# Strong plasmon-Wannier Mott exciton interaction with colloidal quantum wells, a potential platform for ideal single photon sources


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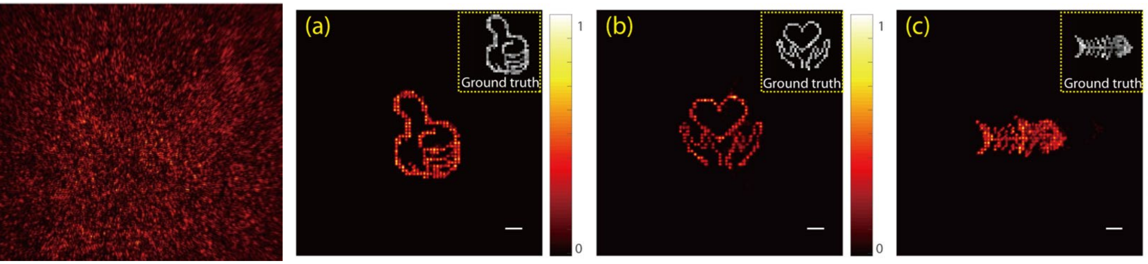
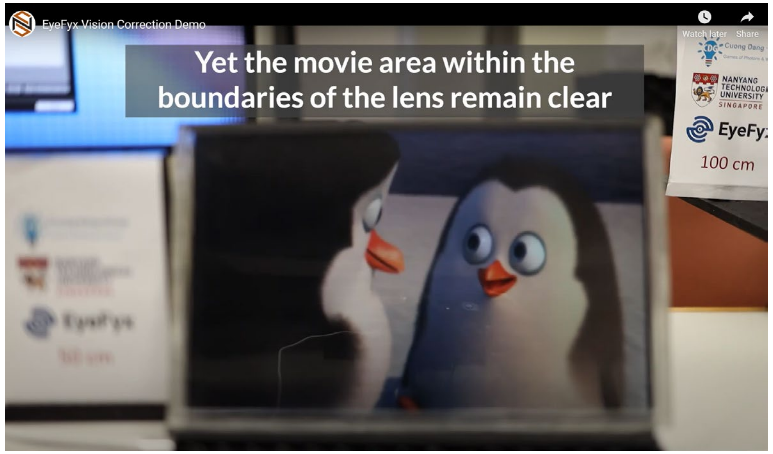
*21st Rencontres du Vietnam*

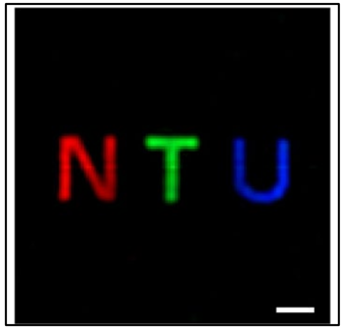
*ICISE, Quy Nhon, Vietnam*

*09 – Oct – 2025*

# Computational Imaging & Displays

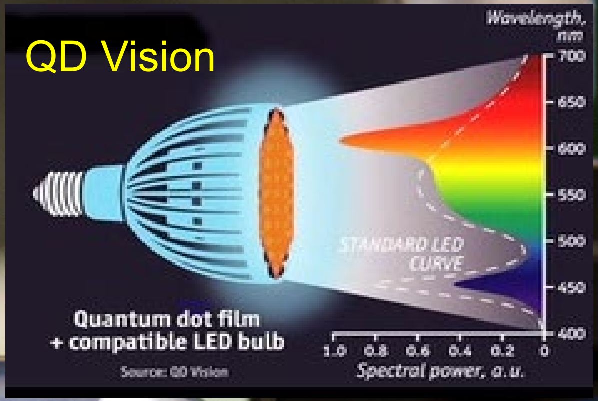



arXiv:2505.01090 (2025)
Laser & Photonics Reviews, 2300712 (2024)
Nature Communications 12, 3150 (2021)
Optica 4 (10), 1209-1213, (2017)
Applied Optics 57 (26), 7533-7538, (2018)
Optics Express 27 (26), 37164-37171, (2019)

# Colloidal Nanomaterials & their OptoElectronic Devices





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**'Best in Show'**

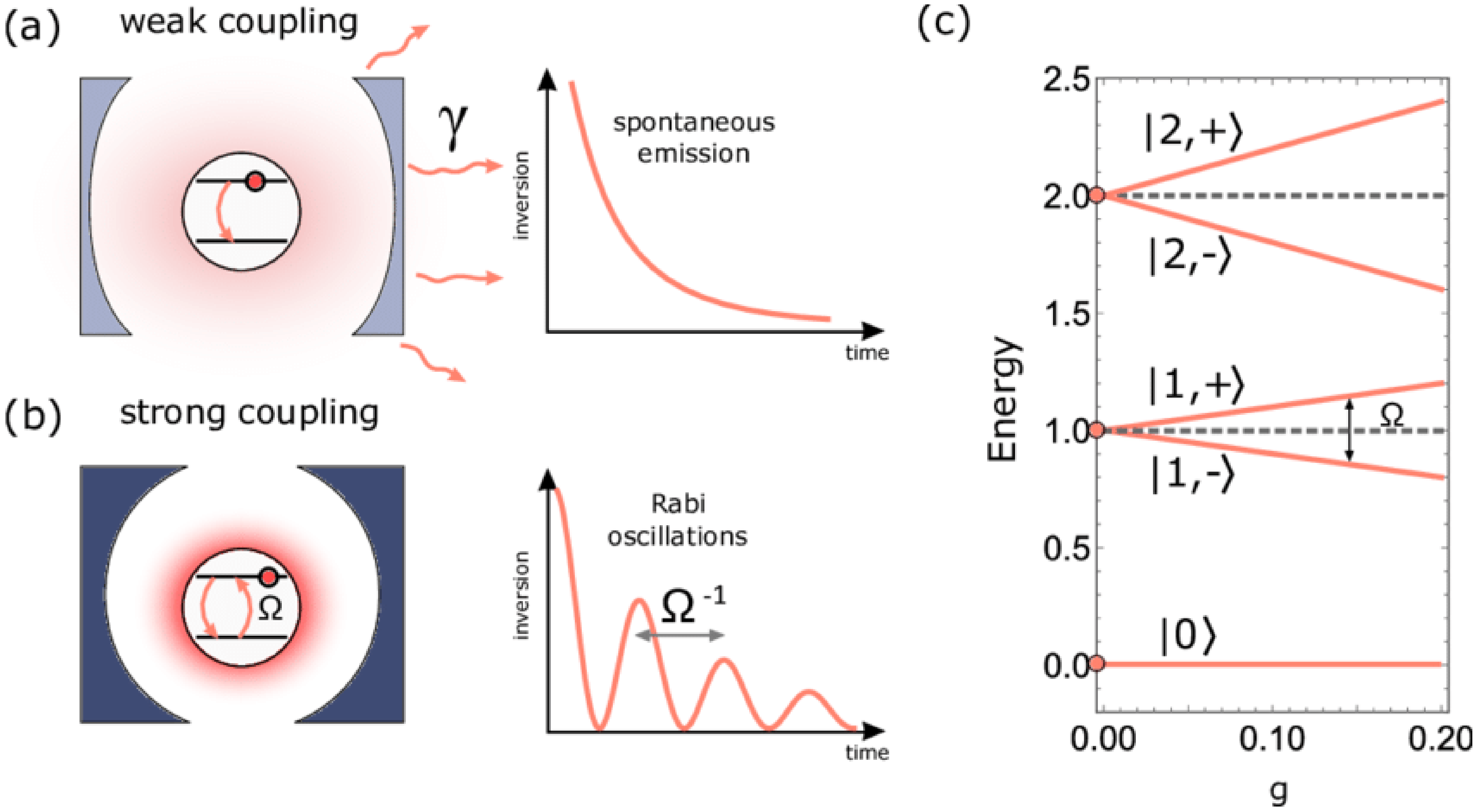
**'Best Home Theatre Product'**

Advanced Materials 37 (13), 2412738 (2025)
Nano Lett. 24, 50, 16064–16071 (2024)
ACS Photonics 10 (5), 1250-1258 (2023)
Laser & Photonics Reviews, 15, 2100034, (2021)
Light: Science & Applications 9 (1), 1-8, (2020)
Science Advances 5 (10), eaav3140 (2019)
Applied Physics Letters 103 (17), 171104, (2013)
Nature Nanotechnology 7 (5), 335-339, (2012)

# Exciton-Photon Coupling

Light-Matter interaction

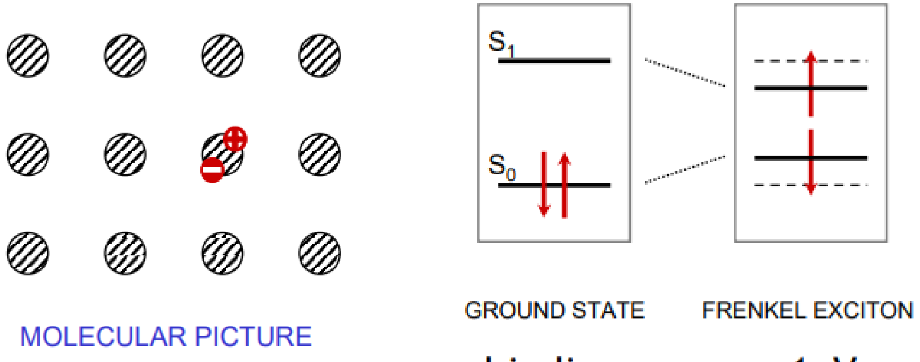
$\vec{\mu}_0^* \cdot \vec{E}_s(\vec{r}_0)$



# Frenkel vs. Wannier-Mott Exciton

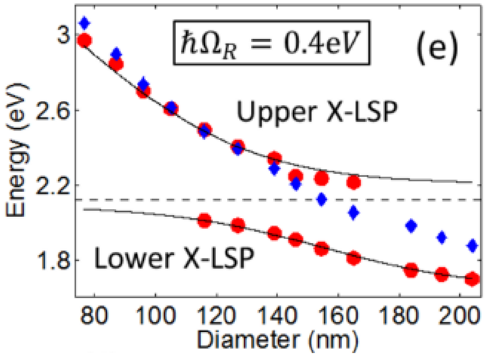


## Organic materials: Frenkel exciton



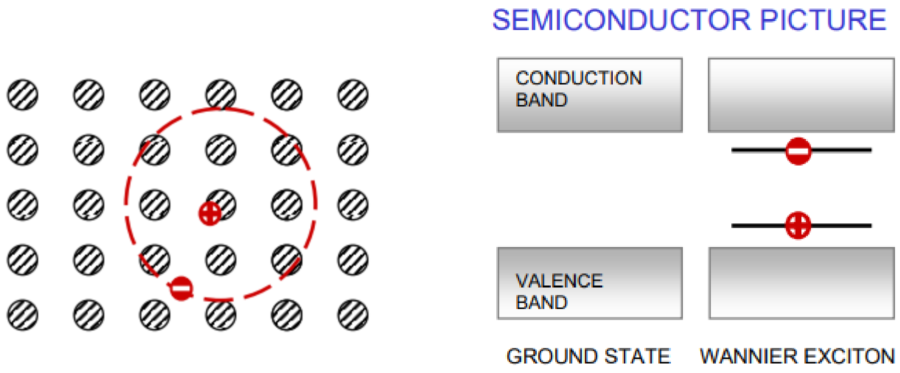

binding energy ~1eV
radius ~10Å

Strong Oscillation Strength

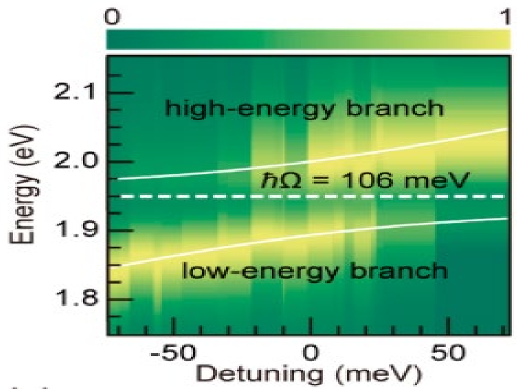



Easy to achieve ultrastrong coupling

## Inorganic materials: Wannier-Mott exciton



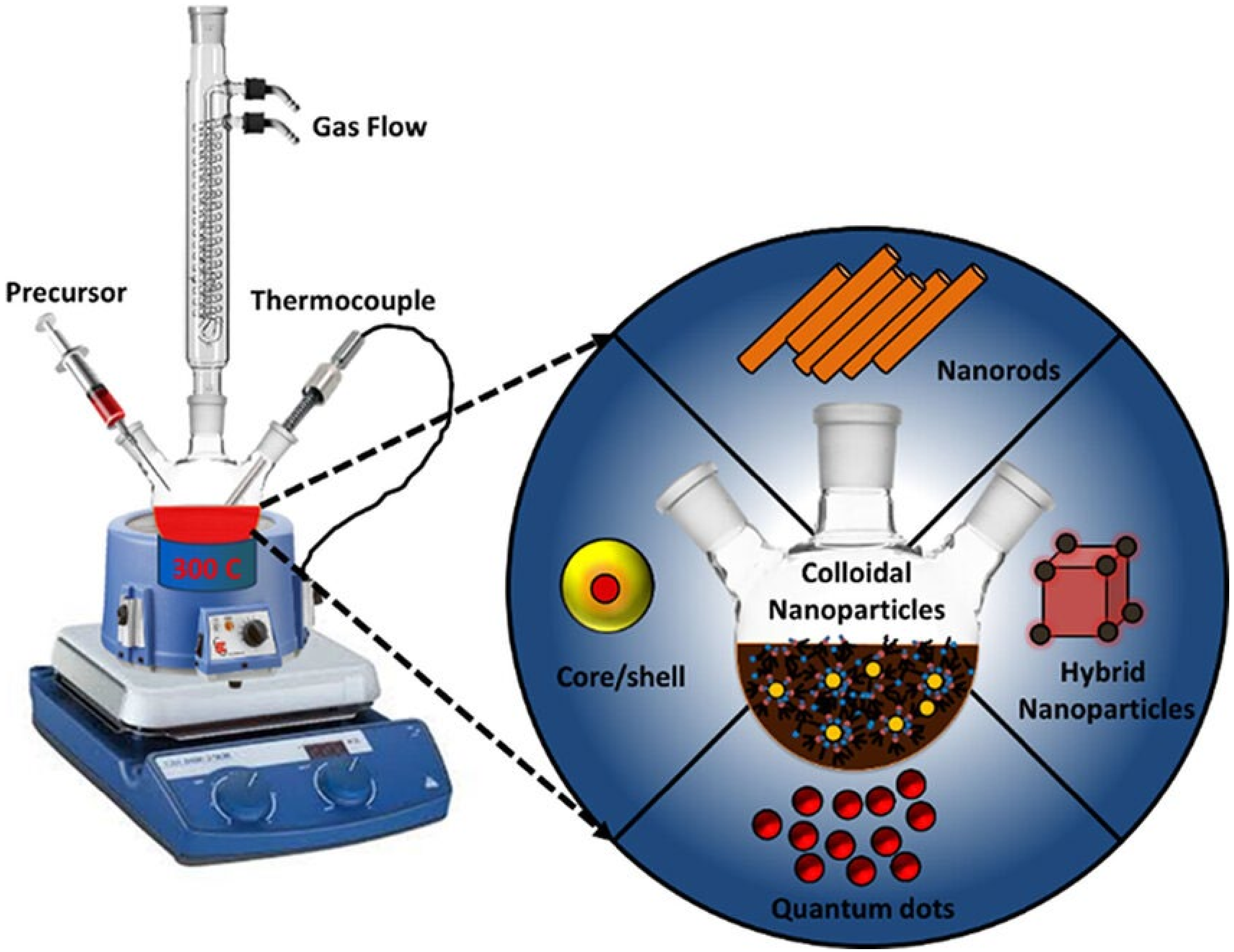

binding energy ~10meV
radius ~100Å




Moderate Oscillation Strength

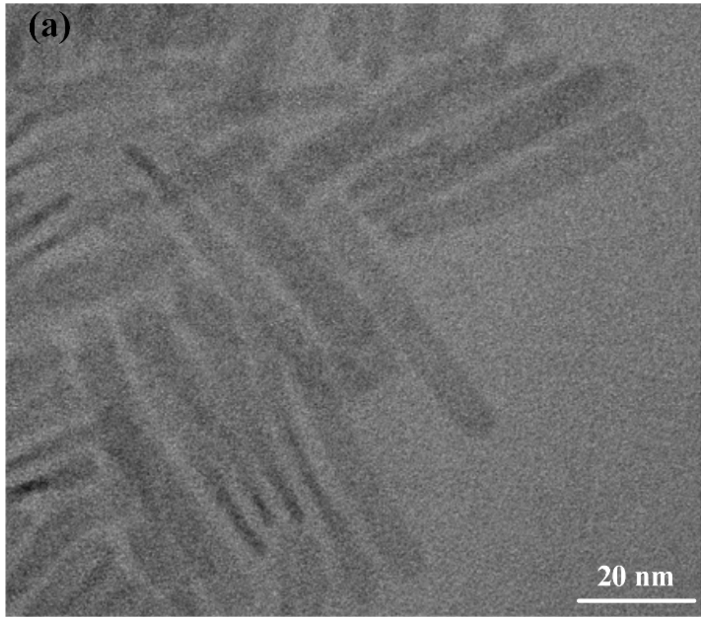
Hard to achieve ultrastrong coupling

# Colloidal Nanoplatelets

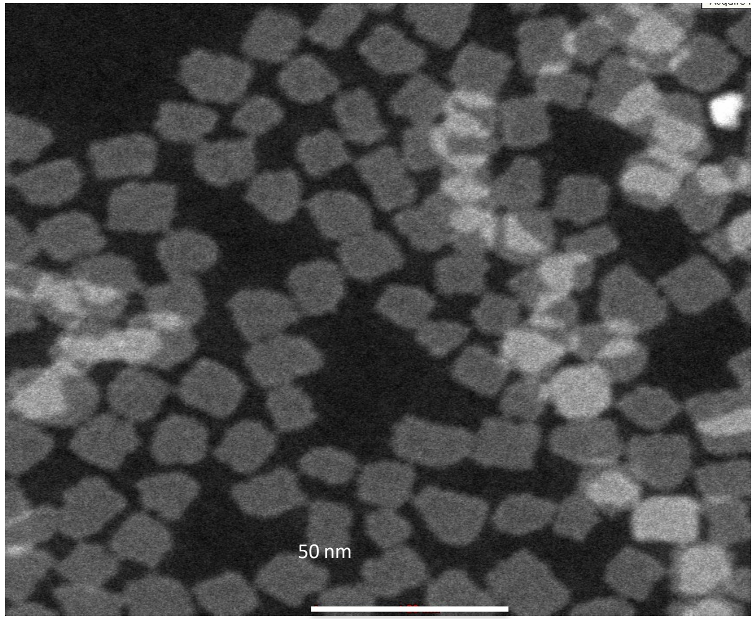


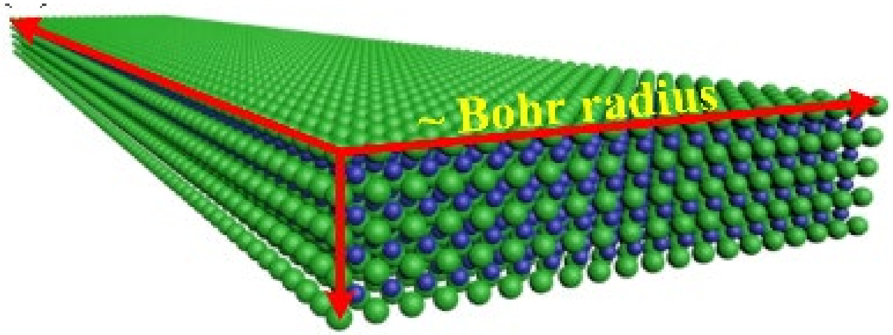

# Colloidal Nanoplatelets

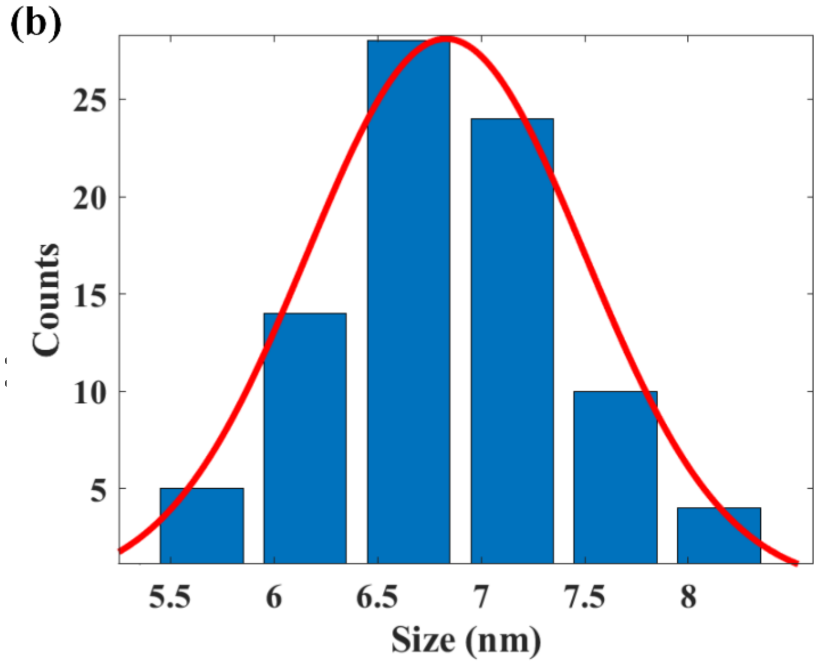
High Aspect Ratio




Low Aspect Ratio




- They are colloidal quantum wells (Quasi-2D semiconductor): thickness: 1.2nm
- Controllable aspect ratio
- Well-resolved excitonic feature: emission linewidth ~40 meV

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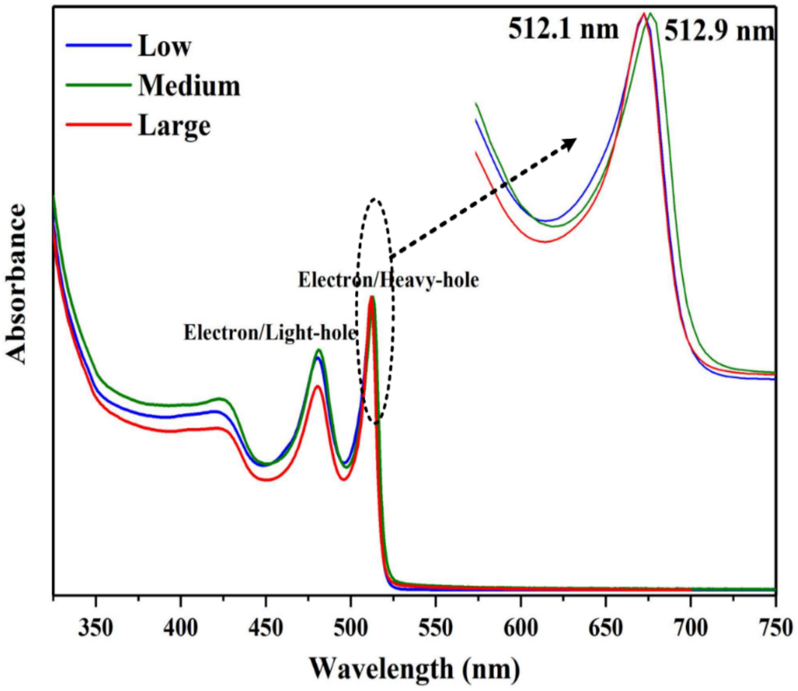
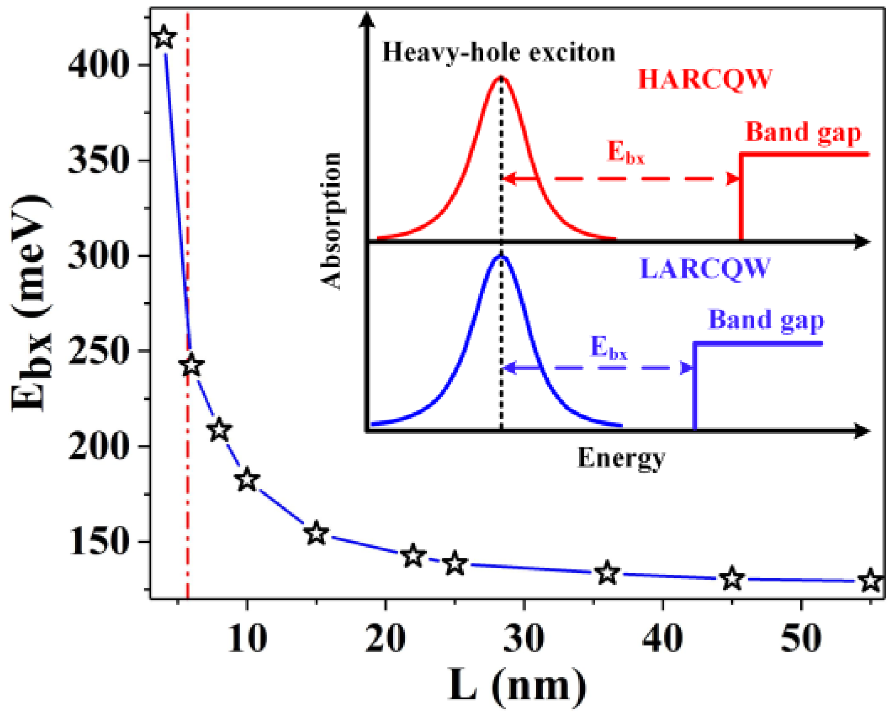
# Enhanced exciton binding energy

- Bohr radius of CdSe: ~5.7 nm
- The enhanced exciton binding energy: > 200 meV




High AR

Medium AR

Low AR

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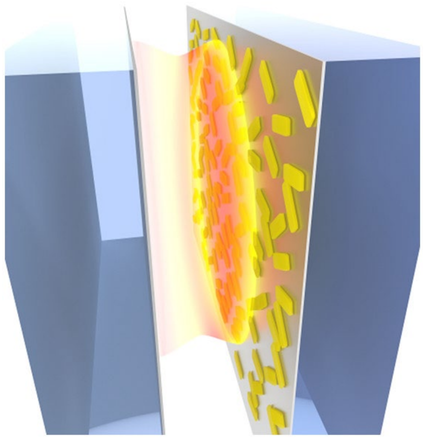
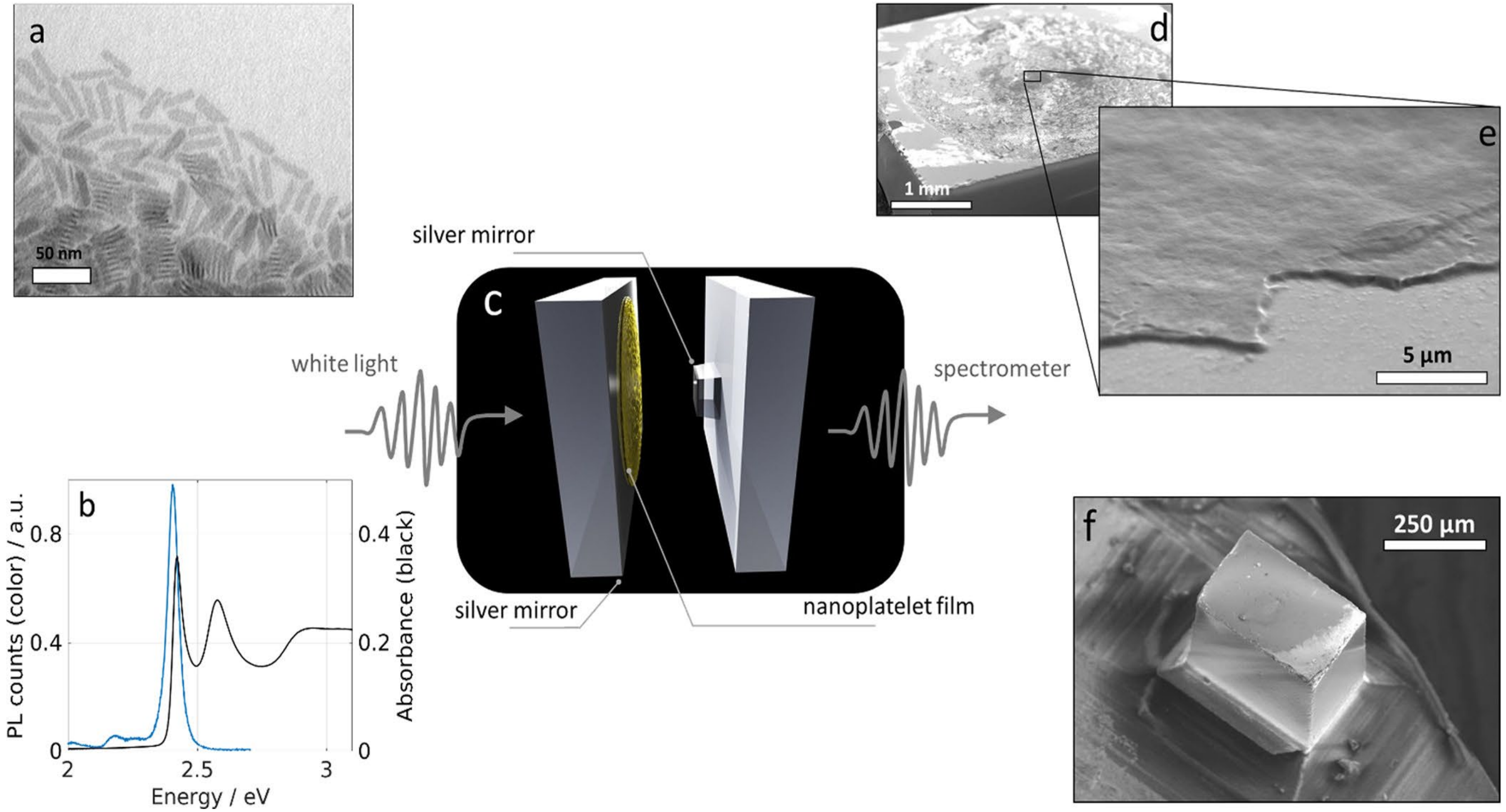
# NPLs: Giant transition dipole moment

Giant transition dipole moment

$\mu = (575 \pm 110)$ D

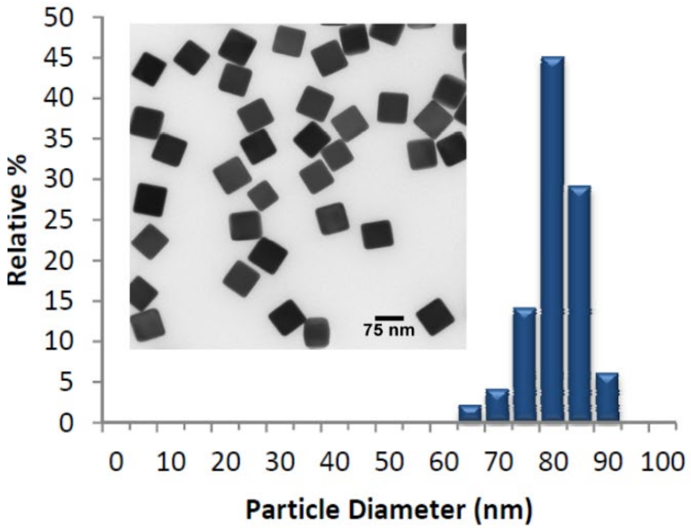


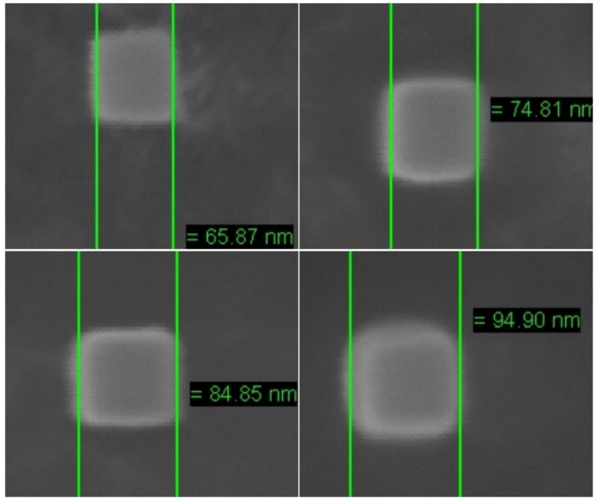


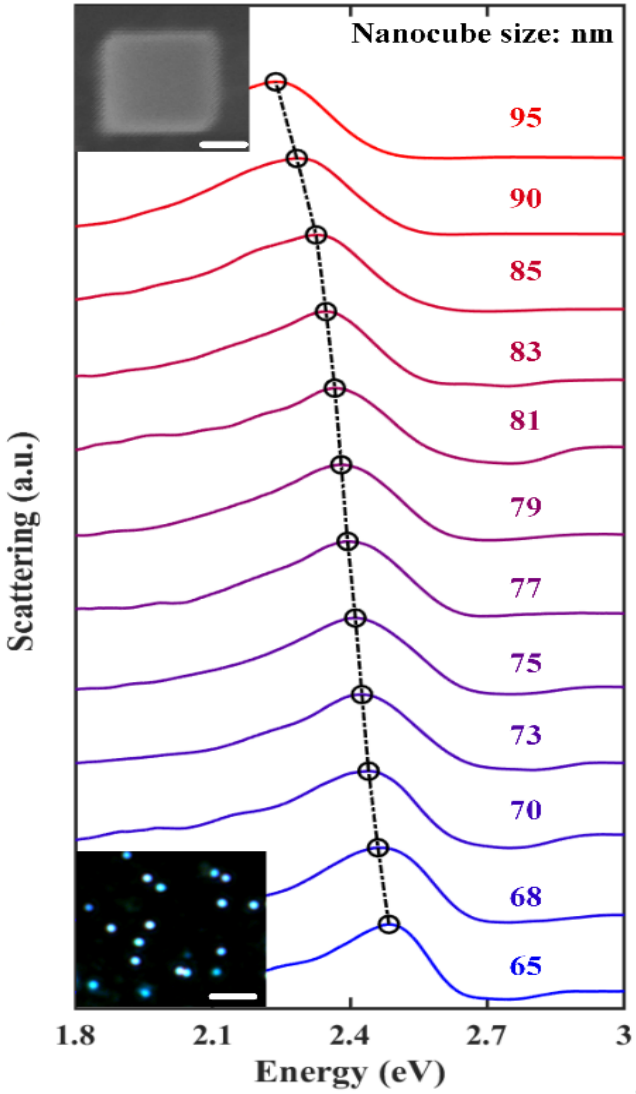

Nano Lett. 2016, 16, 11, 7137–7141

# Silver nanocube: the plasmonic resonant structure

- A wide range of sizes
- Resonant Scattering depends on the size

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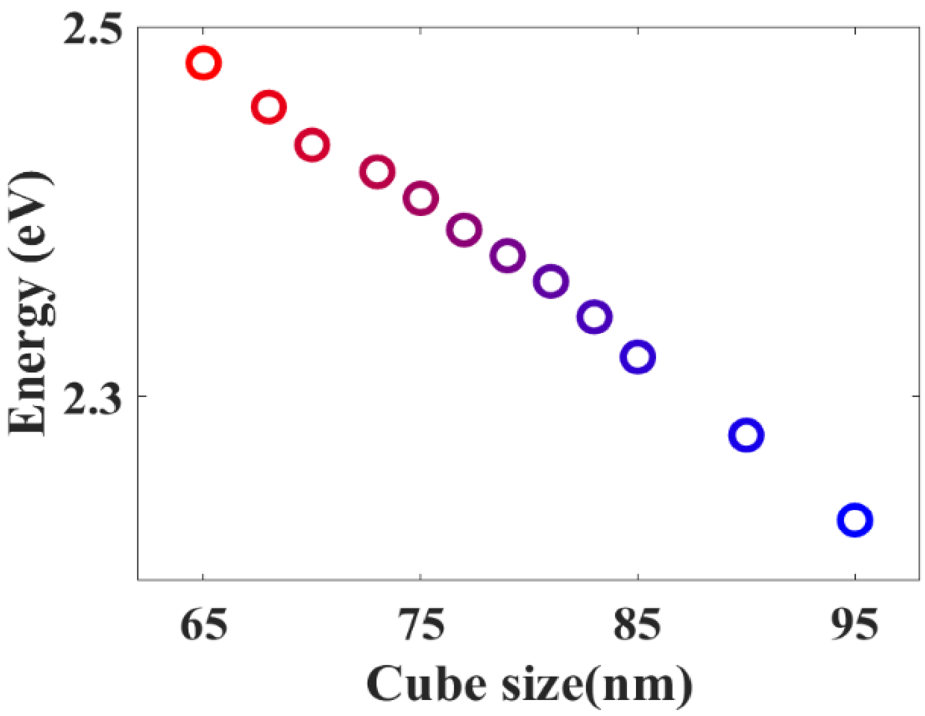
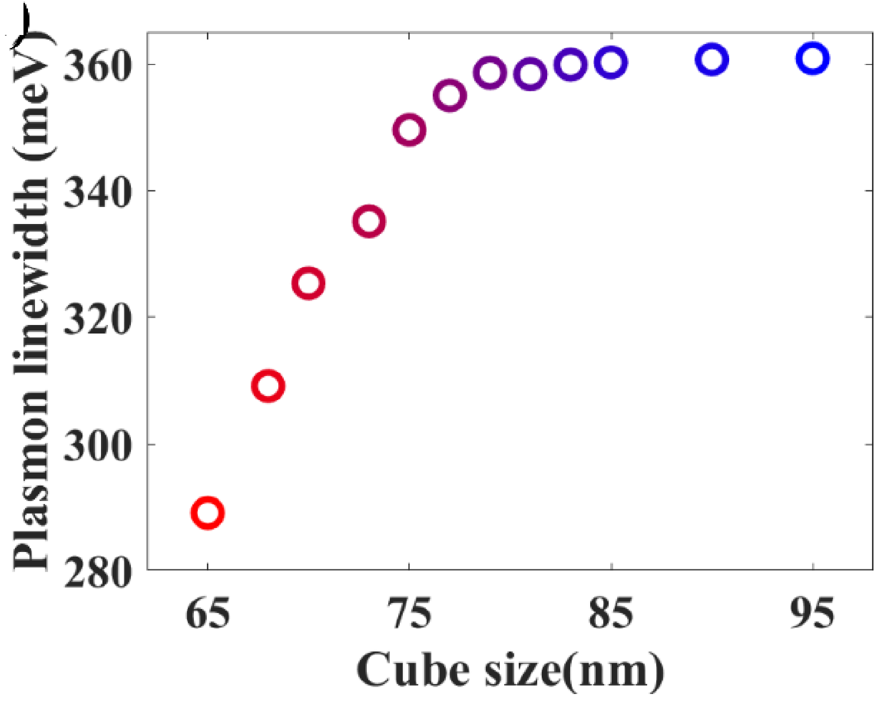
# Silver nanocube: the plasmonic resonant structure






Resonant Effect: Size dependence

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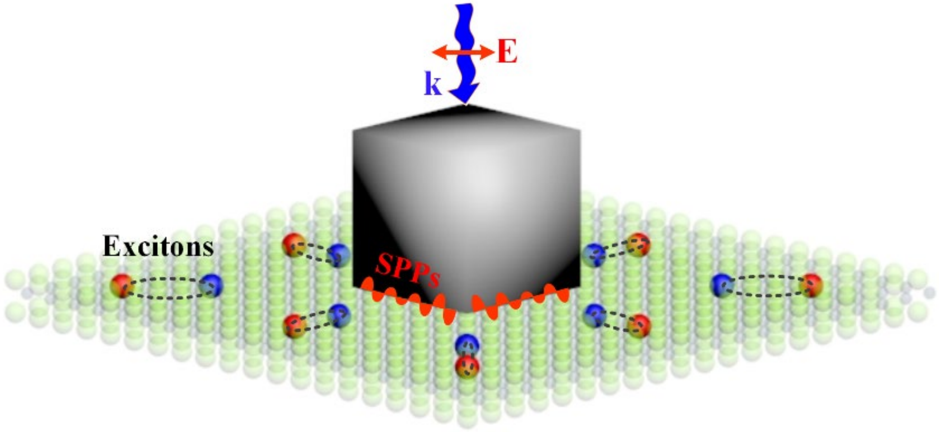
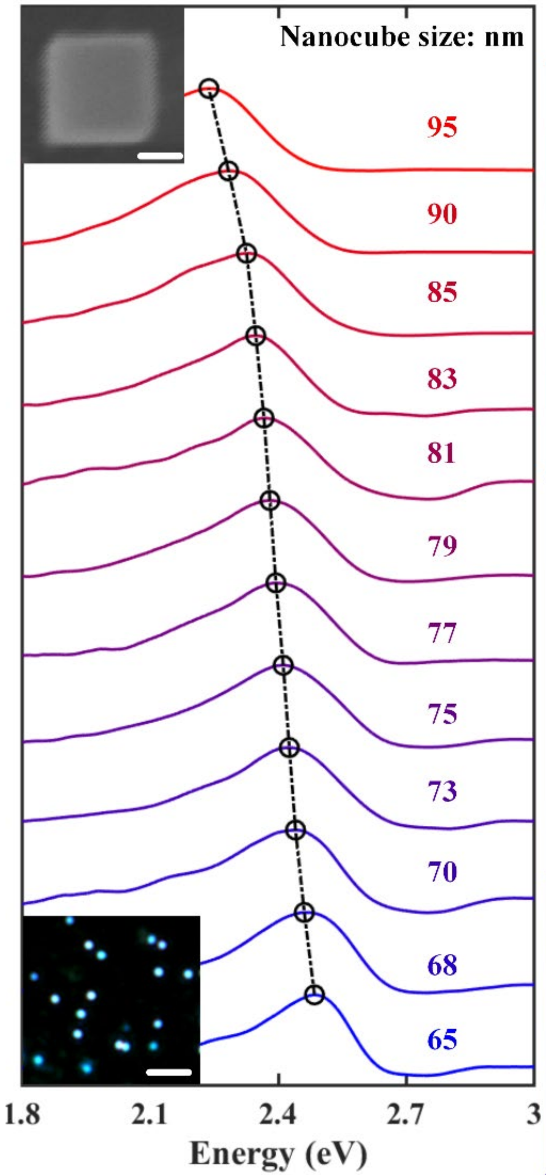
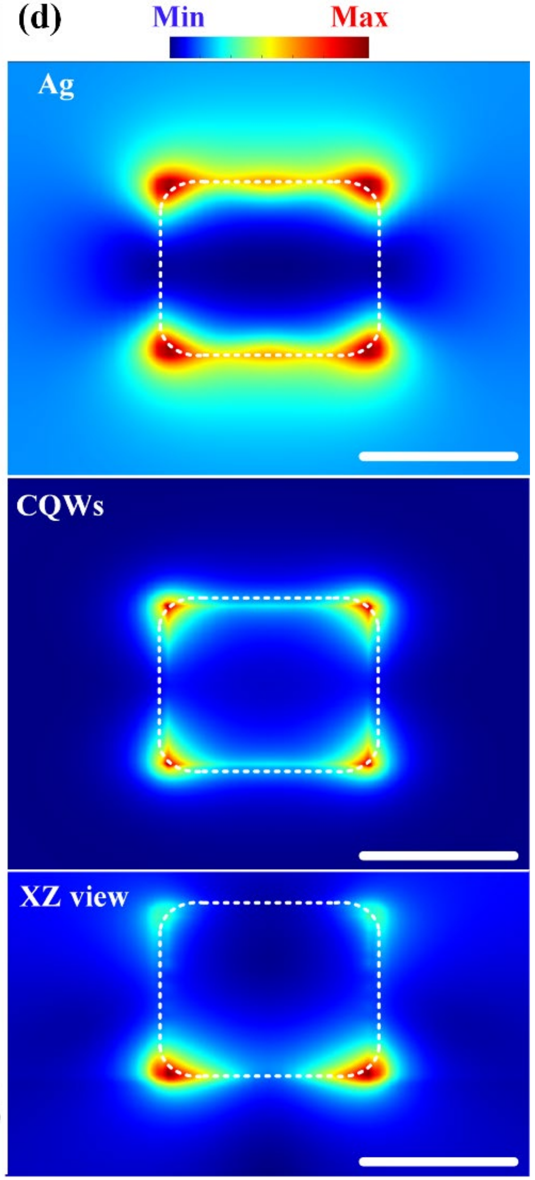
# Silver nanocube: the plasmonic cavity

## In-plane electric field enhancement




- The hottest spot is around the corner: in-plane distribution
- Tune the plasmon energy via varying cube size

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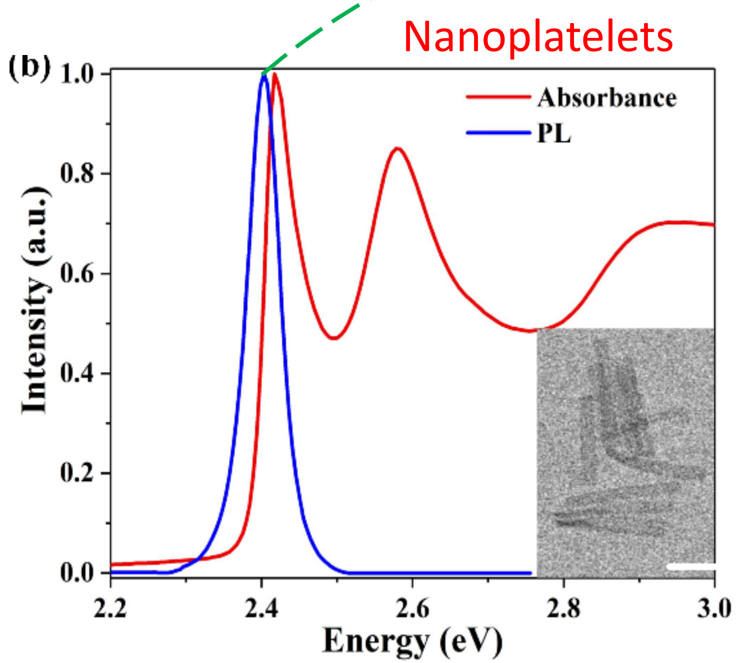
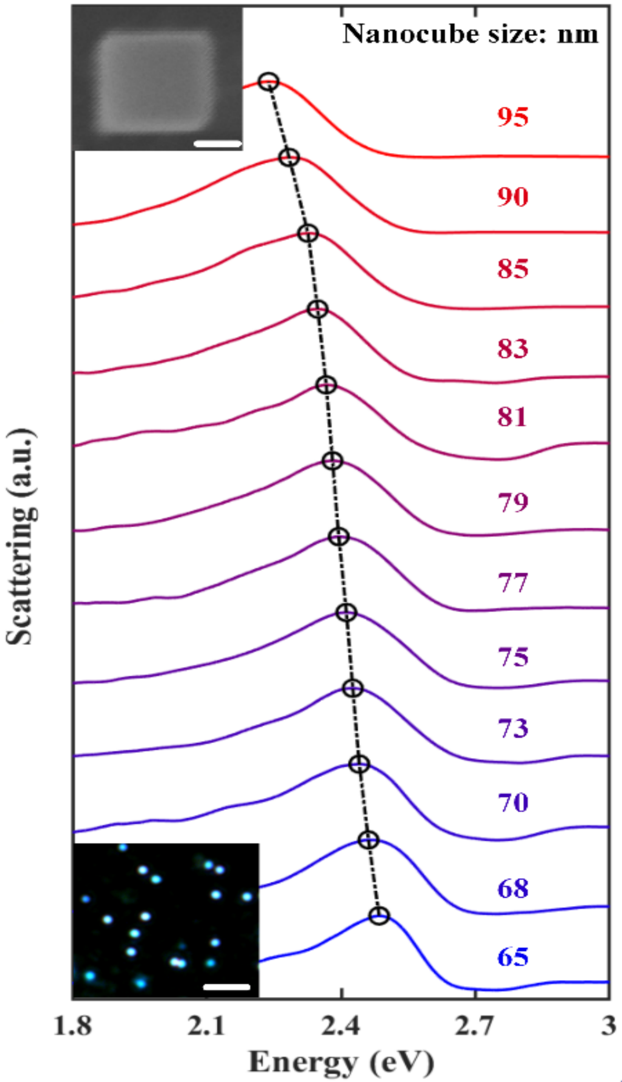
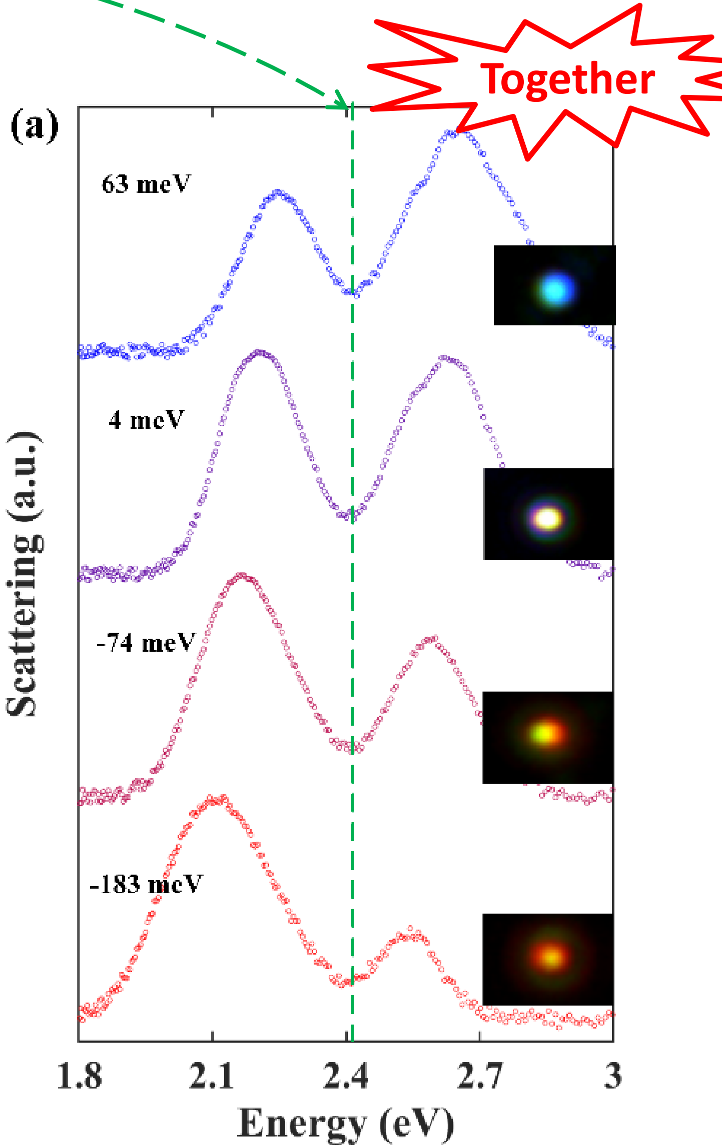
# Ultrastrong coupling




No more single scattering peak

No scattering at exciton energy

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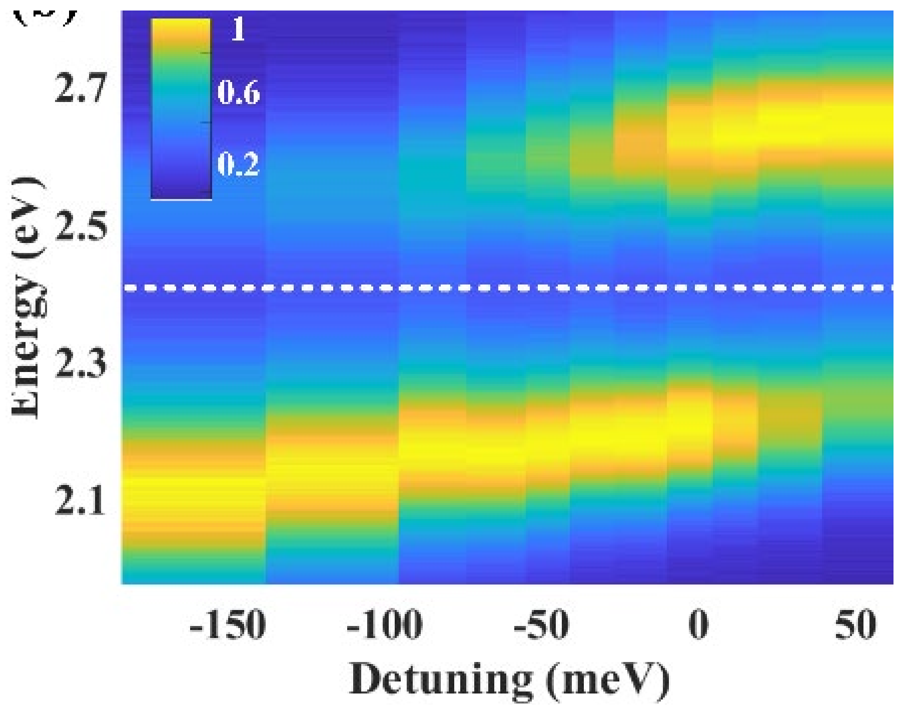
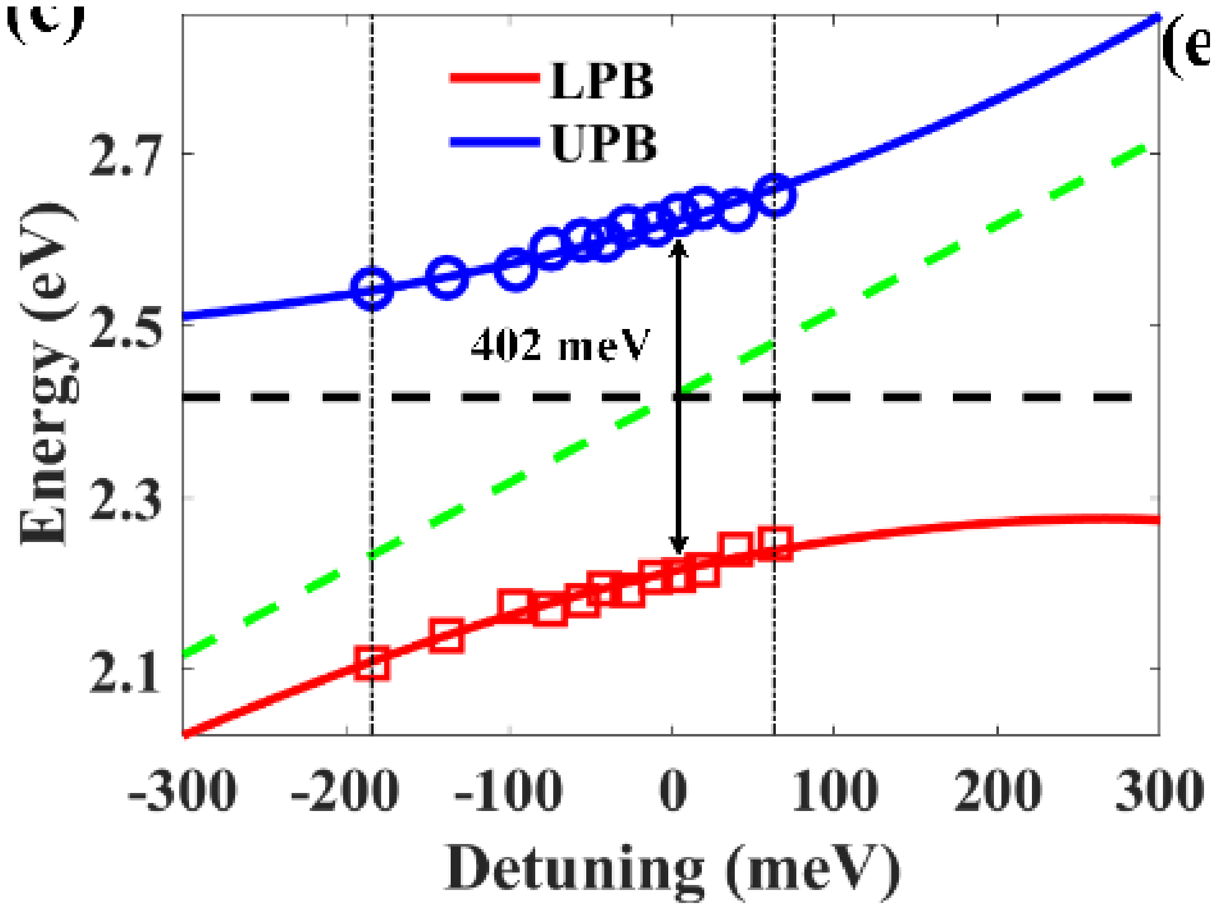
# Scattering: Anti-crossing




Two distinct polariton branches:

LPB: Lower Polariton Branch

UPB: Upper Polariton Branch

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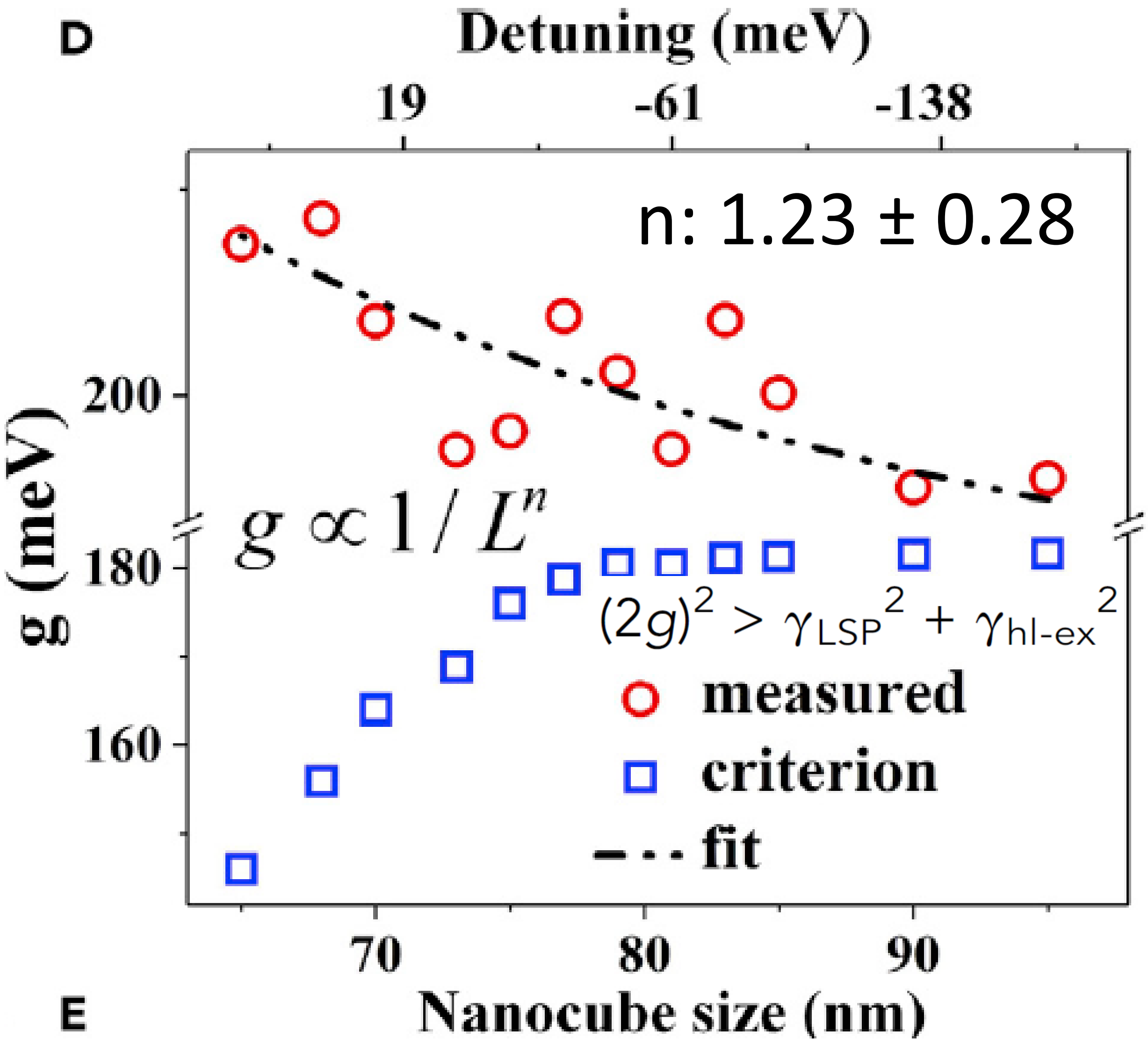
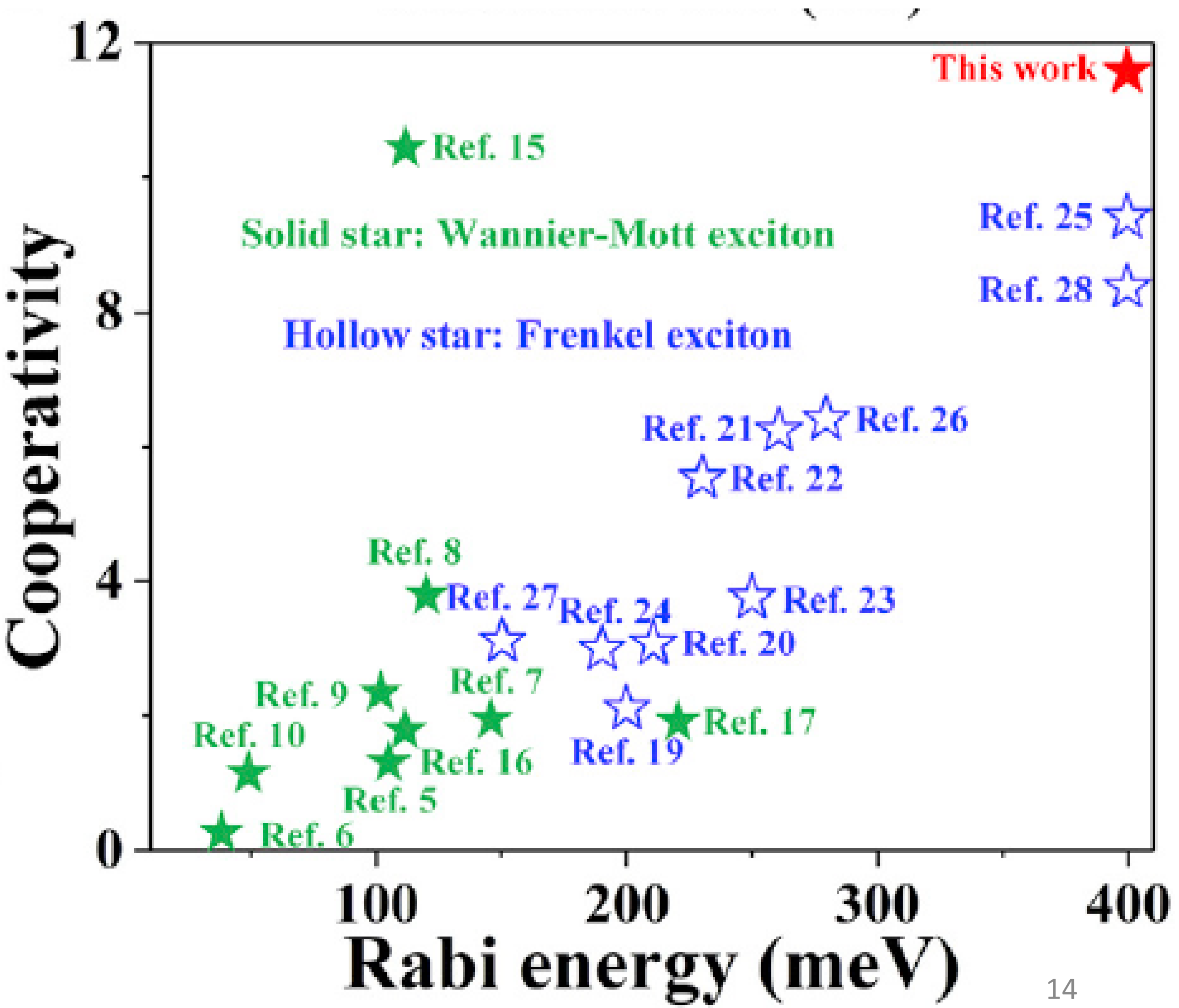
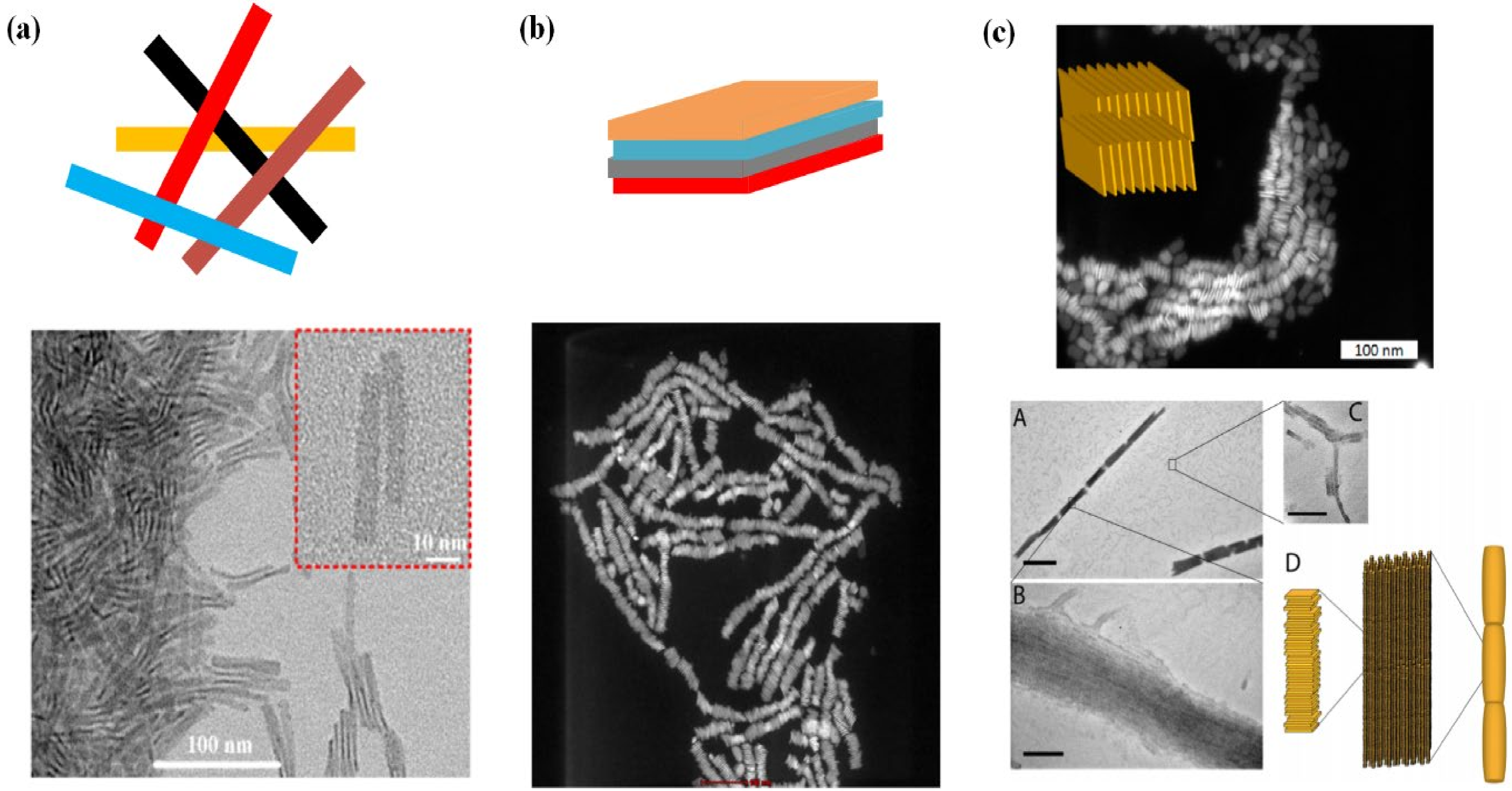
# Ultra-Strong Coupling



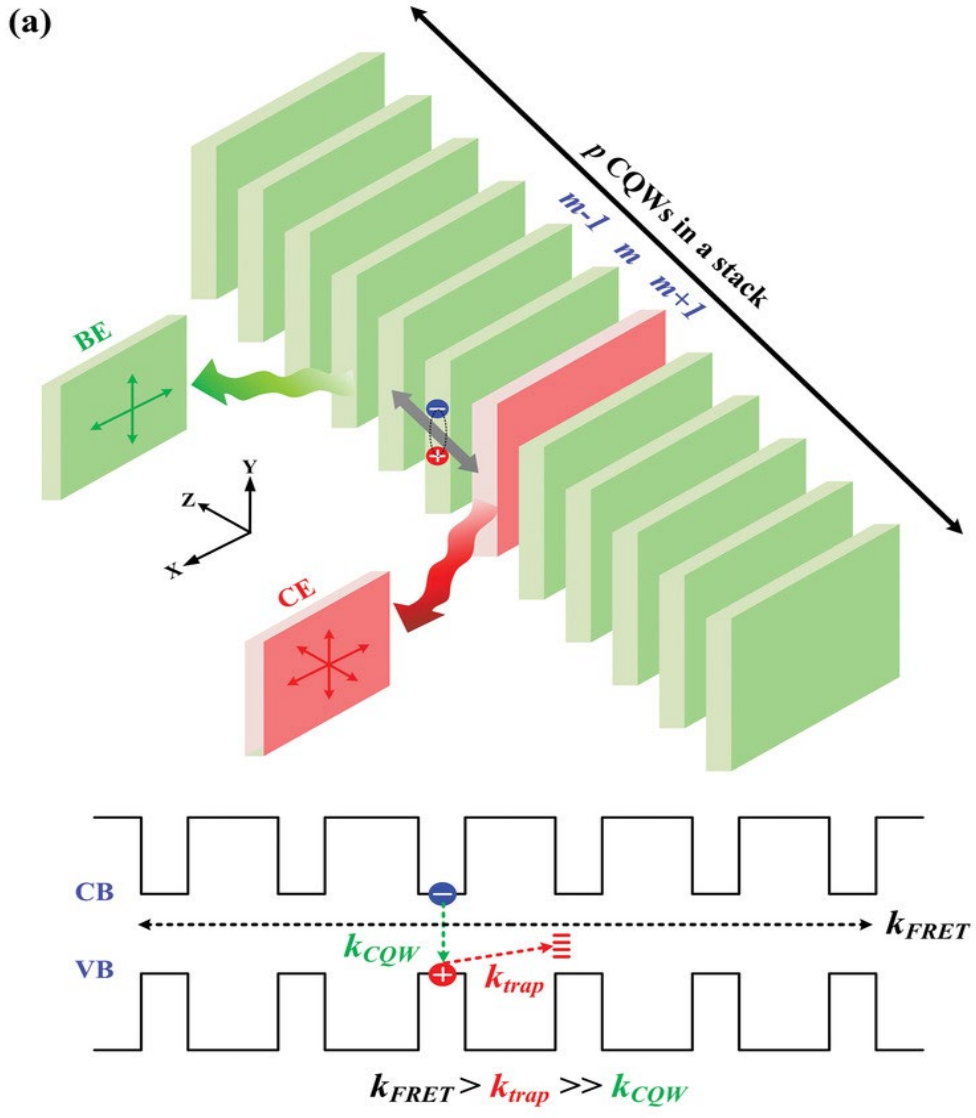
# Non-stacking: suppressed homo-FRET

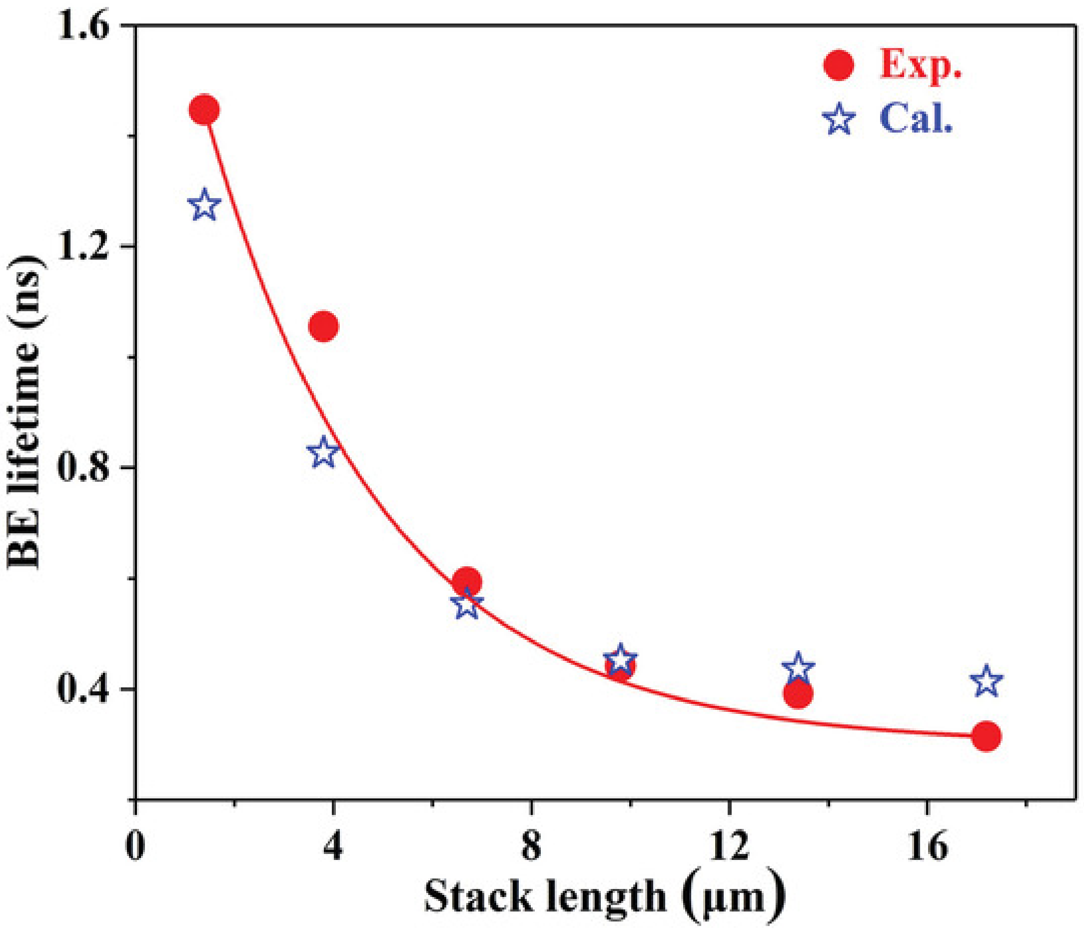



**High aspect ratio** **Medium aspect ratio** **Low aspect ratio**

*Adv. Optical Mater.* 2022, 10, 2101756.

# NPL stacking: homo-FRET

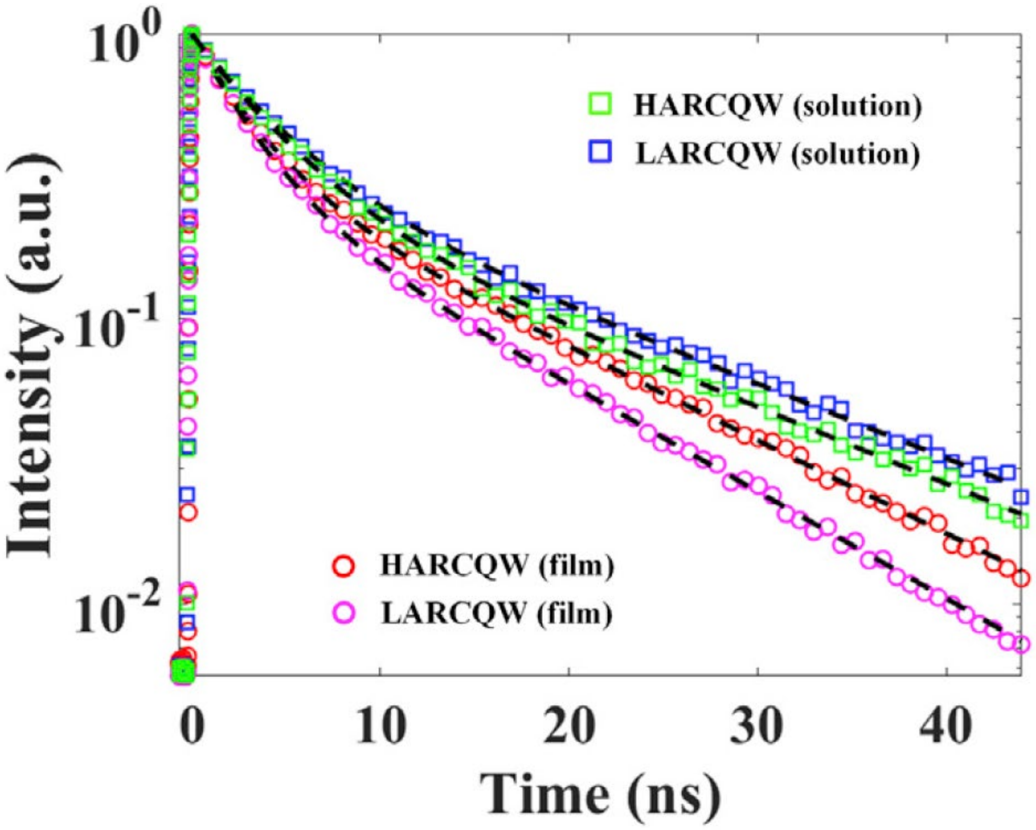



**Homo FRET**: Not preferable for strong coupling

*Adv. Optical Mater.* 2022, 10, 2101756.

# Non-stacking: suppressed homo-FRET




| | $\tau_1$ (ns) | $\tau_1$ (ns) | $\tau_1$ (ns) | $A_1$ (%) | $A_1$ (%) | $A_1$ (%) | $\tau_{avg}$ (ns) |
|---|---|---|---|---|---|---|---|
| **HARCQWs (in solution)** | 0.91 | 4.15 | 16.8 | 60.7 | 30.9 | 8.4 | 3.25 |
| **HARCQWs (film)** | 0.88 | 3.47 | 15.3 | 60.2 | 34.5 | 5.3 | 2.54 |
| **LARCQWs (in solution)** | 0.87 | 4.05 | 16.3 | 55.3 | 36.9 | 7.8 | 3.26 |
| **LARCQWs (film)** | 0.41 | 2.72 | 11.6 | 71.4 | 24.8 | 3.8 | 1.41 |

- Similar lifetime in solution: ~3.2 ns
- Life time of low aspect ratio CQWs in film: ~1.4 ns (FRET efficiency: ~57%)
- Life time of high aspect ratio CQWs in film: ~2.5 ns (FRET efficiency: ~22%)

# Nanoplatelets: Face-down geometry

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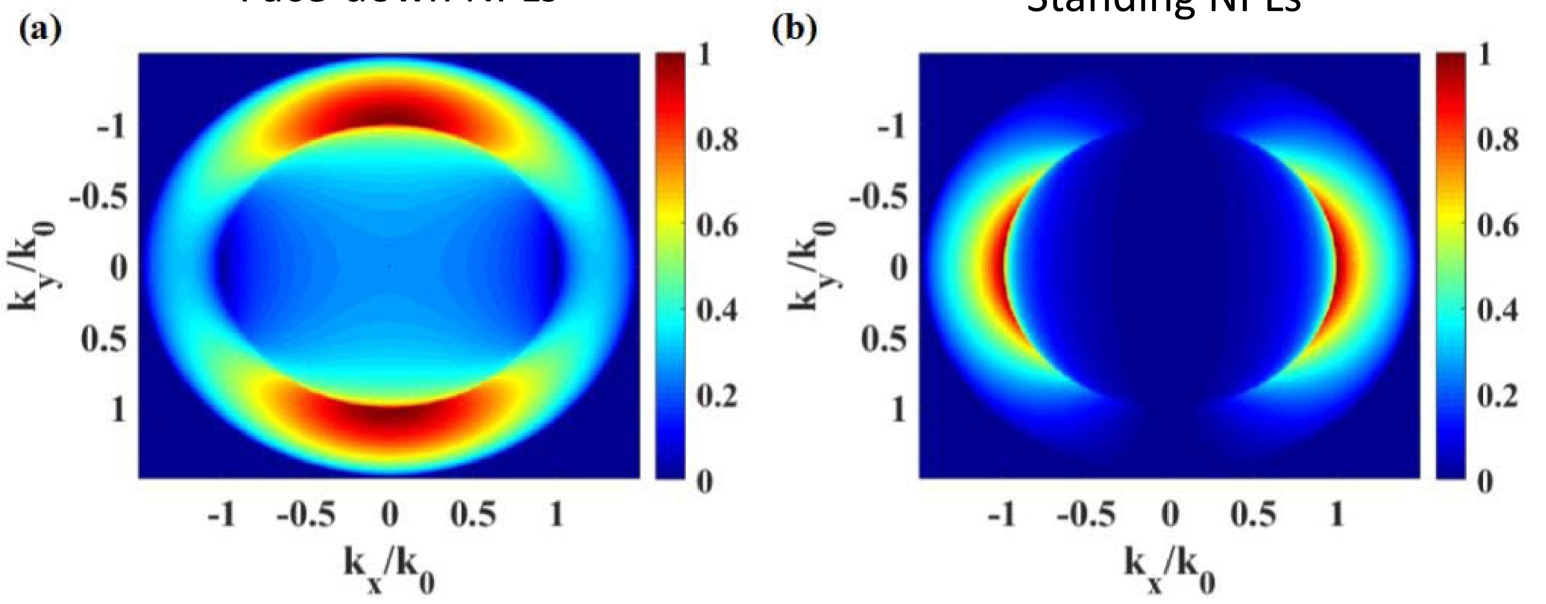
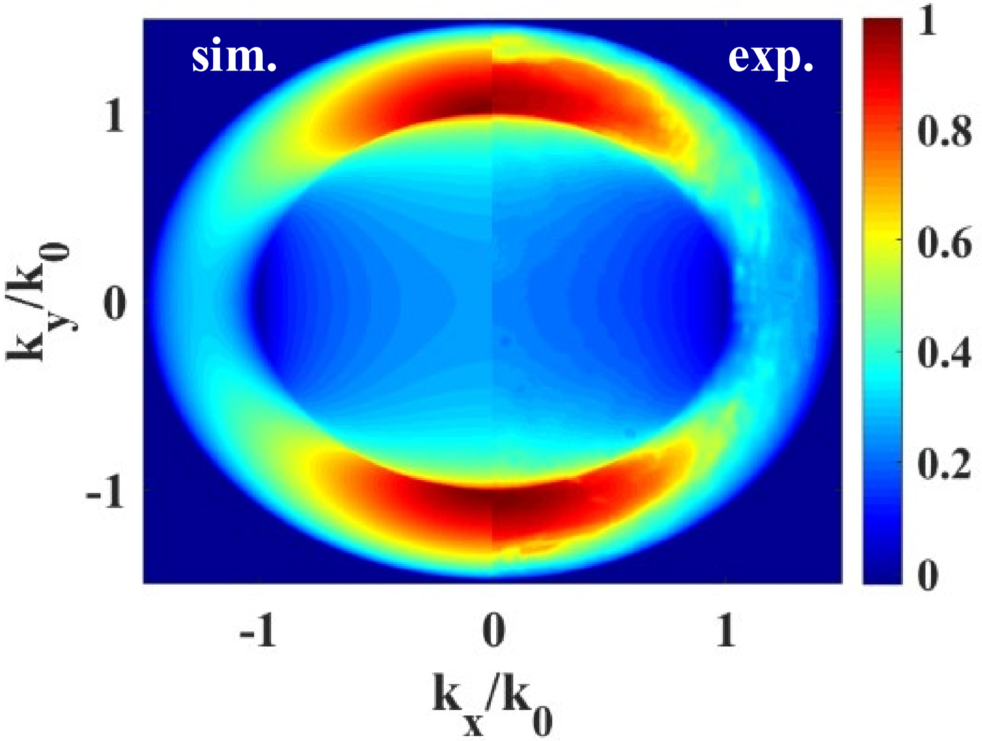
Face-down NPLs

Standing NPLs




- Almost all high aspect ratio CQWs are lying down in the film
- The fraction of in-plane dipoles is ~95%
- Dipoles are in the same plane with enhances plasmonic E field of nanocube

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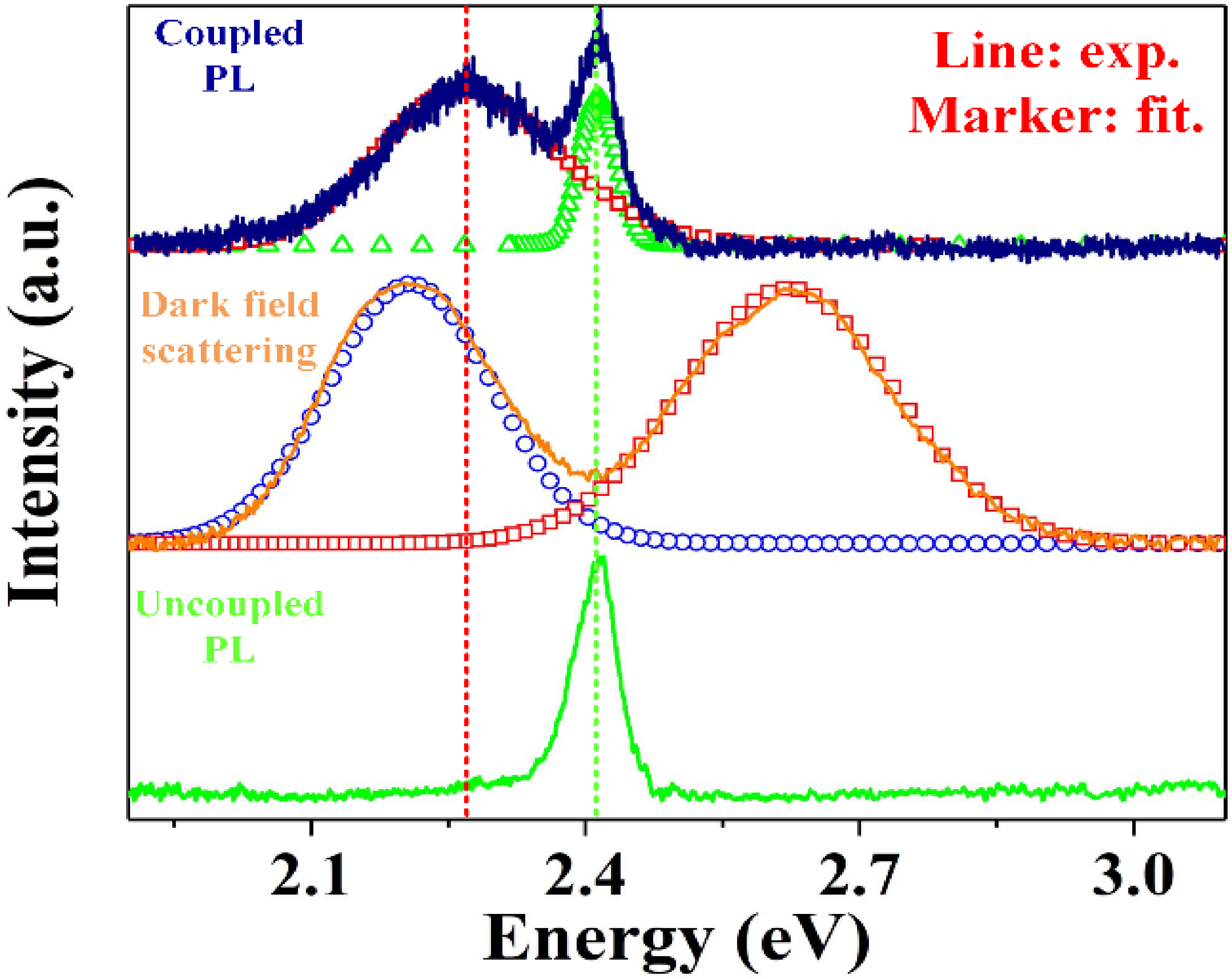
# PL from low polariton branch

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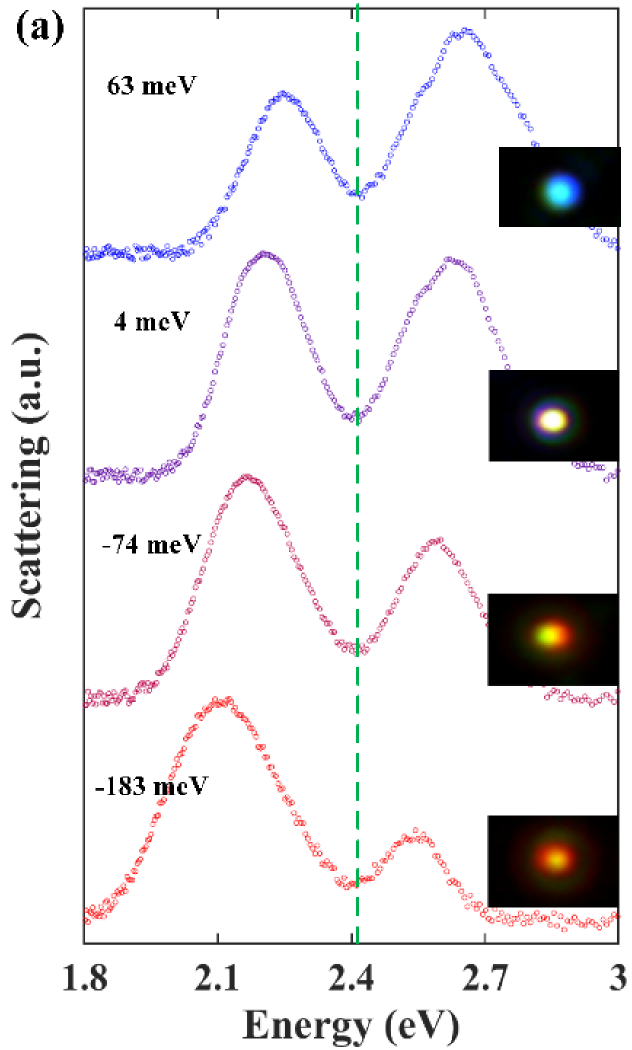
# Summary

- Strong light-matter coupling between CQW's excitons and the plasmonic nanocavity
- Super large Rabi energy and Cooperativity
- Small mode volume of a plasmonic nanocavity and preferable orientation of strong dipole moments are the key to achieve high performance.

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# Thank You

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Renaud Bachelot

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