New materials are of fundamental importance for developing disruptive technologies. A large family of two-dimensional (2D) materials, each having unique properties associated with its ultimate thinness and often distinct symmetry, offer tremendous opportunities to explore novel physics and device concepts. In particular, 2D layered semiconductors and their heterostructures are building blocks for realizing unconventional nano-electronic, photonic and optoelectronic devices. In this talk, I will primarily discuss the unique optoelectronic response of 2D semiconductor devices that reveal the fundamental role of many-body interaction and ultrafast interlayer charge transfer dynamics. I will start by discussing the conduction mechanism of light-emitting tunnel diode consisting of few-layer graphene (FLG), hexagonal boron nitride (hBN), and monolayer WS$_2$. We find that this device exhibits electrically assisted upconversion of near-infrared (NIR) to visible light, which evidences the role of hot carrier tunnelling. We further investigate the role of exciton–exciton annihilation (EEA), a four-body interaction involving the energy and momentum transfer between two holes and two electrons. Our tunnel diode devices exhibit unexpected photoresponse due to generation of non-equilibrium high energy carriers derived from EEA in monolayer semiconductors. In the last part, I will discuss our recent findings on the peculiar magnetic properties of Cr$_2$Ge$_2$Te$_6$, a ferromagnetic semiconductor. We show how heavy electron doping of this material by ionic gating leads to substantial modulation of its Curie temperature and magnetic anisotropy.