

EBSN2019: Electron Beam Spectroscopy for Nanophotonics 2019

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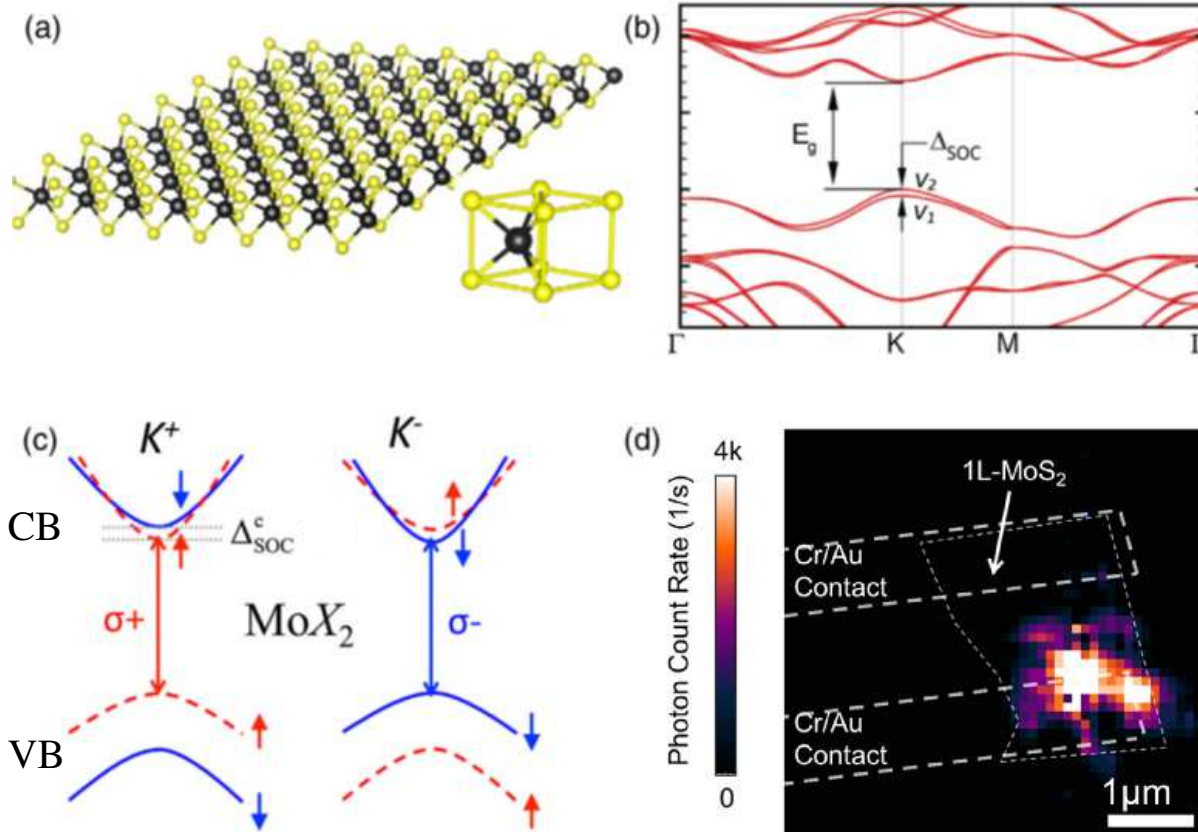
STM-induced excitonic luminescence of a 2D semiconductor

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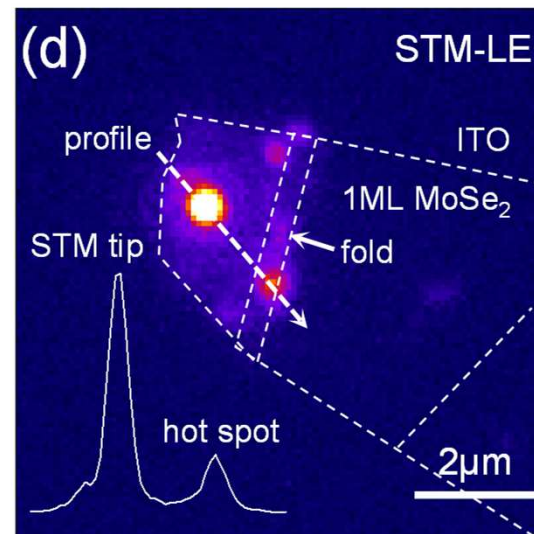
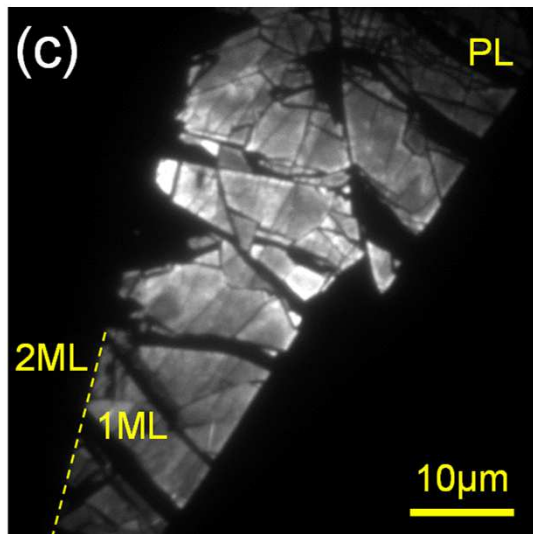
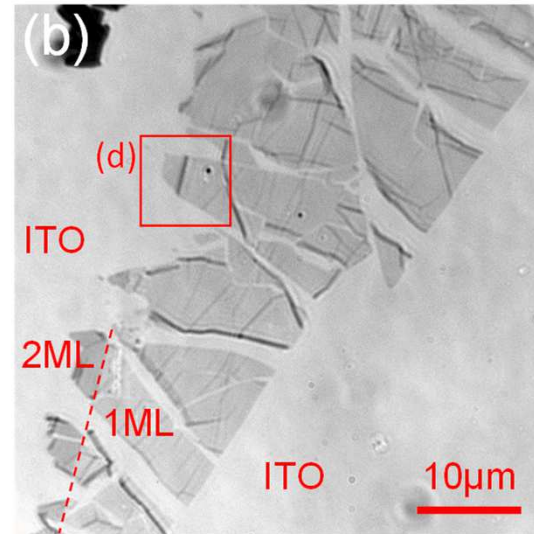
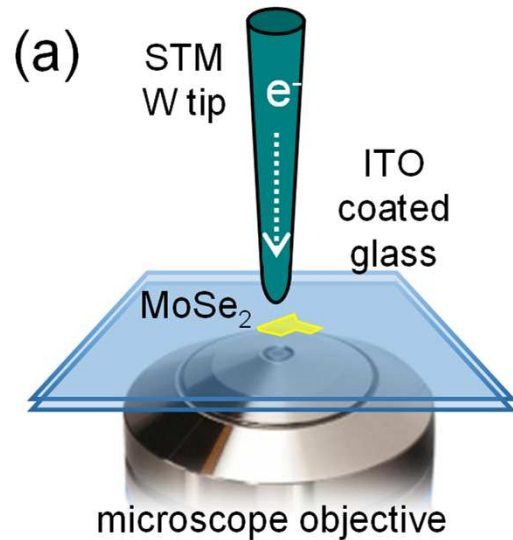
TMD: MX_2
($M = \text{Mo}, \text{W}; X = \text{S}, \text{Se}, \text{Te}$)

Strategic for future optoelectronic devices :

- Strong light-matter interactions
- Direct bandgap at the monolayer limit
- Excitonic effects at room temperature

Understanding TMD's properties requires investigations on the physics of excitons at the nanoscale.

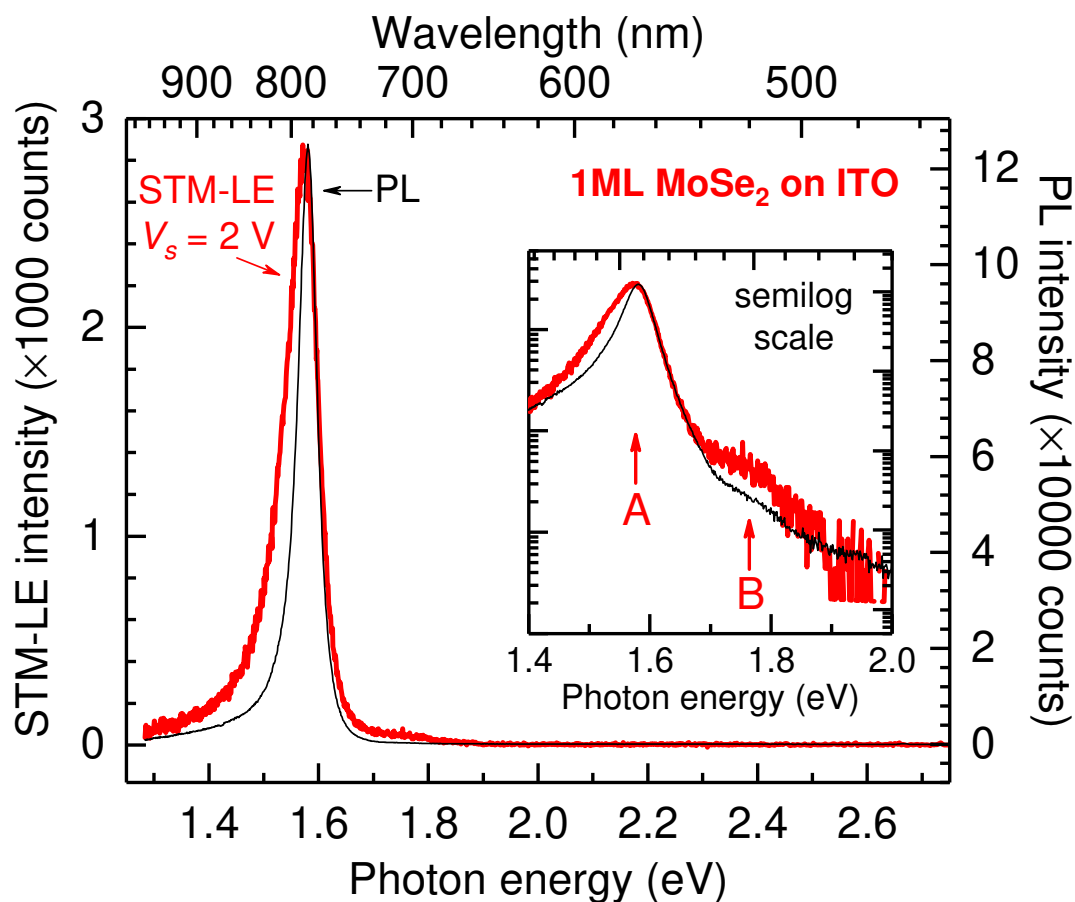
- (a) Ball-and-stick model of TMD monolayers
(b) Typical band structure for MoX_2 monolayers (DFT)
(c) Schematics of the valence and conduction bands in a single-particle picture
(d) Electroluminescence of a single layer MoS_2 field-effect transistor



STM-induced generation of excitons in 2D semiconductors has never been reported, up until now.

Our approach:
monolayer MoSe₂ on ITO/glass,
no surface plasmons within the investigated frequency range,
STM in air + optical microscopy with spatial, angular & spectral resolution.

Excitons in monolayer TMDs at room temperature may diffuse micrometers away from the excitation source before radiatively decaying.

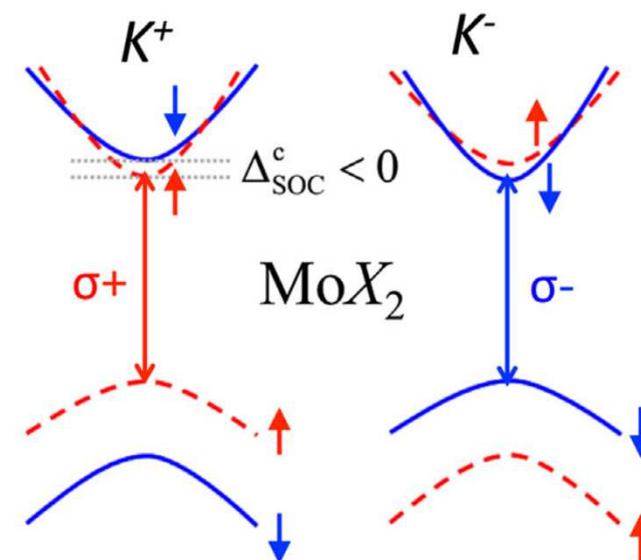


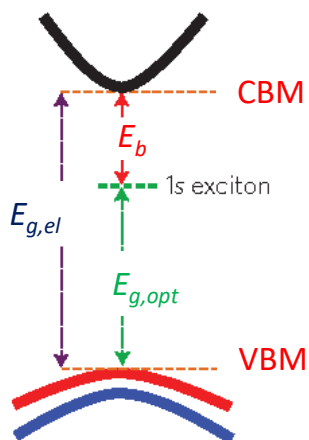
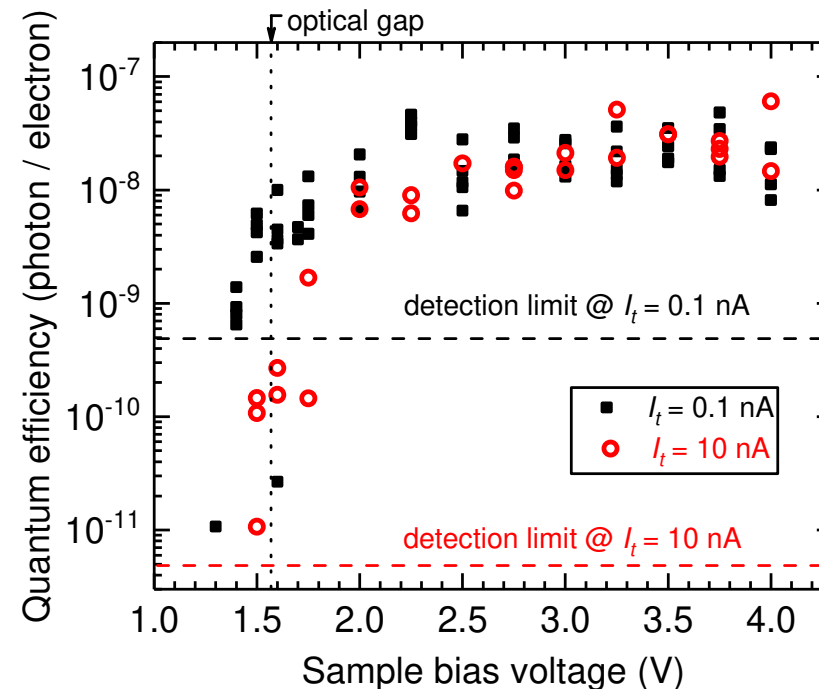
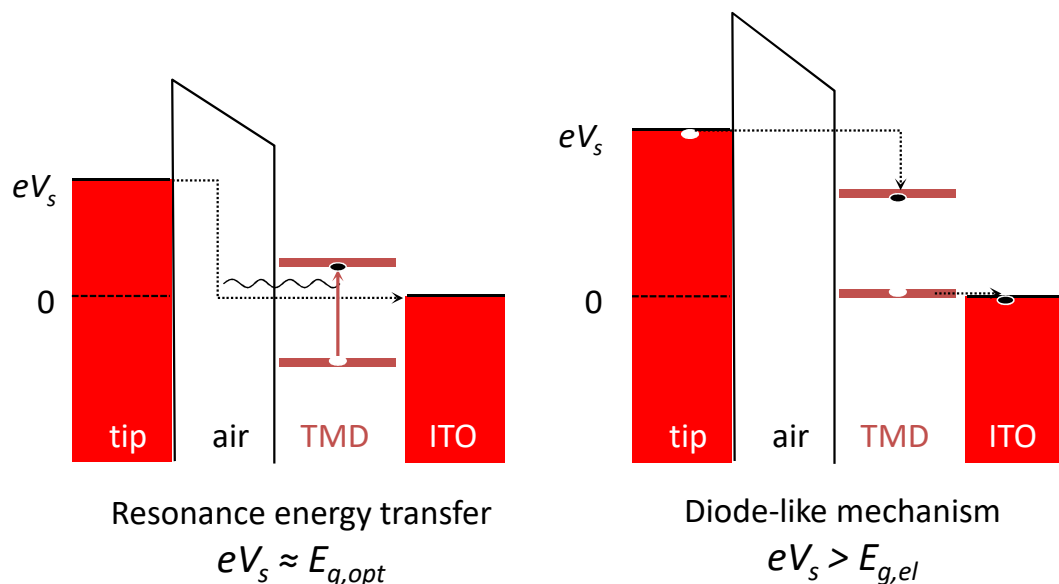
STM-LE spectra match PL spectra

→ same emission mechanism:

radiative decay of A excitons in MoSe₂
(+ hot emission from B excitons).

This rules out other emission mechanisms
(black-body radiation, radiative electronic transitions between tip and surface states)

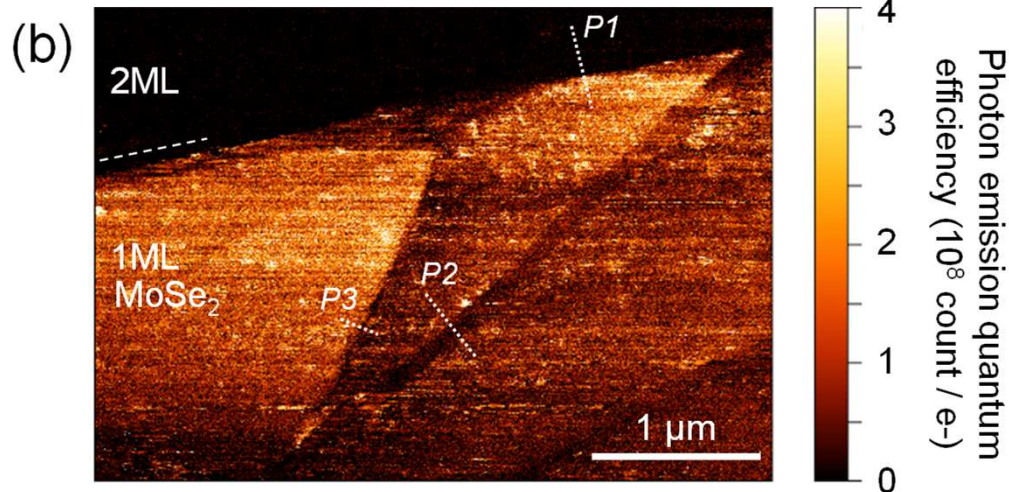
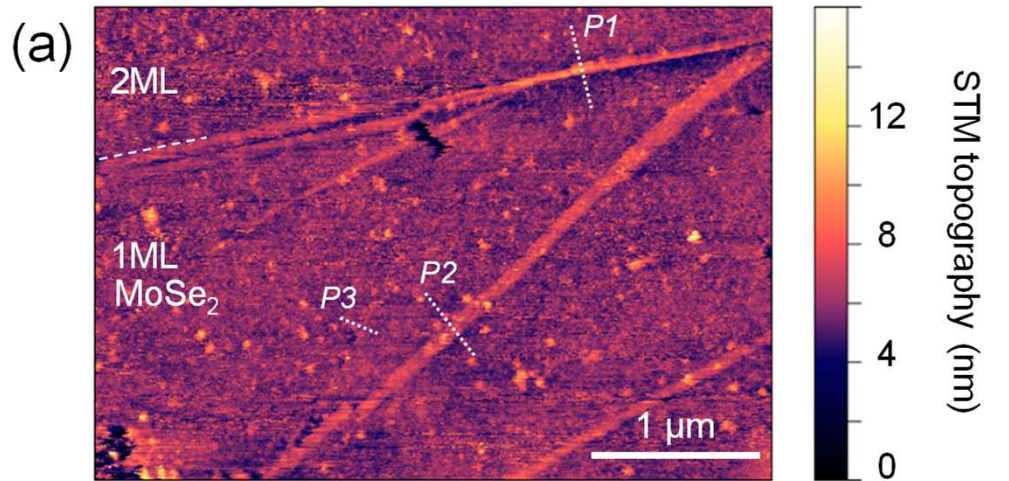




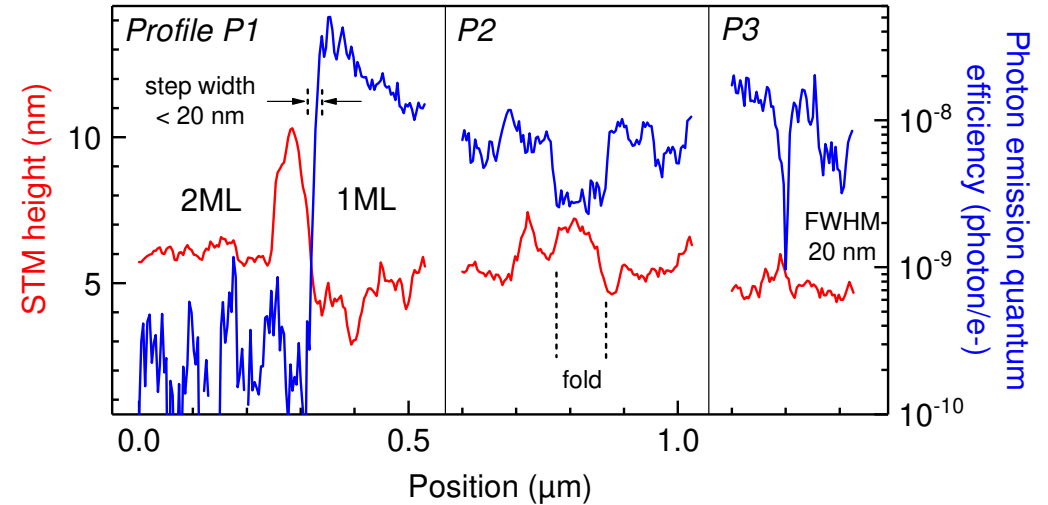
STM-LE onset is at electron energies (eV_s) as low as the *optical* bandgap of MoSe₂. → *Resonance energy transfer* (RET) from the tunneling current to the excitons in the semiconductor.

Differs from the diode-like mechanism (charge injection), which requires an energy level arrangement that does not occur at electron energies lower than the *electronic* bandgap.

STM topography



Photon map



STM-LE reveals geometrical features of the sample with deep subwavelength lateral resolution, which is not attainable in standard optical microscopy.

We report the observation of STM-induced excitonic luminescence from a 2D semiconductor.

Our approach, based on the absence of coupling to a plasmonic tip or nanocavity, makes it possible to probe locally the “native” excitonic properties of a 2D semiconductor.

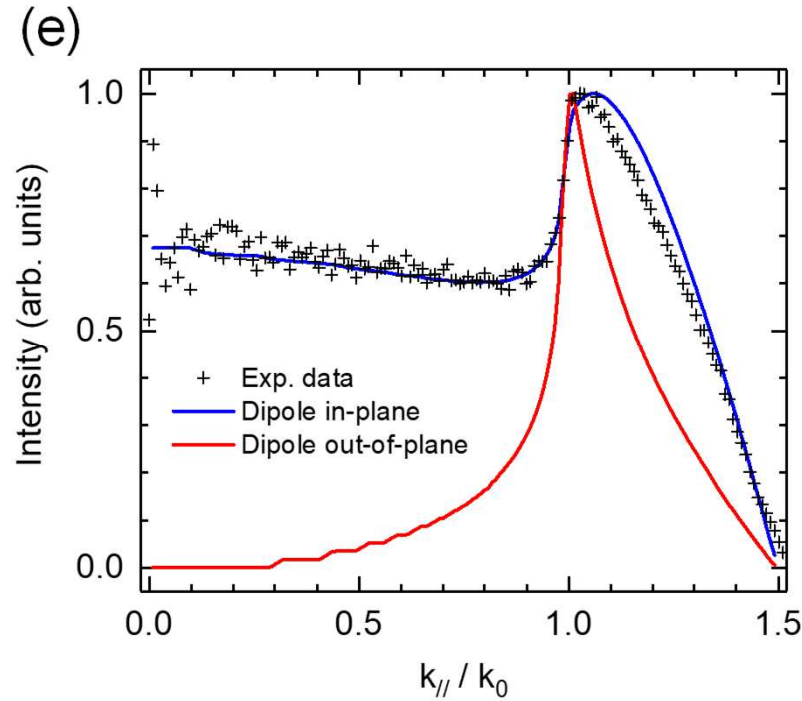
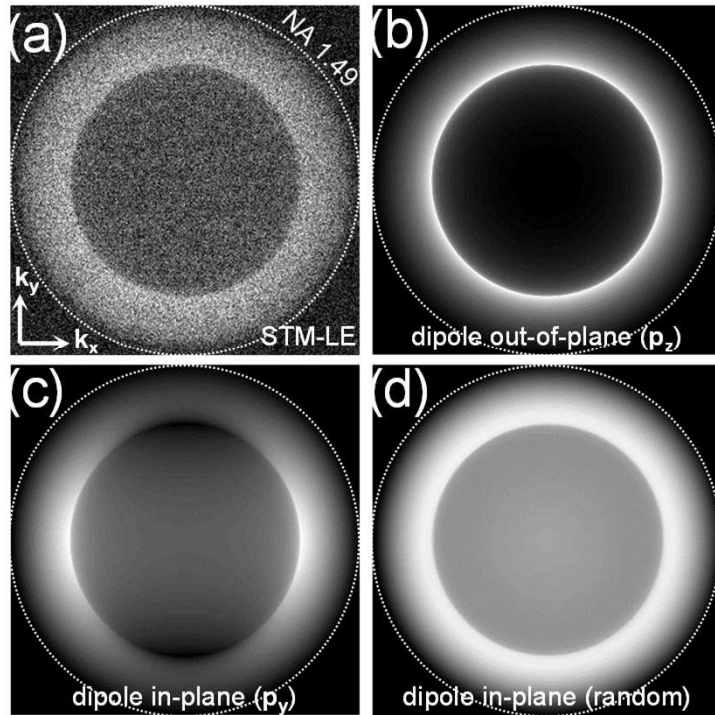
The excited excitons may diffuse over micrometers from the STM tip before radiatively decaying; however, the exciton creation process itself is highly localized, which yields a lateral resolution on the order of 10 to 20 nm in photon maps.

Our results open up broad prospects for investigating the excitonic dynamics and the optoelectronic properties of 2D semiconductors at the nanoscale, which is a key to the development of all technologies based on 2D materials.

Thank you for your attention!



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- (a) Fourier-space optical image of the STM-LE measured on monolayer MoSe_2 .
 (b-d) Theoretical emission patterns in Fourier-space, calculated for an oscillating point-like electric dipole on an air-glass interface.

The dominant emission process is the radiative decay of *bright* (spin-allowed) A excitons, which have their transition dipole moment in the plane of the monolayer.