Supplementary information

Magnetic proximity effect and electrical field tunable valley degeneracy in MoS$_2$/EuS van der Waals heterojunctions

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Comparing with other TMDs/EuS heterojunctions

To verify our results that the MPE exists at the MoS$_2$/EuS interface, we have calculated other TMDs/EuS heterojunctions, such as WS$_2$/EuS and MoSe$_2$/EuS. Fig. S1 shows the charge density difference distribution and the spin density distribution at the interface for MoS$_2$/EuS, WS$_2$/EuS and MoSe$_2$/EuS in chemical and vdW adsorption states, respectively. It can be seen, both in chemical and vdW adsorption states, the charge density distribution at these three interfaces are similar, and spin polarizations are observed at Mo(W) atomic layer. Fig. S2 show the band structure for MoS$_2$/EuS, WS$_2$/EuS and MoSe$_2$/EuS in chemical and vdW adsorption states. The calculated adsorption distance “d”, binding energy $\Delta E$, induced magnetic moments and valley Zeeman splitting $E_z$ are listed in the talble S1 below. We can see the TMDs/EuS have similar adsorption way and distance, and the magneitc proximity effect is generally existed in these systems in different degrees, which is due to due to the intrinsic SOC of these TMCDs, in addition, the different lattice mismatch and atoms configurations at the interface of these systems can also impact the MPE. The calculated valley Zeeman splitting of WS$_2$/EuS and MoSe$_2$/EuS are 33.2 and 15.6 meV in chemical adsorption states, while 4.7 and 2.5meV in vdW adsorption states.
Considering the measured valley Zeeman splitting rate of $-233 \pm 10 \, \mu eV/T$ and $-220 \, \mu eV/T$ for single layer WS$_2$ and MoSe$_2$ in previous studies, the MPE introduces a MEF of 143 T and 20 T for WS$_2$/EuS in the chemical and vdW adsorption cases, while 71 T and 11 T for MoSe$_2$ in the chemical and vdW adsorption cases.

**Figure S1.** The charge density difference distribution at the interface of MoS$_2$/EuS (a, b), WS$_2$/EuS (c, f) and MoSe$_2$/EuS (i, j), in which the left column (a, e, i) indicate the chemical adsorption, and the right column (b, f, j) indicate the vdW adsorption. Also shown are the spin density distribution at the Mo (W) atomic layer of MoS$_2$/EuS (c, d), WS$_2$/EuS (g, h) and MoSe$_2$/EuS (k, l), in which the left column (c, g, k) indicate the chemical adsorption, and the right column (d, h, l) indicate the vdW adsorption.

**Table S1.** The adsorption distance “d”, binding energy $\Delta E$, averaged induced magnetic moments in Mo (W) and valley Zeeman splitting $E_z$ calculated for MoS$_2$/EuS, WS$_2$/EuS and MoSe$_2$/EuS heterojunctions in chemical and vdW adsorption states.
Figure S2. The band structure calculated for MoS$_2$/EuS, WS$_2$/EuS and MoSe$_2$/EuS heterojunctions in chemical and vdW adsorption states.

Comparing several vdW correction methods
To check the vdW correction method used in our study, we also using other vdW correction method to check our results on MoS$_2$/EuS system, such as optB88-vdW$^3$ and optB86b-vdW$^4$, which are also appropriate for layered systems$^5$. Table S2 shows the adsorption distance “$d$”, binding energy $\Delta E$, averaged induced magnetic moments calculated for MoS$_2$/EuS using different vdW correction methods. We can see these three methods give out similar adsorption distance and binding energy, in particular, the magnetic moments induced in Mo atoms are agree well with each other, which indicated the degrees of our estimated MPE at this interface is reasonable. Fig. S3 shows the projected density of states (PDOS) of Mo, S, Eu atoms at the MoS$_2$/EuS interface using different vdW correction methods. From the calculated PDOS, we can see the three different vdW correction has little effect on the electron structure, in particular, the band gap of MoS$_2$. 

Table S2: Adsorption distance “$d$”, binding energy $\Delta E$, and averaged induced magnetic moments calculated for MoS$_2$/EuS using different vdW correction methods.
Table S2. The adsorption distance “d”, binding energy ∆E, averaged induced magnetic moments calculated for MoS$_2$/EuS using different vdW correction methods.

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<th>Adsorption type</th>
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<td>∆E (meV)</td>
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Figure S3. The calculated projected density of states (PDOS) of Mo, S, Eu atoms at the MoS$_2$/EuS interface using different vdW correction methods.

Reference
