Impurity-induced excitations in topological 2D ferromagnet/superconductor van der Waals moire heterostructures

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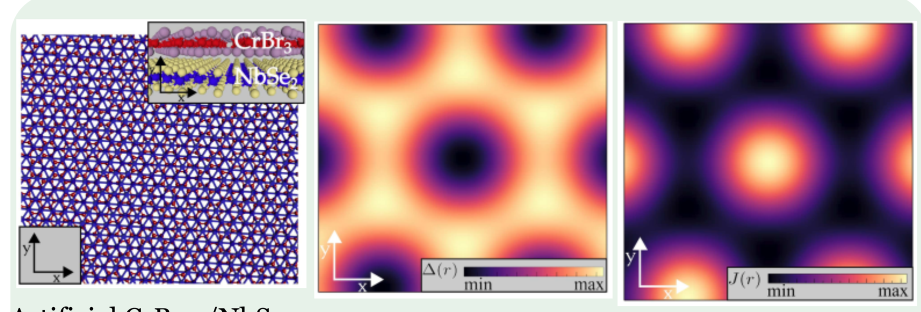
Objectives

Goal: To address the impact of non-magnetic impurities on artificial moire topological superconductors.
Challenge: Impurities in uniform topological superconductors have been widely studied, yet the interplay between local impurities in moire systems has remained relatively unexplored.
Approach: Construct a minimal effective model that accounts for the physics of van der Waals ferromagnet/superconductor heterostructures, such as $CrBr_3/NbSe_2$ heterostructure.

Model:

- A generic topological superconductor, as realized in a CrBr 3 /NbSe 2 heterostructure.
- Focus on the two parameters with sizable modulations, the local superconducting order and the proximity-induced exchange field



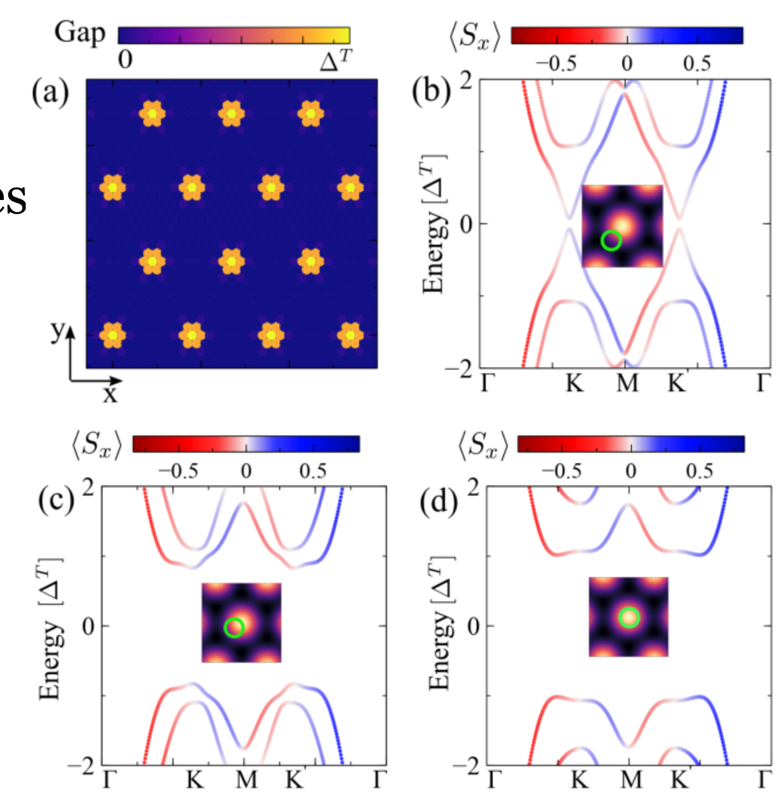
Artificial $CrBr_3$ /$NbSe_2$ moire topological superconductor — Modulation of superconducting coupling — Modulation of exchange coupling

$$\mathcal{H}_0 = \mathcal{H}_{\rm kin} + \mathcal{H}_J + \mathcal{H}_R + \mathcal{H}_{\rm SC} \qquad f(\mathbf{r}) = c_0 + c_1 \sum_{n=1}^{3} \cos(R^n \mathbf{q}\cdot\mathbf{r})$$

$$J(\mathbf{r}) = J_0 + \chi\delta_J f(\mathbf{r})$$
$$\Delta(\mathbf{r}) = \Delta_0 + \chi\delta_\Delta (1 - f(\mathbf{r}))$$

Strong impurities in topological moire superconductors:

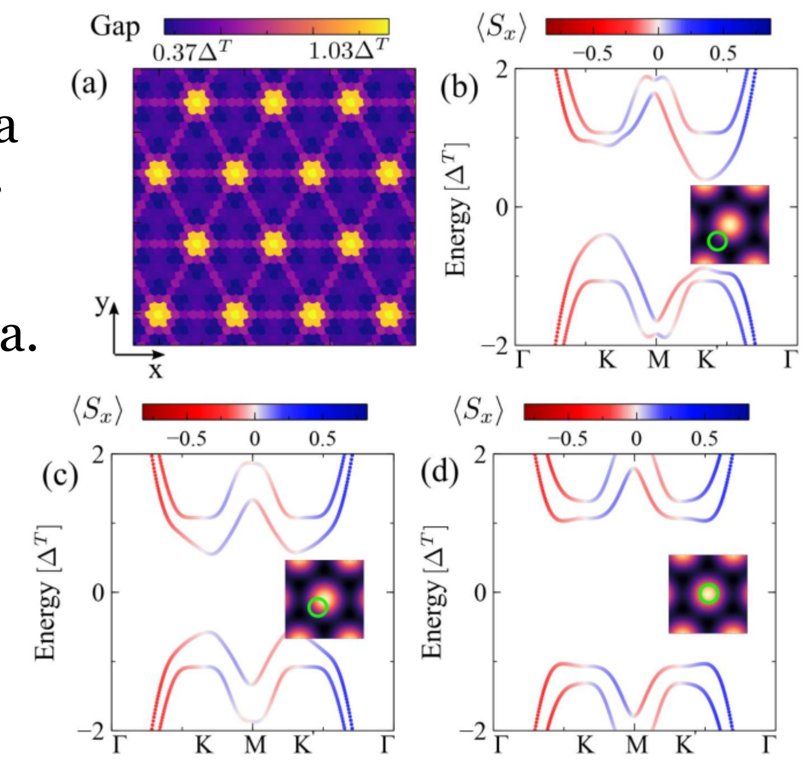
- Strong impurities in the effectivemodel are associated to chemical impurities, and vacancies in the dichalcogendie superconductor.
- Fig. (a), gap of the moire system as a function of the location of a strong impurity (w = 2t) in a 9 × 9 supercell.
- Electronic band structure for different locations of the impurity (Fig. 2bcd).



Weak impurities:

Weak impurity allows keeping a sizable topological gap even for the most detrimental locations awayfrom the exchange maxima.

Electronic structure remains similar for the three impurity locations



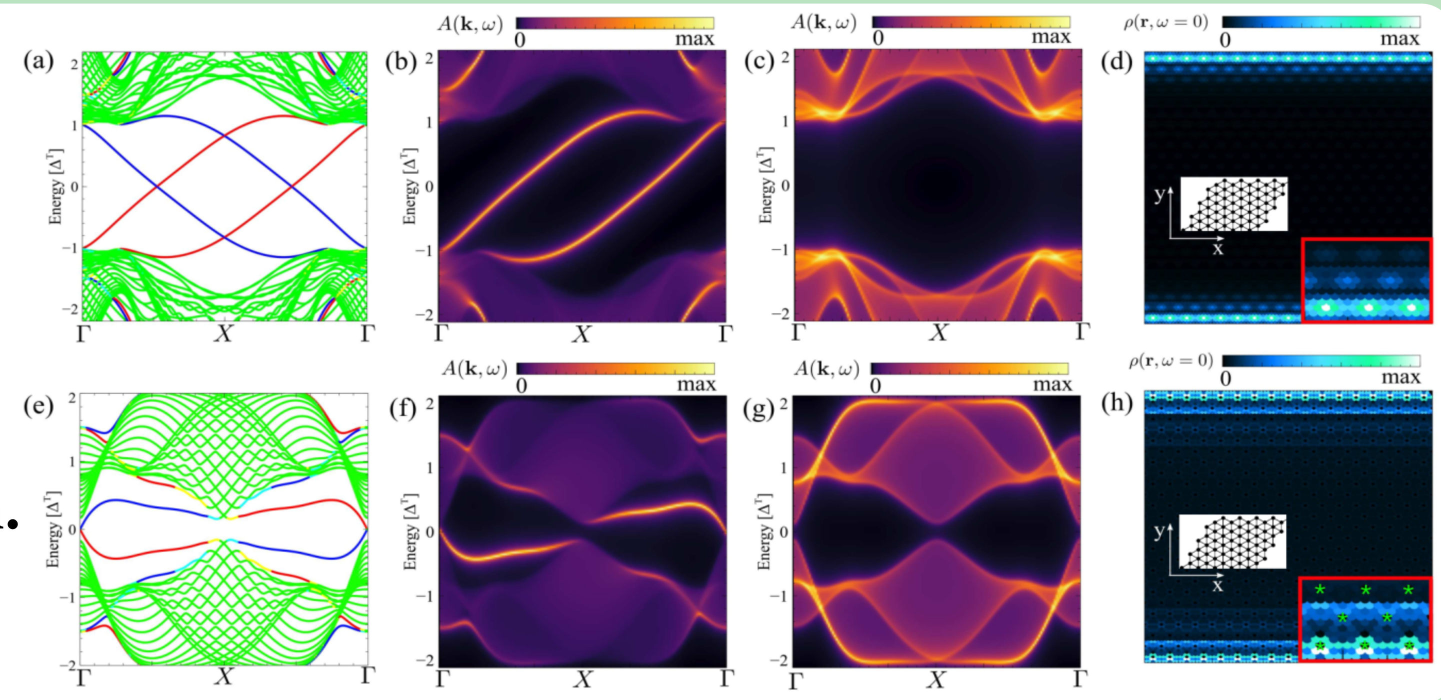
Edge states:

Analyzing the emergence of edge states associated with the moire topological superconducting state in a ribbon.

- Figs. (abcd), pristine system displaying the moire topological superconducting state.
- Figs. (efgh), moire superconductor with a single strong impurity per moire unit cell.

Pristine & defective: modulation of the edge modes follow the moire pattern.

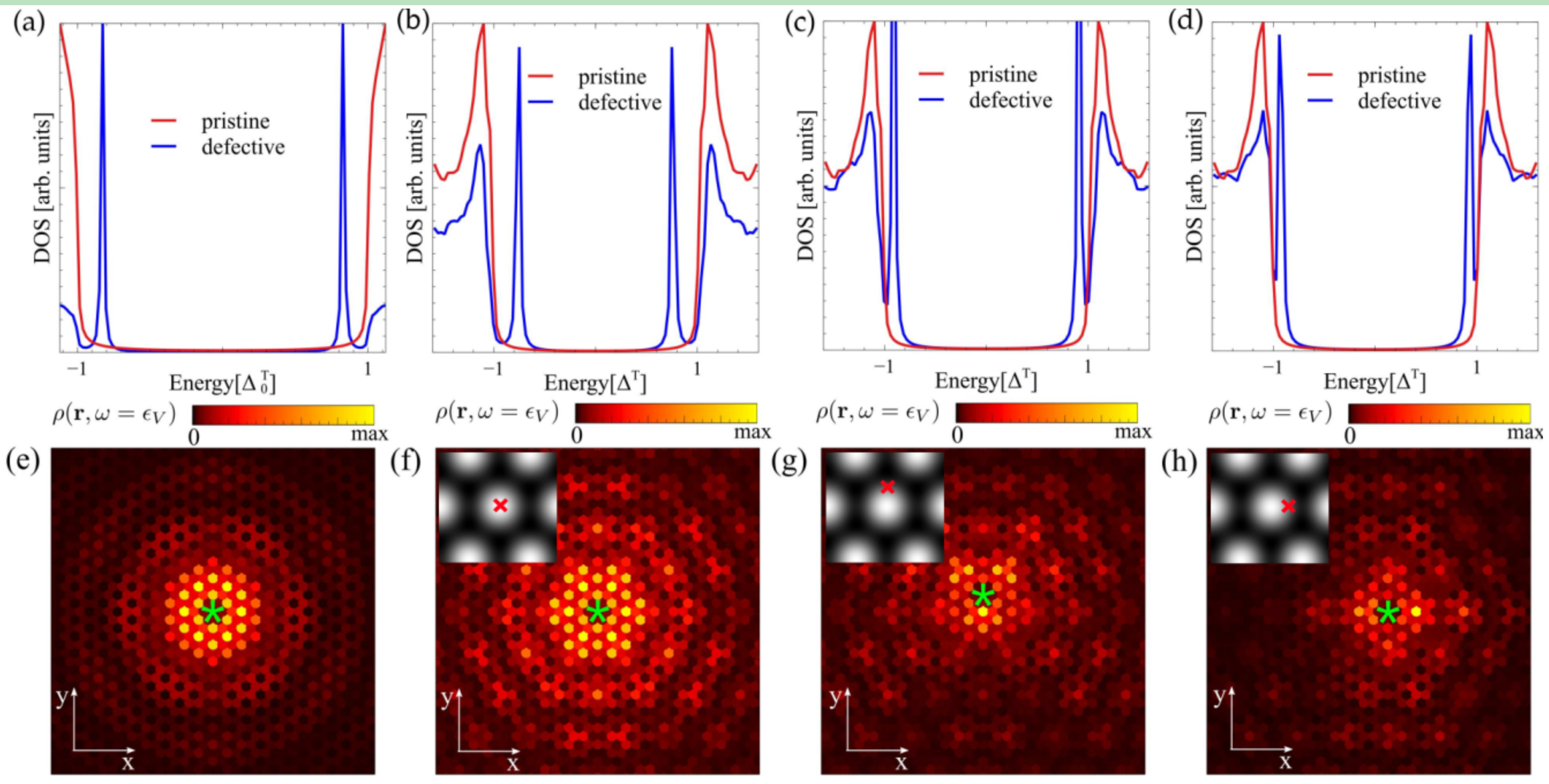
Defective: Topological edge states avoid the location of the impurity



Single impurity limit:

- A single impurity on an otherwise pristine moire system.
- Sysem lack any type of translational symmetry, and therefore an electronic bandstructure associated with a moire Bloch's theorem can not be computed.

Figs. 6ae, impurity in the uniform topological superconductor. The existence of a strong non-magnetic impurity (w = 2t) gives rise to an in-gap state



- Figs. (bcd), (fgh), finite moire pattern and single impurity, for different location of the impurity with respect to the center of the moire pattern.

➡ **Localized in-gap mode around the impurity and intensity oscillations.**

➡ **The interference pattern between the bound state and the moire pattern leads to a strong dependence depending on the location of the impurity.**

Conclusions

- In contrast with conventional artificial topological superconductors, the impact of impurities on a moire system can give rise to radically different properties depending on their location in the moire pattern.

Outlook

Engineered atomic impurities as a powerful and versatile strategy to engineer artificial van der Waals moire topological superconductors.

References

[1] arXiv:2202.11003.
[2]Nano Lett. 2022, 22, 1, 328–333