Interactions Between Exciton-Polarons in Monolayer WS_2

J.B. Muir[a,b], M.A. Conway[a,b], S.K. Earl[a,b], R. Mishra, M. Wurdack[a,c], J.H. Cole[a,d], M.M. Parish[a,e], J. Leveinsen[a,e], D.K. Efimkin[a,e], J.O. Tollerud[b], E.A. Ostrovskaya[a,c], M.S. Fuhrer[a,e] and J.A. Davis[a,b]

[a]*ARC Centre of Excellence in Future Low-Energy Electronics Technologies*

[b]*Centre for Quantum and Optical Science, Swinburne University of Technology, VIC 3122, Australia*

[c]*Research School of Physics, The Australian National University, Canberra, ACT 2601, Australia*

[d]*Chemical and Quantum Physics, School of Science, RMIT University, Melbourne, VIC 3001, Australia*

[e]*School of Physics and Astronomy, Monash University, VIC 3800, Australia*

Interactions between quasiparticles are of fundamental importance and ultimately determine the macroscopic properties of quantum matter. A famous example is the phenomenon of superconductivity, which arises from attractive electron-electron interactions that are mediated by phonons or even other more exotic fluctuations in the material. In this work we introduce mobile exciton impurities into a two-dimensional electron gas and investigate the interactions between the resulting Fermi polaron quasiparticles.

The two-dimensional system we use is monolayer WS_2, which provides an ideal platform for determining the nature of polaron-polaron interactions due to the underlying trion fine structure and the valley specific optical selection rules. We employ multi-dimensional coherent spectroscopy – a technique that is optimized to reveal interactions [1] – with polarization control to identify the specific interaction pathways, and states involved.

At low electron doping densities, we find that the dominant interactions are between polaron states that are dressed by the same Fermi sea. In the absence of bound polaron pairs (bipolarons), we show using a minimal microscopic model that these interactions originate from a phase-space filling effect, where excitons compete for the same electrons. We furthermore reveal the existence of a bipolaron bound state with remarkably large binding energy, involving excitons in different valleys cooperatively bound to the same electron [2]. Our work lays the foundation for probing and understanding strong electron correlation effects in two-dimensional layered structures such as Moiré superlattices.

[1] J.O. Tollerud and J.A. Davis, *Prog. Quantum. Electron.* **55**, 1–34 (2017).

[2] J.B. Muir, et al., arXiv:2206.12007 (2022).