Scientists Discover Rydberg Moiré Excitons

The Rydberg state is widely present in a variety of physical platforms such as atoms, molecules, and solids. In particular, the Rydberg excitons are highly excited Coulomb bound states of electron-hole pairs, first discovered in the semiconductor material Cu_2O in the 1950s. Their solid-state nature, in conjunction with the large dipole moments, strong mutual interactions, and significantly enhanced interactions with the surroundings, holds promises for a wide range of applications in sensing, quantum optics, and quantum simulation. However, compared with their atomic counterparts, namely Rydberg atoms that have been widely explored in recent years, the exploitation of Rydberg excitons is far from reaching their full potential. One of the main obstacles lies in the difficulty of realizing efficient trapping and manipulation of the Rydberg excitons. Lately, the rise of two-dimensional moiré superlattices with highly tunable periodic potentials provides a possible pathway.

In recent years, researchers from the Institute of Physics, Chinese Academy of Sciences including Dr. XU Yang and his collaborators have been exploring the application of Rydberg excitons in two-dimensional (2D) semiconducting transition metal dichalcogenides (such as WSe_2). They developed a new Rydberg sensing technique, which utilizes the sensitivity to the dielectric environment of the Rydberg excitons to detect the exotic phases in a nearby 2D electronic system. Using this technique, they have revealed the abundance of correlated insulating states at fractional fillings in a 2D moiré heterobilayer platform (WSe_2/WS_2). Recently, in collaboration with a team led by Dr. YUAN Shengjun from Wuhan University, they reported the observation of Rydberg moiré excitons – the moiré trapped Rydberg

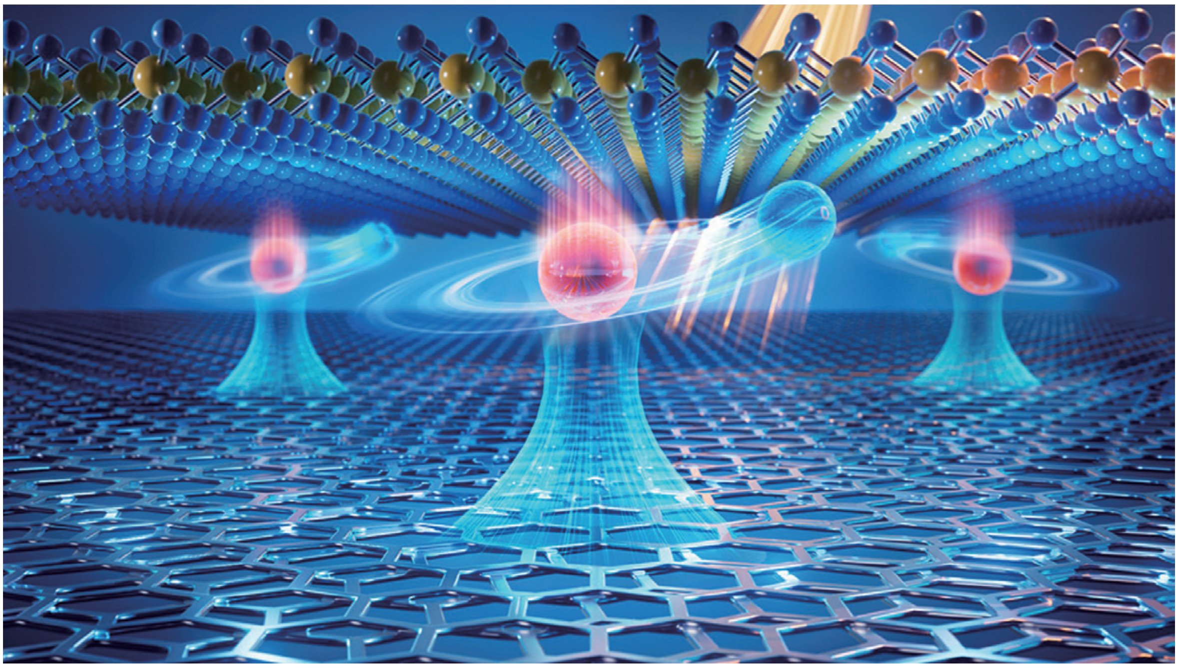

Figure 1: A cartoon showing the Rydberg moiré excitons in the WSe_2/TBG heterostructure.

excitons in monolayer semiconductor WSe_2 adjacent to small-angle twisted bilayer graphene (TBG).

Through low-temperature optical spectroscopy measurements, they first found the Rydberg moiré excitons manifest as multiple energy splittings, pronounced red shift, and narrowed linewidth in the reflectance spectra. By comparing with numerical calculations performed by the group from Wuhan University, they attribute these observations to the spatially varying charge distribution in TBG, which creates a periodic potential landscape (so-called moiré potential) for interacting with the Rydberg excitons. The strong confinement of the Rydberg exciton is achieved through the largely unequal interlayer interactions for the constituent electron and hole of the Rydberg exciton by the spatially accumulated charges centered in the AA-stacked regions of TBG. The Rydberg moiré excitons hence realize electron-hole separation and exhibit the character of long-lived charge-transfer excitons.

They demonstrated a novel method of manipulating Rydberg excitons that can be hardly achieved in bulk semiconductors. The long-wavelength (tens of nm) moiré superlattice here renders an analog to the optical lattices created by a standing-wave laser beam or arrays of optical tweezers for Rydberg atom trapping. The tunable moiré wavelengths, the *in-situ* electrostatic gating, and a longer lifetime ensure great controllability of the system, with a strong light-matter interaction for convenient optical excitation and readout. Their study could bring up new opportunities for the next-step realization of the Rydberg-Rydberg interactions and coherent control of the Rydberg states for further application in quantum information processing and quantum computation.

This study entitled "*Observation of Rydberg moiré excitons*" was published in *Science*.

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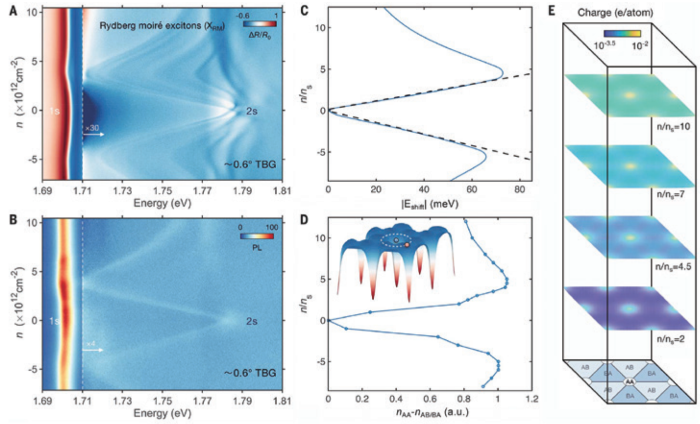

Figure 2: Spectroscopic evidence of the Rydberg moiré exciton formation in WSe_2 adjacent to 0.6° TBG and numerical calculations of the spatial charge distribution in TBG at different doping levels.

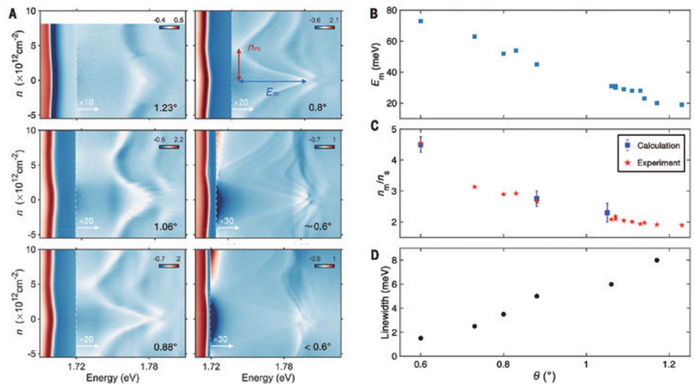

Figure 3: Twist angle dependences and crossover to the strong-coupling regime.

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