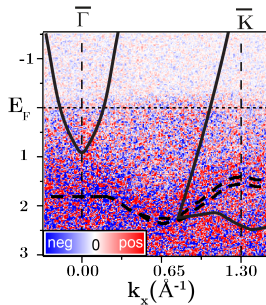
MoS₂/Au(111)

• MoS₂/Au(111)

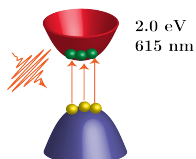
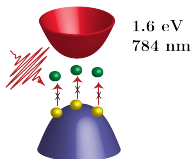
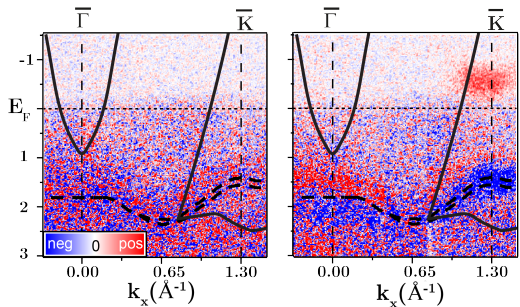


A. Grubisic-Cabo et al., Nano Lett. 15., 2015

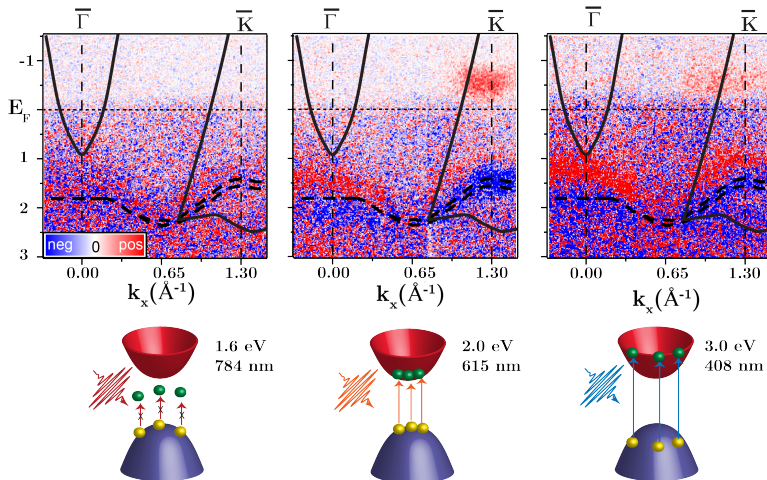
MoS₂/Au(111) 1.6 eV Excitation



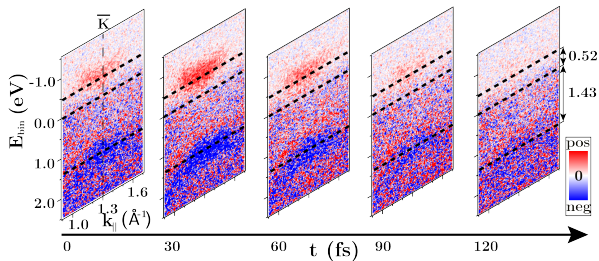
MoS₂/Au(111) 2.0 eV Excitation



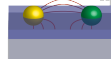
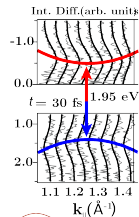
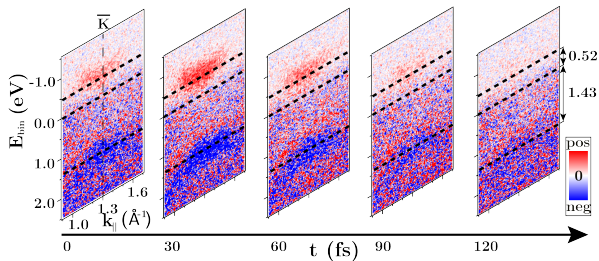
MoS₂/Au(111) 3.0 eV Excitation



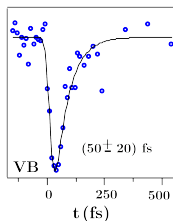
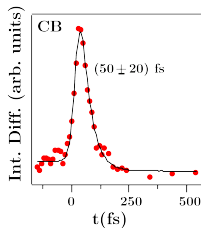
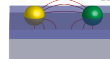
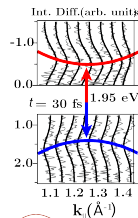
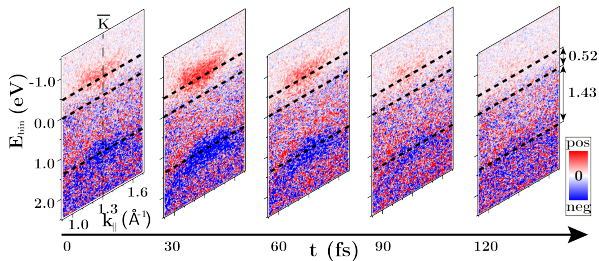
Snapshots



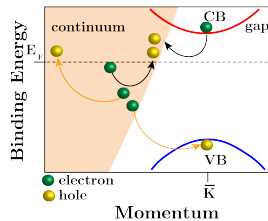
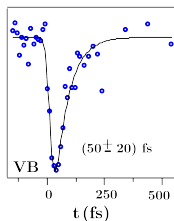
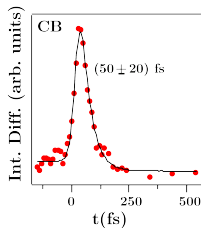
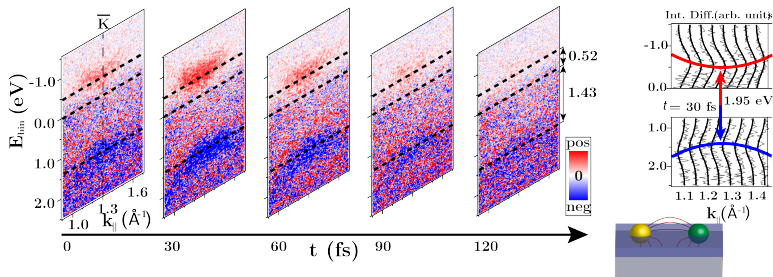
Snapshots



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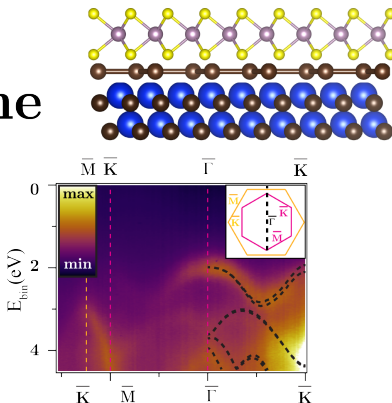
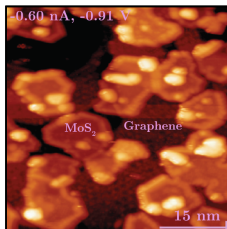


Snapshots



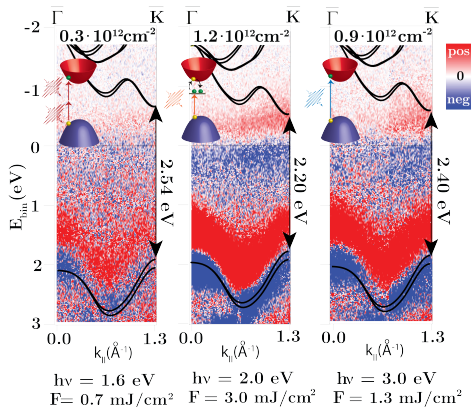
MoS₂/graphene

• MoS₂/graphene

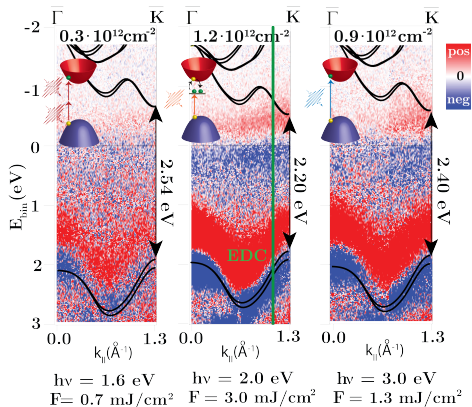


S. Ulstrup et al., ACS Nano 10, 2016

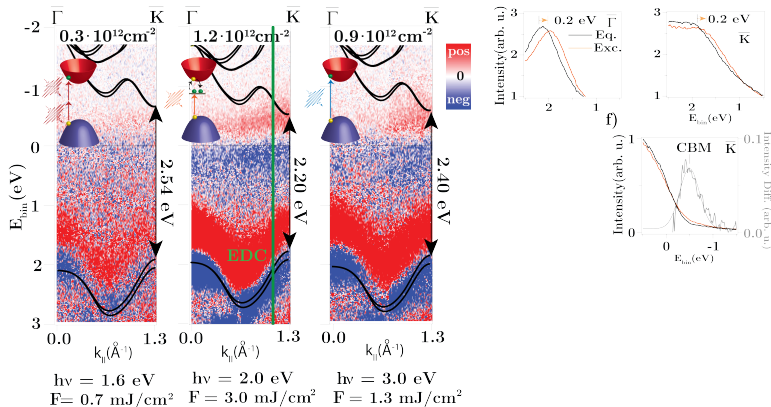
MoS₂/graphene Excitations



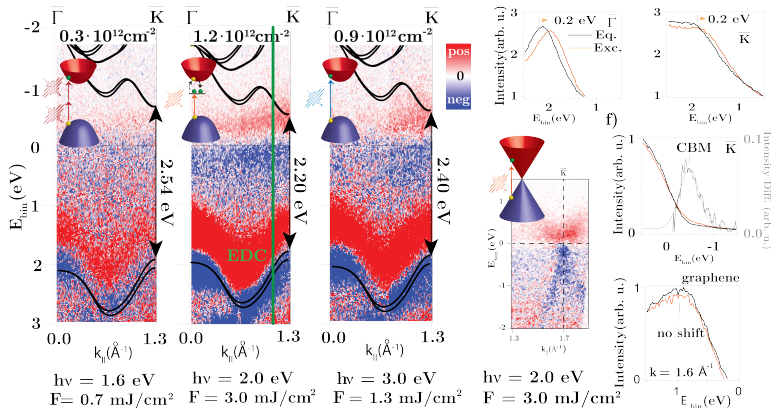
MoS₂/graphene Excitations



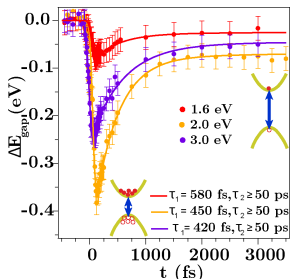
MoS₂ Band Shift



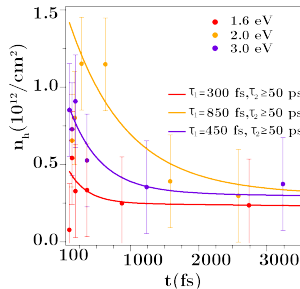
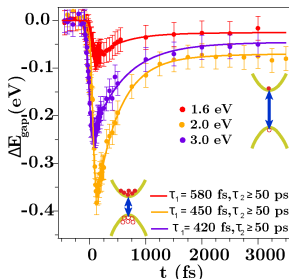
MoS₂/gr - Graphene States



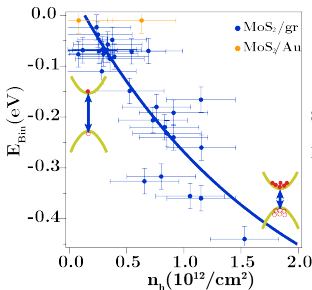
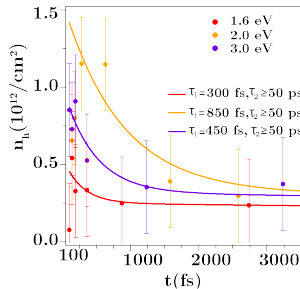
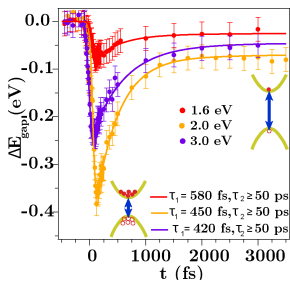
MoS₂/gr Band Gap Renormalisation



MoS₂/gr Band Gap Renormalisation



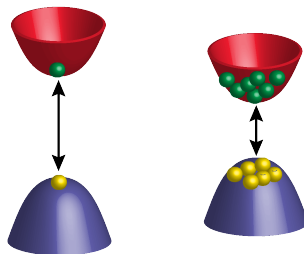
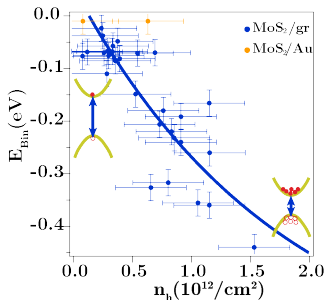
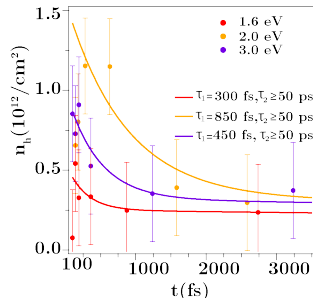
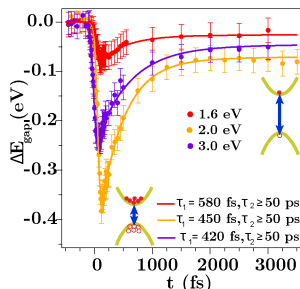
MoS₂/gr Band Gap Renormalisation



Steinhoff et al. Nano Lett. 14, 3743-3748, 2014

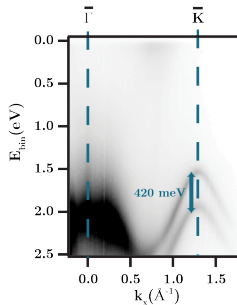
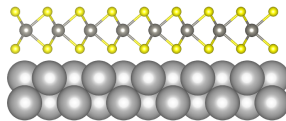
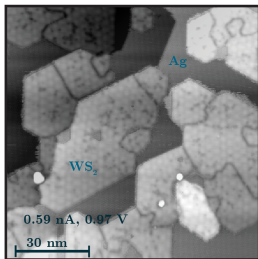
Renormalisation of ≈ 500 meV for $n \approx 10^{12}/\text{cm}^2$

MoS₂/gr Band Gap Renormalisation



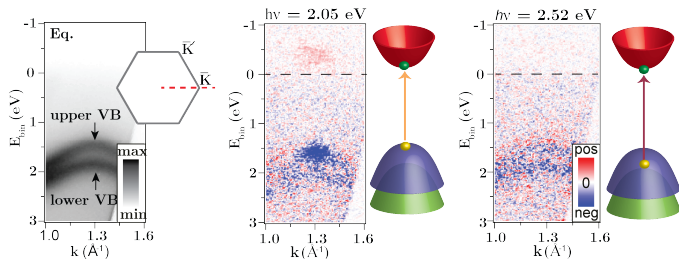
WS₂/Ag(111)

• WS₂/Ag(111)

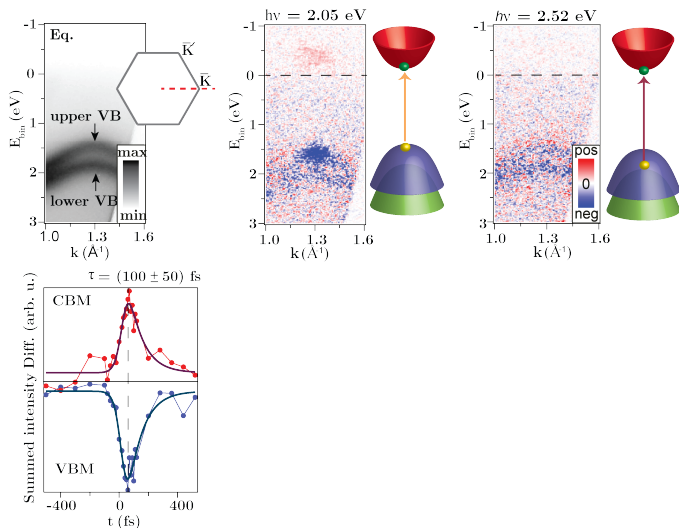


S. Ulstrup et al., PRB 95, 2017
M. Dendzik et al., PRB 96, 2017.

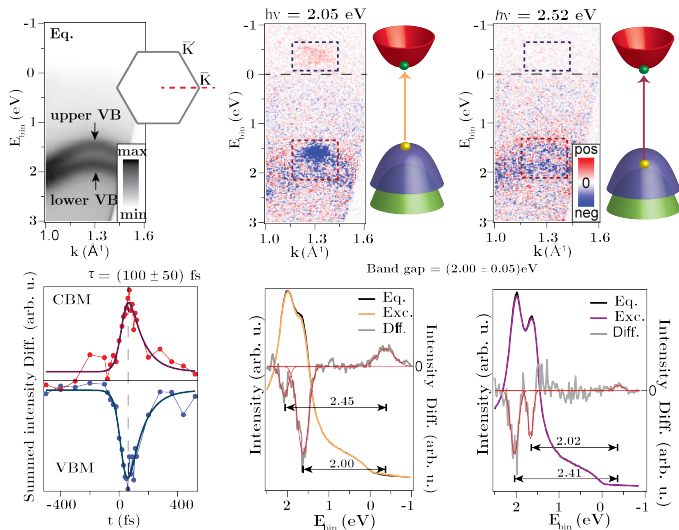
WS₂/Ag(111) - Linear Polarisation



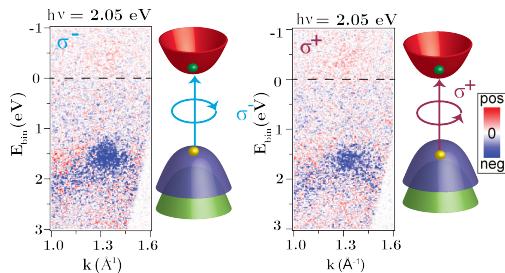
WS₂/Ag(111) - Linear Polarisation



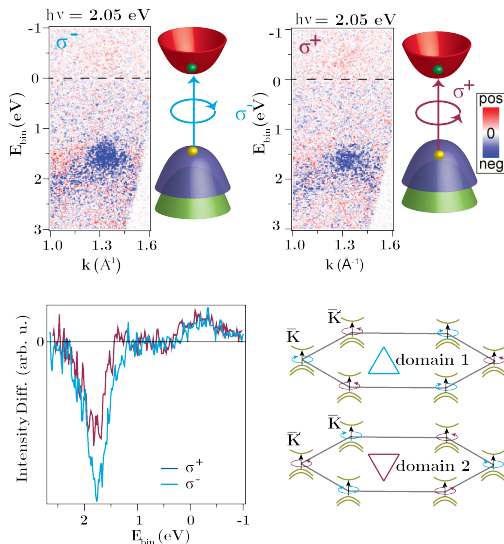
WS₂/Ag(111) - Band Gap



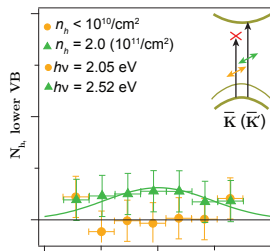
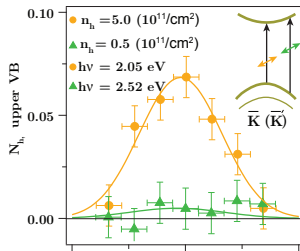
WS₂/Ag(111) - Circular Polarisation



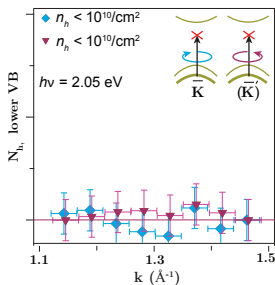
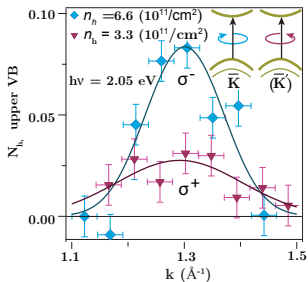
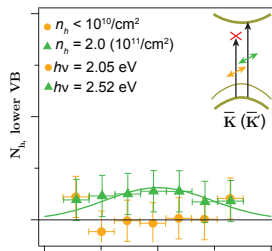
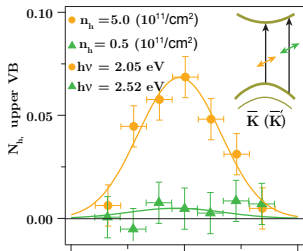
WS₂/Ag(111) - Existence of 2 Domains



WS₂/Ag(111) - Carrier Density

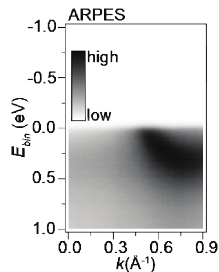
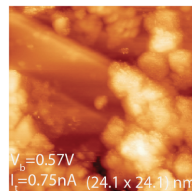
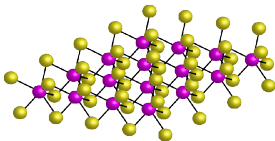


WS₂/Ag(111) - Carrier Density

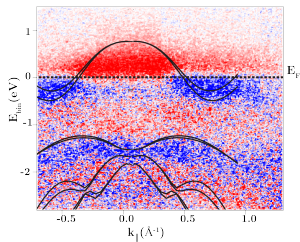
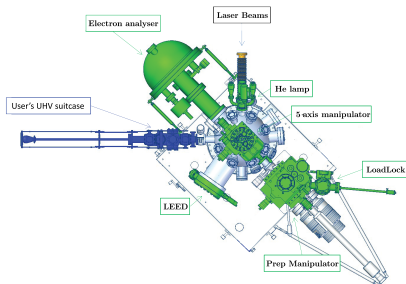


TaS₂/graphene

- TaS₂/graphene

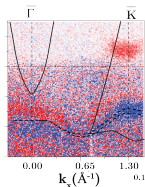


TaS₂/graphene

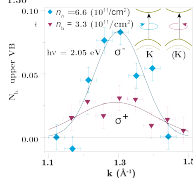
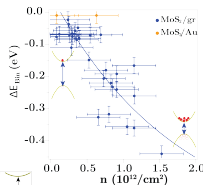


Summary

- Substrate induced band gap renormalisation - $\text{MoS}_2/\text{Au}(111)$
- Dynamic band gap renormalisation - $\text{MoS}_2/\text{graphene}$
- Control over valley degrees of freedom - $\text{WS}_2/\text{Ag}(111)$
- Measurements on a true 2D metal - $\text{TaS}_2/\text{graphene}$

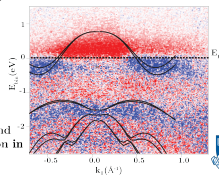


Static band gap renormalisation in $\text{MoS}_2/\text{Au}(111)$ and dynamic in $\text{MoS}_2/\text{graphene}$ heterostructure



Control over spin and valley degrees of freedom in $\text{WS}_2/\text{Ag}(111)$

Carrier dynamics and band renormalisation in 2D metal



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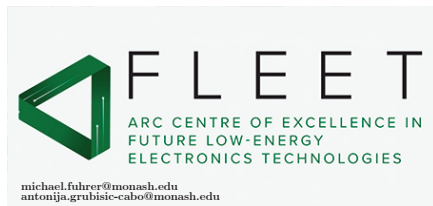
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ARC CENTRE OF EXCELLENCE IN
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Thank you for your attention!

Supplementary

Carrier Density - Model

