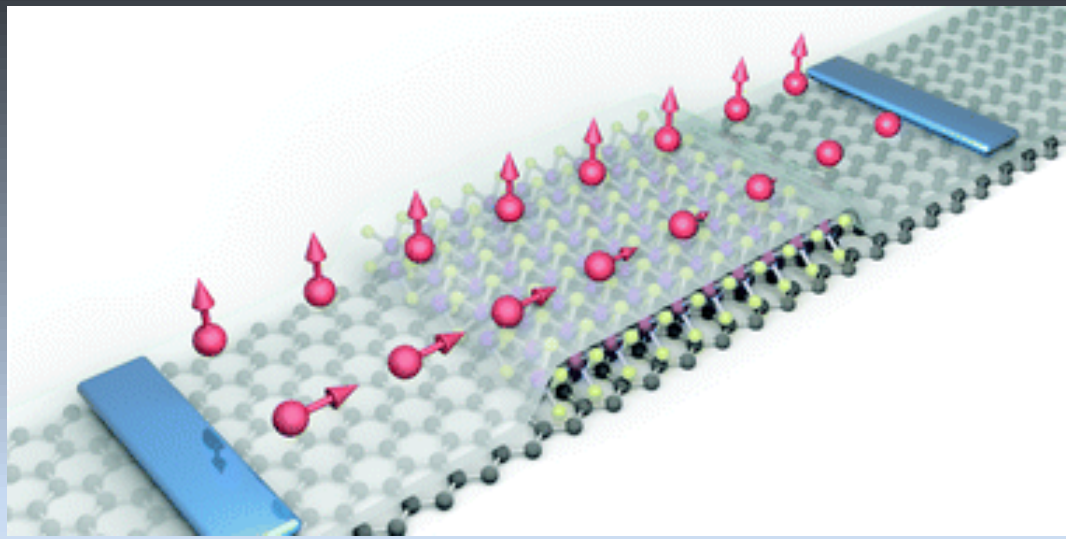
Spin-orbitronics in Graphene/Transition Metal Dichalcogenide heterostructures

Jose H. Garcia



ICN2
Institut Català de Nanociència i Nanotecnologia
EXCELENCIA SEVERO OCHOA

Graphene 2018
June 26 - 29
Dresden (Germany)

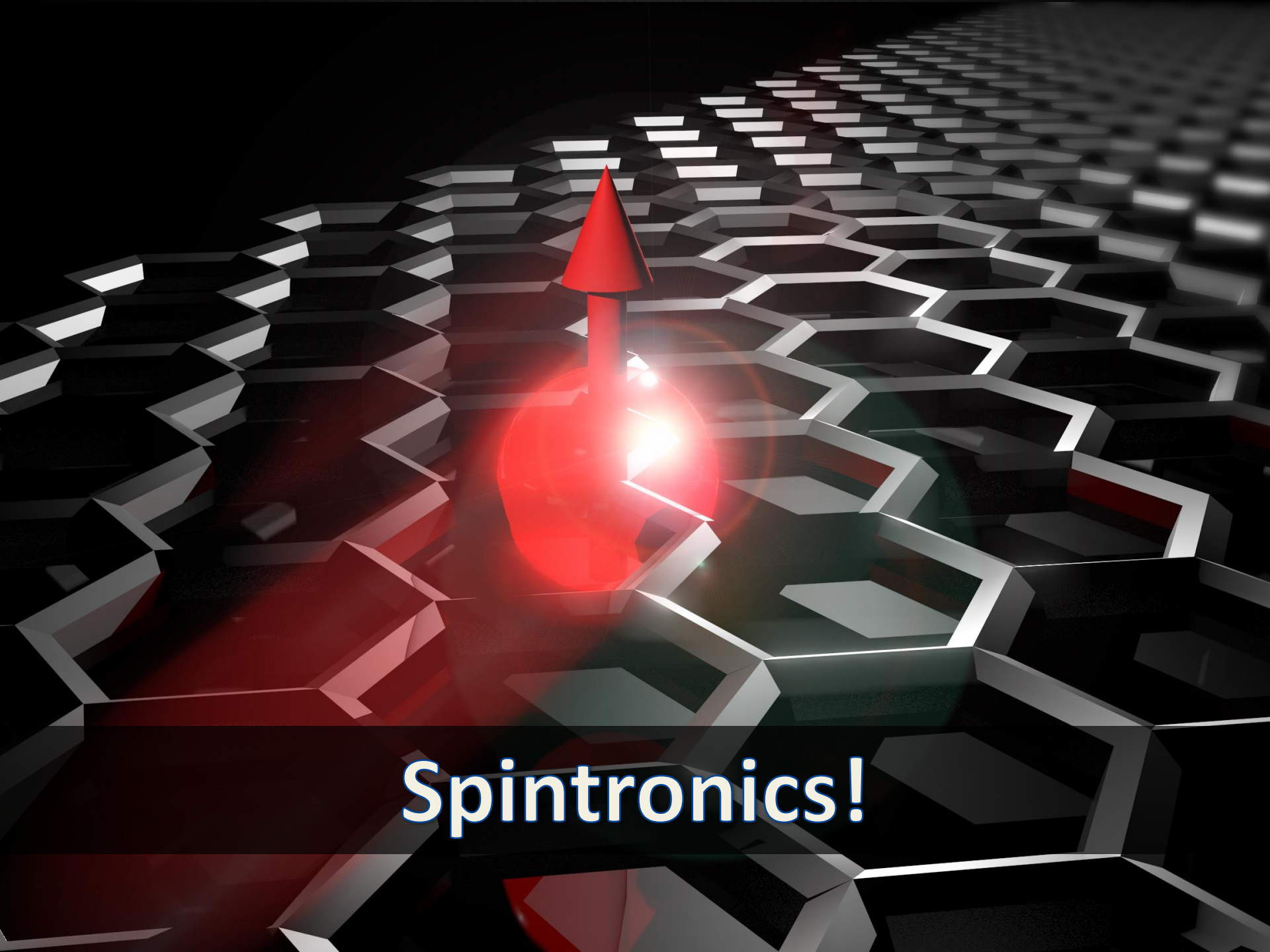
Do we need to go beyond traditional electronics?

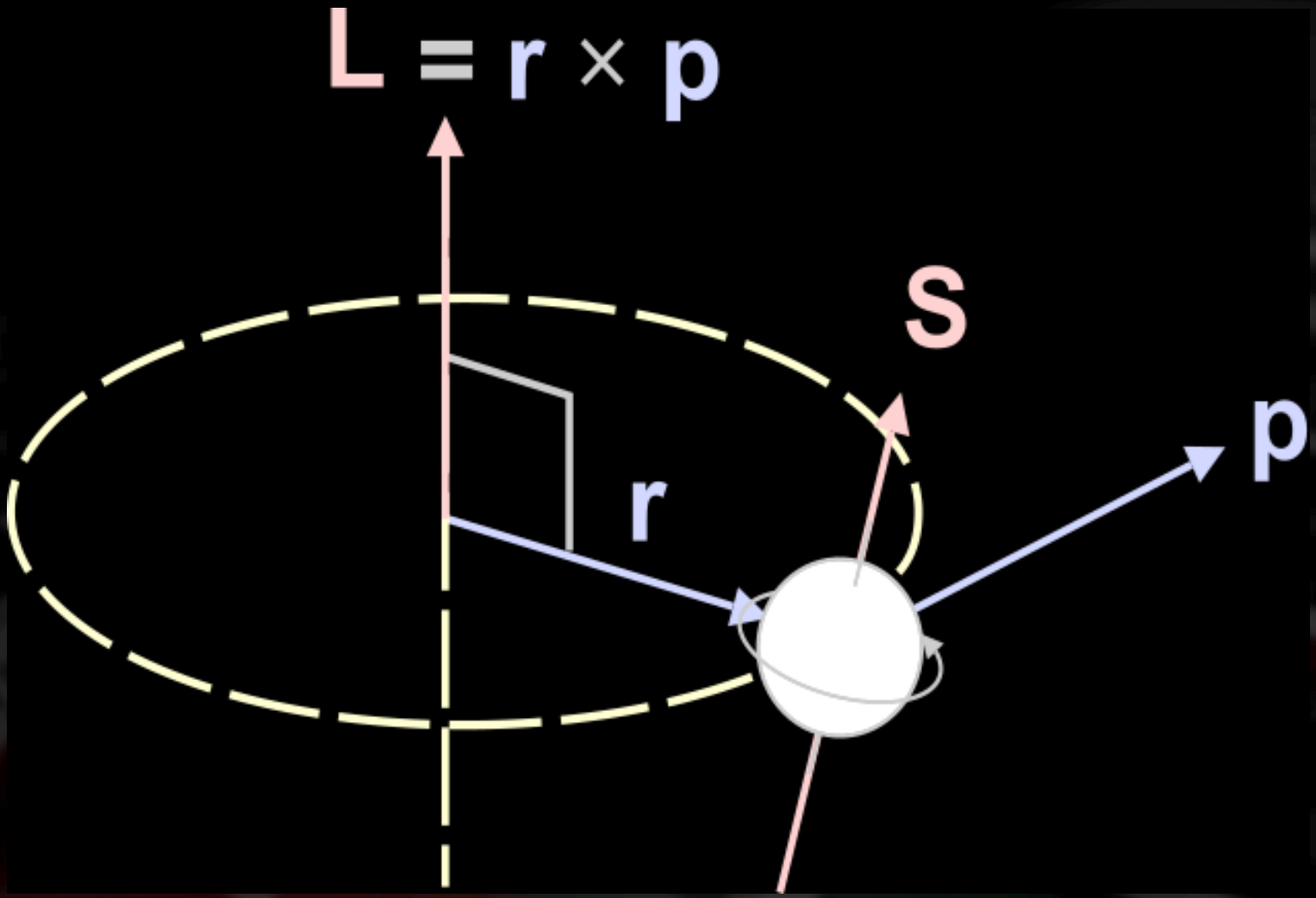
What are the needs?

Computer Power

Energy efficiency

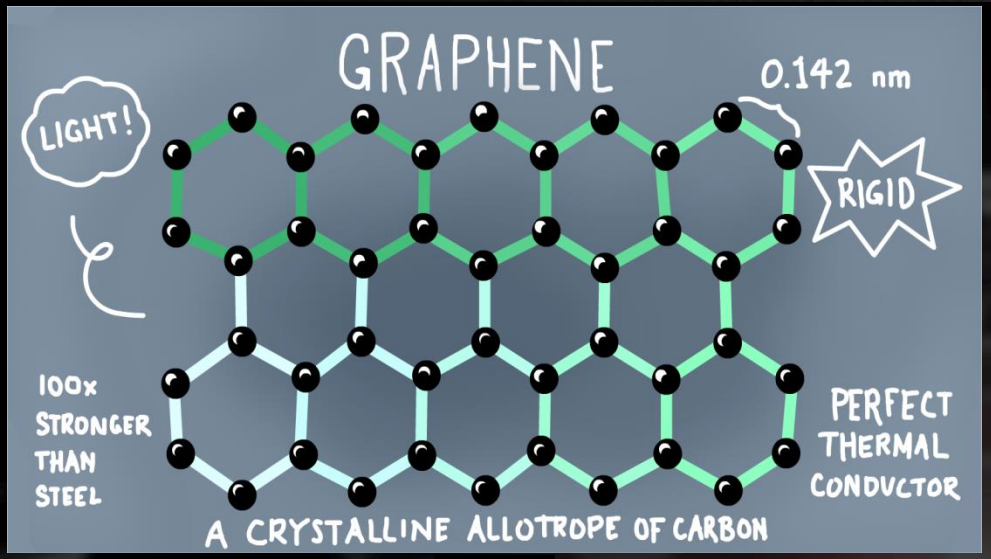
Memory


Spintronics!



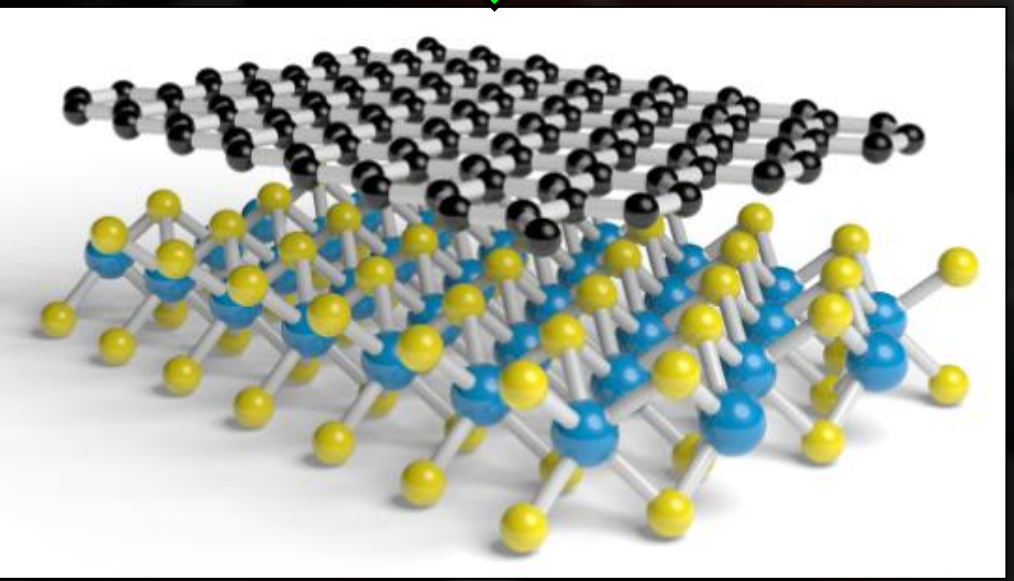
Spin-orbit coupling

$$H_{SOC} = \lambda_{SOC} \boldsymbol{L}(\vec{p}).\boldsymbol{S}$$



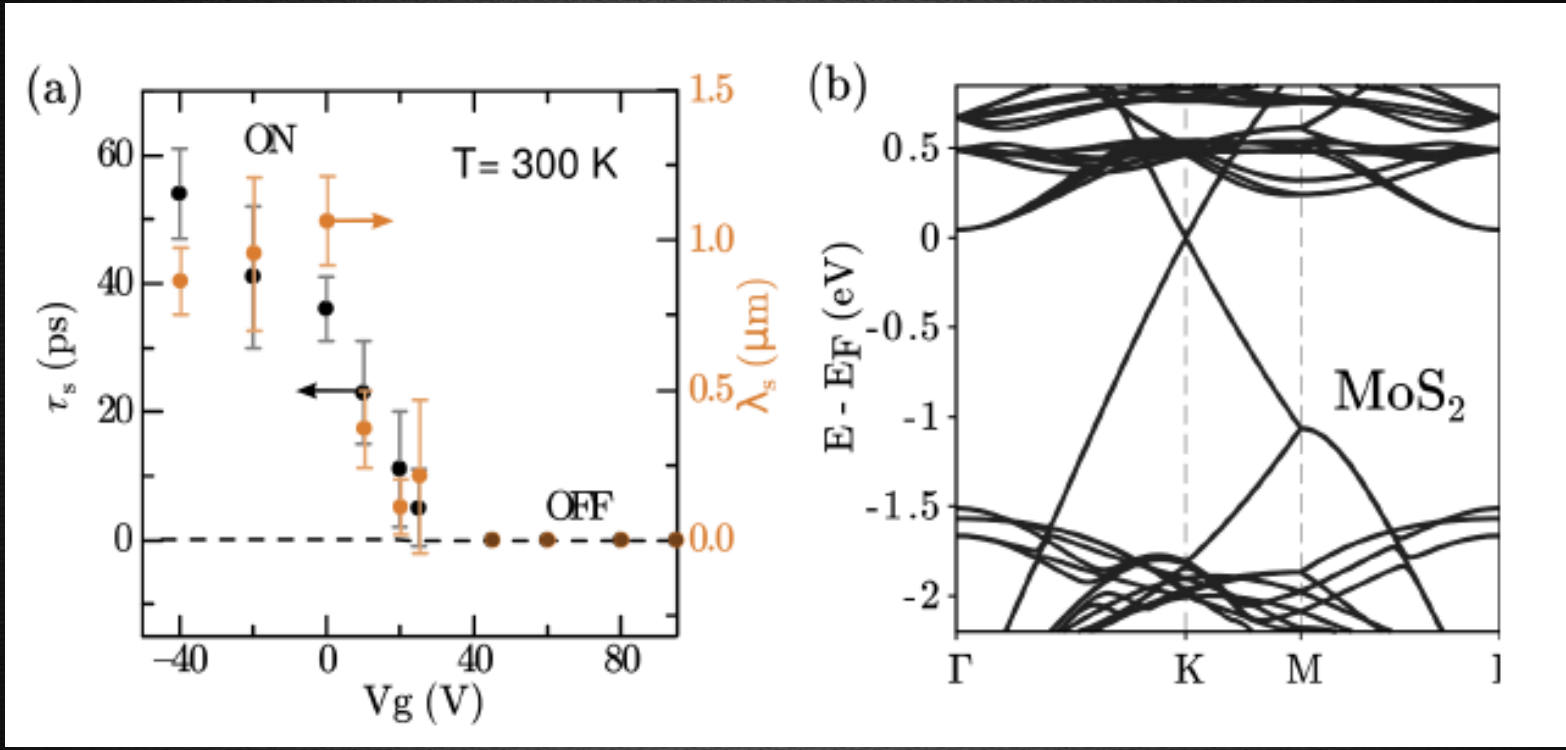
Negligible spin-orbit

Garcia et al. Chem. Soc. Rev., 47, 3359 (2018)



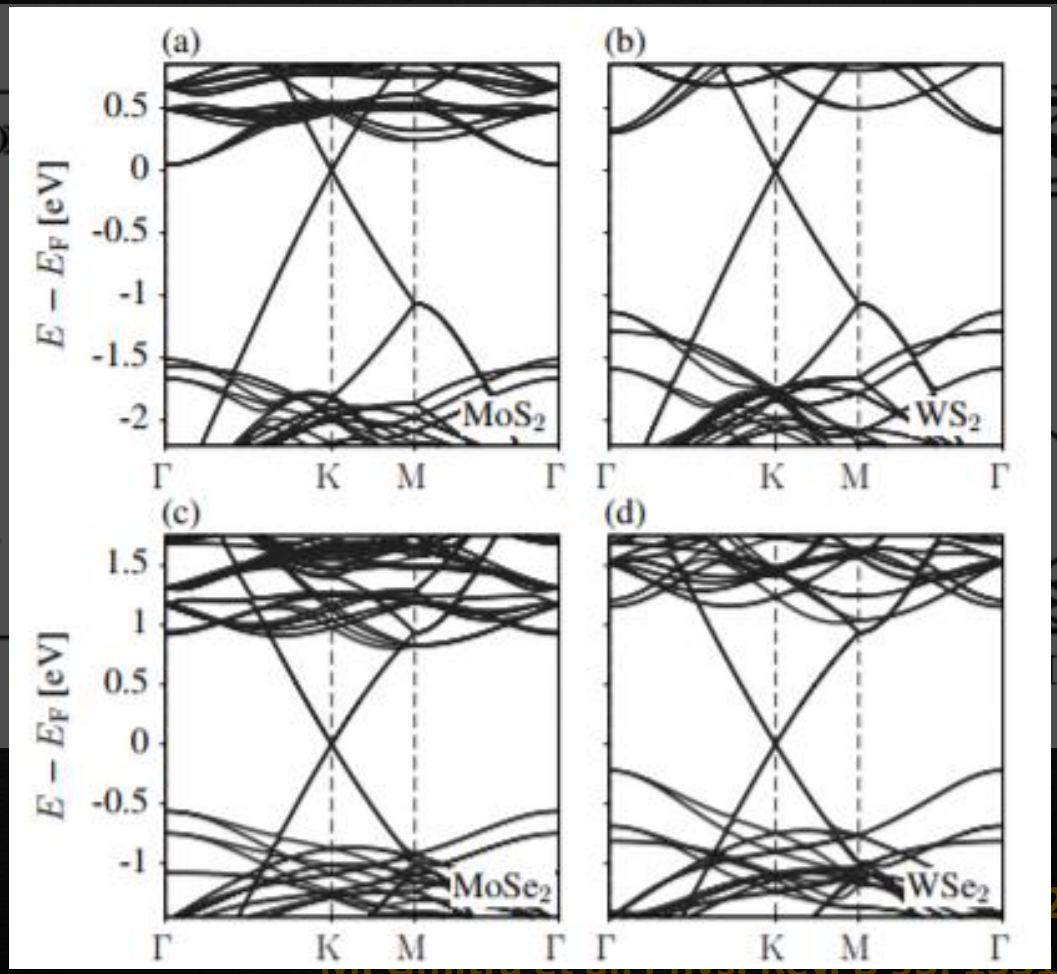
Usable spin-orbit

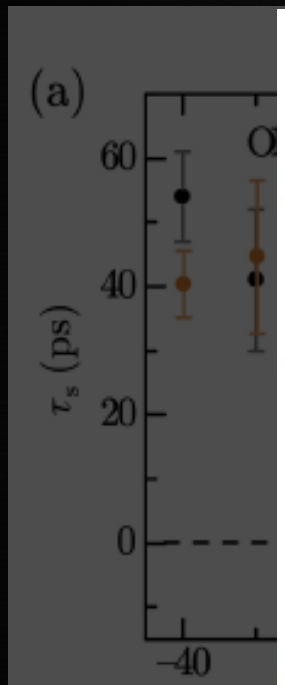
Electronic properties of Graphene/TMDs heterostructres

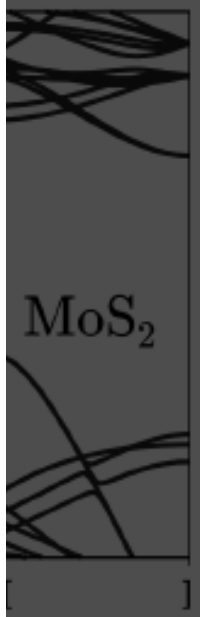


Yan, W. et al. Nat. Commun. 7, 13372 (2016).
M. Gmitra et al, Phys. Rev. B 93, 155104(2016)
Dankert, A. & Dash, S. P. Nat. Commun. 8, 16093 (2017)

Electronic properties of Graphene/TMDCs heterostructres







2 (2016).
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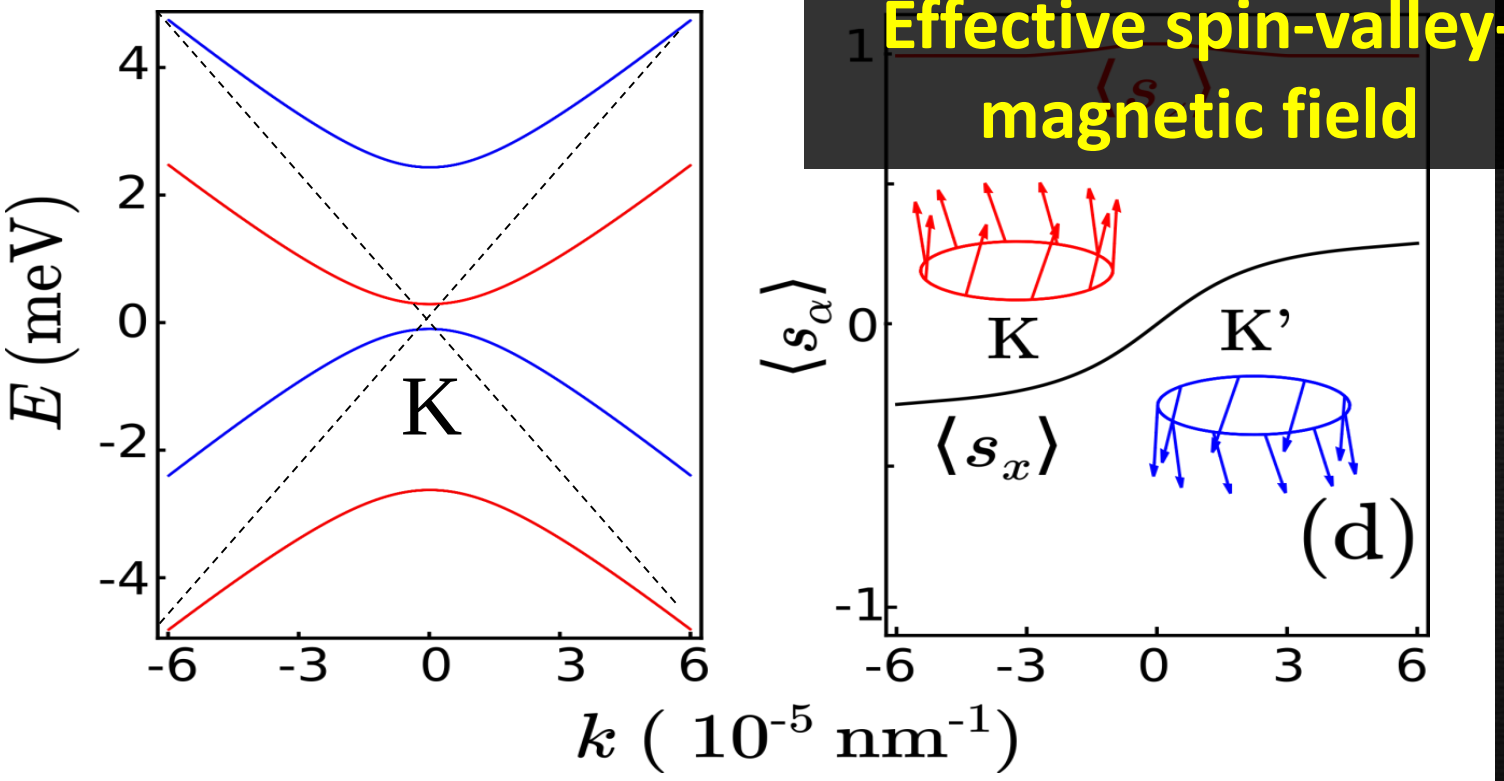
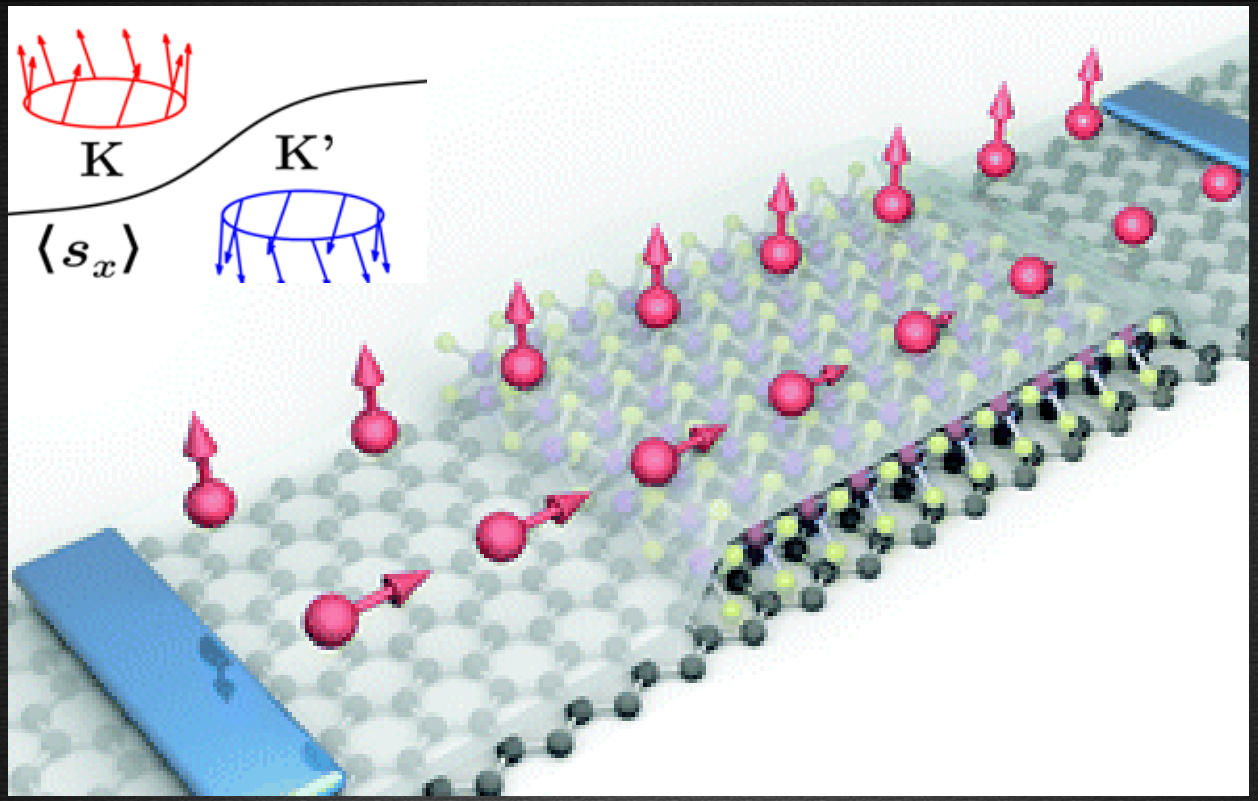
Dankert, A. & Dash, S. P. Nat. Commun. 8, 16093 (2017)

Band Structure and Spin texture in Graphene/TMDCs



$$H_{\mathrm{VZ}}^{\mathrm{K},\mathrm{K}'} = \pm \lambda_{\mathrm{VZ}} s_z$$

The valley-Zeeman and the spin-lifetime anisotropy

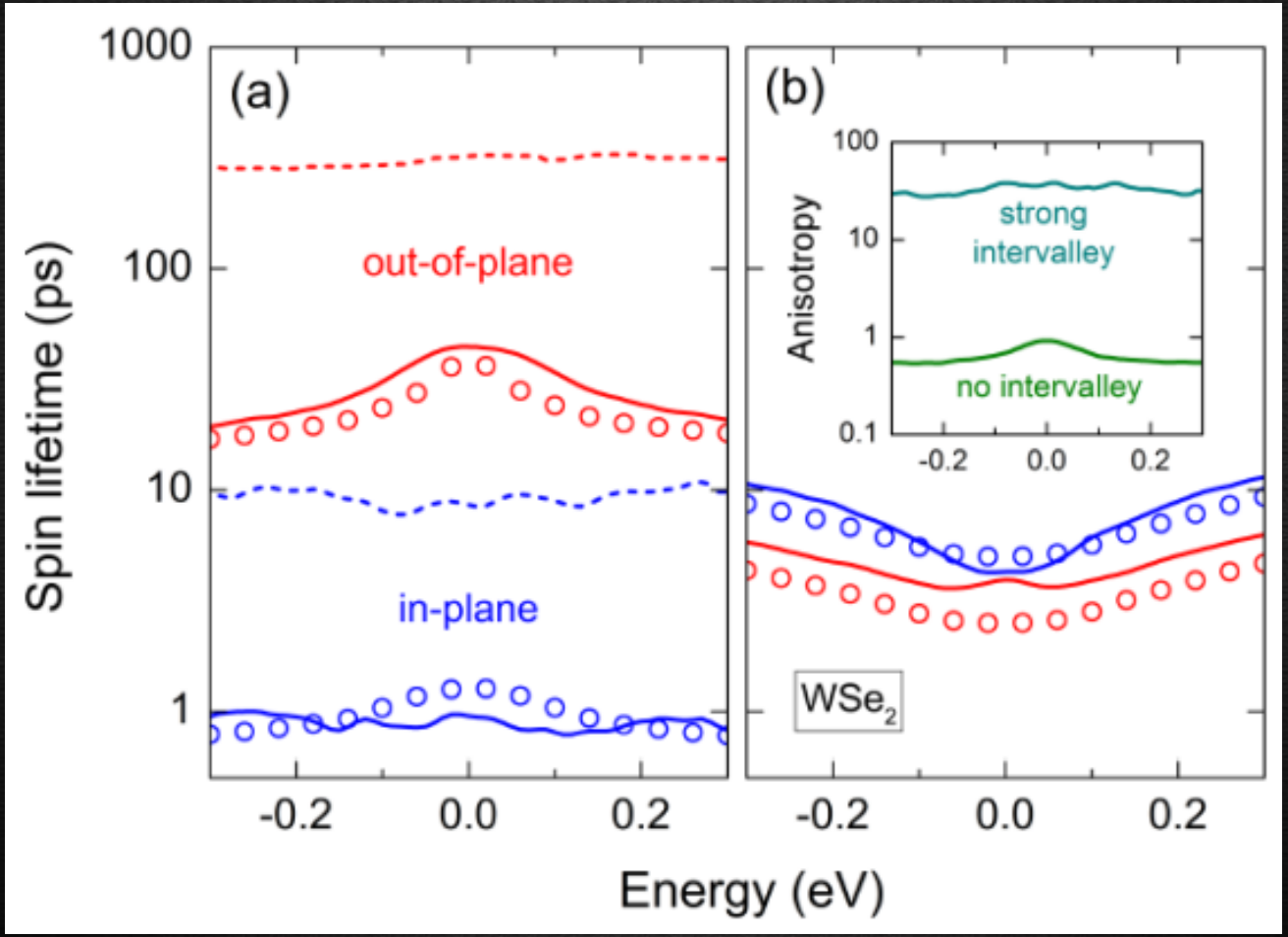


$$\frac{\tau_s^{\perp}}{\tau_s^{\parallel}} = \left(\frac{\lambda_{VZ}}{\lambda_R}\right)^2 \frac{\tau_{iv}}{\tau_p}$$

Cummings et al. Phys. Rev. Lett. 119, 206601 (2017)

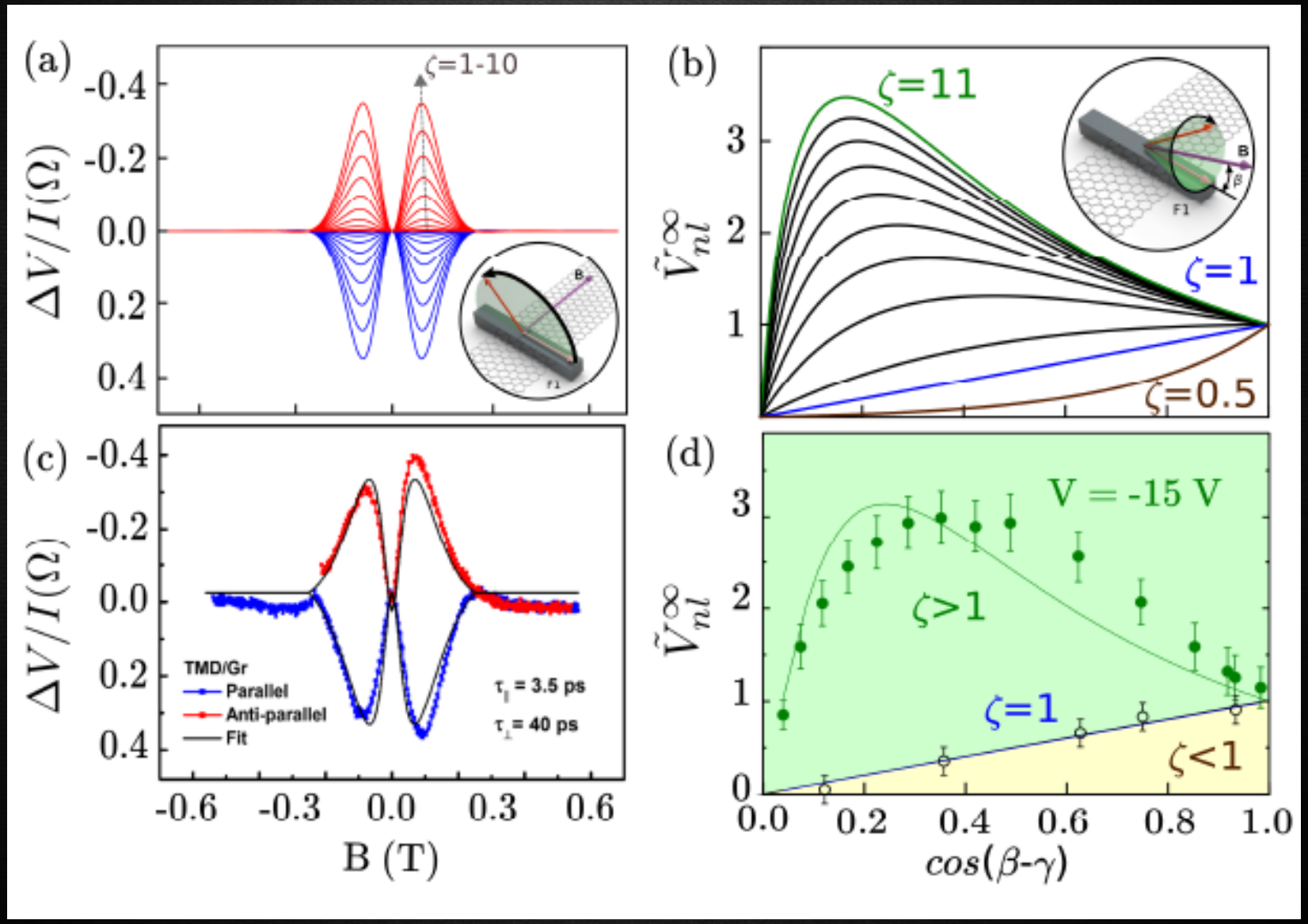
The valley-Zeeman and the spin-lifetime anisotropy

Cummings et al. Phys. Rev. Lett. 119, 206601 (2017)



Theory vs Experiments

Garcia et al. Chem. Soc. Rev., 47, 3359 (2018)



Theory vs Experiments

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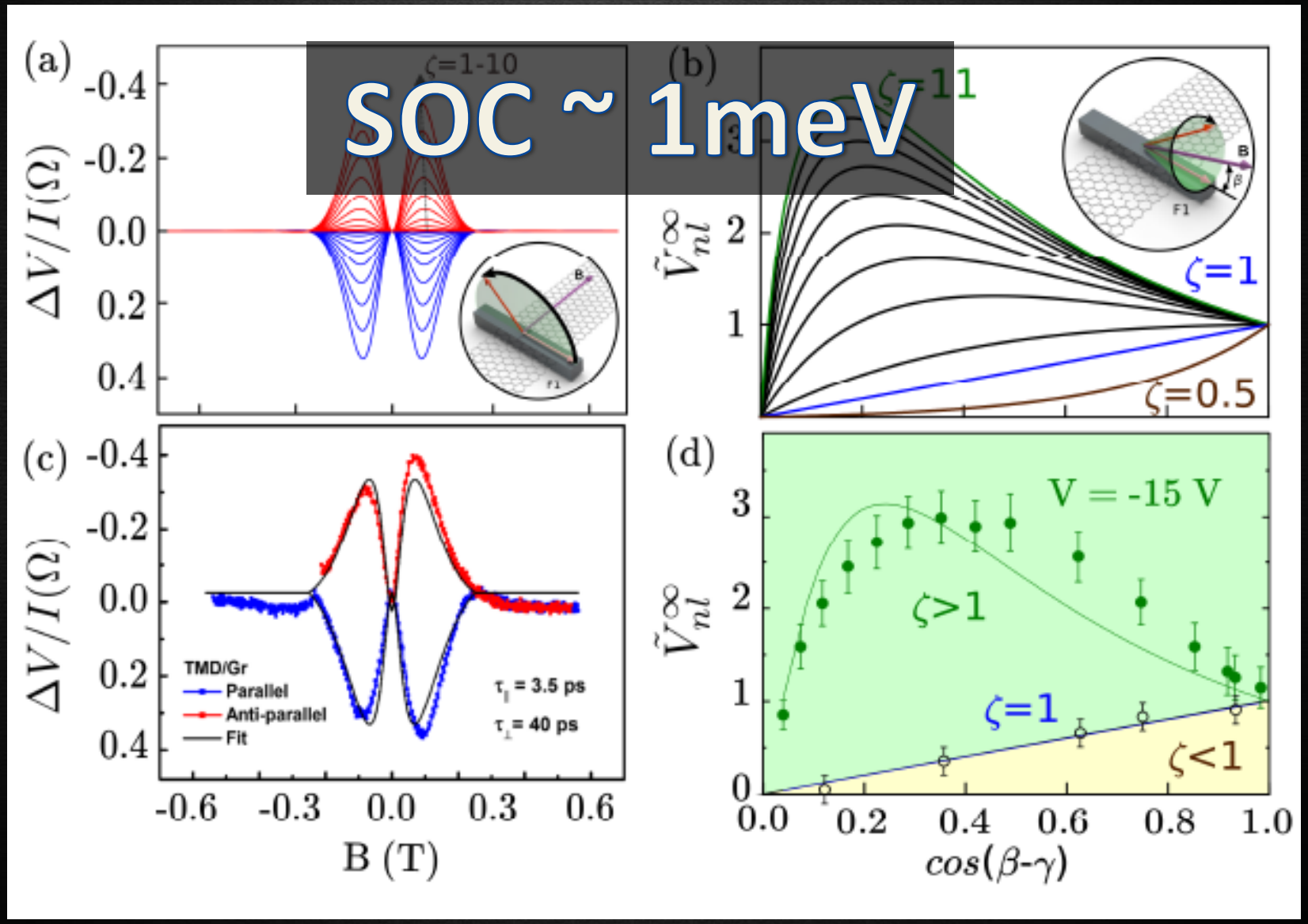
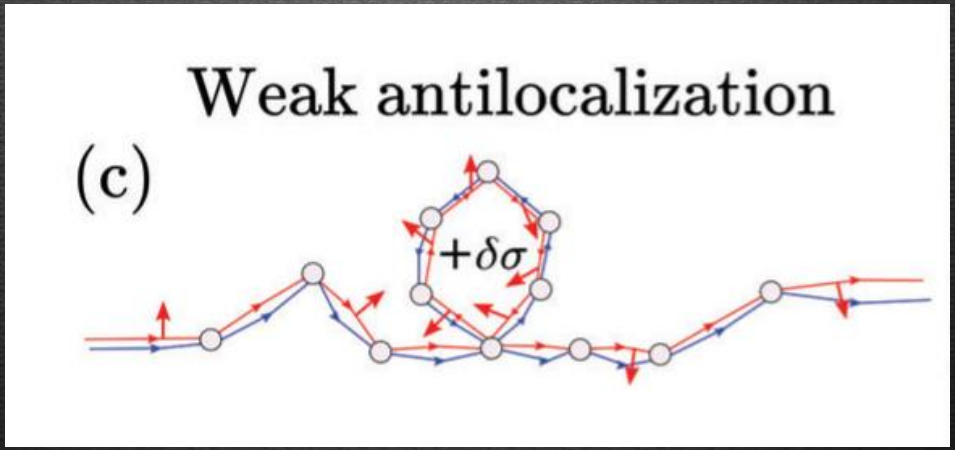


Weak anti-localization in Graphene/TMDs

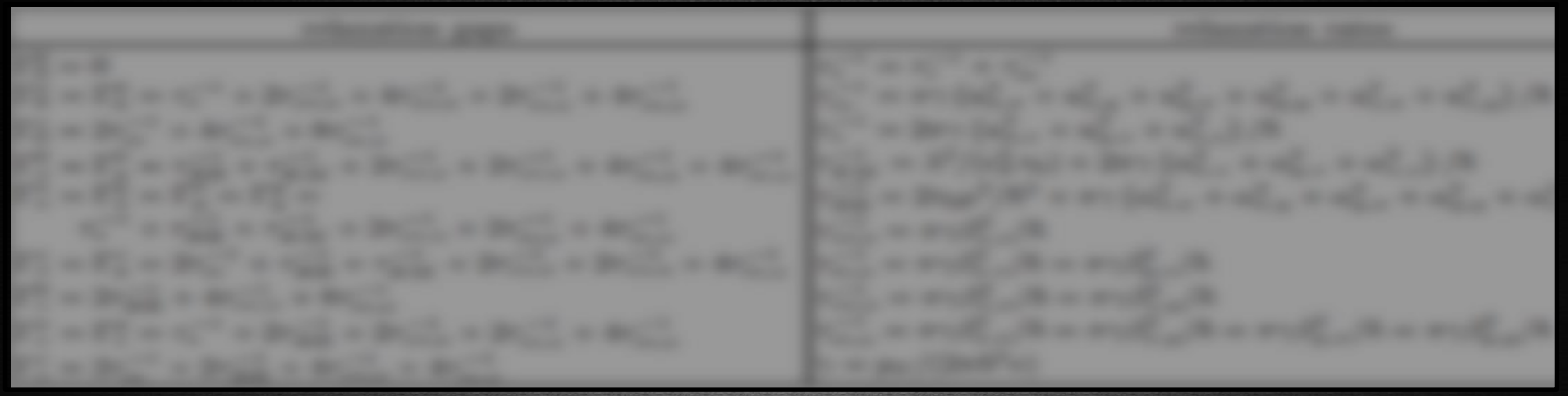
relaxation gaps	relaxation rates
$\Gamma_0^0 = 0$	$\tau_*^{-1} = \tau_z^{-1} + \tau_{iv}^{-1}$
$\Gamma_0^x = \Gamma_0^y = \tau_*^{-1}$	$\tau_{iv}^{-1} = \pi\gamma\left(u_{x,x}^2 + u_{x,y}^2 + u_{y,x}^2 + u_{y,y}^2 + u_{z,x}^2 + u_{z,y}^2\right)/\hbar$
$\Gamma_0^z = 2\tau_{iv}^{-1}$	$\tau_z^{-1} = 2\pi\gamma\left(u_{x,z}^2 + u_{y,z}^2 + u_{z,z}^2\right)/\hbar$
$\Gamma_x^0 = \Gamma_y^0 = \tau_{BR}^{-1} + \tau_{KM}^{-1}$	$\tau_{KM}^{-1} = \lambda^2/(\epsilon_F^2\tau_0)$
$\Gamma_x^x = \Gamma_y^y = \Gamma_x^x = \Gamma_y^y =$	$\tau_{BR}^{-1} = 2\tau_0\mu^2/\hbar^2$
$\tau_*^{-1} + \tau_{BR}^{-1} + \tau_{KM}^{-1}$	
$\Gamma_x^z = \Gamma_y^z = 2\tau_{iv}^{-1} + \tau_{BR}^{-1} + \tau_{KM}^{-1}$	
$\Gamma_z^0 = 2\tau_{BR}^{-1}$	
$\Gamma_z^x = \Gamma_z^y = \tau_*^{-1} + 2\tau_{BR}^{-1}$	
$\Gamma_z^z = 2\tau_{iv}^{-1} + 2\tau_{BR}^{-1}$	

$$\Delta\sigma(B_z) = -\frac{1}{2\pi}\sum_{s,l} c_s c_l F\left(\frac{B_z}{B_\phi + B_s^l}\right), \qquad B_s^l \propto \Gamma_s^l$$



McCann& Fal'ko Phys. Rev. Lett. 108, 166606 (2012)

Weak anti-localization in Graphene/TMDs



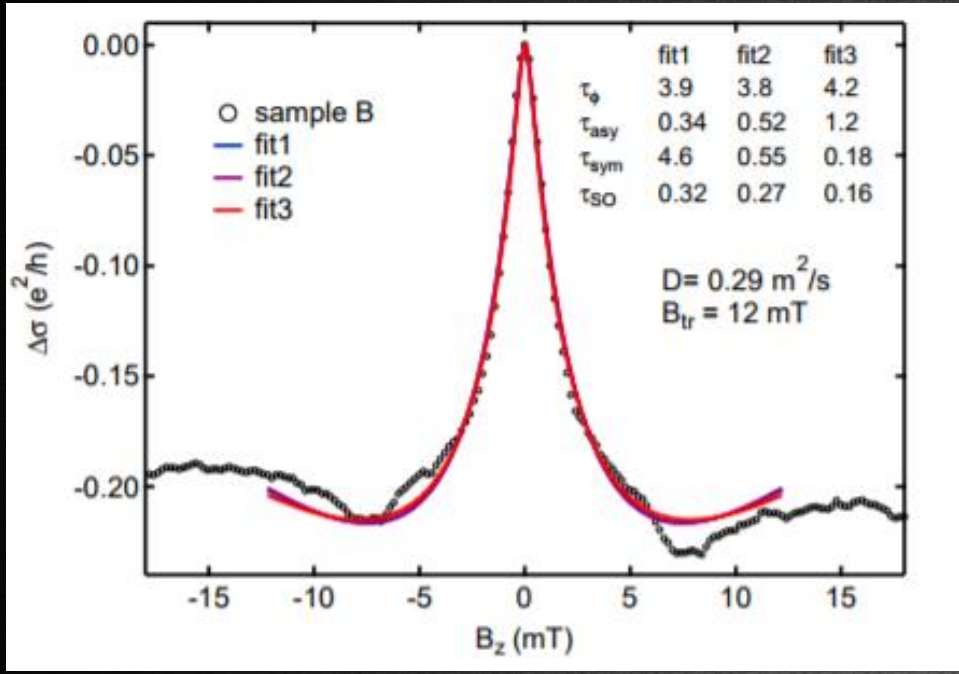
$\tau_{asym} = \tau_R$ → WAL

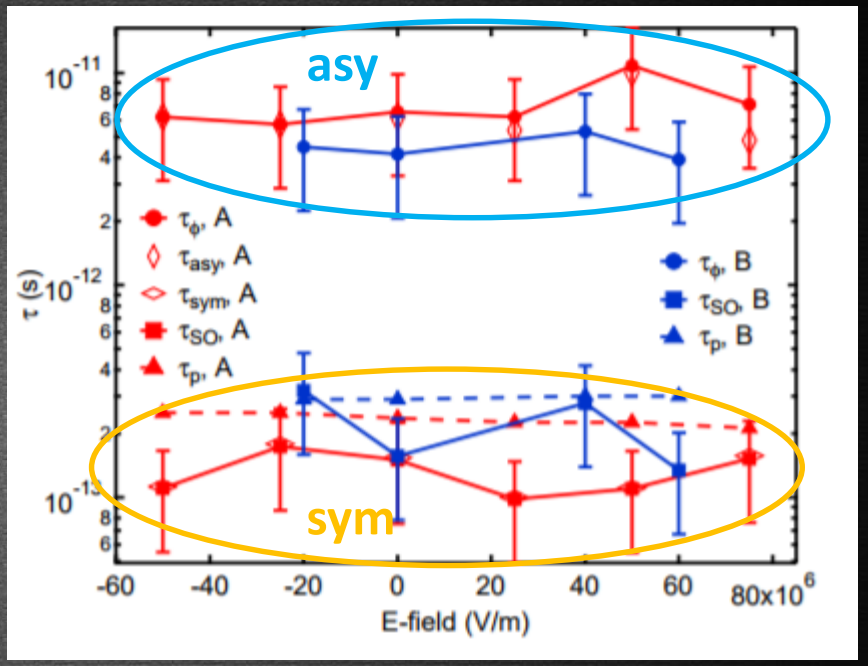
$Short\ \tau_{i,v}$

$\tau_{sym} = \tau_{VZ}$ → $Behavior\ at\ High\ magnetic\ field$

Weak anti-localization in Graphene/TMDCs

Zihlmann et al. Phys. Rev. B 97, 075434 (2018))



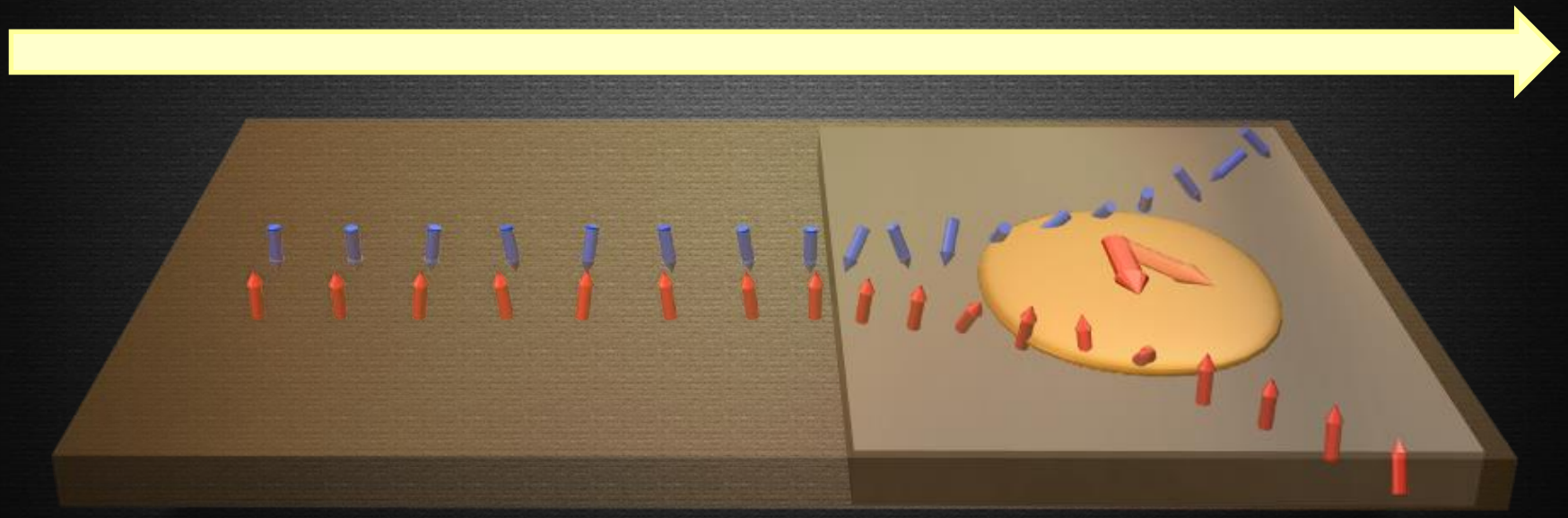


$$\frac{\tau_{sym}}{\tau_{asym}} = \frac{\tau_{VZ}}{\tau_R}$$

Anisotropy!

Spin manipulation

Electric field

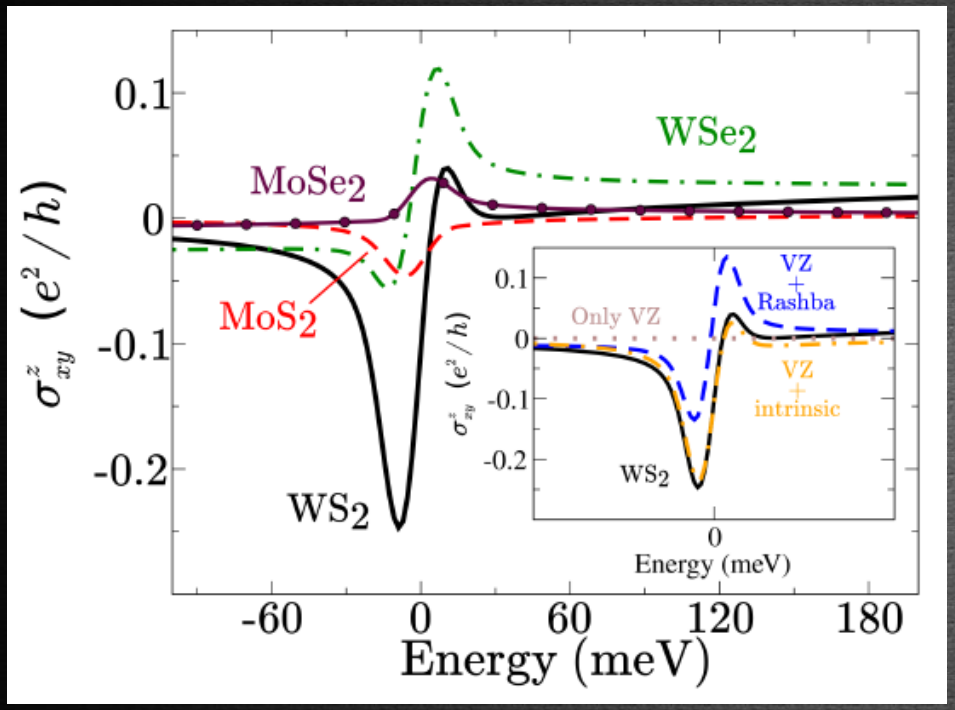


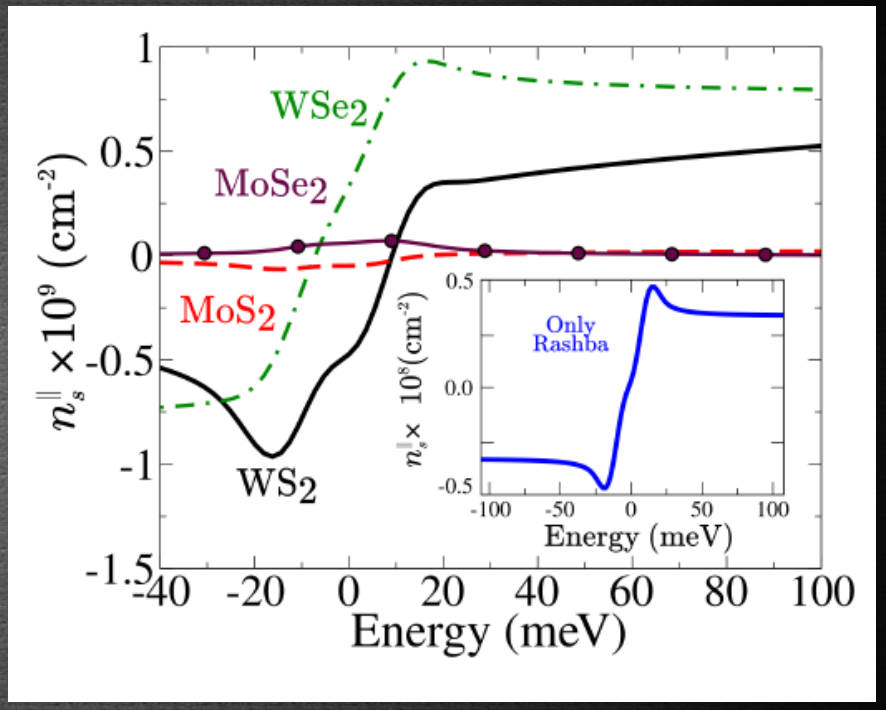
Spin-Hall Effect

Inverse Spin Galvanic Effect

Spin Hall effect and ISGE

Garcia et al. Nano Lett. 17 , 5078 (2017)

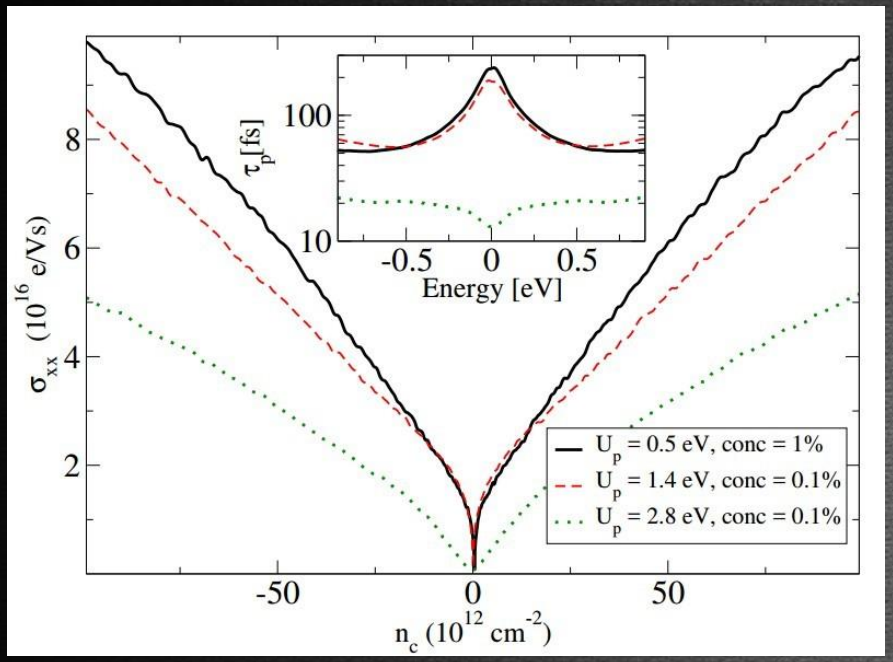


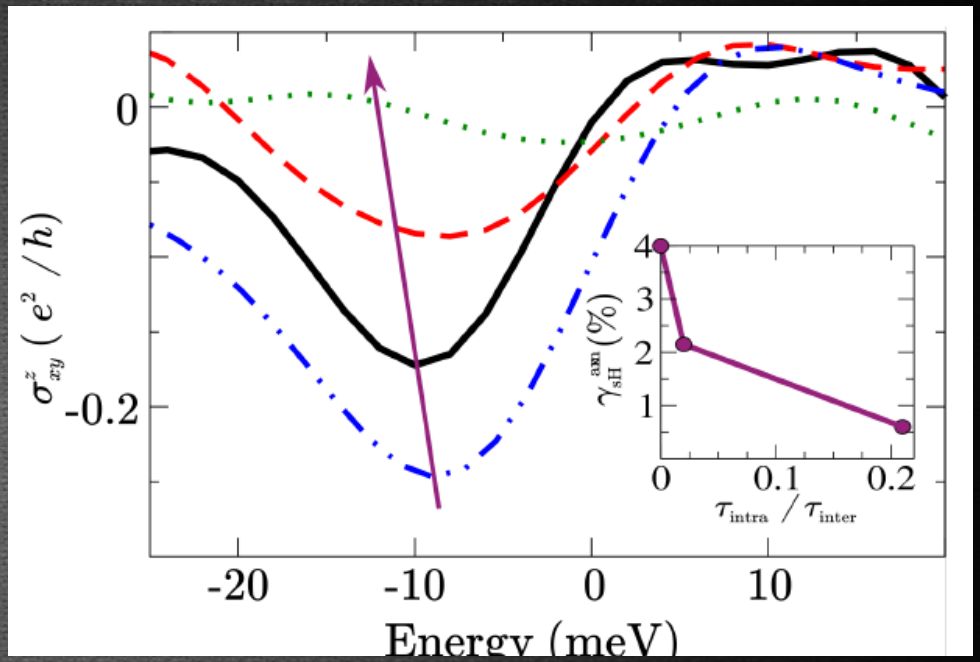


The valley-Zeeman increases both SHE and ISGE effects

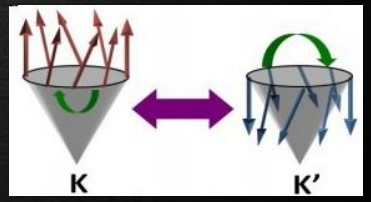
SHE and the effect of disorder

Garcia et al. Nano Lett. 17 , 5078 (2017)





Intervalley-scattering is detrimental to SHE



Conclusion

Graphene/TMDs heterostructures are an exceptional platform for **spintronics** due to its particular combination of **valley-Zeeman and Rashba spin-orbits.**

Intervalley scattering is crucial for describing the spintronic properties of these systems.

Theoretical and Computational Nanoscience group

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Marc Vila

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Stephan Roche

GRAPHENE FLAGSHIP

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Chemical Society Reviews

Garcia et al. Chem. Soc. Rev., 47, 3359 (2018)

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The End