# Good Vibrations: Plasmon-Exciton Coupling in Gold/Molybdenum Disulfide Hybrid Systems

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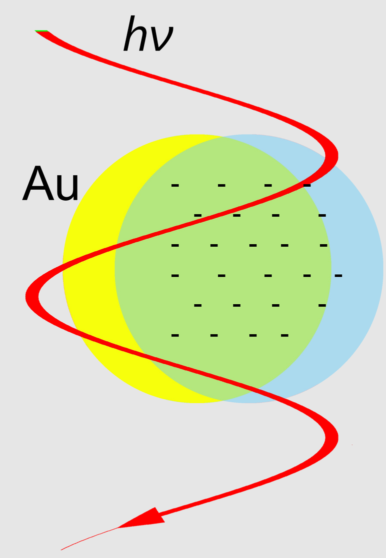
## Introduction

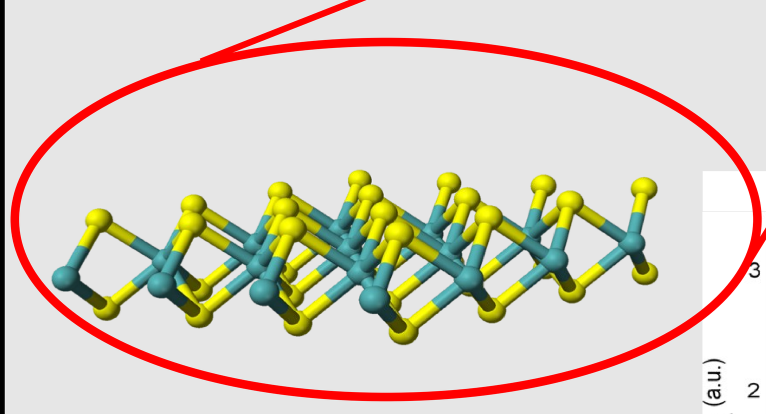


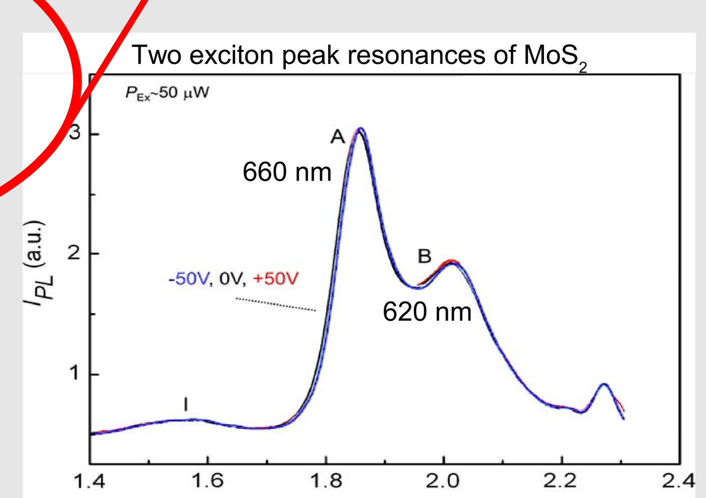

### Plasmons

- Coupling of photons to free electrons within metals
- Plasmon resonances defined by nanoparticle geometry
- Nanoscale regions of intense electric fields
- Generates coherent oscillations of the electron cloud.

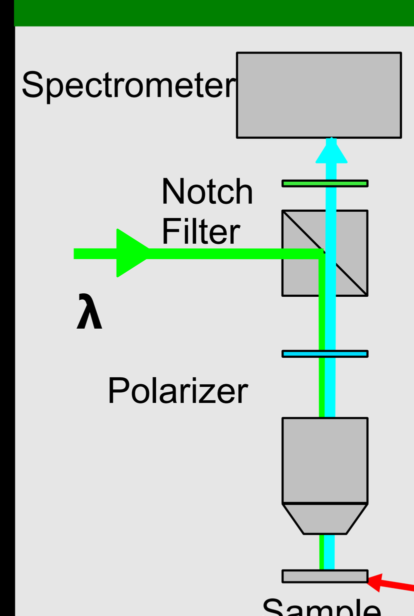
### Molybdenum Disulfide

- Mechanically exfoliated from molybdenite
- Three atom thick crystaline structure
- Highly translucent
- Optically excitable
- Strong exciton binding energy (0.5 eV)

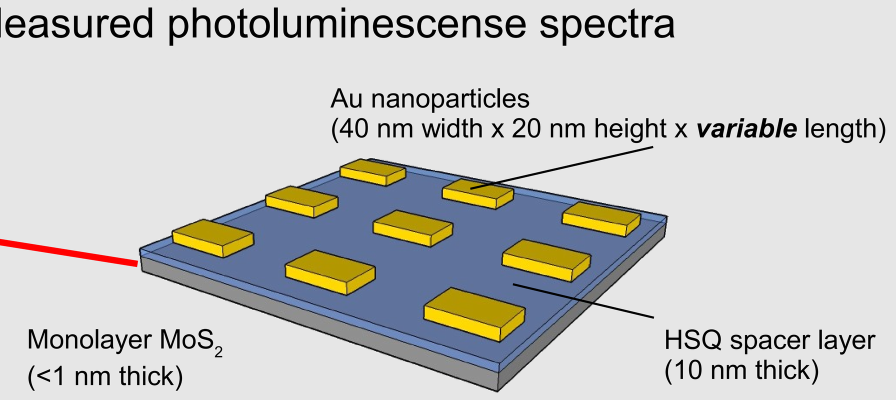





## Methods




- Mechanically exfoliated $MoS_2$ flake onto silicon and glass substrates
- Applied HSQ spacer layer onto flake to reduce potential hot electron transfer
- Patterned nanorods using e-beam lithography
- Deposited gold using thermal evaporation
- Measured photoluminescense spectra

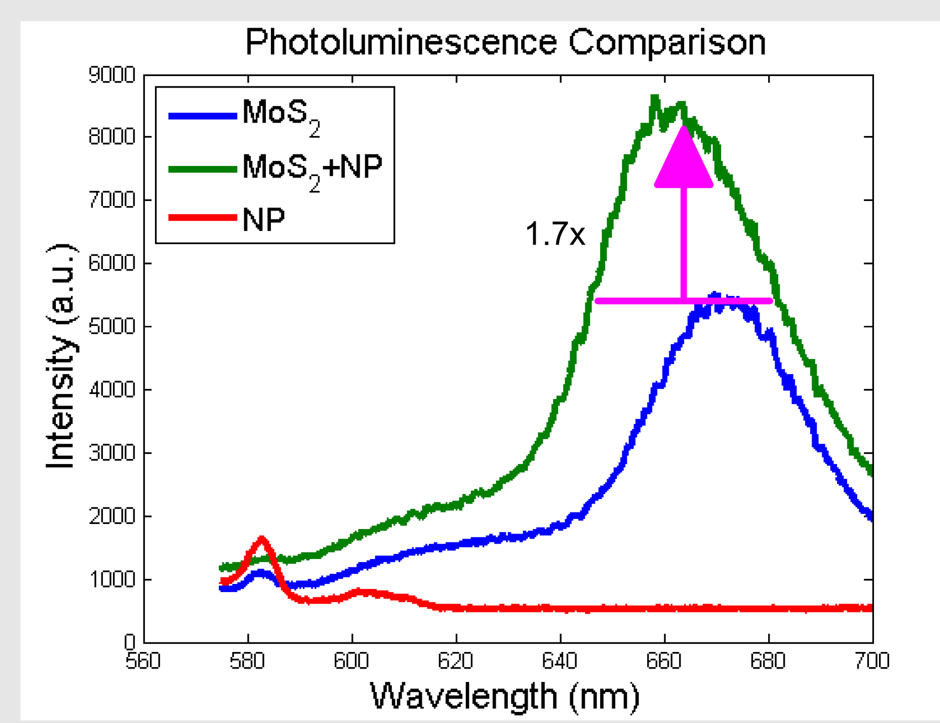



## Objective

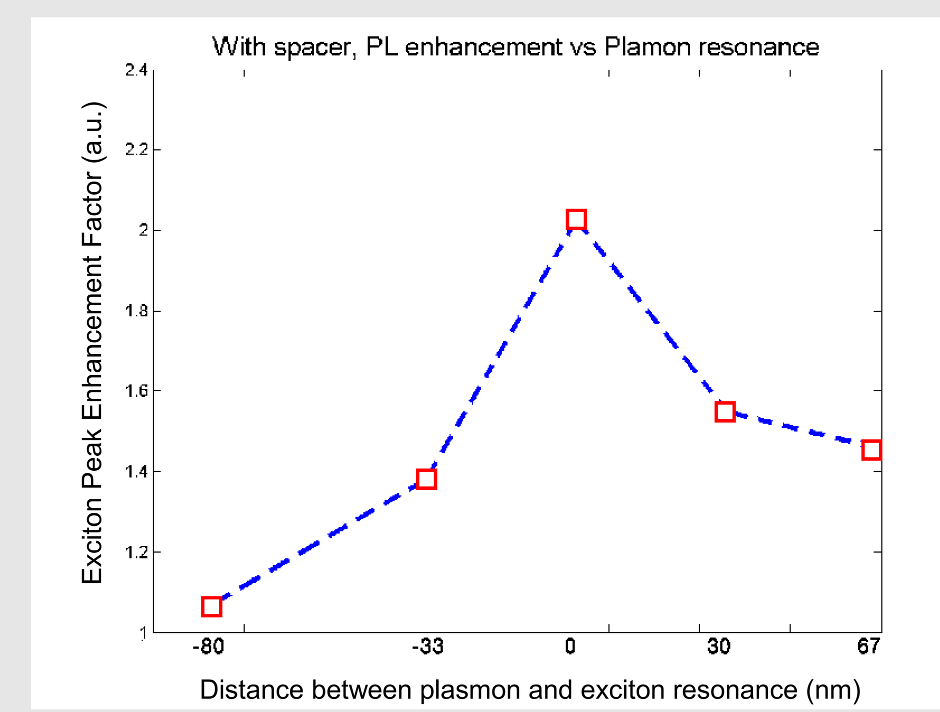
Explore exciton-plasmon hybrid system coupling in 2-dimensional materials.

- Determine enhancement of intrinsic optical properties of $MoS_2$.
- Attempt to produce exotic bound exciton-plasmon states.

## Results: Enhanced Photoluminescence

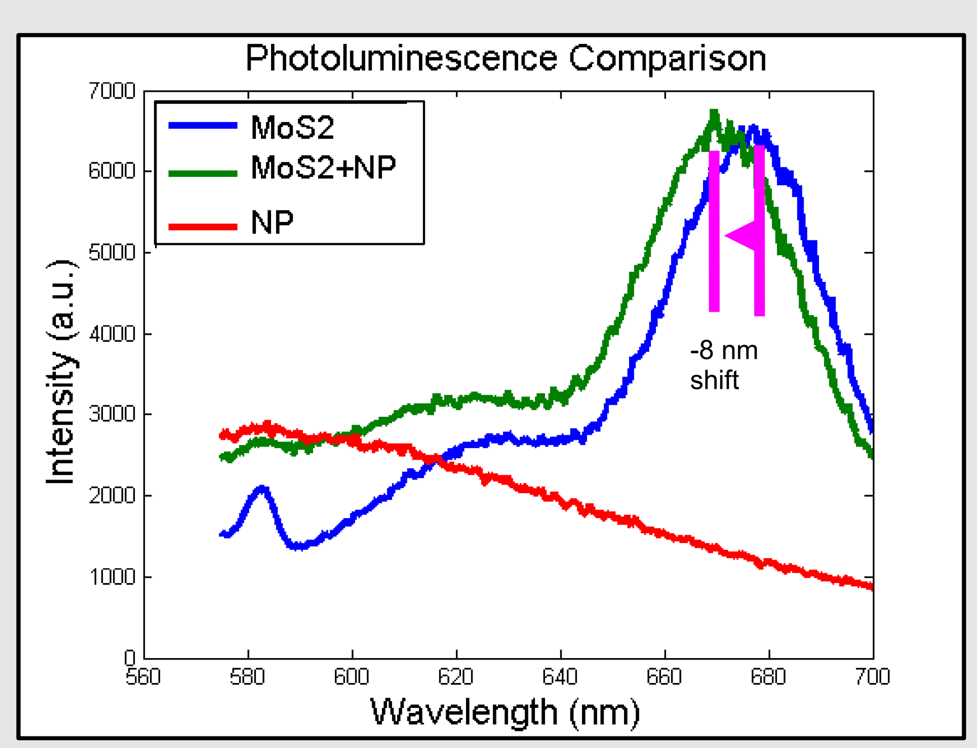



Both A and B exciton peaks are enhanced in presence of gold nanorods.

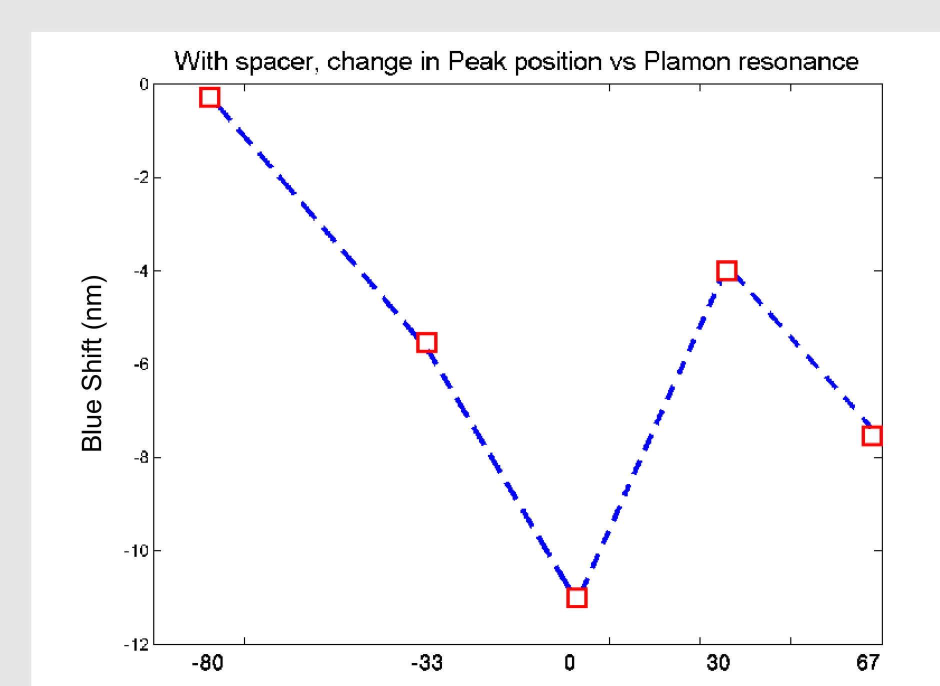



We shift the plasmon resonance to modulate the relative difference in energy between the plasmon and exciton resonances. As the distance between the plasmon and exciton resonances decreases, coupling efficiency increases.

## Results: Exciton Energy Shift




Exciton peaks blue shift in presence of gold nanorods



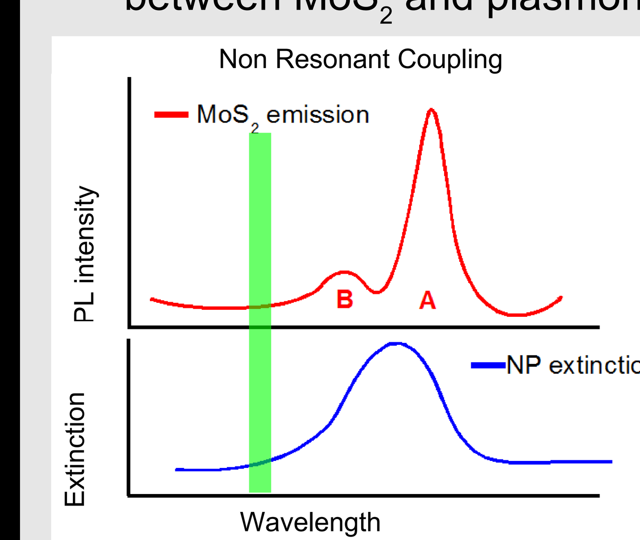

As coupling efficiency increases, we also see an increase in the blue shift of the exciton peaks.

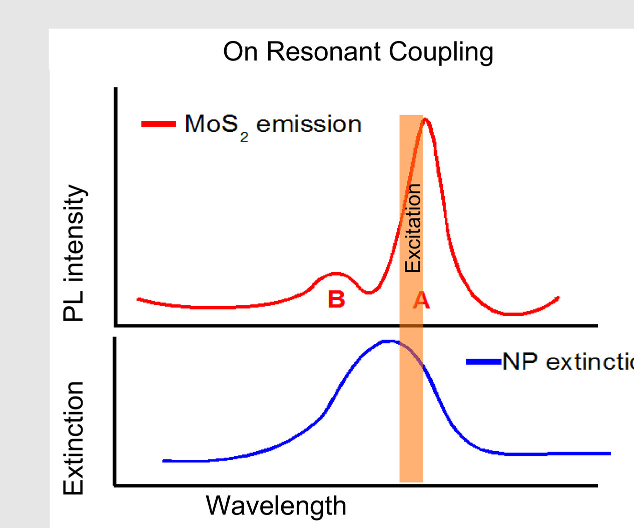
## Conclusions

- Enhancement of PL at least indicates weak plasmon-exciton coupling (Purcell effect).
  - Here the plasmon effectively acts as an antenna for photons.
- Energy shift in PL implies a stronger degree of coupling.
  - The blue shifted peak could be the high energy Rabi splitting peak, an indicator of strong coupling.
  - The HSQ spacer layer ensures that blue shift is not due to direct electron transfer.
  - The suspected coupling mechanism is coherent dipole-dipole coupling.

## Future Work

- Vary HSQ thickness to determine distance dependence of plasmon-exciton coupling.
- Extinction microscopy to see Rabi splitting or Fano resonances further supporting strong binding.
- Explore the extent of non-resonant vs on-resonant coupling between $MoS_2$ and plasmons.




## Acknowledgments

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## References

Maier, Stefan A. Plasmonics: Fundamentals and Applications. New York: Springer, 2007.

Manjavacas, A ; García De Abajo, F J ; Nordlander, P. Nano Letters, 2011, Vol.11(6), pp.2318-23

Newaz, AKM; Ziegler, J.I.; Caudel, D. Solid State Communications, 2013,Vol. 155, pp.49–52