# Transport phenomena in 2D Dirac materials with strong spin-orbit effects

Aires Ferreira[1]

[1] Department of Physics, University of York, York YO10 5DD, United Kingdom

Spin-orbit coupling has attracted enormous attention due to its pivotal role in nontrivial topological insulating phases and numerous relativistic transport effects with potential applications in spintronics [1]. Recently, 2D van der Waals (vdW) heterostructures built from graphene and semiconducting dichalcogenides have emerged as strong contenders for fundamental studies of spin-orbit phenomena. When graphene is paired with group-VI dichalcogenide monolayers [$MX_2$ (M = Mo, W; X = S, Se)], its band structure develops rich non-collinear spin textures, paving the way to a new generation of gate-tuneable 2D devices enabling optical and electrical manipulation of spins (fig. 1) [2].

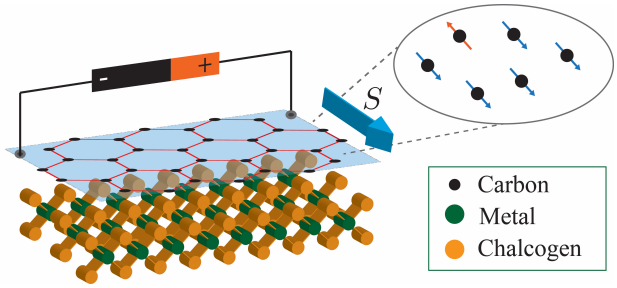


**Figure 1**. Graphene on top of a semiconducting base with two types of atoms. Spin and momentum of conduction electrons are locked at right angles due to interfacial Rashba effect. The application of a gate voltage induces a net spin polarization, a transport phenomenon known as inverse spin galvanic effect (ISGE) or Edelstein effect [3].

This lecture will review recent progress towards understanding transport phenomena in vdW heterostructures with interfacial spin-orbit coupling. After an introduction to 2D Dirac materials with multiple SU(2) (spin, valley and pseudo-spin) degrees of freedom, I will discuss the conditions for the emergence of dual relativistic transport effects, i.e., ISGE and spin Hall effect (SHE). Coupled charge-spin transport in 2D Dirac materials is shown to be modulated by Berry curvature effects and scattering mechanisms strongly dependent on the sublattice/spin texture of interface-induced spin-orbit interactions. Of particular interest is graphene on $MX_2$, where sublattice-resolved spin-orbit coupling endows each valley with net spin polarization: $S_K = -S_{K'}$. Such a "valley-Zeeman" effect enables a wealth of interesting new physics, from all-optical injection of spin currents [4] and highly anisotropic spin relaxation [5] to a robust skew scattering mechanism [2]. Finally, I will discuss charge carrier transport in ferromagnetic vdW heterostructures, where 2D magnetized Dirac bands with non-collinear spin texture in momentum space engender an anomalous Hall effect with a distinctive experimental signature [6].

[1] A. Soumyanarayanan *et al*. Nature 539, 509 (2016)
[2] M. Milletari *et al*. Phys. Rev. Lett. 119, 246801 (2017); Dyrdał & Barnaś, 2D Materials 4, 034003 (2017); J. H. Garcia *el al*., Chem. Soc. Rev. 47, 3359 (2018)
[3] M. Offidani, R. Raimondi & A. Ferreira. Phys. Rev. Lett. 119, 196801 (2017)
[4] M. Gmitra & J. Fabian, PRB 92, 155403 (2015). Y. K. Luo Nano Lett. 17, 3877 (2017).
[5] M. Offidani and A. Ferreira, https://arxiv.org/abs/1807.09275
[6] M. Offidani and A. Ferreira (2018); accepted in Physical Review Letters