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WHAT STARTS HERE CHANGES THE WORLD

Enhancement Due to Photonic Coupling in Nanocavity Structures

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Outline and Key Concepts

Quantum emitters

(plasmonic) cavities

Transition Metal Dichalcogenide

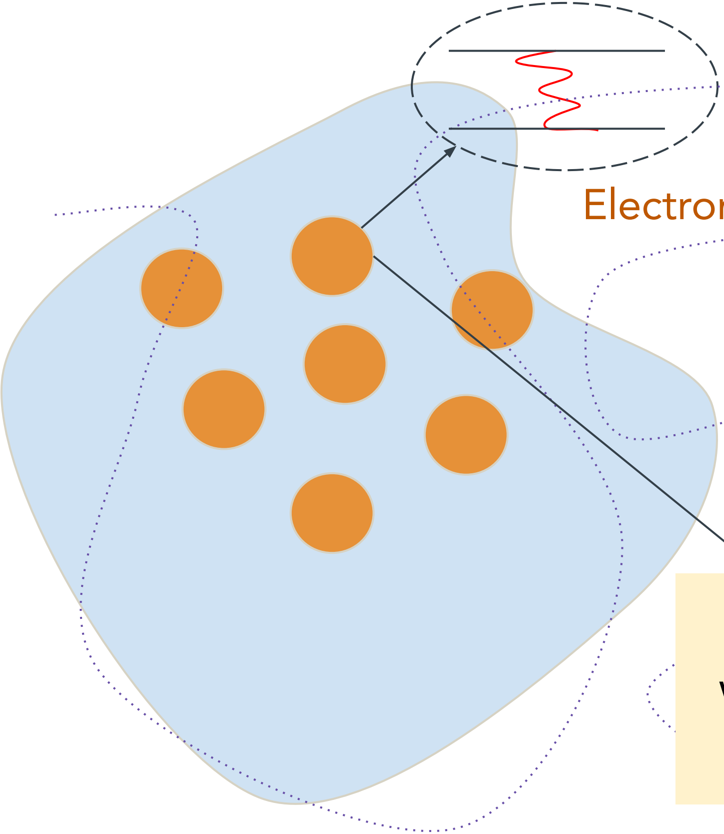
nanocubes

Our Sample

Dark-field spectroscopy

Photoluminescence

How do quantum emitters work?



2-level Quantum emitter

Electromagnetic environment

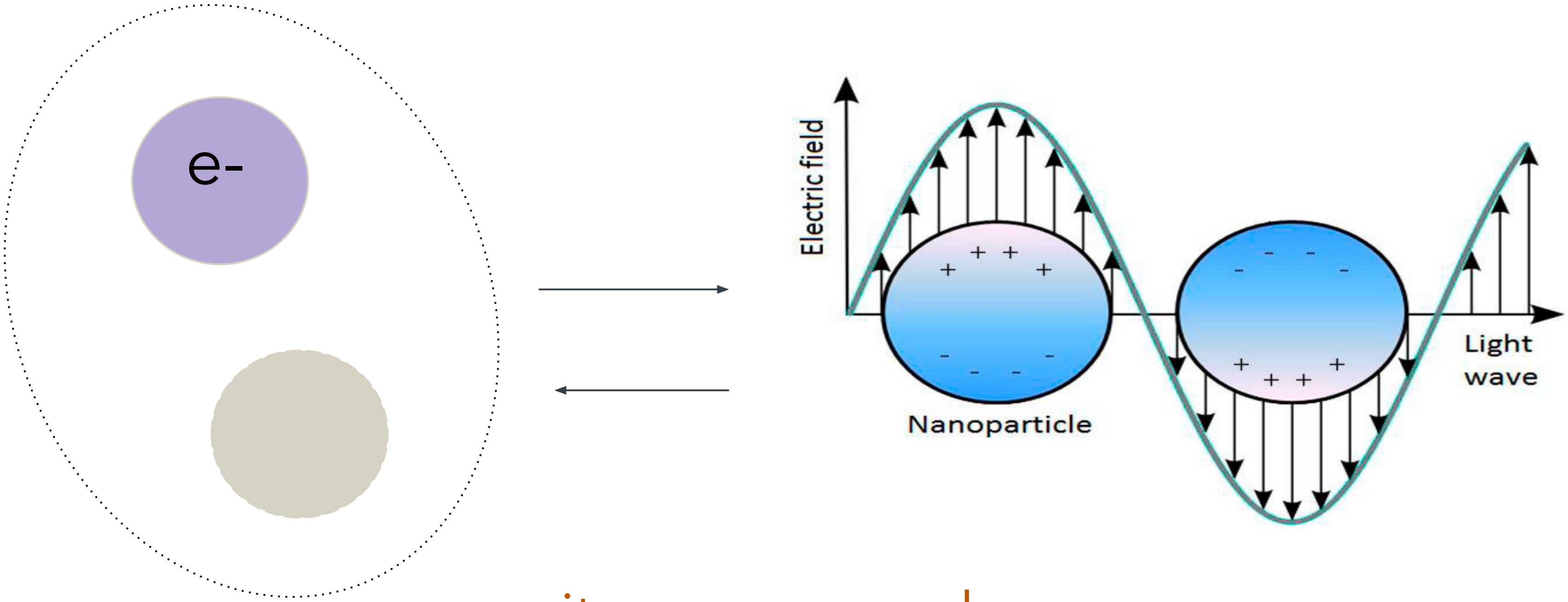
Optical properties!

Spontaneous photon emission!

How can we alter this environment to favorably influence the decay rate of the system?

multiple 2-level systems with differing polarization or wavelength

Why can a nanoscale quantum emitter can have emitting behavior?



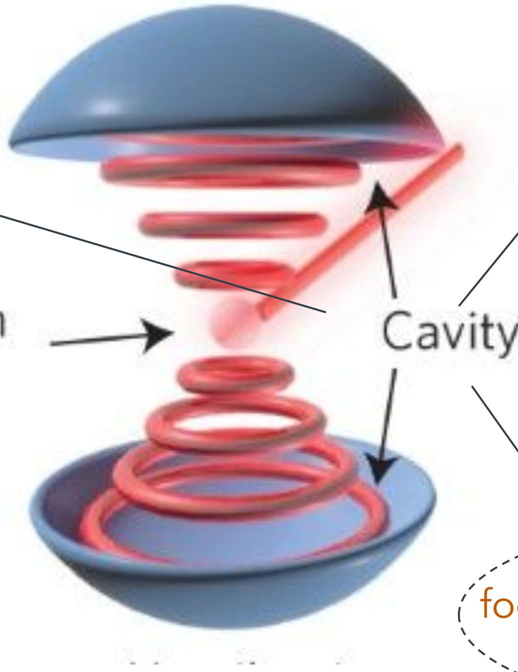
exciton plasmon

What is the interplay between quantum emitters and cavities?

coupled resonantly
exchange photons

enhanced photon
emissions into free space

Quantum
emitter



Cavity

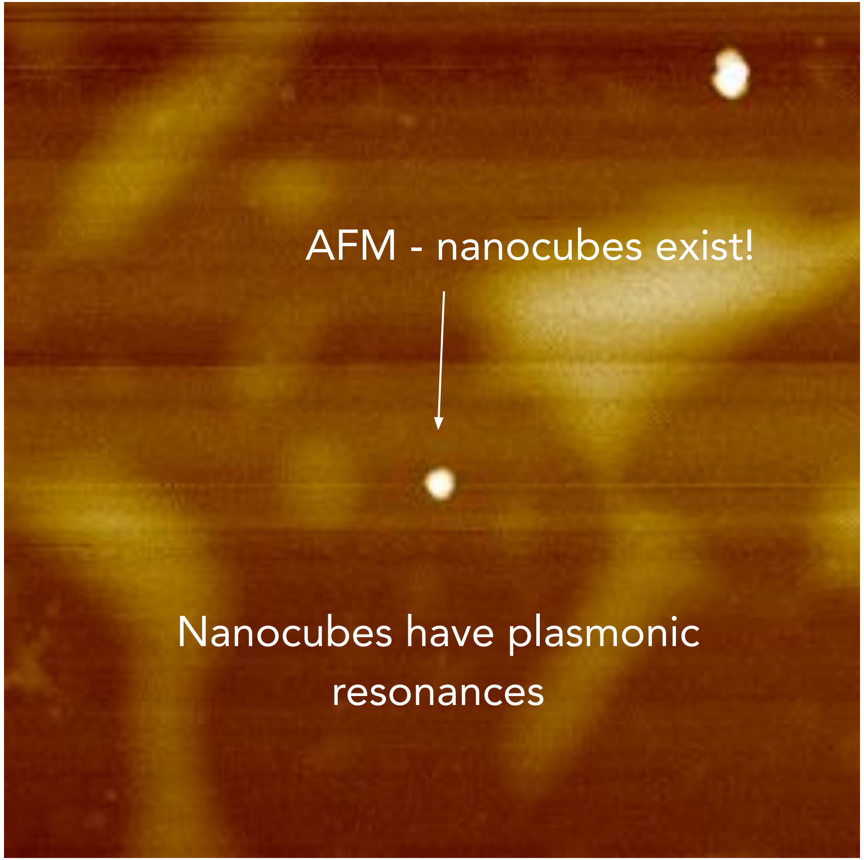
contains plasmonic
resonances

emits into the plasmonic
cavity

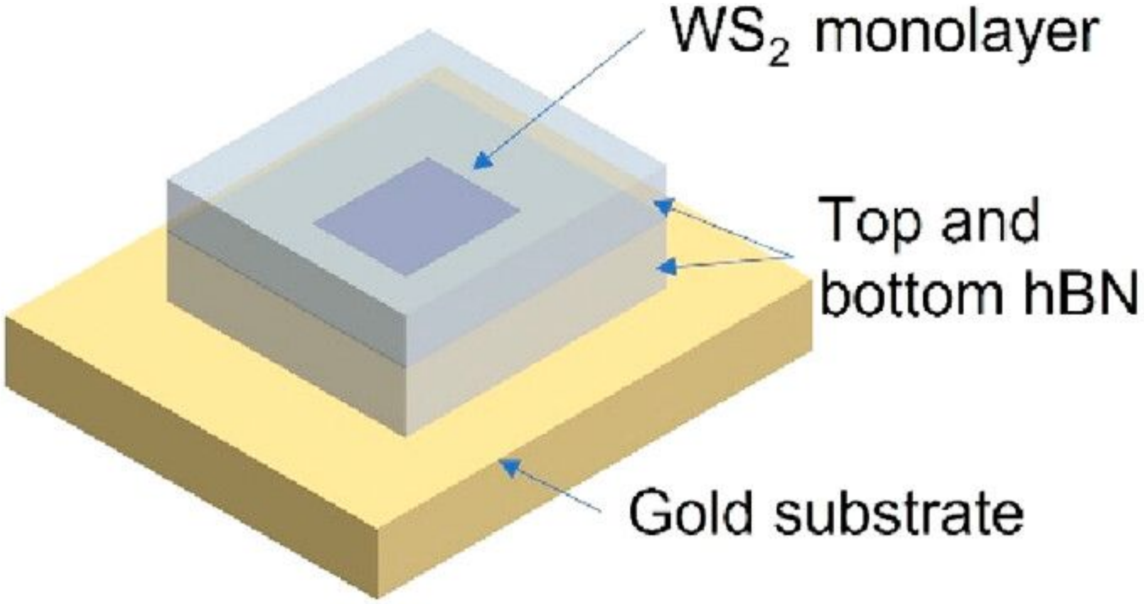
focuses the emission fields into a
mode volume

Nanocube

- shorten the lifetime of exciton emission via plasmonic nanostructures (nanocubes)



TMD - Transition Metal Dichalcogenide



Exciton resonances!

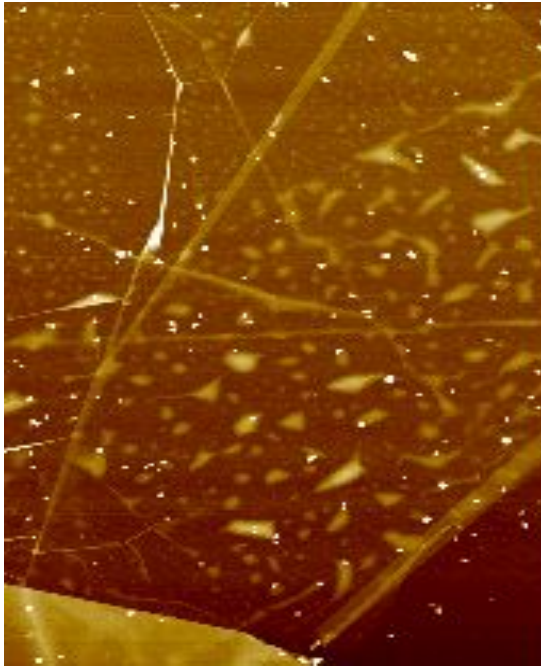
What are the effects of weak coupling between plasmonic nanocavities and excitons?

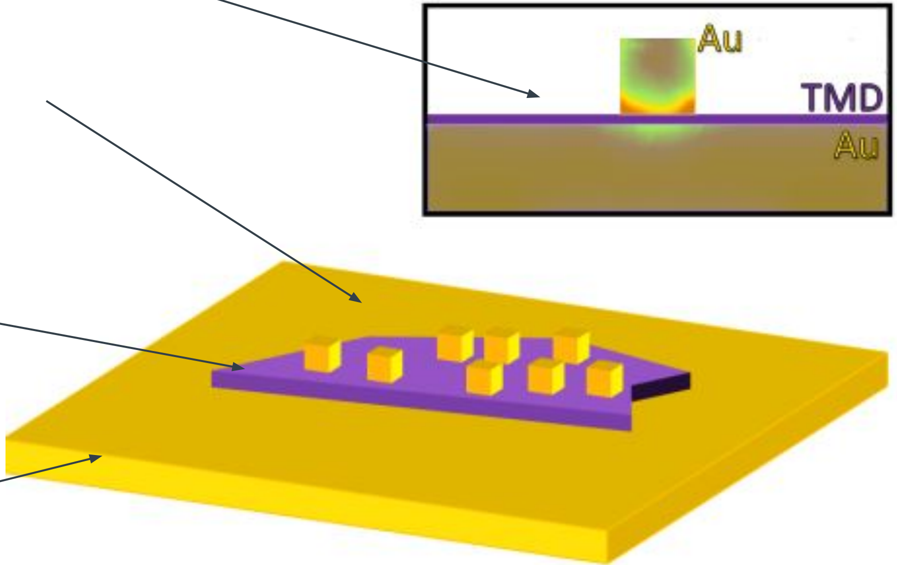
How does plasmon-exciton coupling effect emission enhancement?

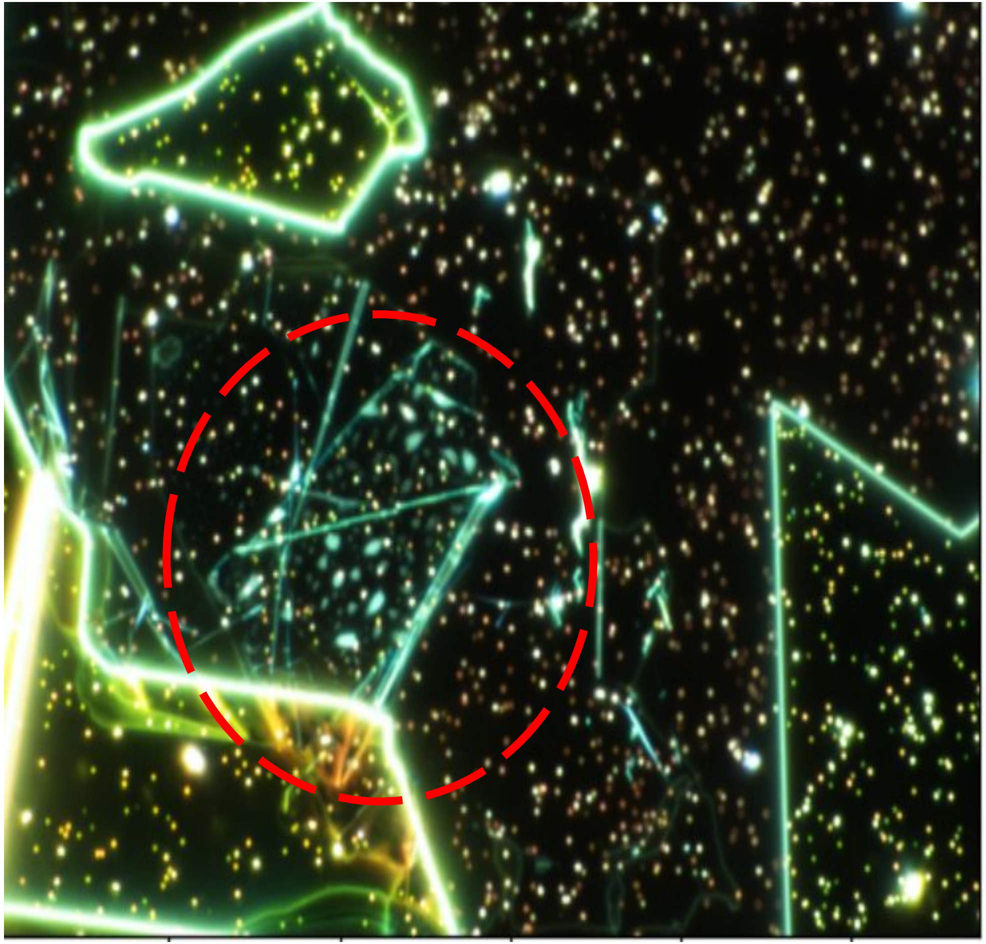
The Sample

Material: *Monolayer TMD*

Film-Cube *Separation: 8-9 nm*

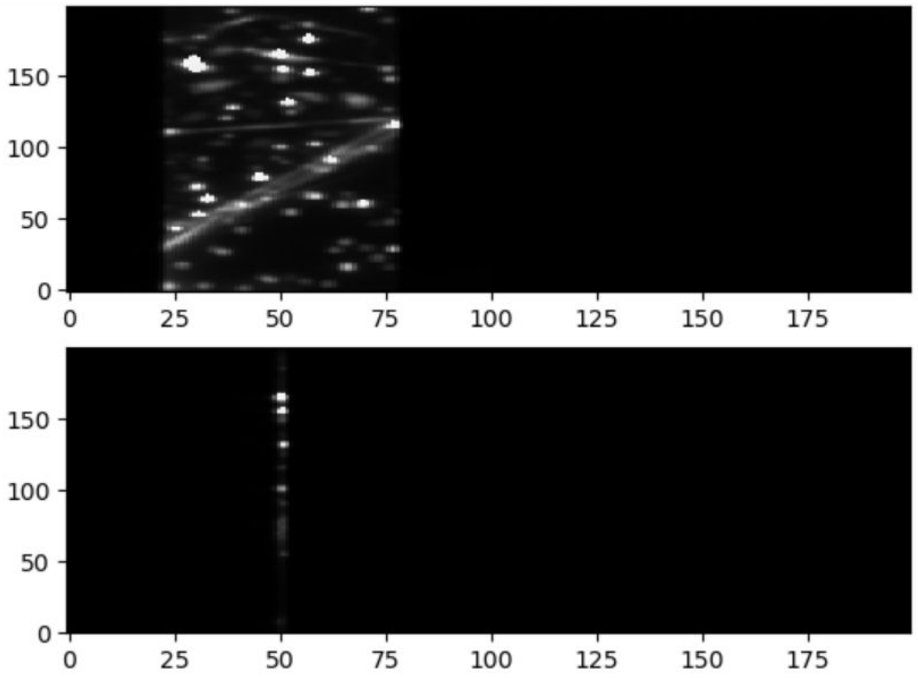






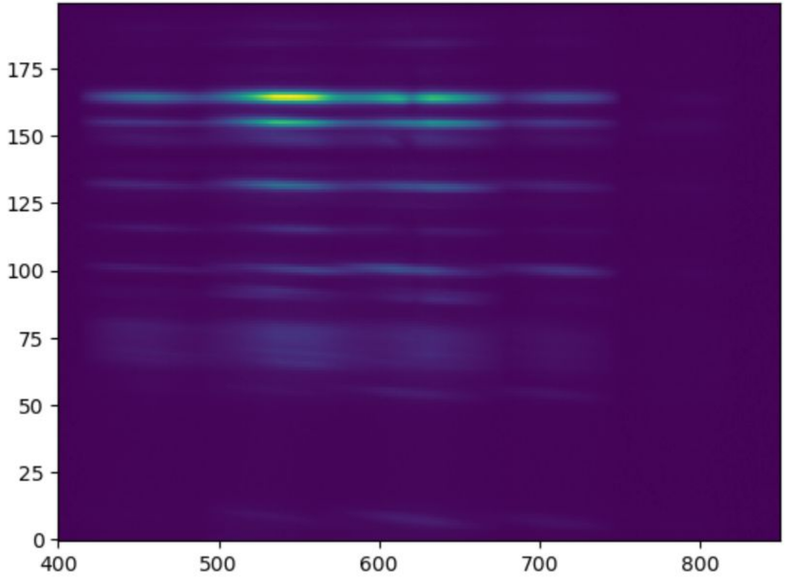
Dark-field Spectroscopy

- white light scattering by nanocavities
- measure plasmonic resonances



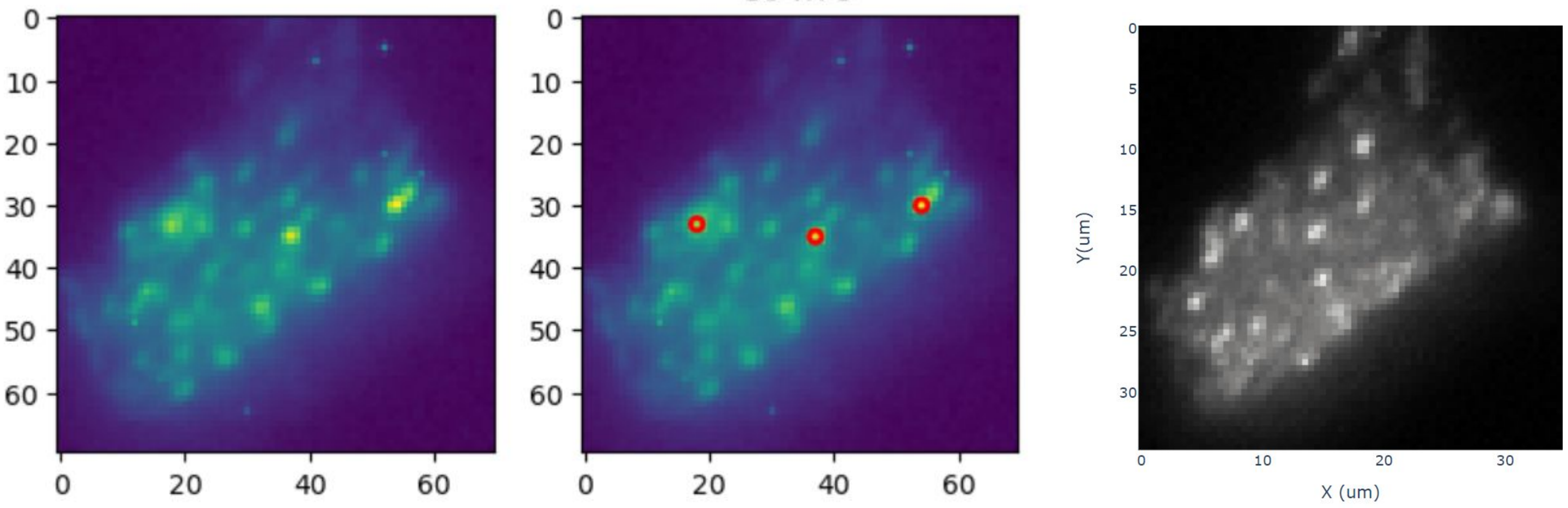
Focusing on a single nanocube point

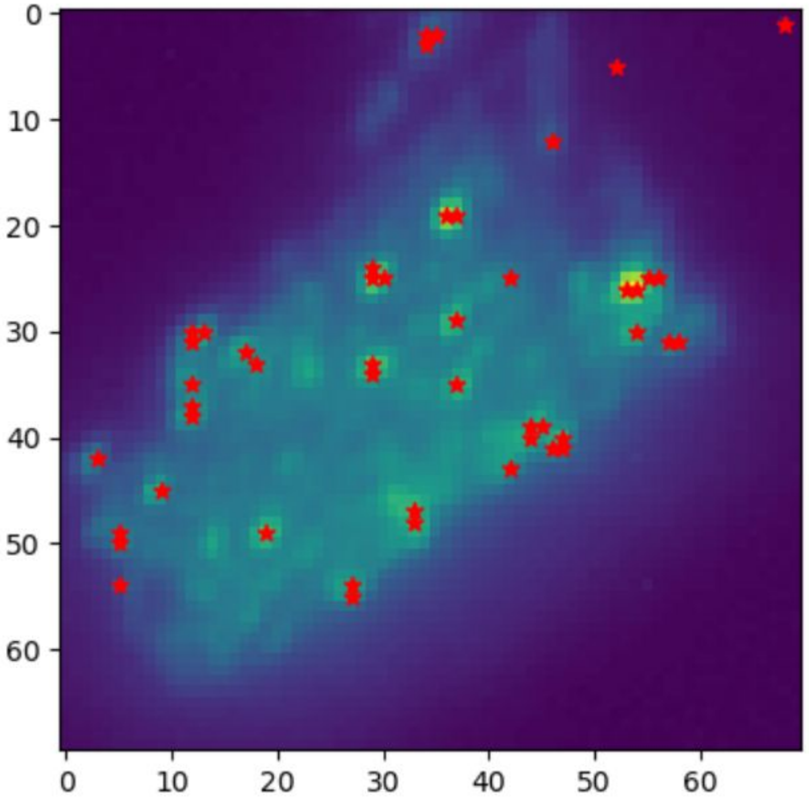
Emission spectrum of a nanocube

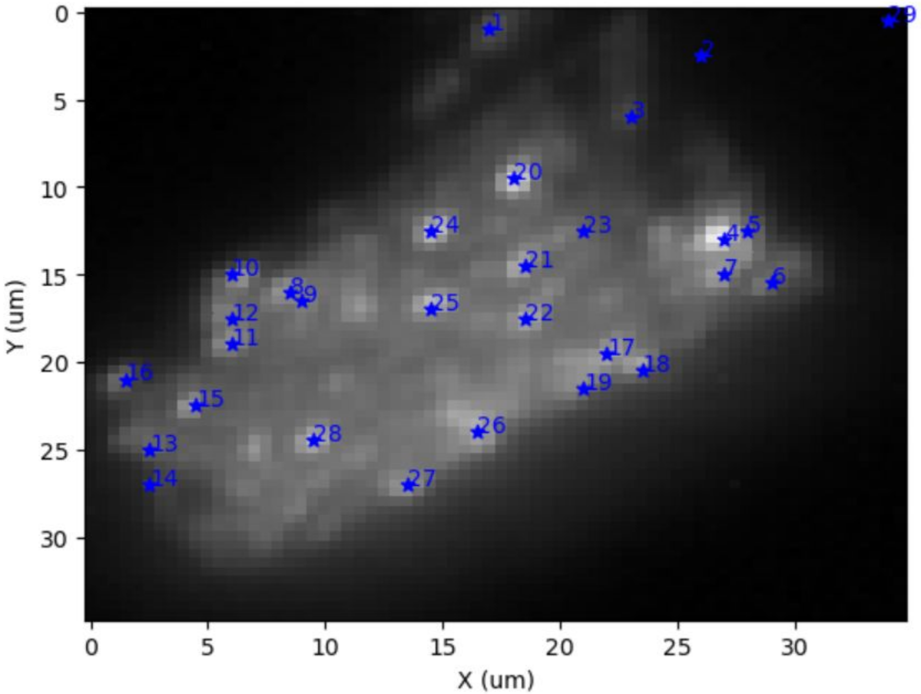


Hyperspectral Spatial Image

- well localized points with nanocubes
- intensity coming out of these points is enhanced

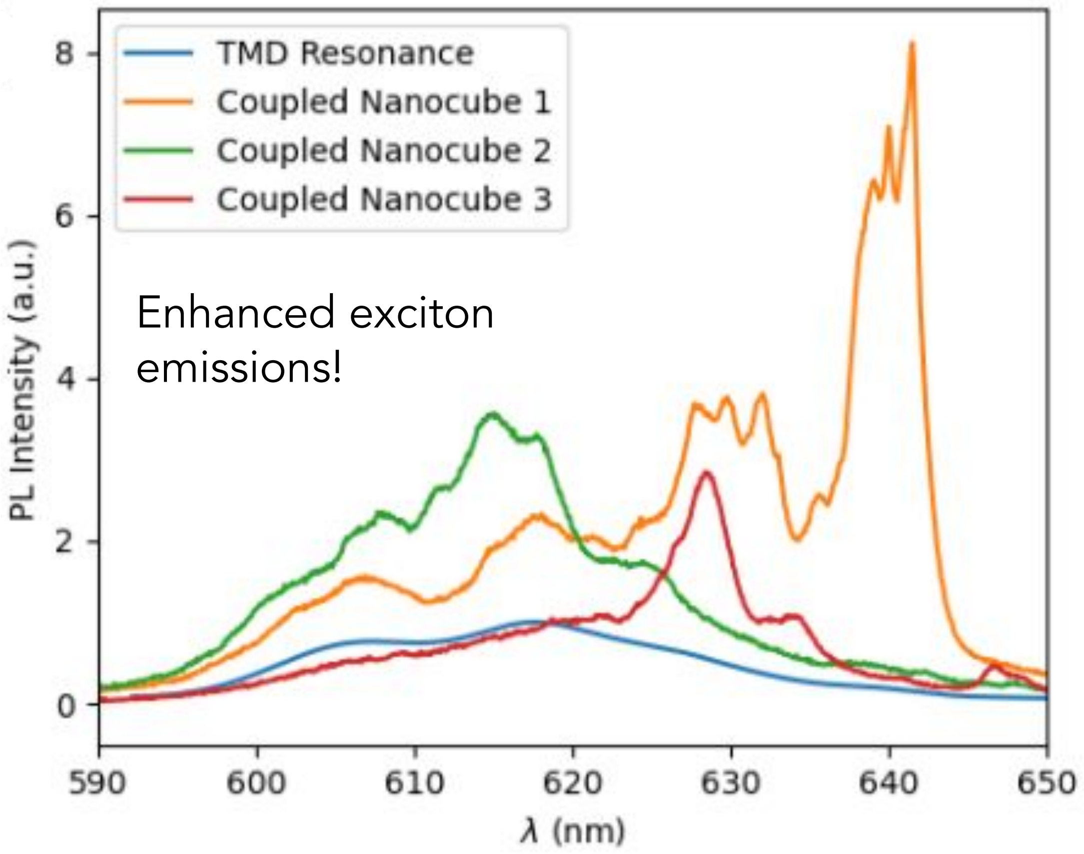





Y (um)
X (um)

Photoluminescence (PL)

- excite sample at different wavelengths
- measure exciton resonances
- longer wavelengths enhanced
- greater, non-uniform intensity enhancement along nanocubes
- overlap between the wavelengths where plasmonic resonances and enhancement occur



Future Applications

- insight to optical properties of quantum emitters
- manipulate emitters by altering their EM environment
- enhance previously weak emissions
- nanophotonic devices
- manipulating light-matter interaction at the nanoscale

Acknowledgements

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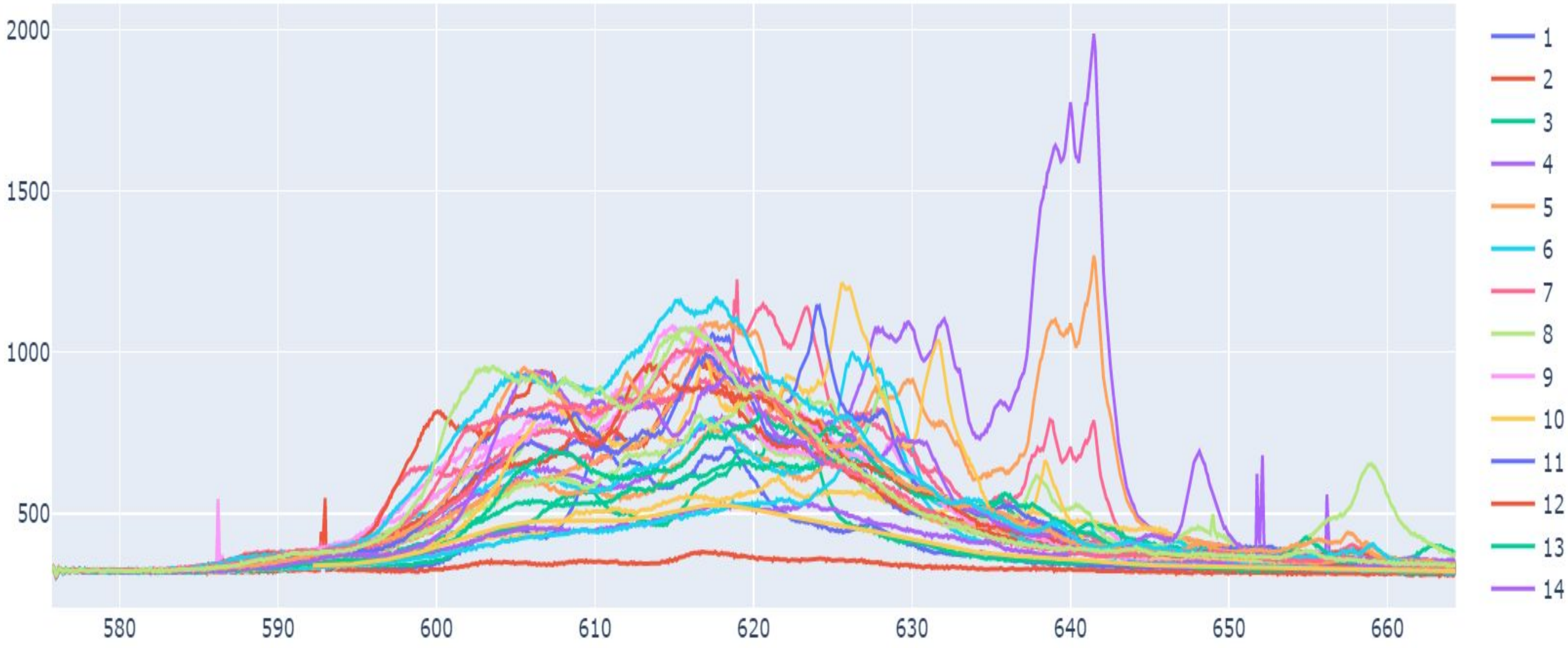
HIDDEN SLIDES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Coupling parameters:

- emitter's decay in free space $\Gamma _0$\\
- cavity's loss rate κ\\
- emitter-cavity coupling coefficient g\\

This is dependent on the overlap of the photonic cavity and the resonances of the 2-level system. Due to the interplay between the photonic cavity and the system, we are able to enhance some processes at the expense of others. For instance, if the resonances of the plasmonic cavity are vertical, they selectively enhance dipole emitters with a vertical dipole. Not only are we increasing the lifetime, but we are also altering our characterization and probability of the emission.

Cavities can impact emitters in a few ways:

- decay rate enhancement --- The weak coupling of a 2-level emitter to a cavity leads to the modification of the spontaneous emission rate. The emitter can have multiple radiative modes and some nonradiative processes
- emission redirection --- the intrinsic radiation pattern of a quantum emitter is omnidirectional, making it hard to collect emitted photons. Cavities can redirect the emission to the desired optical mode with an efficiency $\eta _{NA}$. Different modes can have different efficiencies.
- absorption enhancement --- cavities alter the absorption cross-section of the emitter which causes absorption enhancement and lowers the saturation power needed from the pump laser.

Weak Coupling Regime

We are concerned with the weak coupling regime $g < \kappa$, $\Gamma _0$. Here, the photon is released by an excited emitter due to spontaneous emission and lost to far-field radiation modes leaving the cavity in a vacuum state. In this case, the cavity becomes the system's environment and results in a modified decay rate $\Gamma = F \Gamma _0$ where $F = \frac{3}{4\pi ^2} Q \frac{\lambda ^3}{V}$ (Purcell factor - represents the shortening of lifetimes; losses ensure that it is not directly related to the number of emitted photons), $Q \approx \frac{1}{\kappa}$ (cavity quality factor), and the cavity mode volume $\frac{V}{\lambda ^3}$. The advantage of the weak coupling regime is that for emitted photons, the probability that they will be reabsorbed by the emitter is low compared to the likelihood of the photon escaping the cavity.

Methods

- Use AFM to confirm nanocubes
- Pick nanocube points of interest
- Map their plasmonic resonances using dark-field spectroscopy
- Use PL to graph enhancement due to exciton emission

Does an overlap between the plasmonic resonances and exciton excitation exist?