Connecting the Dots: Engineering Quantum States for Technology and Fundamental Physics

Michael Scheibner

UC Merced

UNSW Sydney
Mar. 25th 2025

My Background

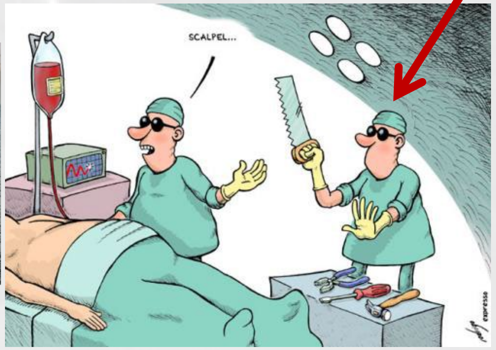
Agriculture

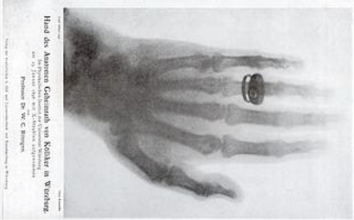
Wine making

Construction

Sailing

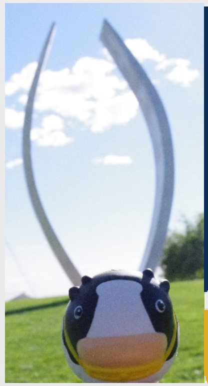
Surgery





Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

THE UNIVERSITY of NEW MEXICO



UCMERCED

Quantum Matter Group

Assoc. Prof. Physics, UC Merced, mscheibner@ucmerced.edu

Research Expertise

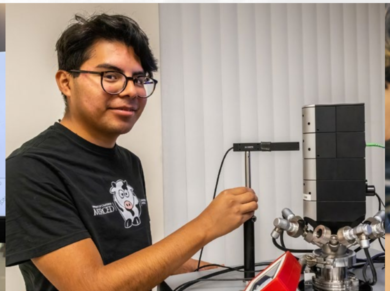
- *Semiconductor*
  - *Opto-electronics, -phononics*
  - *Ultrafast dynamics*
- *Single & Coupled Quantum Dots*
- *2D materials & atomic-emitters*

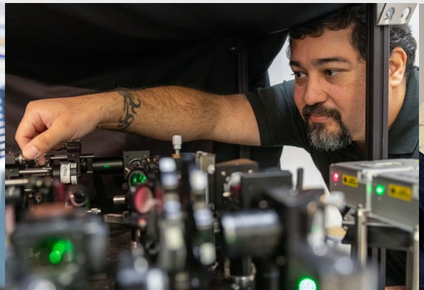
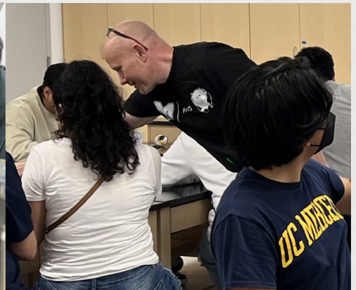
Research Interests

- *Quantum Materials & Structures*
- *Coupled quantum systems*
- *Quantum(-enhanced) Sensing*
- *Fundamental-Applied Physics*

Selected Projects & Programs

- *Quantum-enhanced Motion sensing using spins in quantum dots (PI, UCM-NRL)*
- *Advanced Quantum Sensing for Geoenvironments*
- *Hands-on Quantum Materials Lab (PI), Instrumentation grant*
- *NRT-CONDESA (CoPI, UCM-LLNL), Lead-Core 3*
- *VISION-PREM (PI/Director, UCM-IMOD-stc) Venture for Innovation in Self-assembly and Integration of Optoelectronic Nanostructures*
- *Quantum workforce development with experiential learning*



Today's program

- Introduction
  - UC Merced
  - The Quantum Matter Group (QMG) Lab
- Basics of quantum matter:
  - Focus on: Quantum Dots & Quantum Dot Molecules
- Examples of how to use quantum emitters
  - Quantum-enhanced Motion Sensing
  - (Taming) Phonons
  - Outlook

UC Merced

UC Merced – Latest Development

UCMERCED

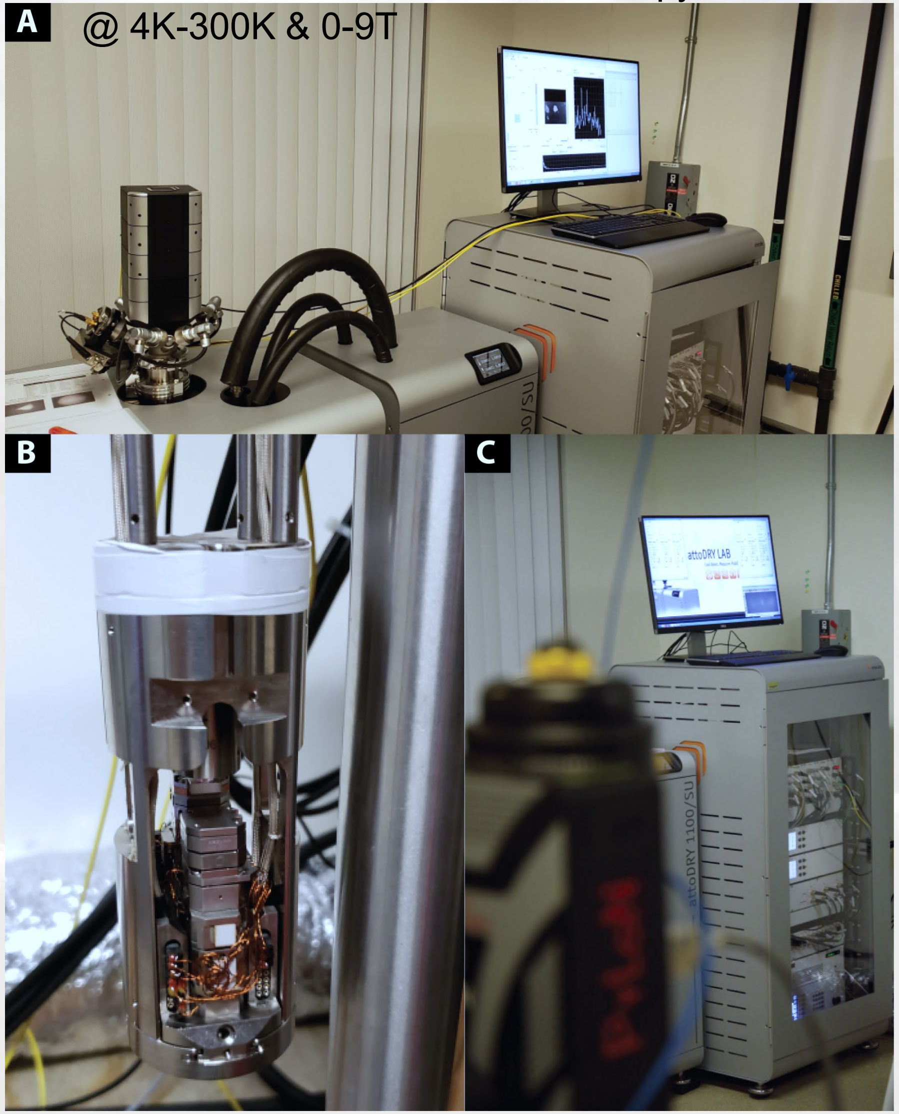
All News | Research | Accolades | Events | Athletics | For Journalists

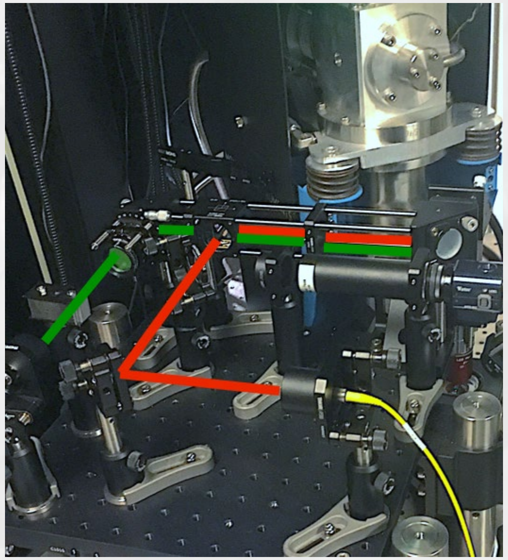
February 13, 2025

UC Merced has earned the prestigious R1 Carnegie research classification within the university's first 20 years.

A Peak into the (old) QMG lab

Atomic-Force & Confocal Microscopy
@ 4K-300K & 0-9T





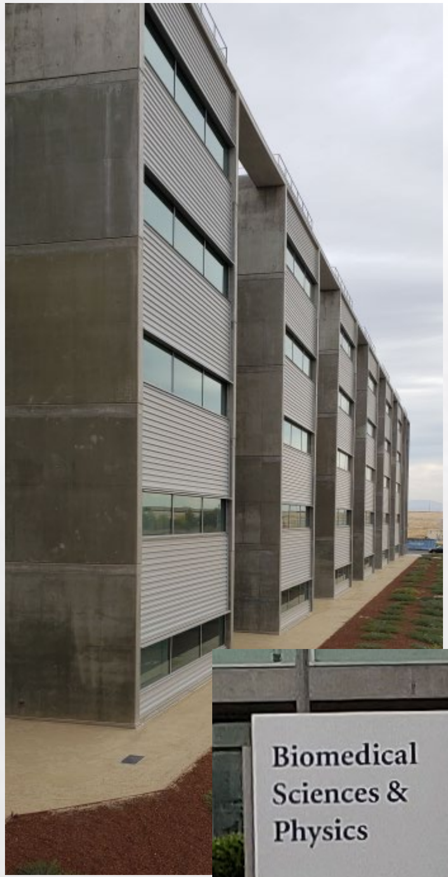
Opto-mechanics

Lasers

FTIR

Triple Raman Spectrometer

2020-Lab on the Move

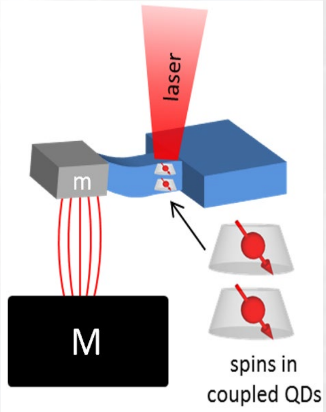


…arrived: 2025 The Quantum Matter Group in the lab

Bruce, Edbertho, Hayley, Derrick, Muzzakkir, Joe, Michael

Related Projects & Programs

Quantum-enhanced motion sensing using entangled spins in quantum dots (UCM, NRL, (VT); DTRA)



GraSP: <u>Gra</u>vity- <u>S</u>pin-<u>P</u>robe

Semiconductor quantum emitters for probing gravitational signatures at the quantum scale (UCM, CSUF, UWA, UNSW, UCF, NETL)

Gravitational Aharonov-Bohm effect, Chiao, *et al.*, Phys. Rev D 109, 064073 (2024)
https://doi.org/10.1103/PhysRevD.109.064073
Energy-level shift of quantum systems via the scalar electric Aharonov-Bohm effect, Chiao, *et al.*, Phys. Rev A 107, 042209 (2023).
https://doi.org/10.1103/PhysRevA.107.042209

ONDESA
CONVERGENCE OF NANO-ENGINEERED DEVICES FOR ENVIRONMENTAL AND SUSTAINABLE APPLICATIONS

National Research & Training Grant (NRT)
(UCM, LLNL; NSF)

Thrust 3: Advanced Quantum Sensing for Geoenvironments.

Quantum-enhanced inertial sensing:

- Mass density distributions
- Motion (water flows)
- Magnetic properties of soil (clays)

VISION

Venture for Innovation in Self-assembly and Integration of Optoelectronic Nanostructures
(UCM, IMOD-STC; NSF)

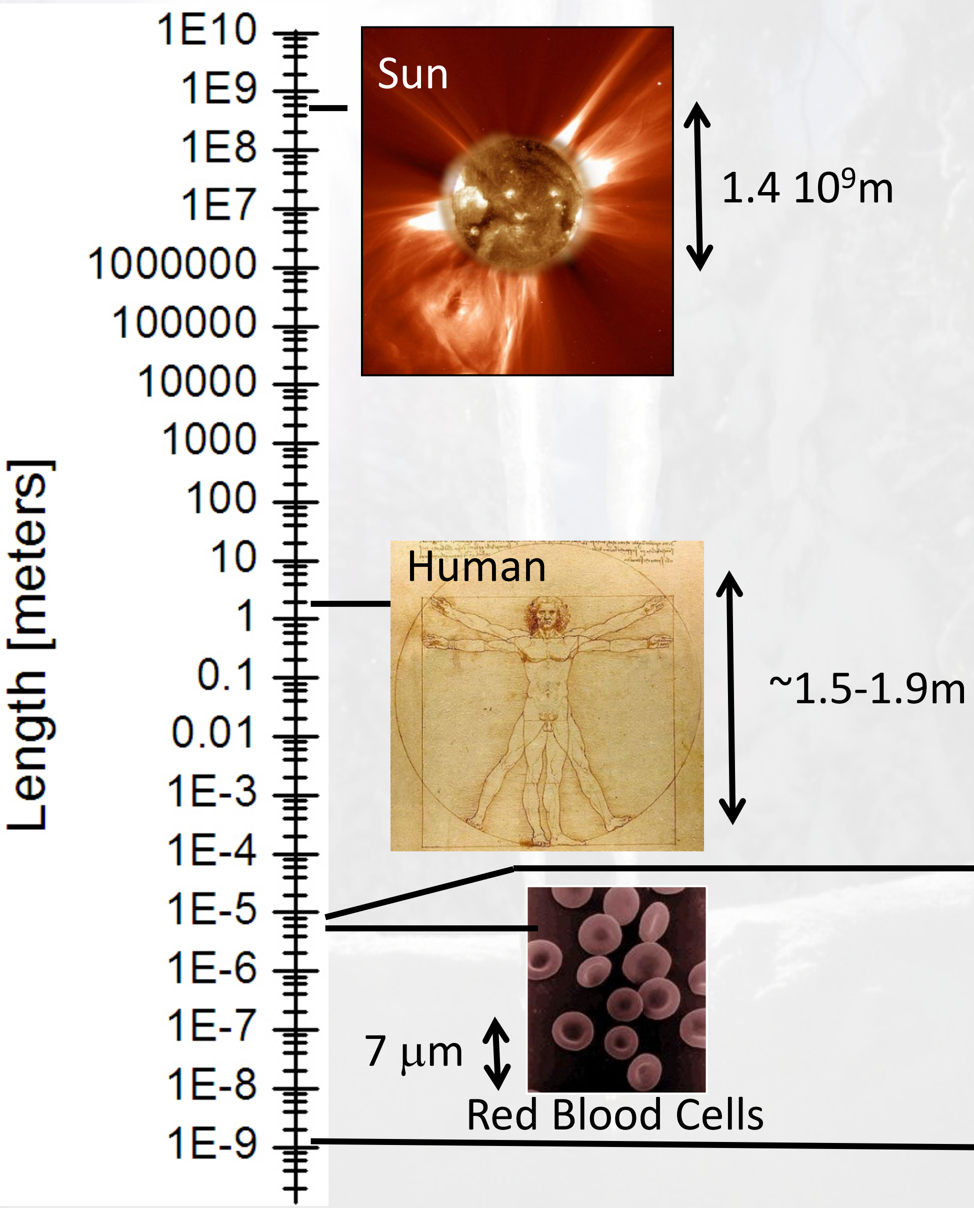
- RT-1: Quantum Dot Meta-Structures
- RT-2: Atomic Emitters in 2D
- RT-3: Composite Optoelectronic Structures

VISIONPREM.UCM

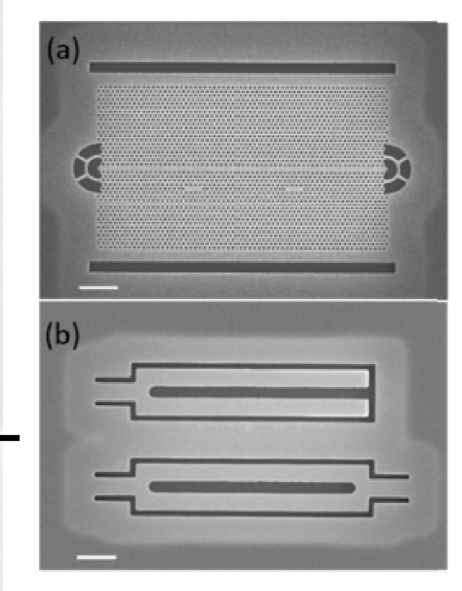
Coupled quantum dots basics

From Quantum Dots to dot molecules

Working Scale



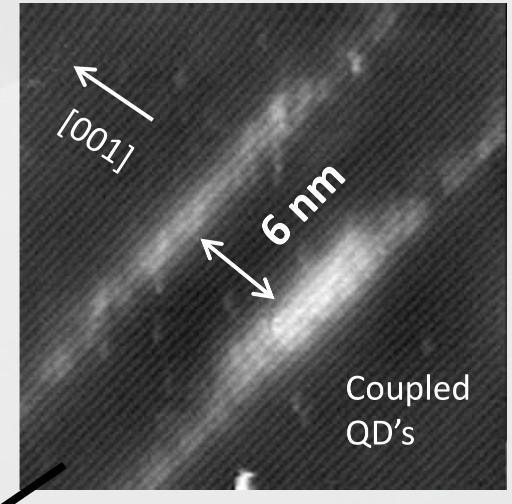
$$\frac{\textbf{Sun}}{\textbf{Human}} \approx \frac{\textbf{Human}}{\textbf{Quantum Dot}}$$



Carter, et al., GoMaTech (17)

We work with:

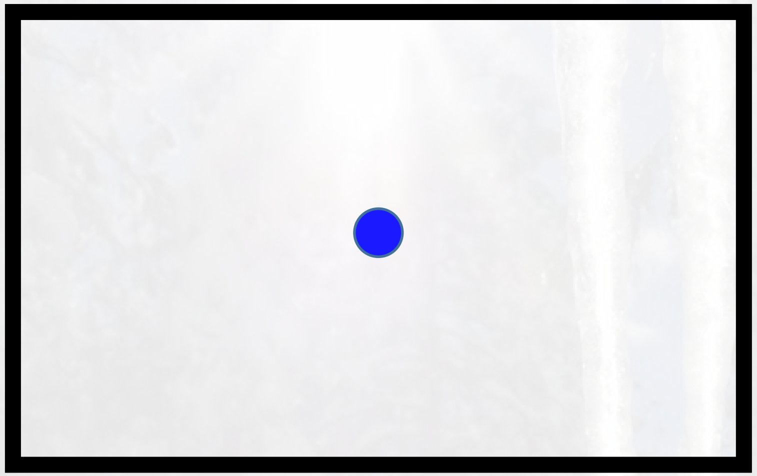
InAs/GaAs Quantum Dots:

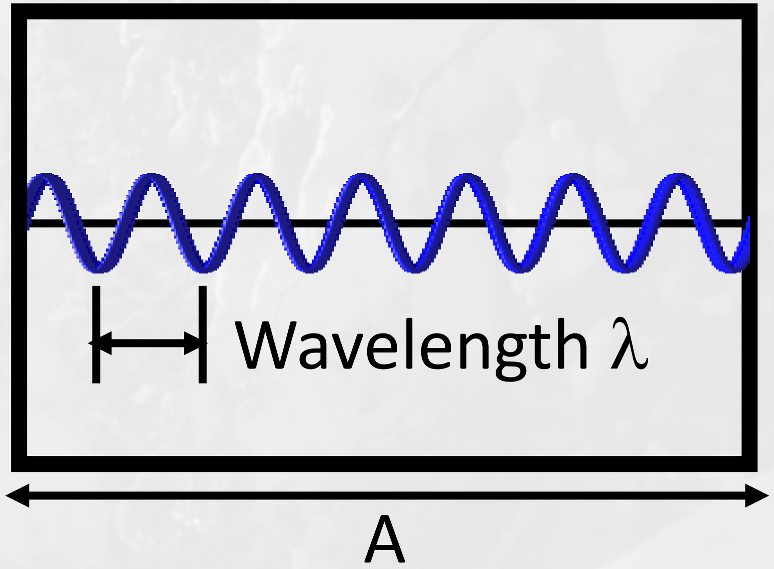


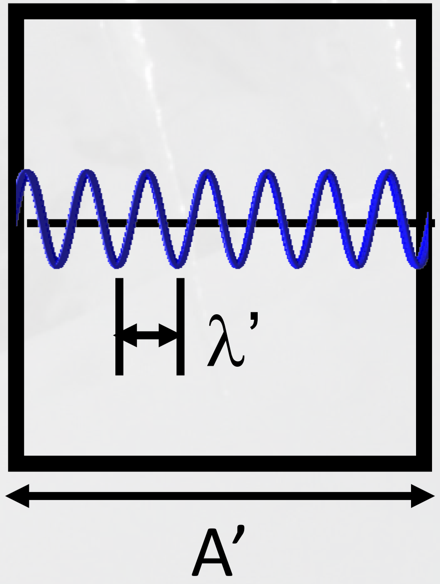
Scheibner, *et al.*, Nature Phys. (08)

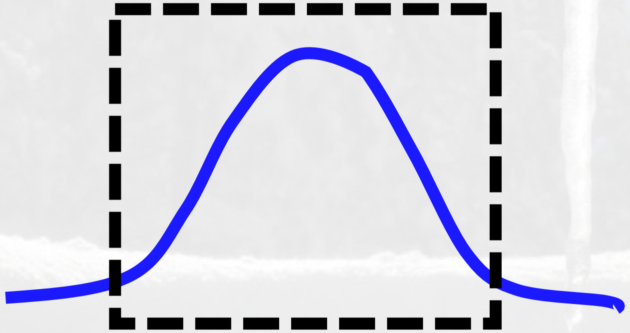
What's Quantum?

Particle/Wave in a box









Wave must disappear at the walls (*)

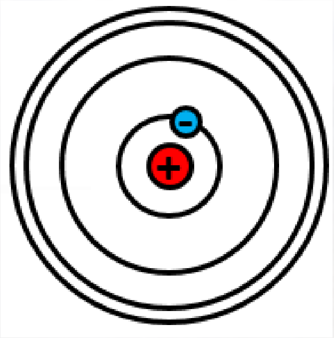
Energy ~ 1/λ

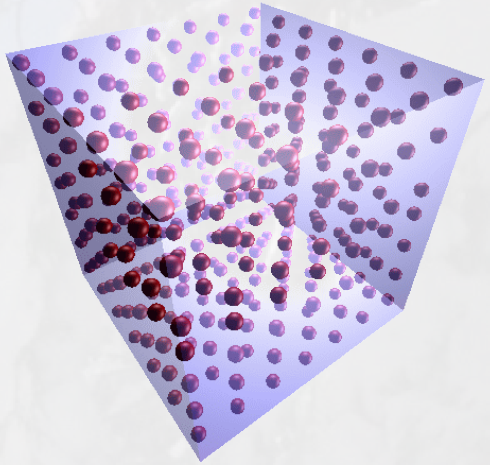
Energy Quantization & more

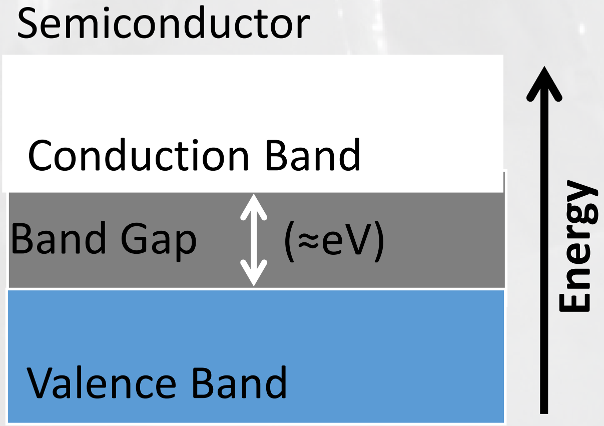
Particles can exist in classically forbidden regions, tunnel, be in two or more places at once,…

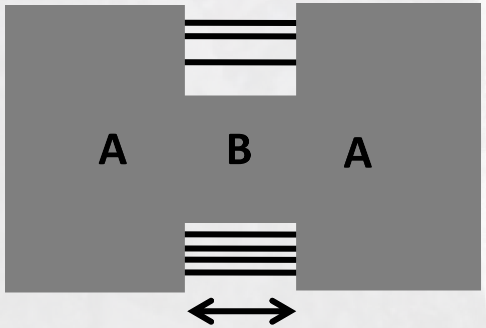
(*) If walls are infinitely high

'Artificial' Quantum Matter





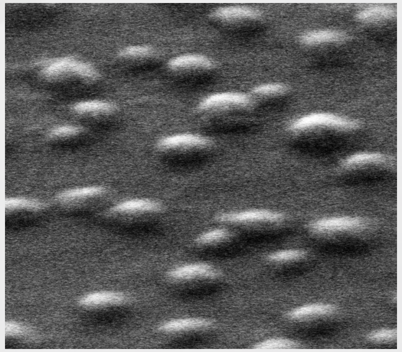




Nanometer Scale

(in all 3 dimensions)

Spatial confinement yields a discrete atomic energy level structure



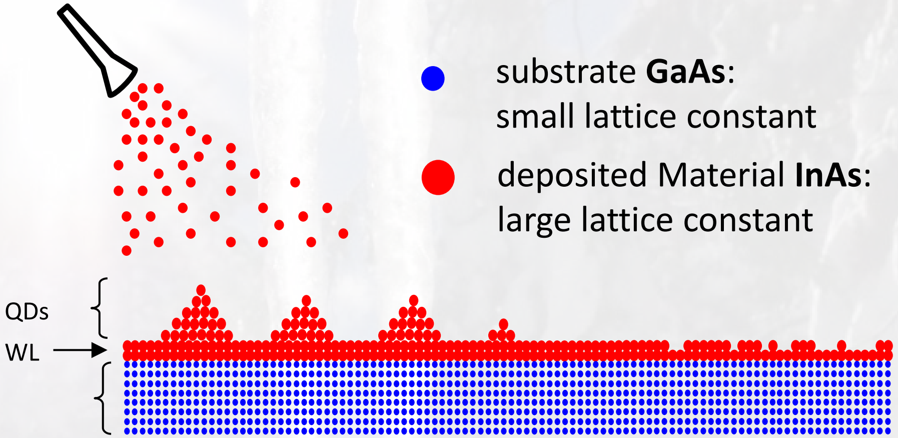
- 10-20 nm wide
- 2-10 nm high

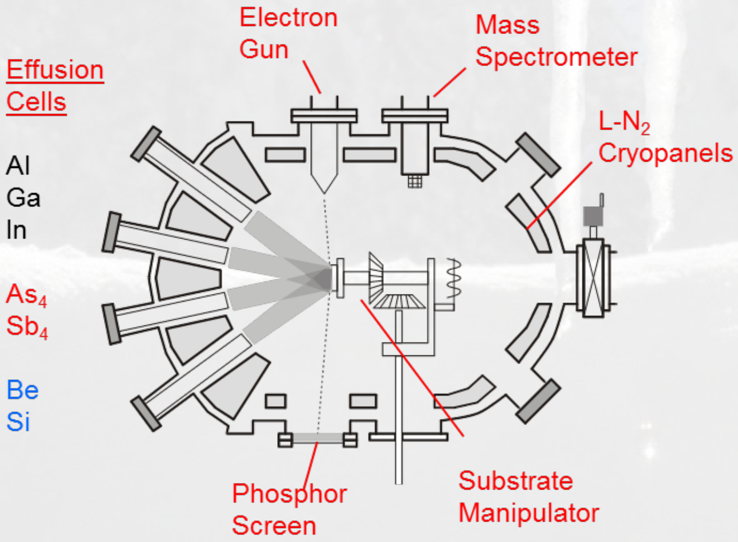
Quantum Dots ↔ Artificial Atoms

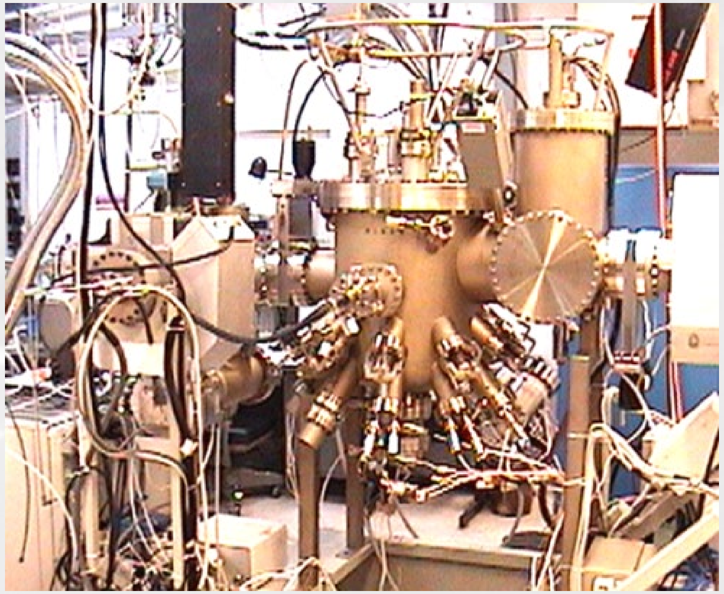
Atoms → Molecules → Crystals → Artificial Atoms (Dots) → Artificial Molecules → …

QD Growth

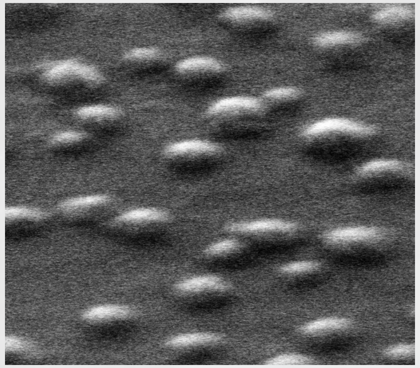
Molecular Beam Epitaxy of 'self-assembled' InAs QDs





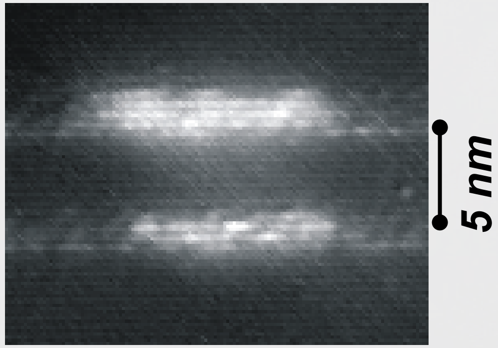

MBE at the Naval Research Lab

Randomly nucleated QDs



- 10-20 nm wide
- 2-10 nm high

Vertically stacked QDs



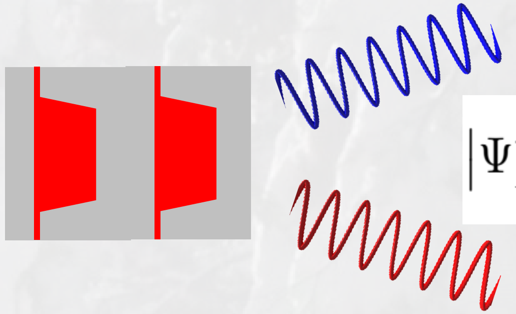
- Strain from first QD nucleates a second

Why Stack Quantum Dots?

FUNCTIONALITY

D. Nash, T. Darville, theconversation.com (2020)

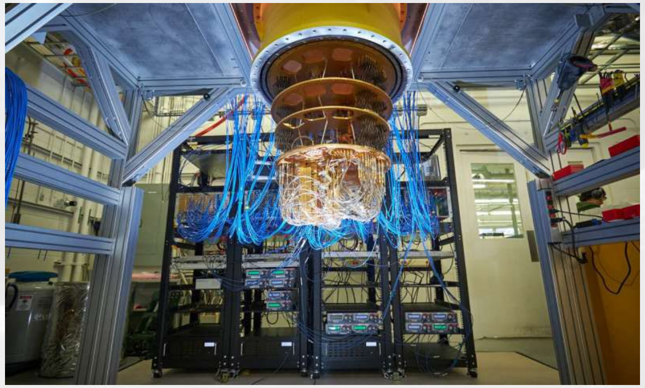
Quantum technology and quantum-enhanced technology



On-demand single photons &

$$|\Psi^{+}_{HV}\rangle = \frac{1}{\sqrt{2}}\left(|H\rangle_1 |H\rangle_2 + |V\rangle_1 |V\rangle_2\right)$$

Entangled photons



B. Yirka, phys.org (2020)

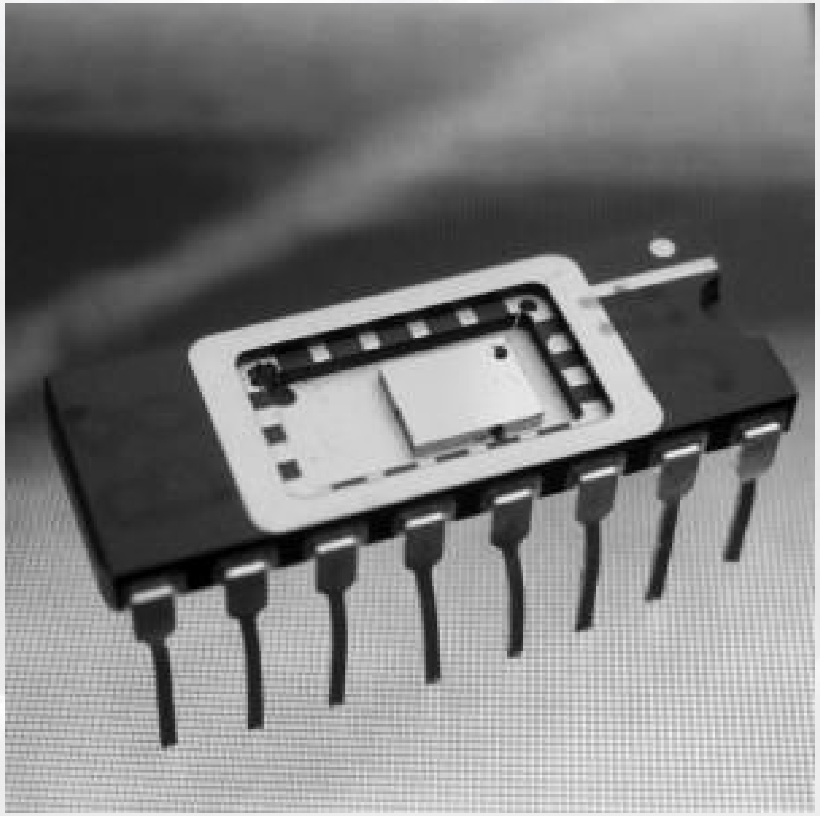
Coupled dots….

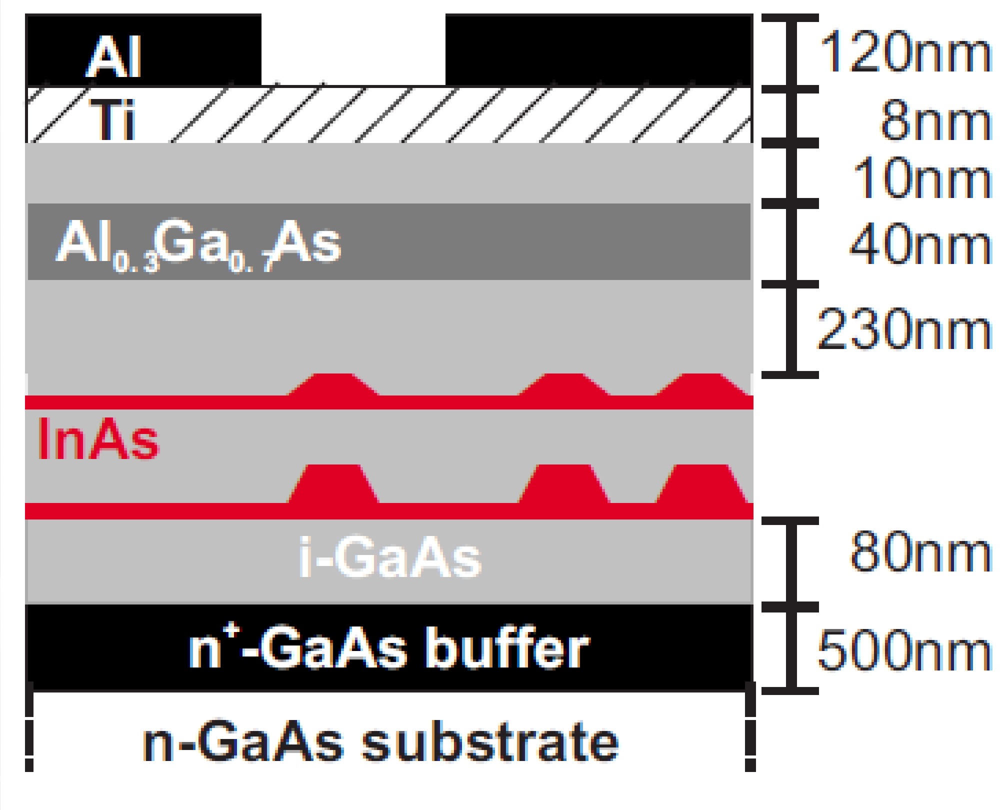
more control….

upscaling….

improved tools..

Quantum Dot Molecule Samples

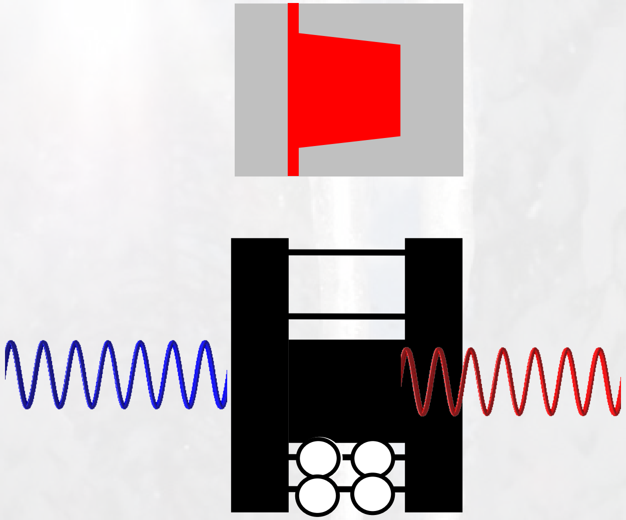


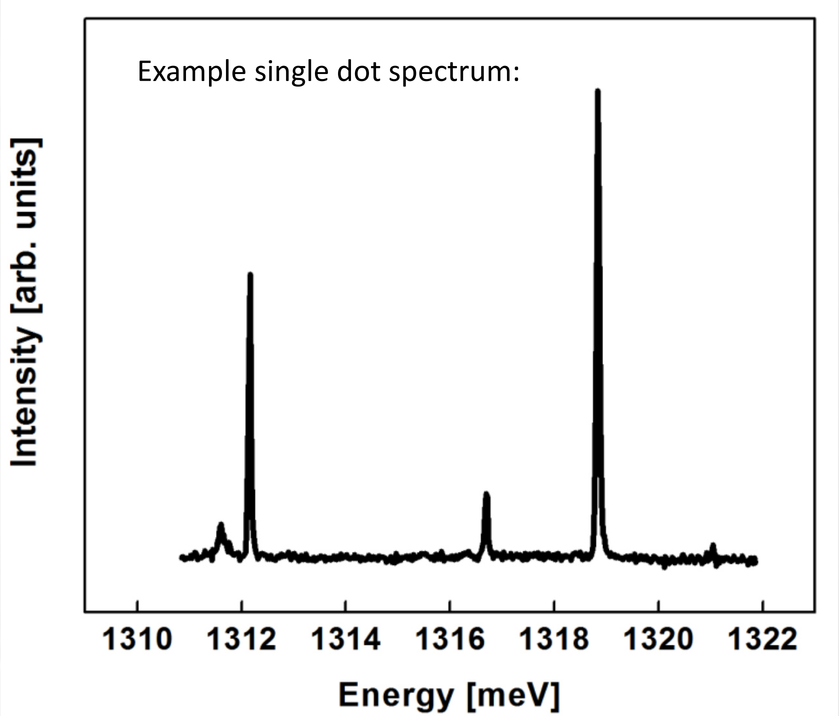


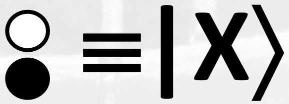
Schottky diode device structure

Scheibner, *et al.*, PRB 75, 245318 (07)

Optical spectroscopy



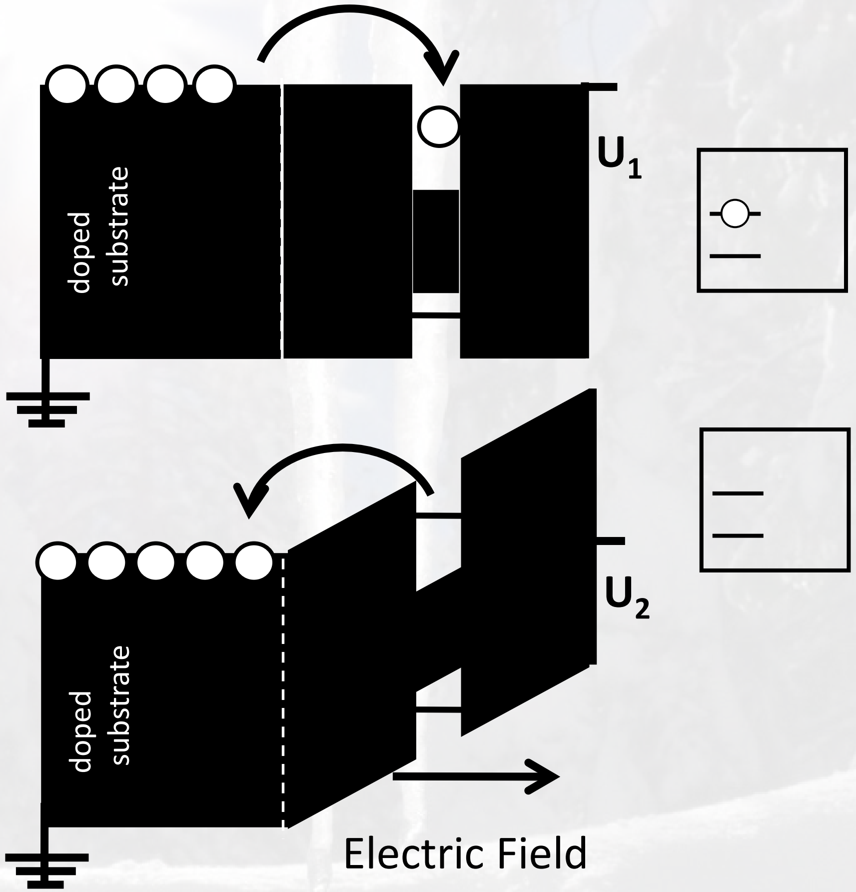


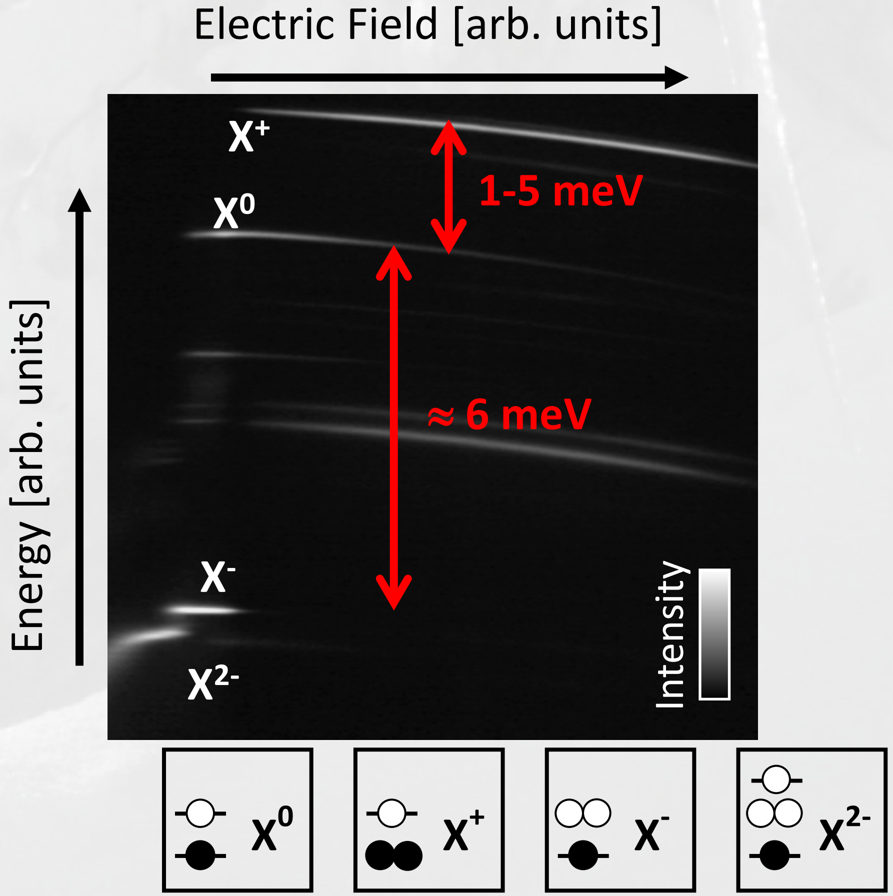


Electron-hole pair (Exciton)

- **Photon:**
  - Absorbed by QD
    - ⇒ Promotes electron into conduction band
  - Emitted by QD
    - ⇒ recombination of electron-hole pair

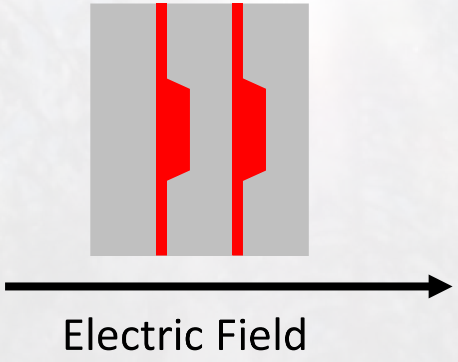
Electric Field

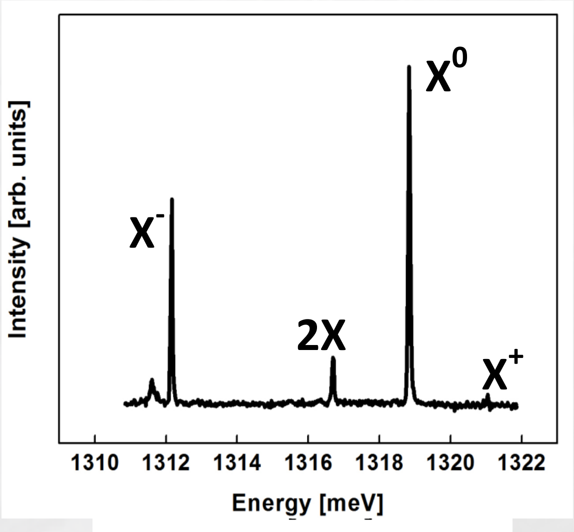


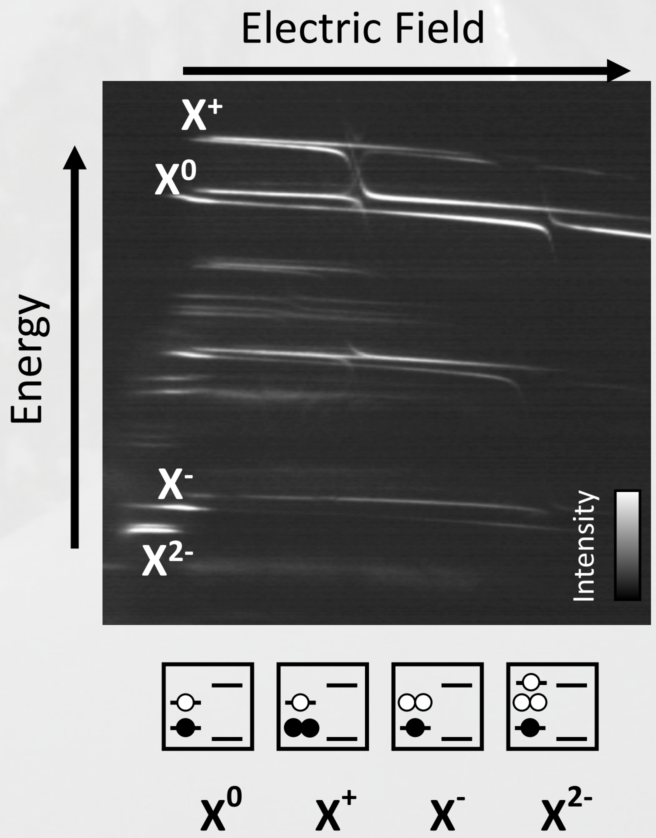


- Add/subtract charges AND Spins
- Quantum Confined Stark Effect (shifts the optical transition energy)

Coupled Quantum Dots



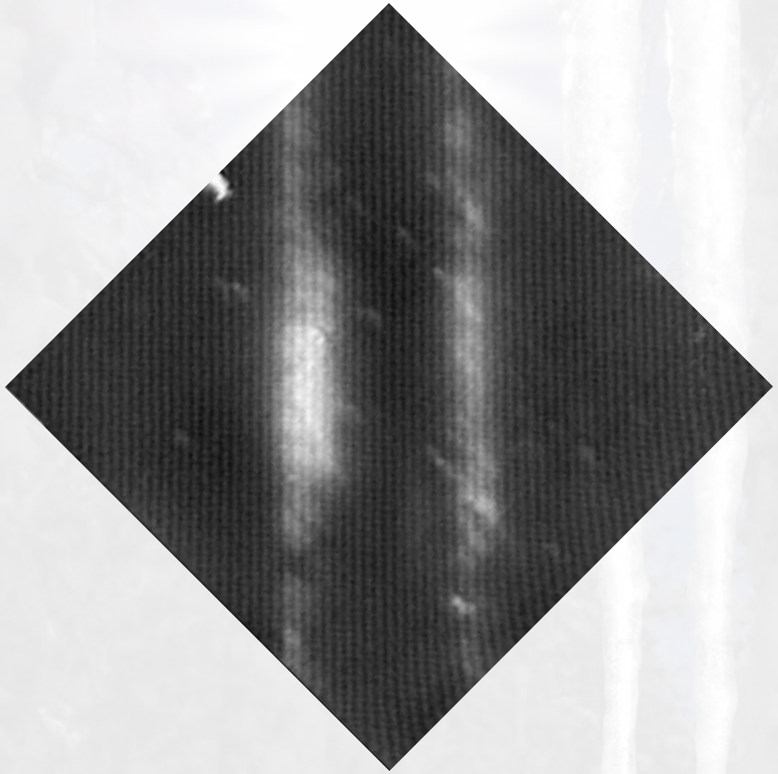


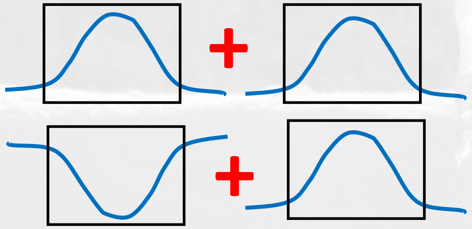


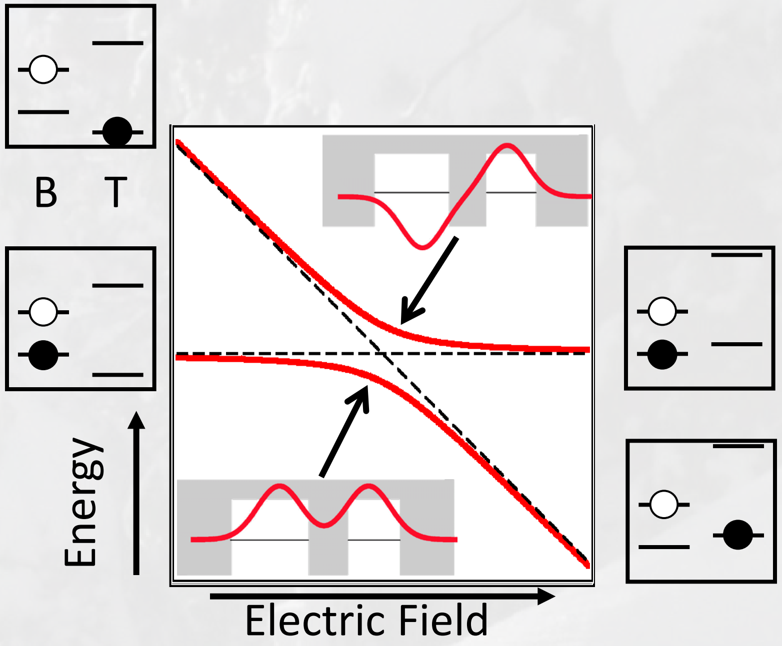
Stinaff , Scheibner *et al.* Science (06),
Bracker, Scheibner et al APL (06),
Scheibner et al. PRL (07),…

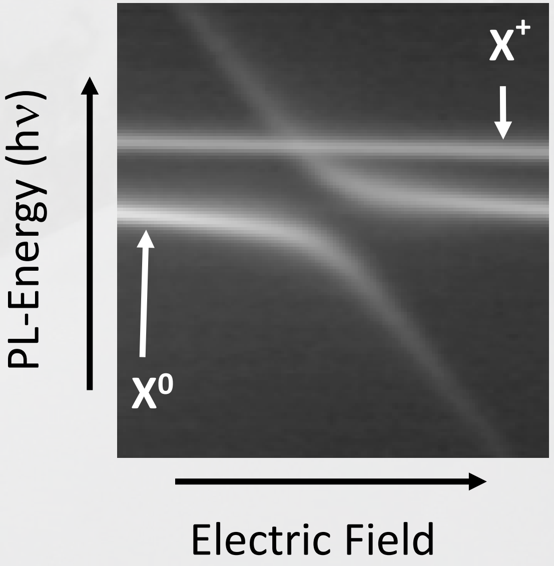
… controllable interactions between two dots …

Tunneling

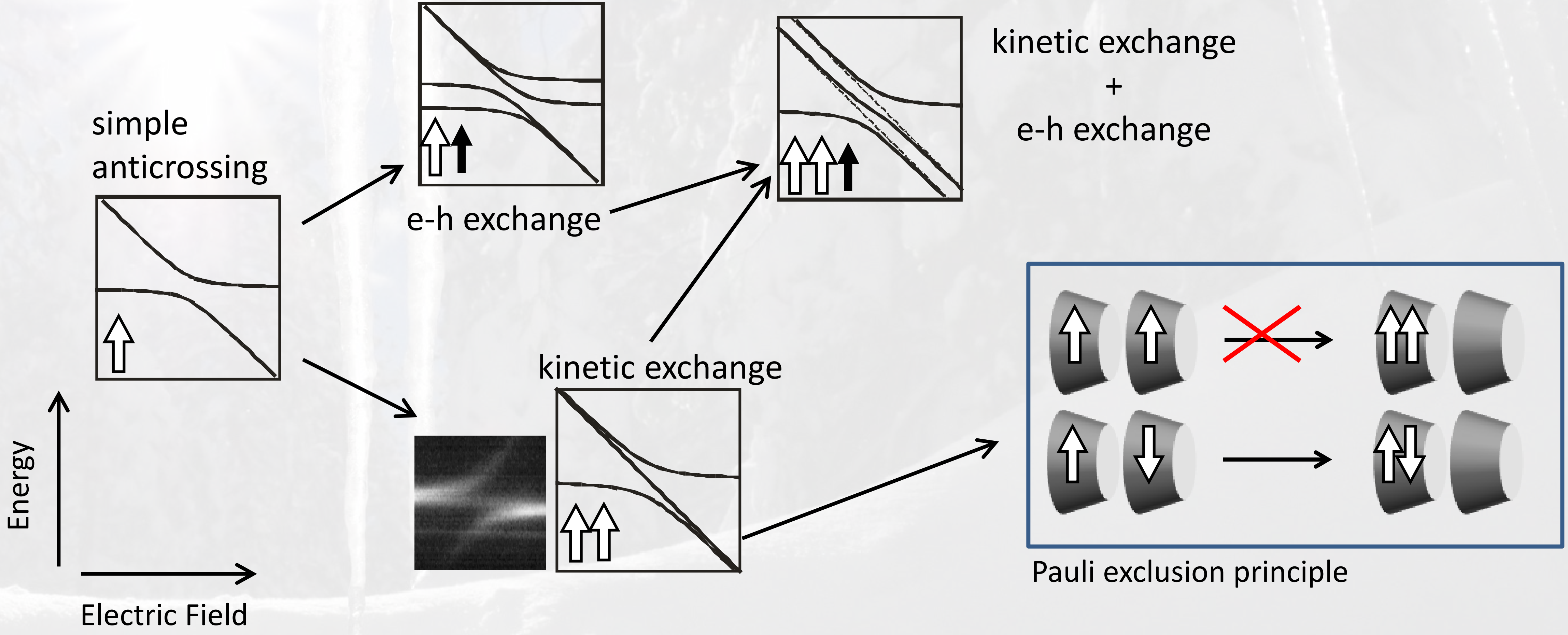








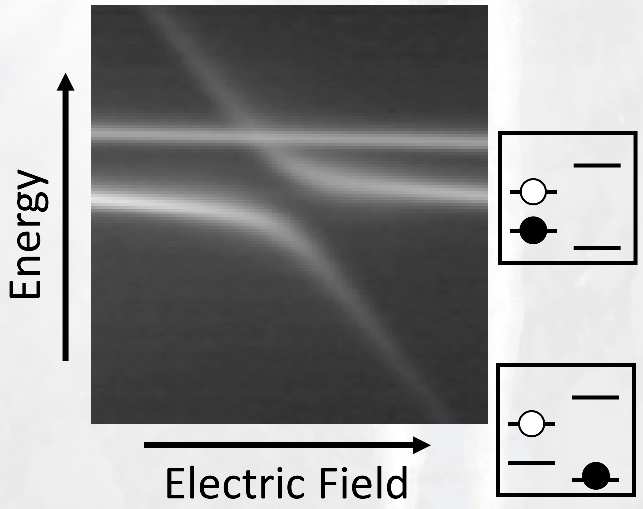
Tunneling and Spin

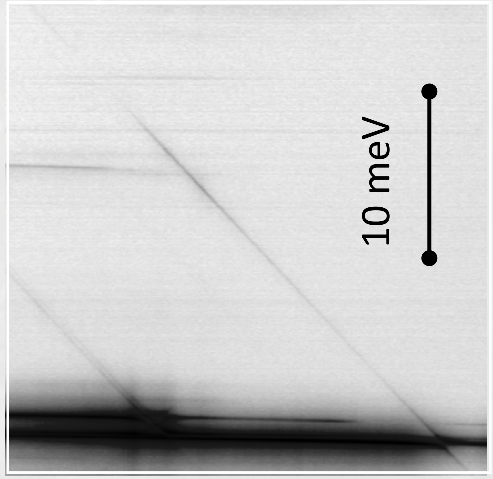


...electrically tunable spin-spin interaction...

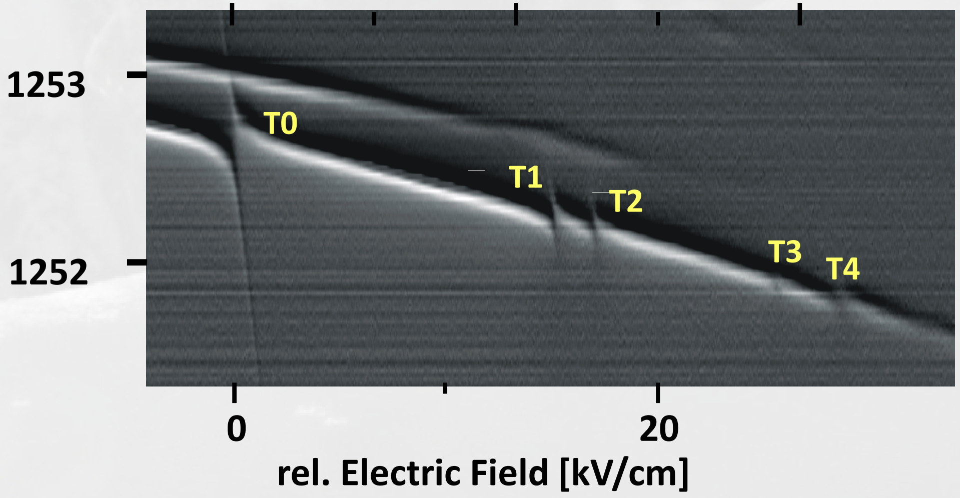
Scheibner, *et al.*, PRB 75, 245318 (07)

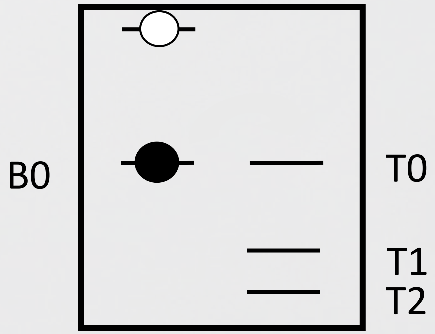
Coupled Quantum Dot Tunability





Stinaff, Scheibner, *et al.* Science (06),
Scheibner, *et al.,* Nature Phys. (08)
Scheibner et al. SSC (09),
Kerfoot, et al. Nature Comm. (14) ,...

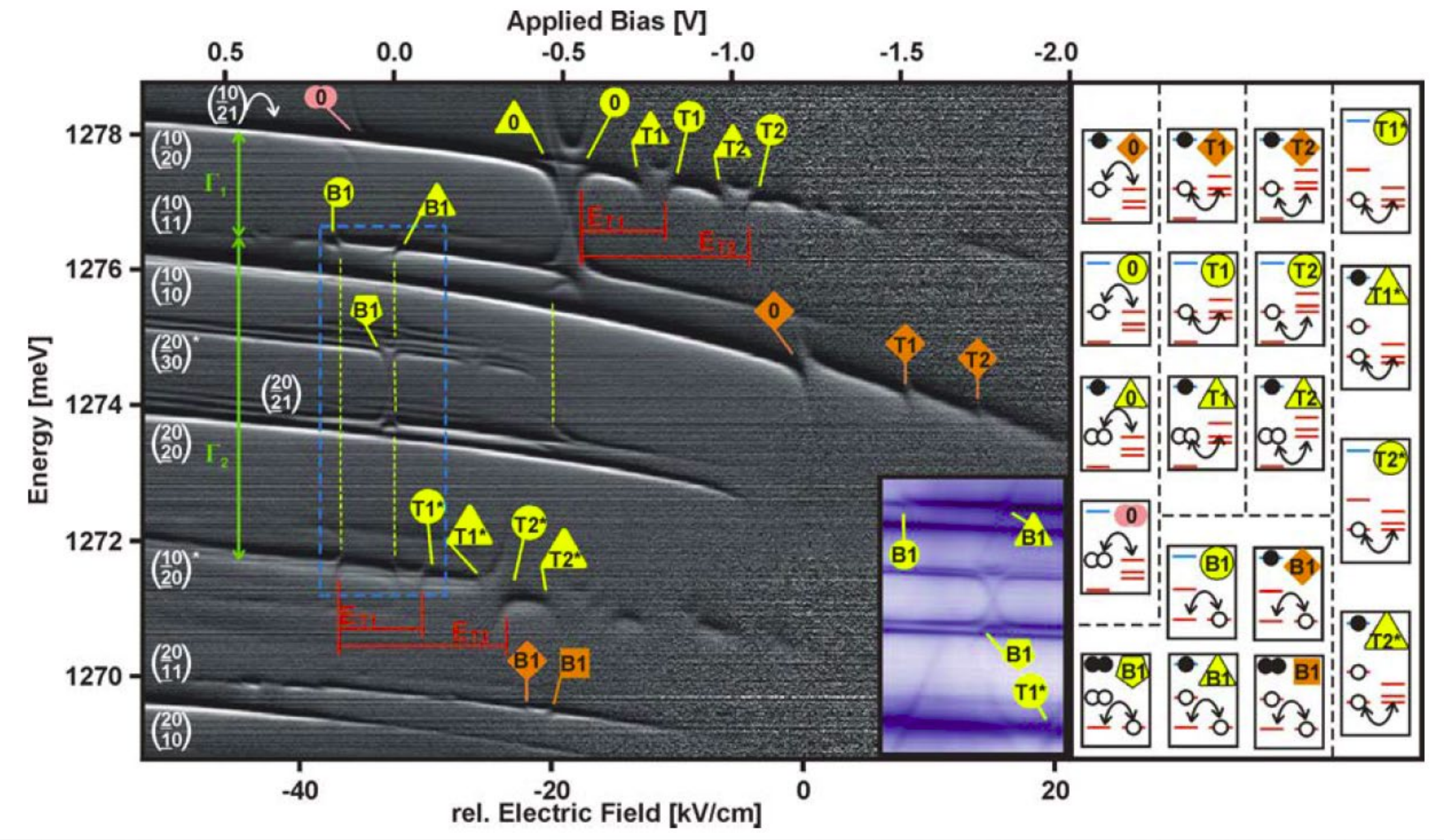


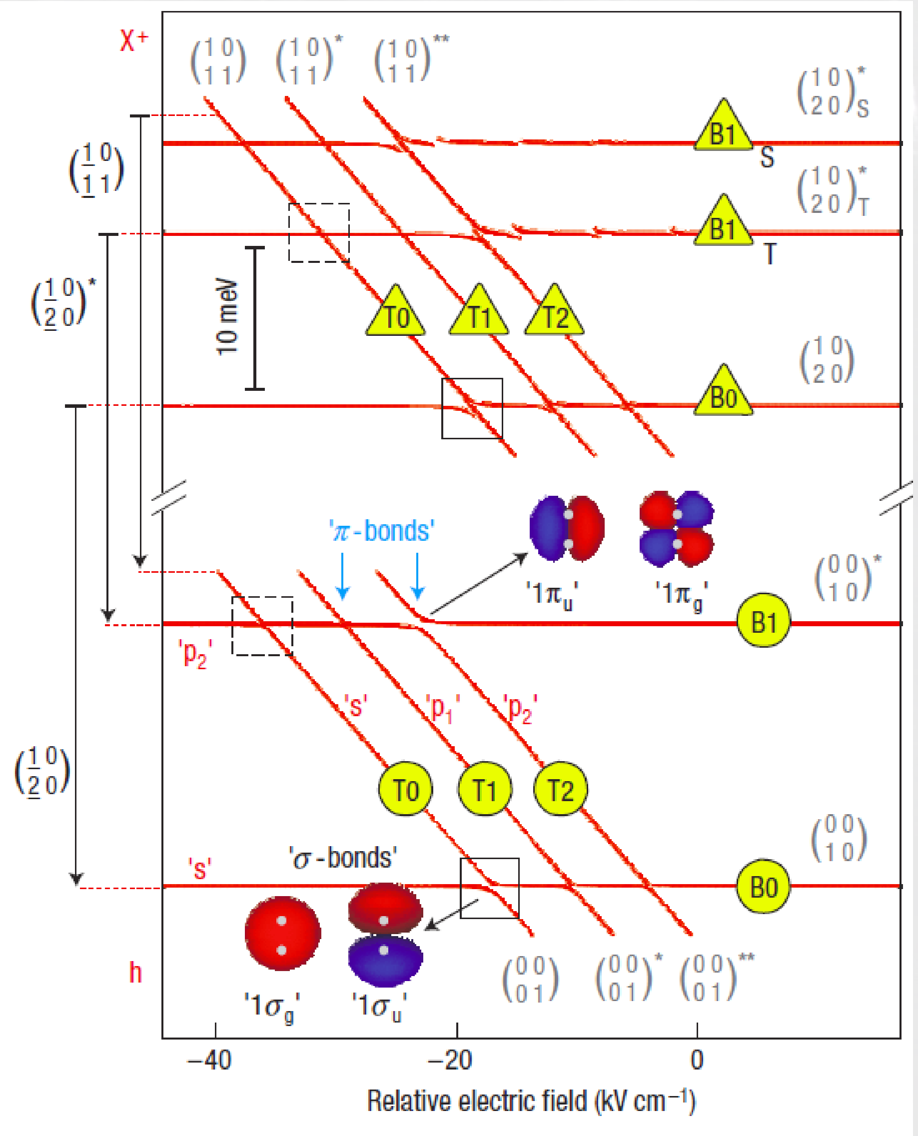


Control over:
- wave function overlap
- transition energies
- energy level
- state symmetry
- ....

... versatile control over quantum states...

Just 2 Dots:





Two 0-dimensional solid-state systems harbor a world of opportunities!

Scheibner, *et al.*, Nature Phys. (08)

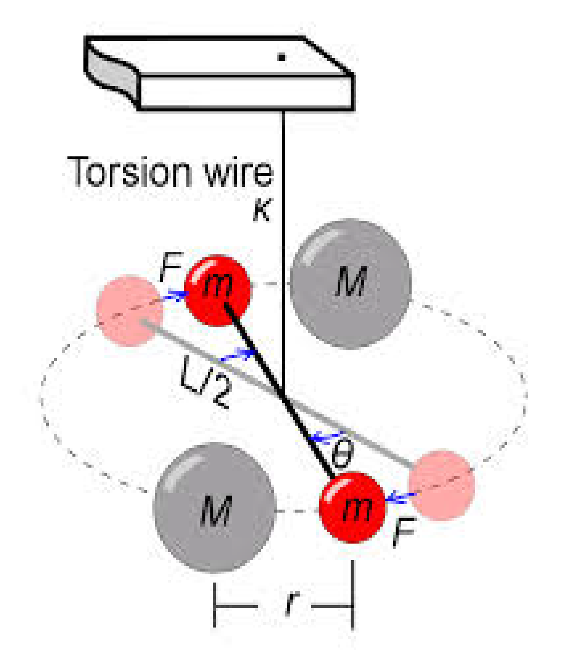
Examples

Quantum-enhanced motion sensing

GraSP: Gravity- **S**pin-**P**robe

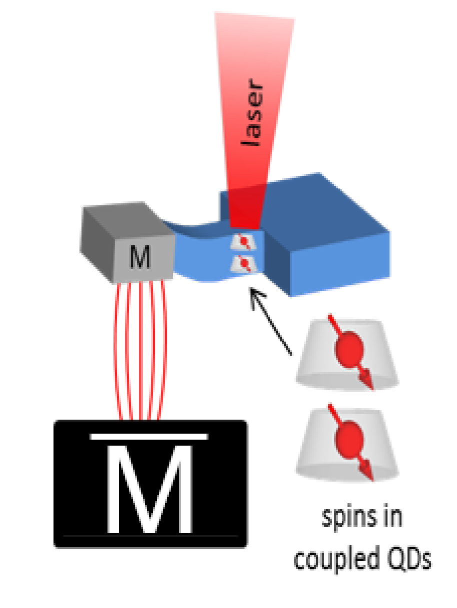
Dots vs. Gravity

A modern take an a Classical Experiment



Cavendish Torsion Balance

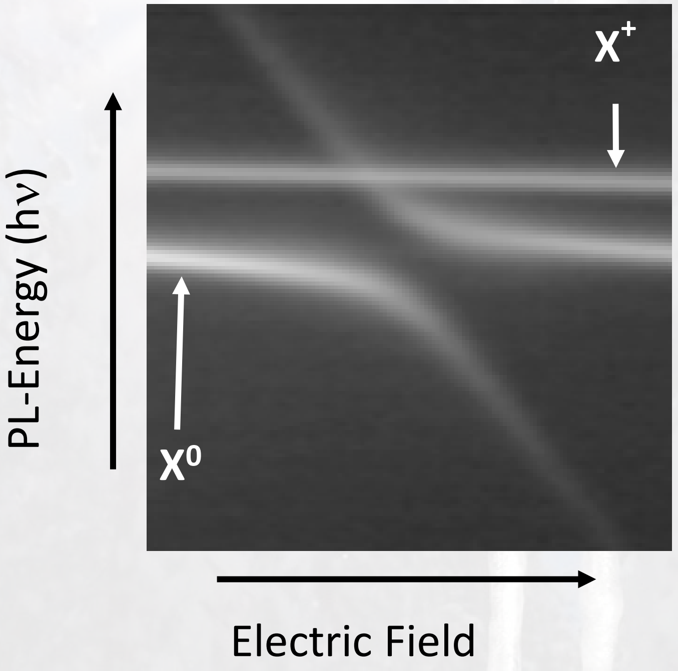
Source: Wki

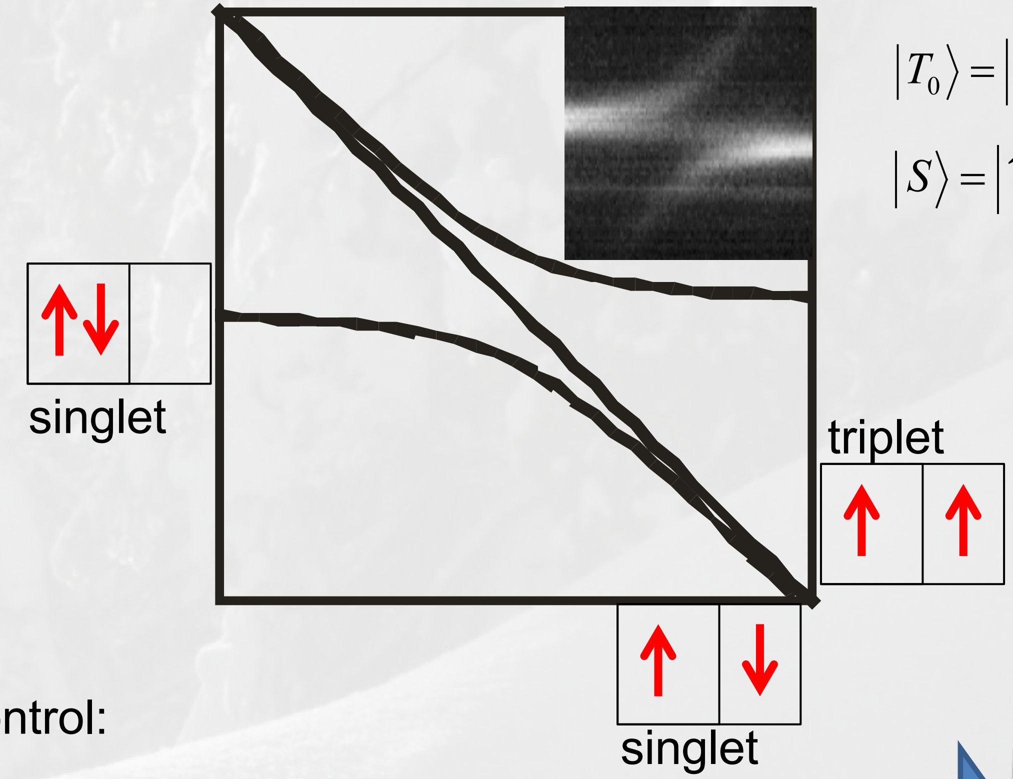


Gravity- **S**pin-**P**robe

Cavendish Balance	GraSP
Two masses	Two spins & mass
Spatial separation	
Rigid connection	Entanglement
Angle resolution	Coherence
Torsion	Strain
Sensed in one way	Sensed in multiple ways

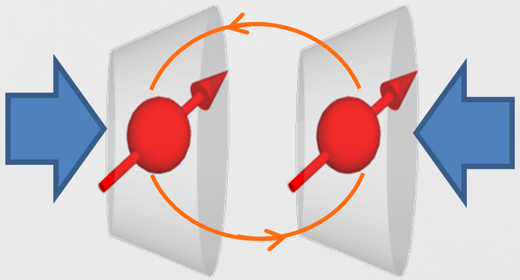
Background





$$|T_0\rangle = |\uparrow\rangle_1|\downarrow\rangle_2 + |\downarrow\rangle_1|\uparrow\rangle_2$$

$$|S\rangle = |\uparrow\rangle_1|\downarrow\rangle_2 - |\downarrow\rangle_1|\uparrow\rangle_2$$



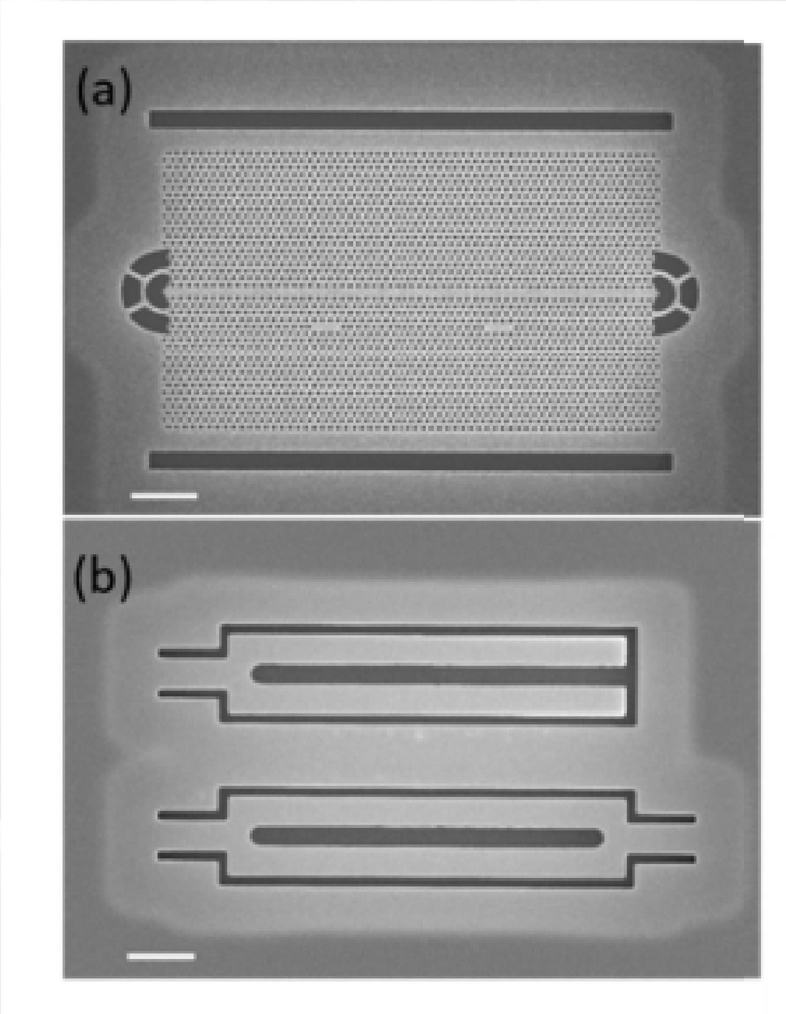
Dot separation and crystal parameters control:

- Transition energy
- Sensitivity to electric field
- Coupling of electrons/holes to the lattice
- Coherent tunneling → anticrossing splitting → singlet/triplet splitting

Applying strain affects all these aspects

Scheibner, et al., SSC (2009), PRL. (2007), PRB (2007))

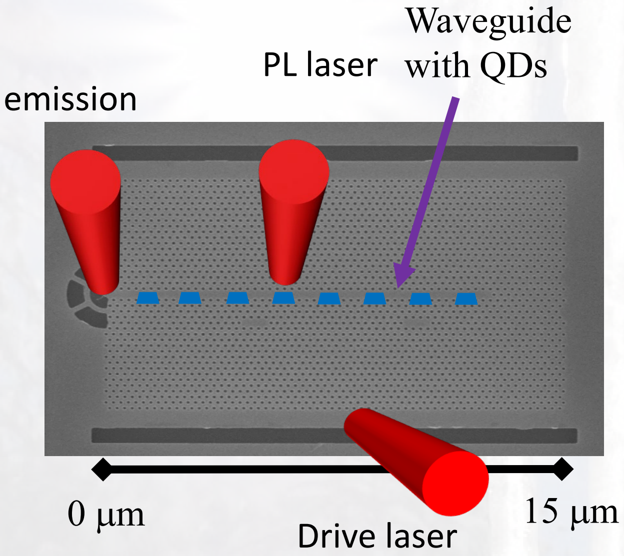
Mechanical Micro-Resonators



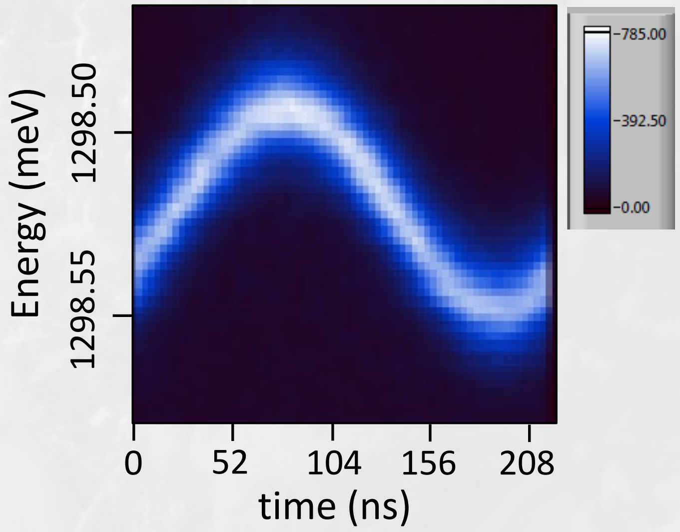
SEM image of
photonic
crystal membrane

SEM image of
tuning
fork structures

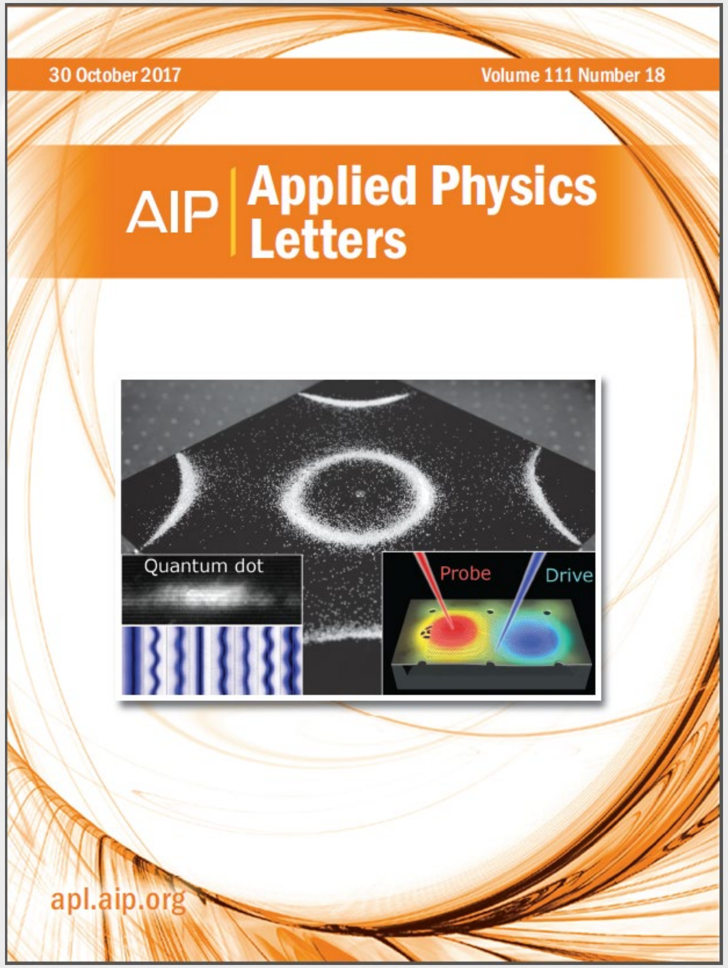
QD-mechanical coupling in a membrane



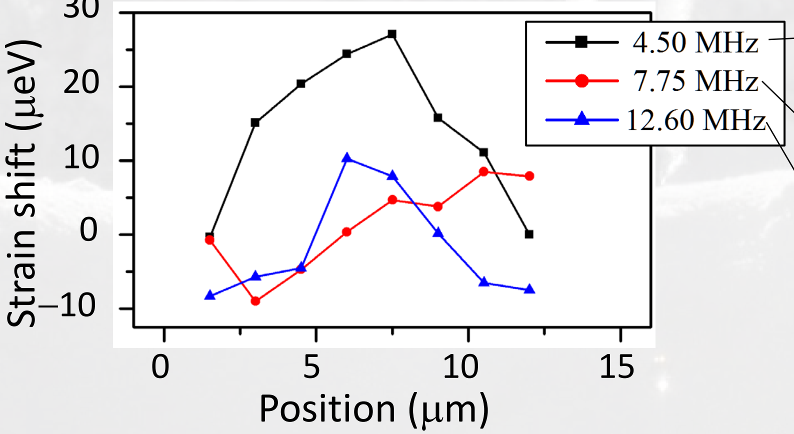
QD emission when driven at 4.5MHz

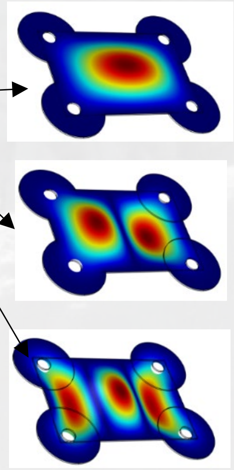


Shifts ±27 μeV



Mapping QDs along waveguide for different flexural modes





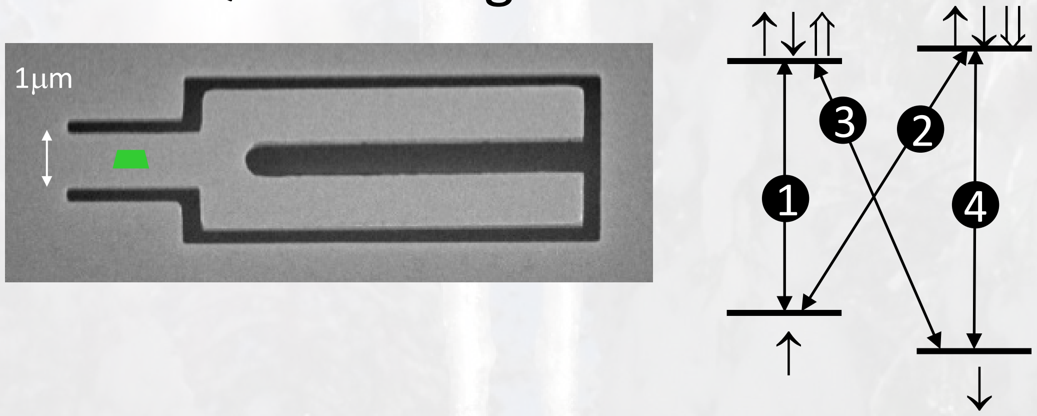
- Gives time-dependent strain from nanometer-sized objects
- Response of QDs stronger than displacement at higher frequencies

S. Carter, et al., APL 111, 183101 (2017)

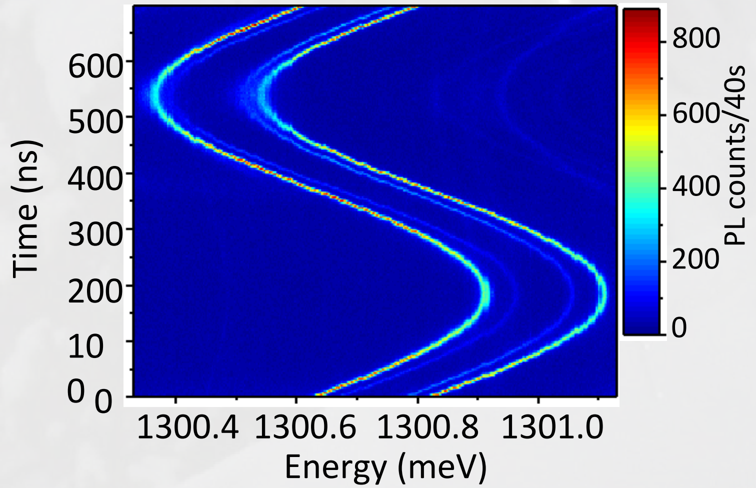
Hole-Spin Coupling to Strain/Motion

Optically drive mechanical resonance and measure time-dependent changes in optical properties

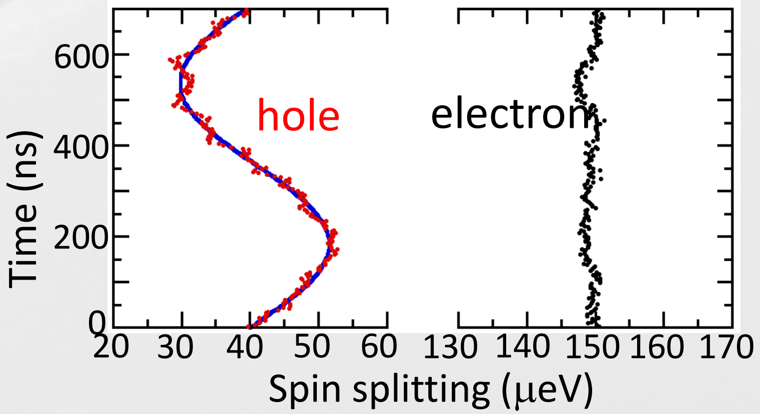
InAs QD in tuning fork



QD emission synchronized to vibration in 6T magnetic field



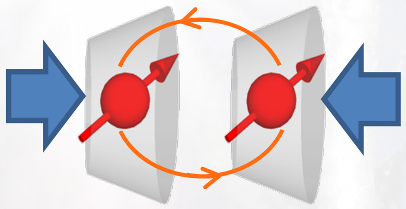
Spin splittings vs. time



- **±25% change in hole spin splitting**
- No clear change in electron spin
- Hole spin transitions ~1000 times sharper than optical
- Coupling ~17 THz/strain $\rightarrow g_0 \sim$ 2kHz
- *With improved collection*, estimate sensitivity of 2 × 10^{-11} strain/Hz^{½} for single QD

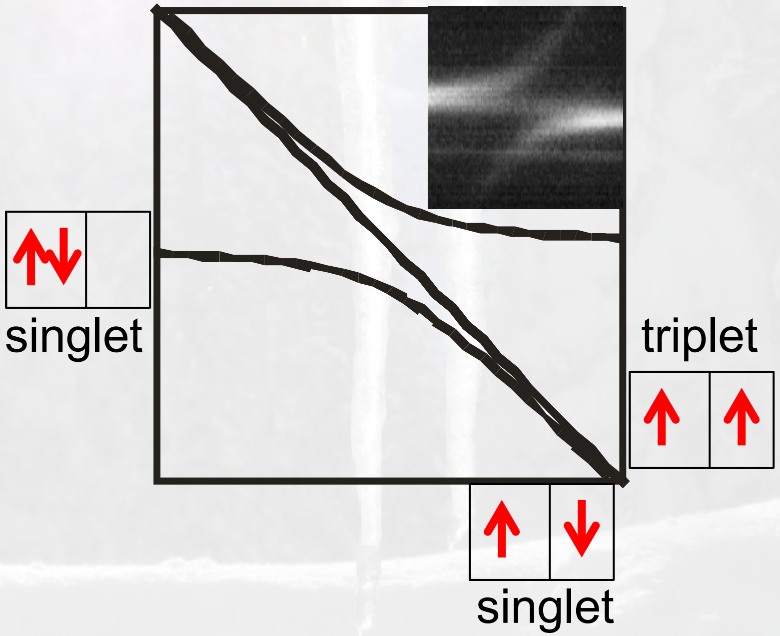
S. Carter, et al., PRL 21, 246801 (2019)

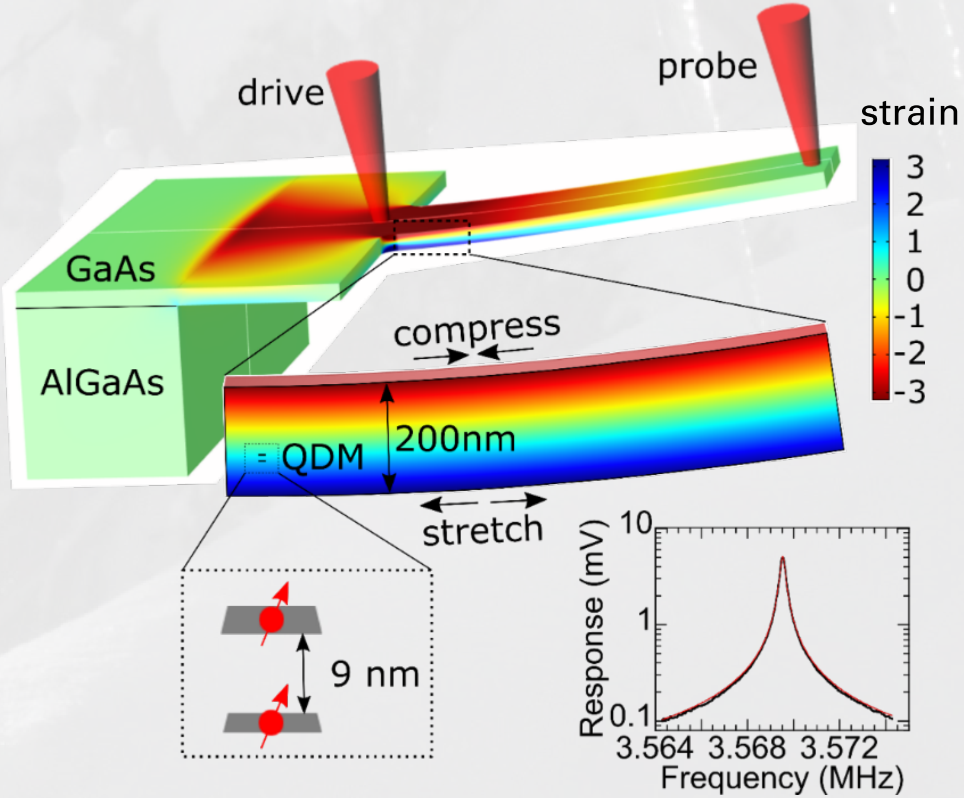
Entangled Spins coupled to Strain/Motion



$$|T_0\rangle = |\uparrow\rangle_1|\downarrow\rangle_2 + |\downarrow\rangle_1|\uparrow\rangle_2$$

$$|S\rangle = |\uparrow\rangle_1|\downarrow\rangle_2 - |\downarrow\rangle_1|\uparrow\rangle_2$$

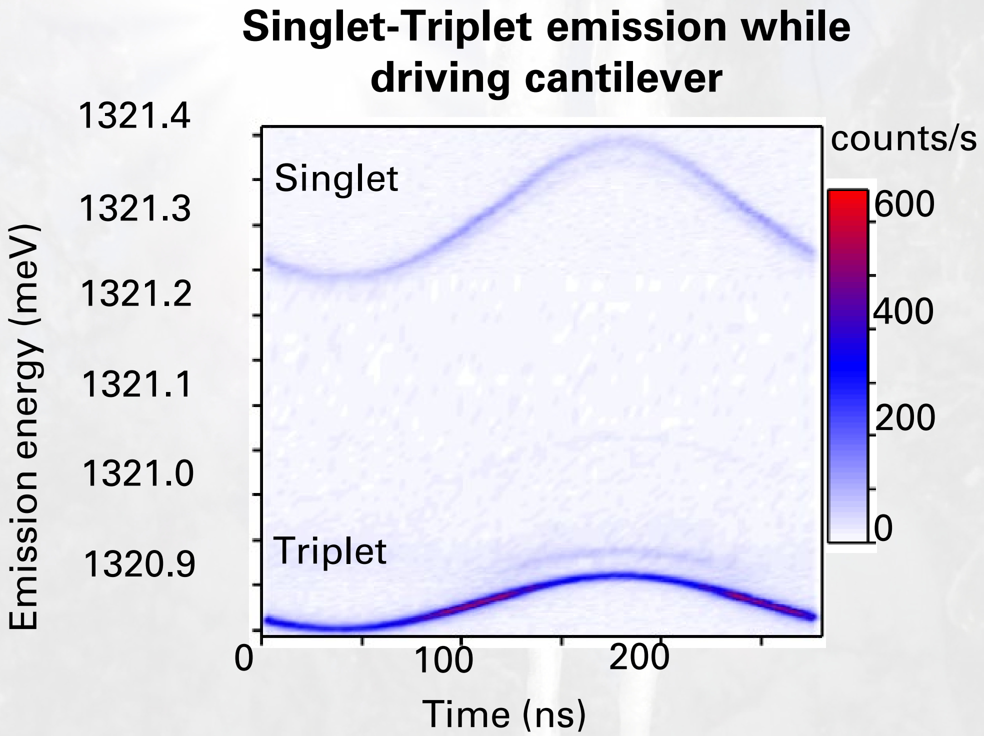


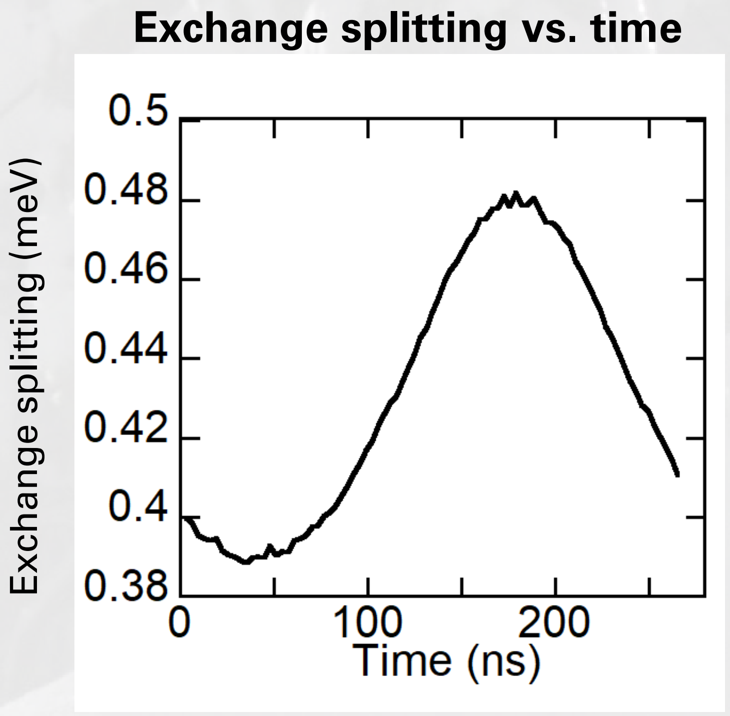


Each QD feels a different strain

S. Carter, et al., Nano Lett. (2019)

Entangled Spins coupled to Strain/Motion





- Singlet shifts 2.5 times more than the triplets
- 30 times higher spin-strain coupling than single hole spin

$G_{ex} \sim 340$ THz/strain

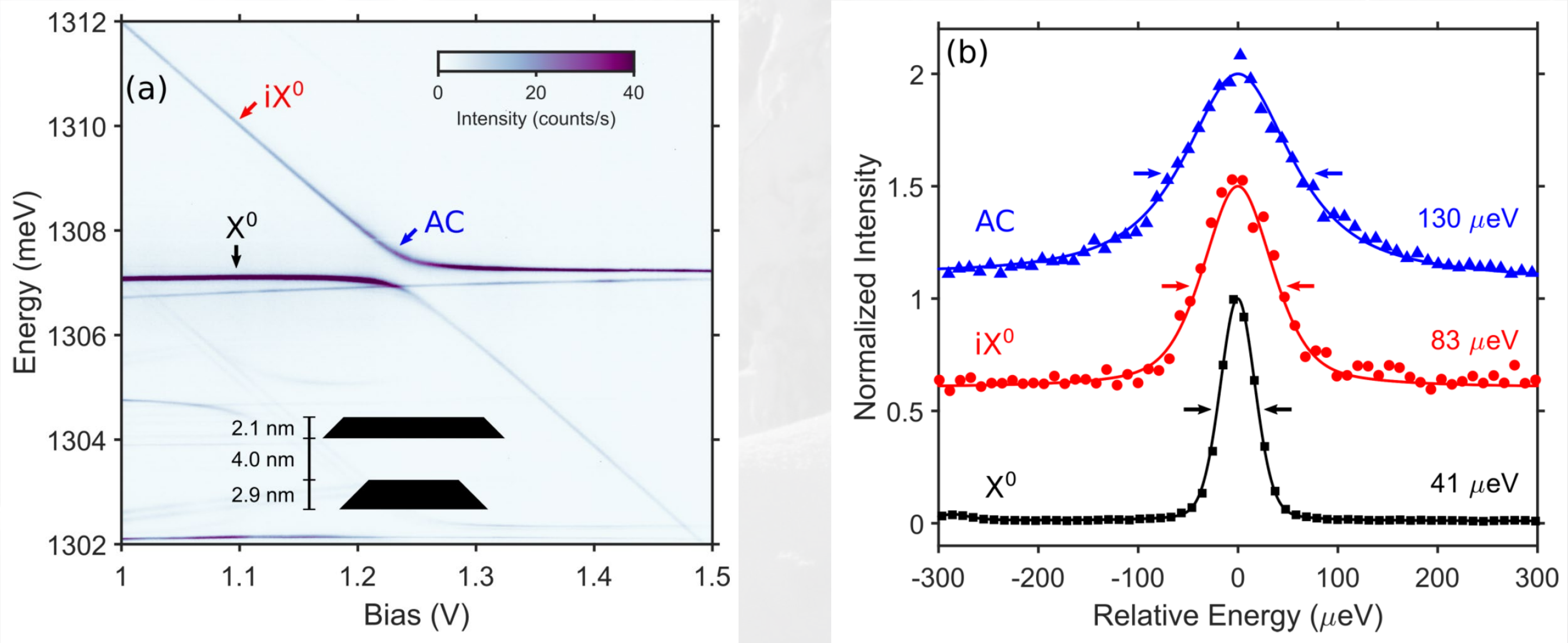
With *optimal collection and* $T_2 = 1\ \mu s$, expect *ac* strain sensitivity of ~10^{-12} strain/Hz$^{1/2}$

S. Carter, et al., Nano Lett. (2019)

Examples

Taming phonons

Linewidths and Tunneling



P. Kumar, C. Jennings, et al., PRB 102, 085423 (2020)

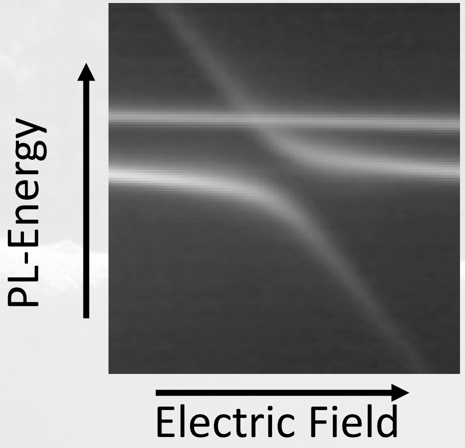
Engineering Electron-Phonon Coupling

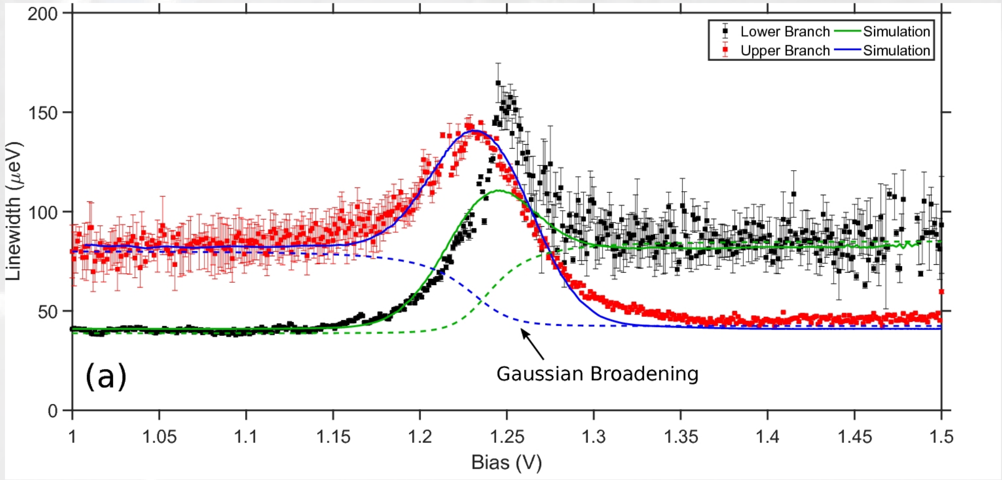
Excitonic transition linewidth

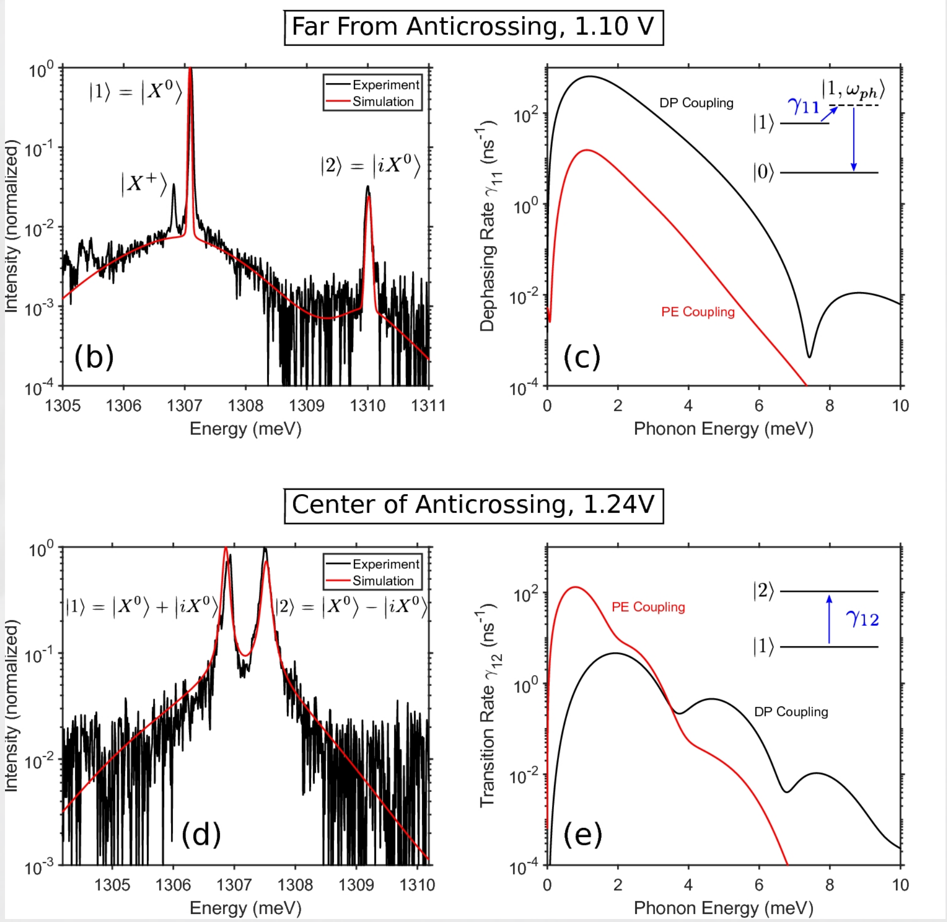
- Resonant enhancement of linewidth at tunnel resonances
- Pronounced at tunnel resonances of ~1 meV

Model of phonon coupling between exciton states

- Deformation potential
- Piezoelectric interactions
- Piezoelectric interactions dominate for phonon energies in the range of ~1meV.





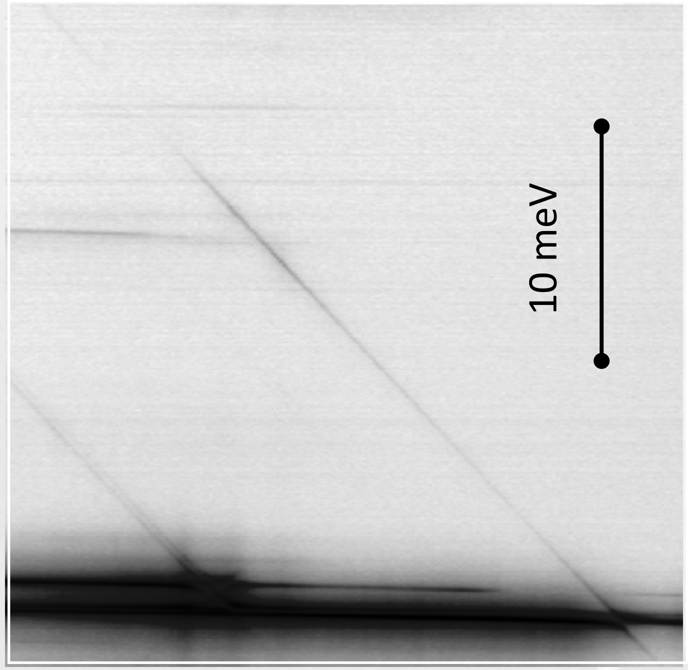


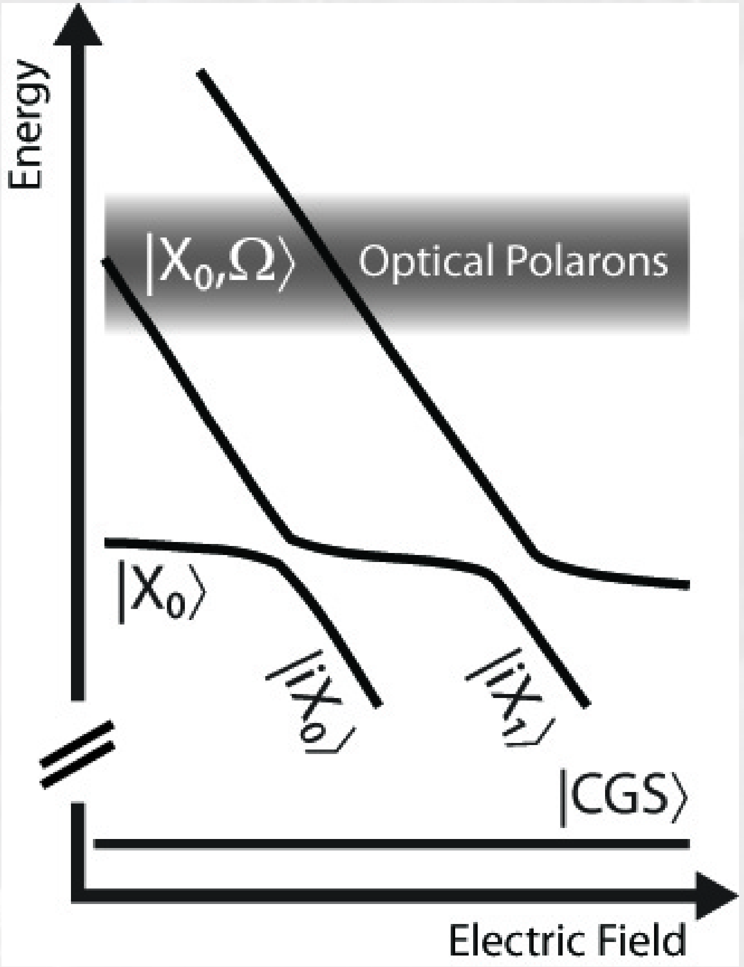
Do enhanced piezoelectric interactions enable higher motion sensitivity or motion control?

P. Kumar, C. Jennings, et al., PRB 102, 085423 (2020)

What about higher energy phonons?

Make use of large tuning range:





$|X_0\rangle$ - Direct exciton (SQD-like)

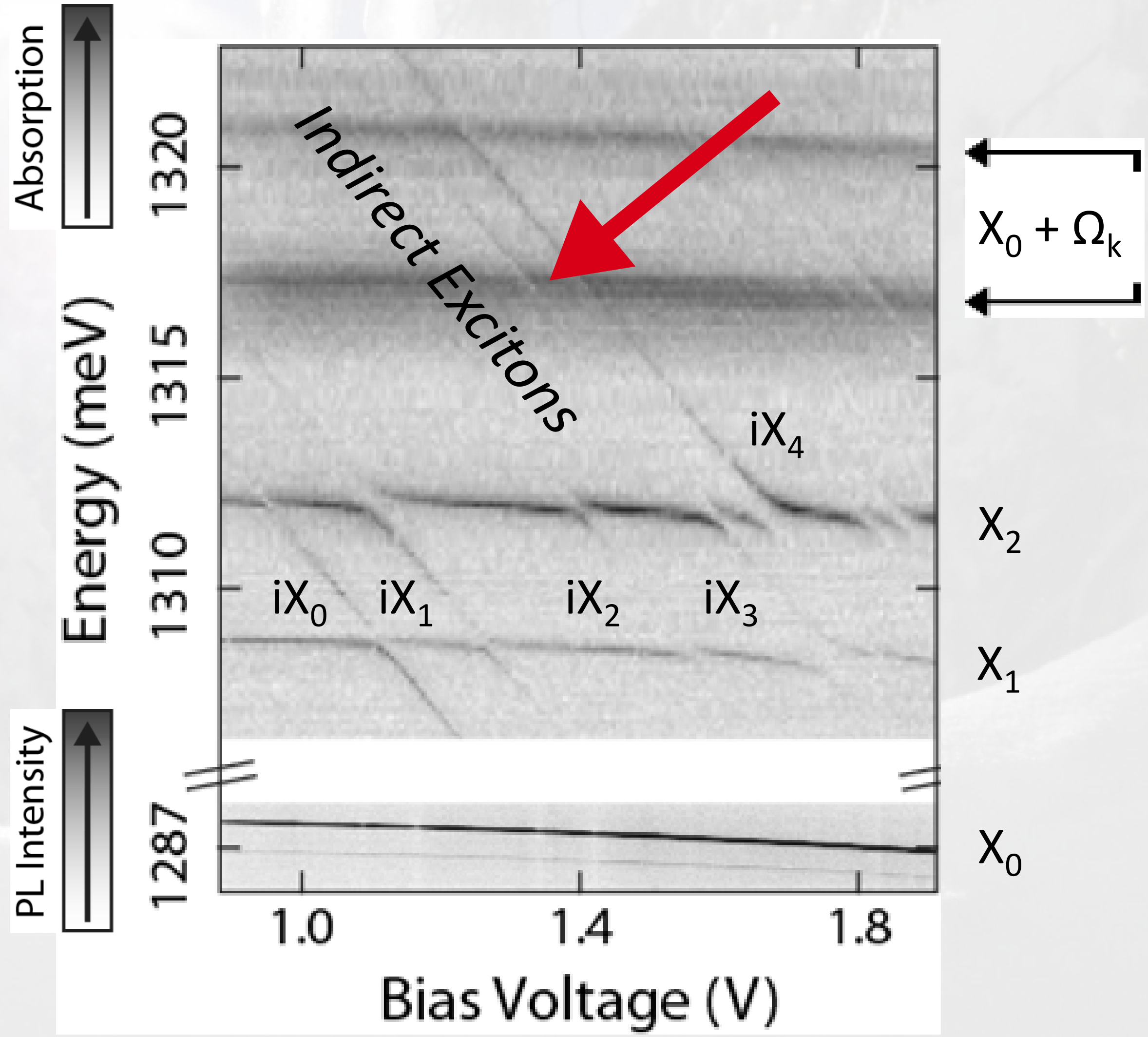
$|iX_n\rangle$ - Indirect exciton

$|X_0,\Omega\rangle$ - (optical) Polaron

Requires excited state spectroscopy

M. Kerfoot et al., *Nature Communications, 5:3299 (2014)*

QDM Excited States



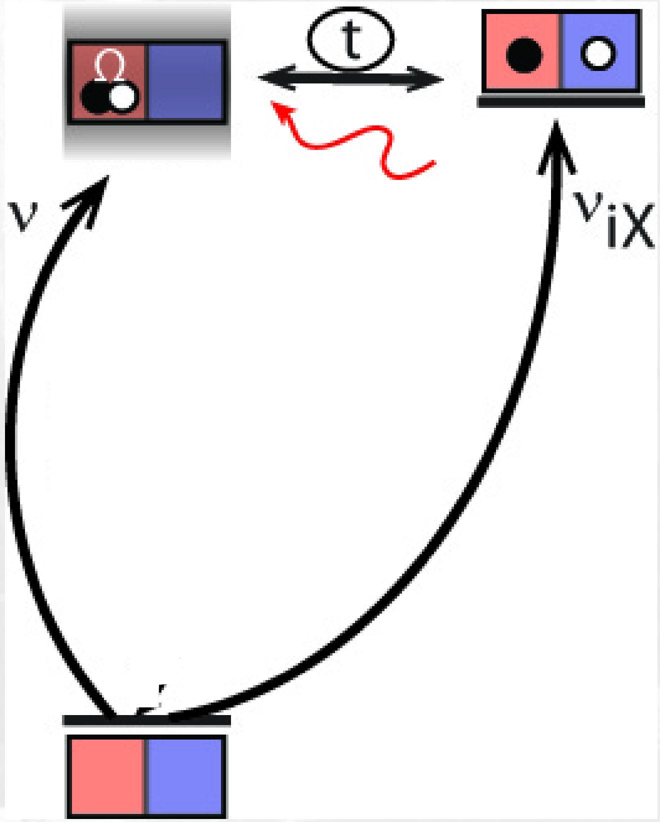
Polaron Continuum
(Ω_k: 28 – 37 meV)

M. Grundmann et al., PRB 52, 16 (1995)

Direct Excitons

M. Kerfoot et al., *Nature Communications, 5:3299 (2014)*

Interference



Fano-Resonance
[U. Fano, Nuovo Cimento 12, 154 (1935)]

⇓

$$|MP\rangle = |iX_n\rangle \pm |X_0,\Omega\rangle$$

Formation of a Molecular Polaron

M. Kerfoot et al., *Nature Communications, 5:3299 (2014)*

Fano Effect

$$I(\omega) = \frac{2\pi}{\hbar}\sum_f \left|\langle f|\hat{V}|0\rangle\right|^2 \cdot \delta(\varepsilon_f - \hbar\omega) = \hbar\omega \cdot \frac{2}{\hbar} \cdot G(\omega)$$

Fermi's Golden Rule
to calculate absorption

$$G(\omega) = -\pi\nu_\Omega\rho \cdot Im \cdot \left[q_{Fano}^2 \frac{\Delta_{ph}\left(1 + \frac{1}{q_{Fano}} F_{ph}(\omega)\right)^2}{\hbar\omega - \varepsilon_{iX} + i\gamma_{iX} - \Delta_{ph} \cdot F_{ph}(\omega)} + F_{ph}(\omega) \right]$$

Optical Green's function

$$F_{ph}(\omega) = \frac{1}{\pi}\int_{-D}^{+D} d\delta\varepsilon_{ph} \frac{1}{\hbar\omega - \varepsilon_{QD1} - \hbar\omega_{ph,0} - \delta\varepsilon_{ph} + i\gamma}$$

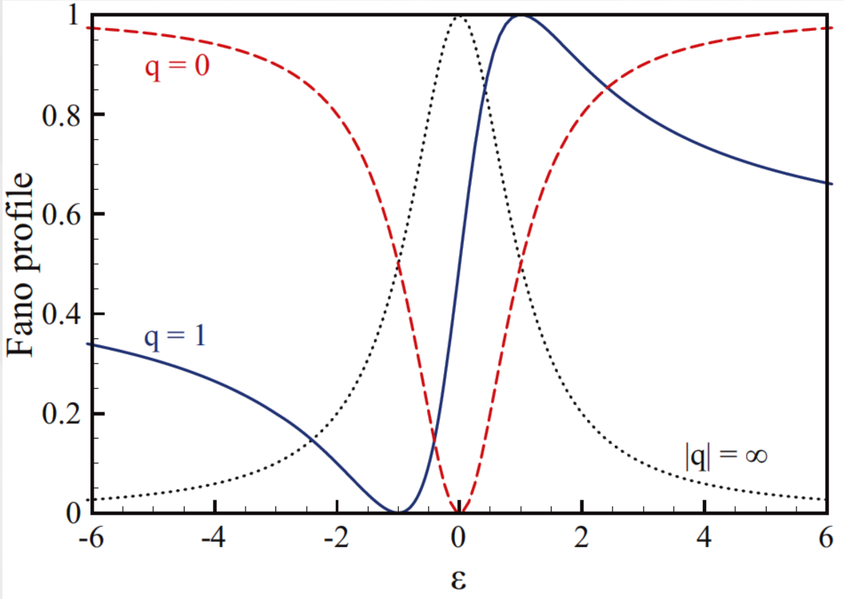
$$q_{Fano} = \frac{\nu_{iX} t}{\nu_\Omega \Delta_{ph}} = \frac{\nu_{iX}}{\nu_\Omega t\pi\rho}$$

Asymmetry factor of
absorption line shape

$$\Delta_{ph} = t^2\pi\rho$$

Additional broadening
due to tunnel coupling

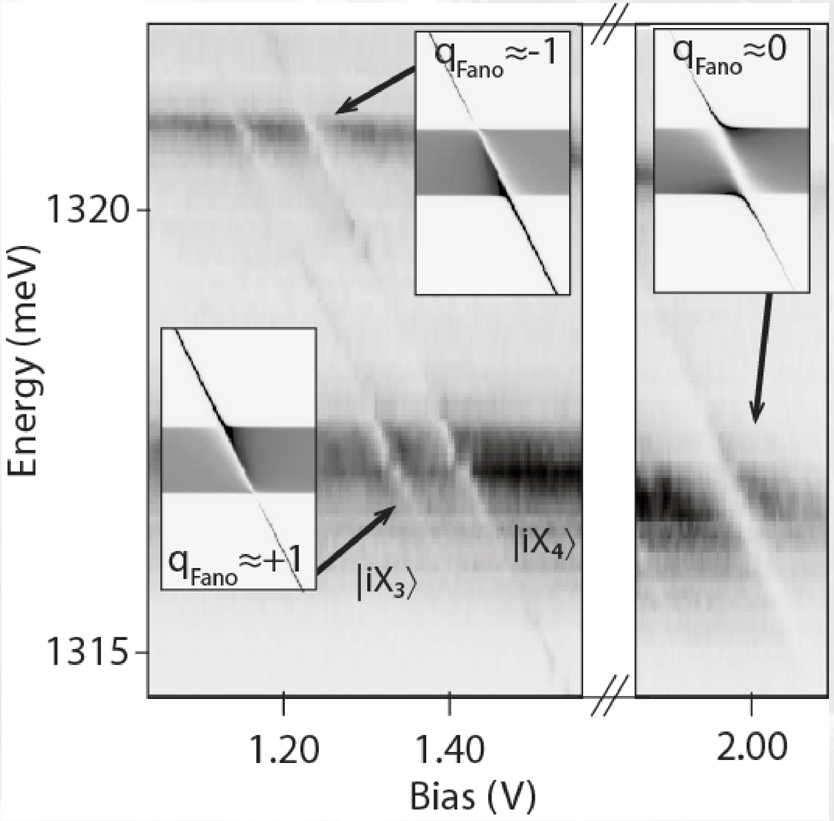
A. Govorov, Ohio Univ.

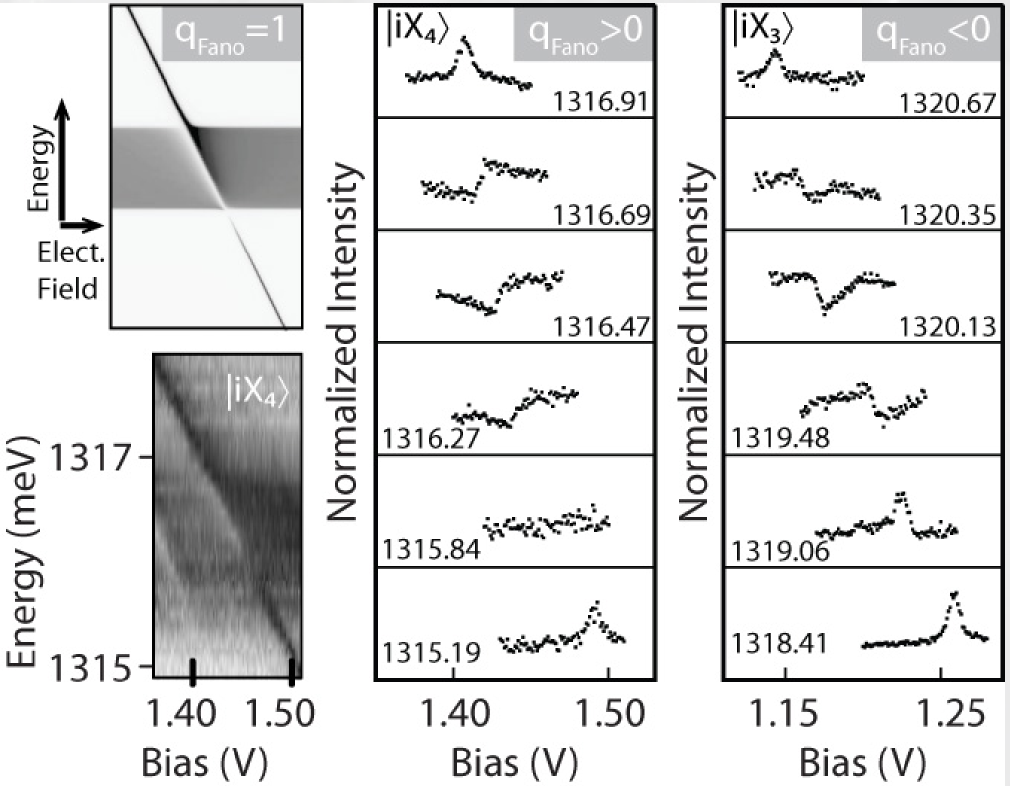


A. Miroshnichenko, et al.,
Rev. Mod. Phys., V 82, (2010)

M. Kerfoot et al., *Nature Communications, 5:3299 (2014)*

Verification of Fano Effect

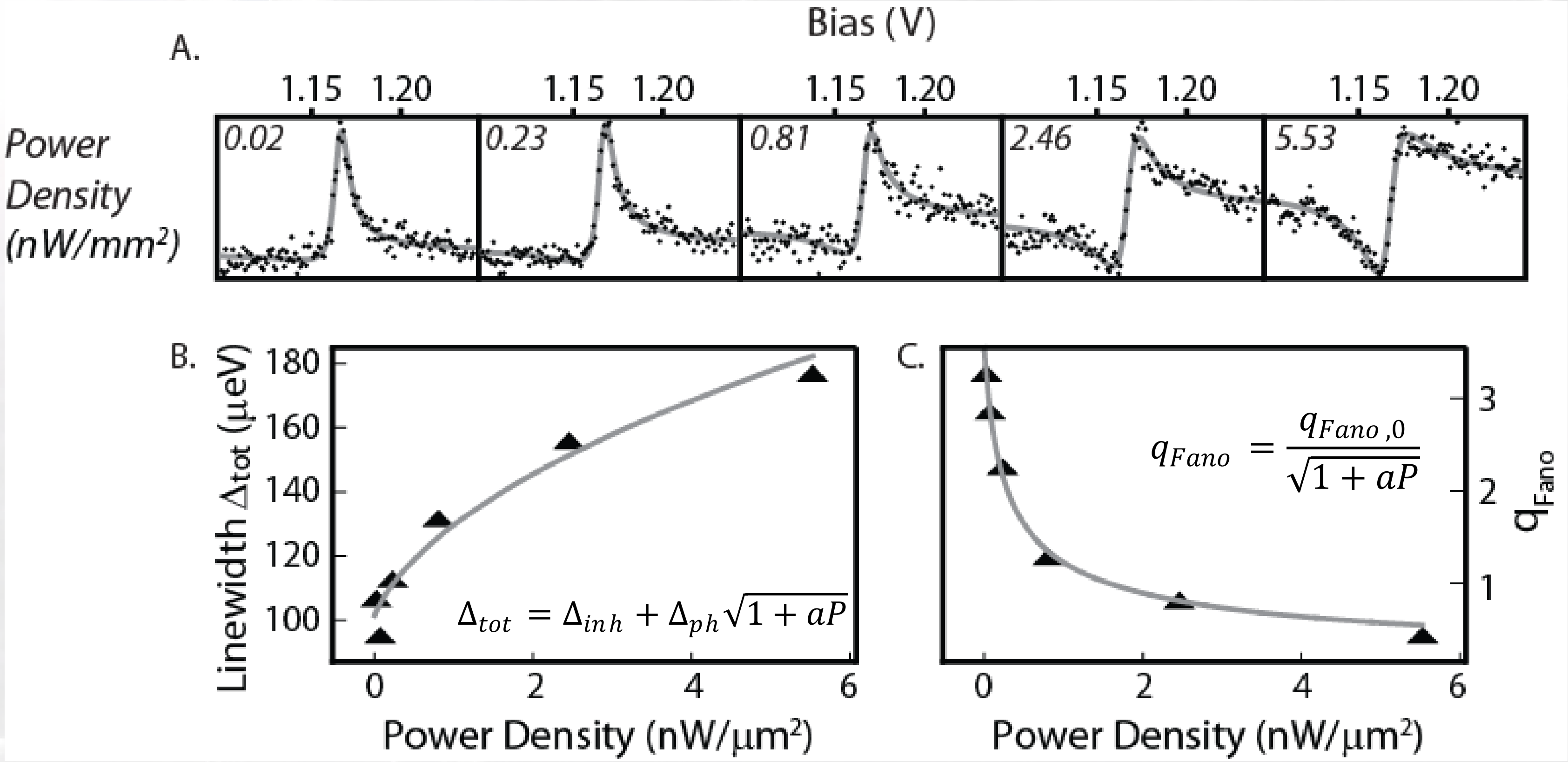




Wide variety of transparency windows

M. Kerfoot et al., *Nature Communications, 5:3299 (2014)*

Non-Linearity



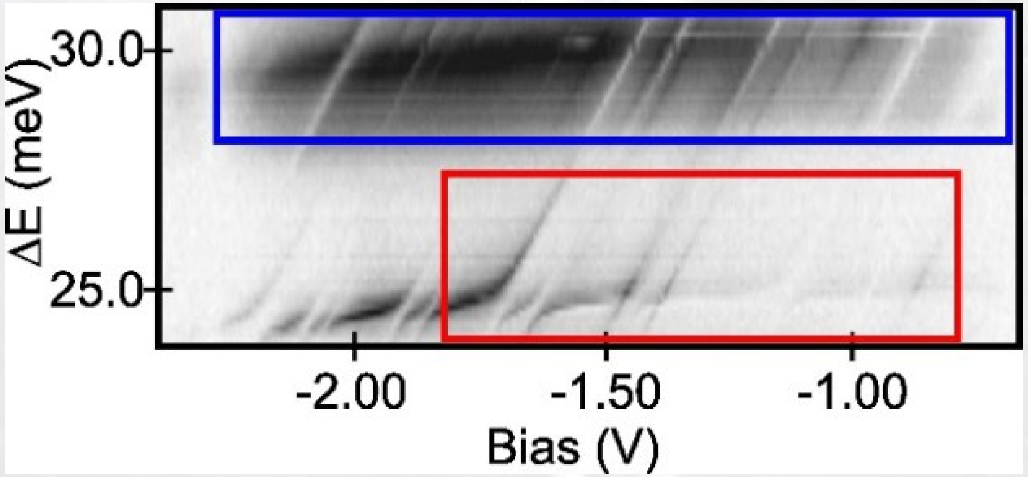
Transparency tunable by bias, energy & power

M. Kerfoot et al., *Nature Communications, 5:3299 (2014)*

Outlook

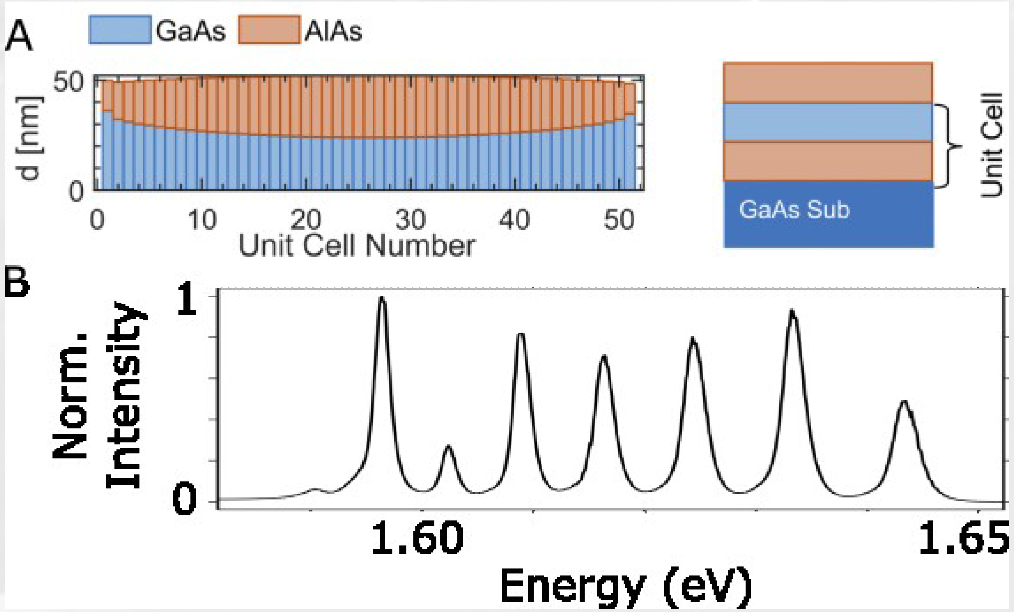
New Application Fields, Challenges, and Opportunities

Harnessing Acoustic Phonons



$$q_{Fano} = \frac{v_{iX} t}{v_{\Omega} \Delta_{ph}} = \frac{v_{iX}}{v_{\Omega} t \pi \rho}$$

Modify the density of states via **phonon** cavities:



Combine CQD and Phonon Cavity Designs

Density of states is significantly lower for acoustic phonons

High power? Maybe, but leads to broadening and heating

M. Hanif et al., *Adv. Funct. Mater., 34, 2404299 (2024)*

Electrical Scalar Aharonov-Bohm Effect

$$H = H_0 + eV(t).$$

$$V(t) = V_0 \cos\, \Omega t$$

$$i\hbar \frac{\partial \psi}{\partial t} = H\psi = [H_0 + eV(t)]\psi$$

$$\psi(\mathbf{x}, t) = X(\mathbf{x})T(t).$$

$$-eV + i\hbar \frac{d \ln T}{dt} = E \quad \text{and} \quad H_0 X = EX.$$

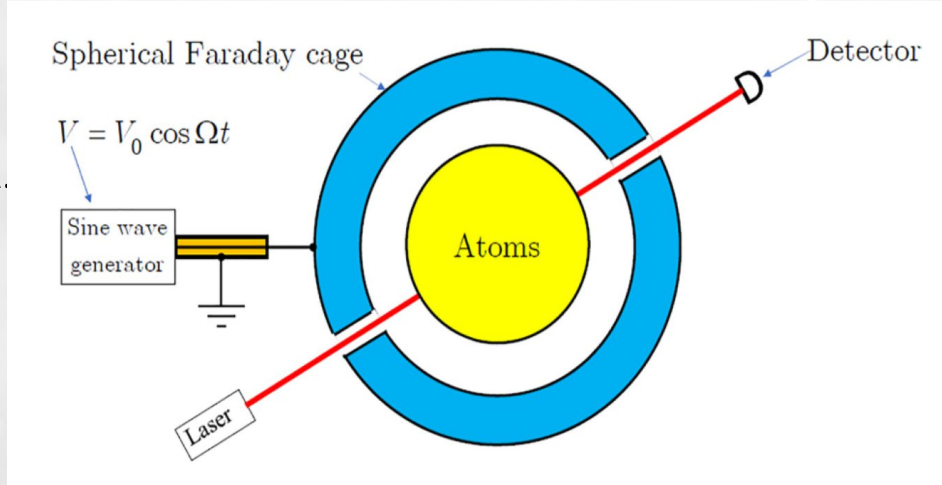
$$T(t) = \exp\left(-\frac{i}{\hbar}E_i t - i\alpha\, \sin\, \Omega t\right) = \exp\left(-\frac{i}{\hbar}E_i t - i\varphi(t)\right)$$

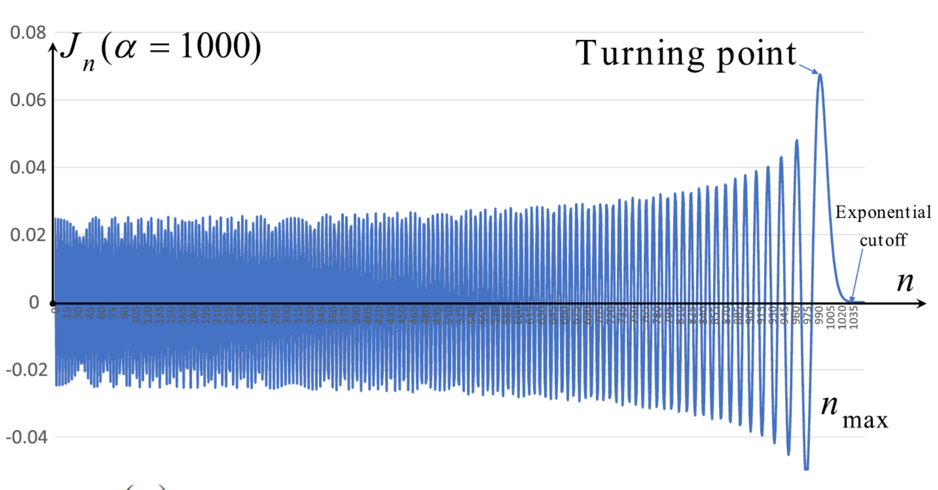
$$\alpha = \frac{eV_0}{\hbar\Omega}$$

$$\exp[-i\varphi(t)] = \exp(-i\alpha\, \sin\, \Omega t) = \sum_{n=-\infty}^{\infty} (-1)^n J_n(\alpha) \exp(in\Omega t)$$

$$\psi_i(\mathbf{r}, t) = \Psi_i(\mathbf{r}) \sum_{n=-\infty}^{\infty} (-1)^n J_n(\alpha) \exp\left(-\frac{i(E_i - n\hbar\Omega)t}{\hbar}\right)$$

R.

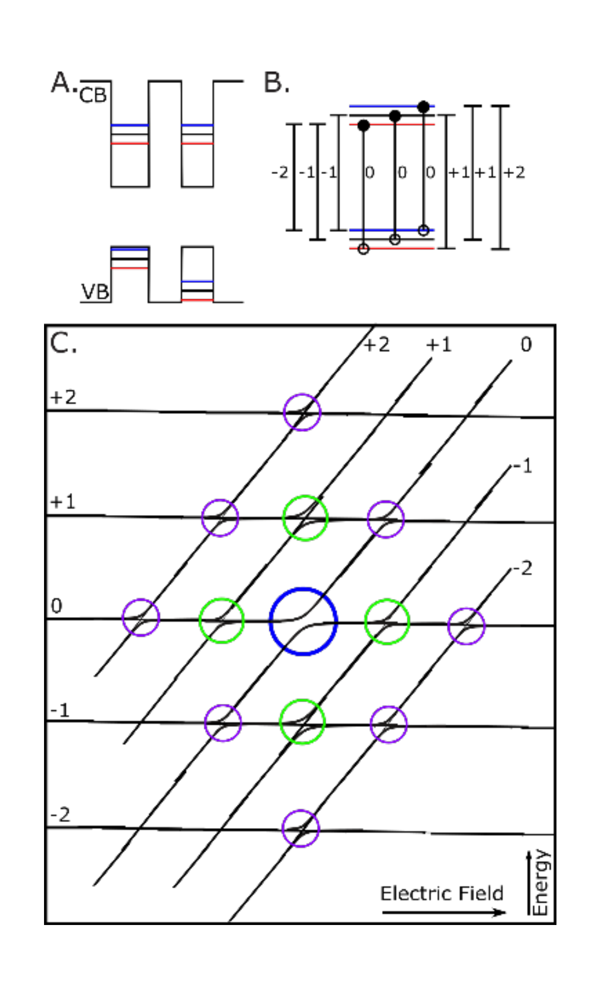




$$E_i^{(n)} = E_i \pm n\hbar\Omega$$ with $n_{max} \approx \alpha$

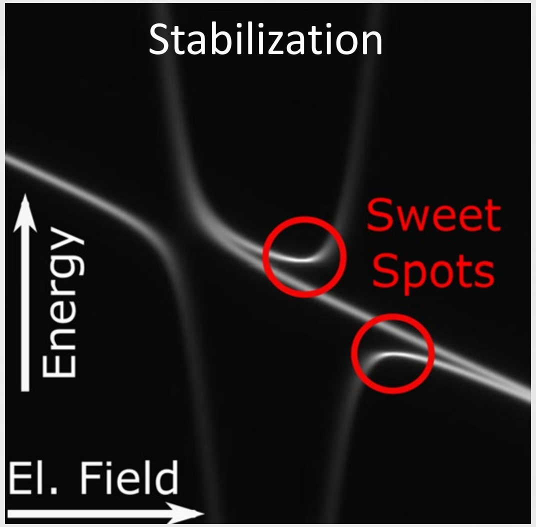
Temporally Periodic Potential ⇒ Jacobi-Anger Side band formation

Coupled Dots for SABE

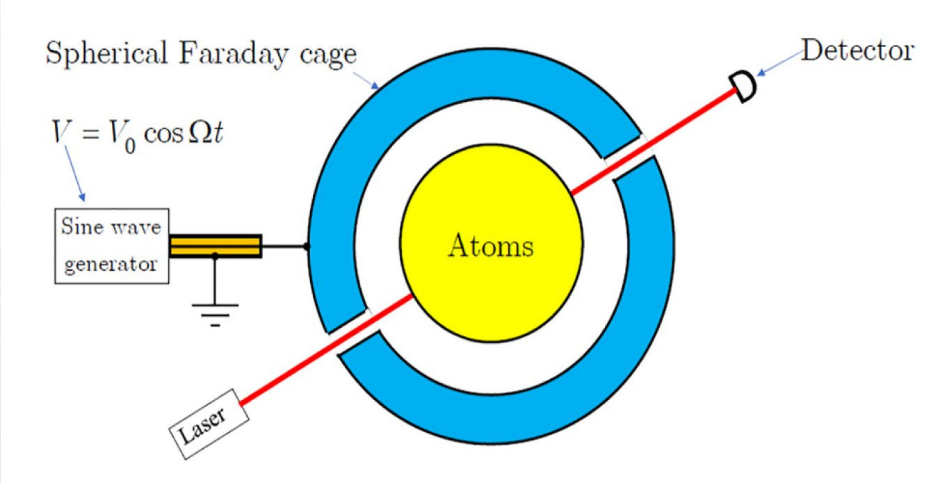


Coupled Quantum Dots Provide:

- Multitude of states with different properties (charge, dipole moment, spin, etc.)
- Ability to coherently couple/hybridize these states
- Ability to engineer the wave functions and
  - Stabilize states against noise and decoherence
  - control the interactions
- Ability to generate coherent quantum interferences between different species
  - Different charge states
  - Opto-electronic states and phonons and/or mechanical resonator modes
  - …

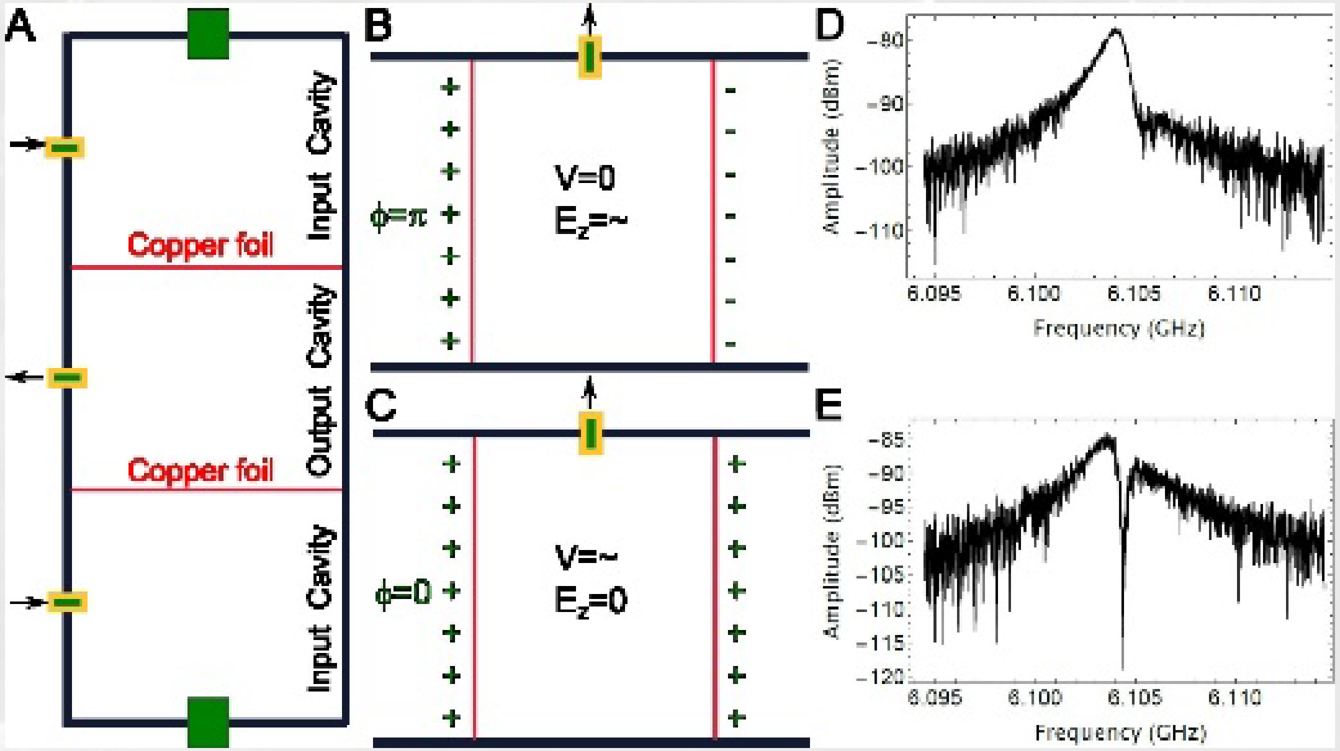


Electrical Scalar Aharonov-Bohm Effect



R. Y. Chiao et al., *PRA, 107, 042209 (2023)*

Need:
Electric Potential Modulation without
Electric Field modulation

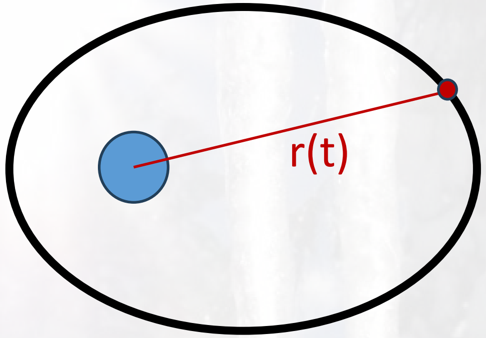


Coupled Microwave Cavities by Michael Tobar's group @ UWA

Incorporate CQDs with cavity system

M. T. Hazton et al., *Phys. Rev. Appl., 23, 024058 (2024)*

Gravitational Scalar Aharonov-Bohm Effect



Pure potential variation obtained by nearly circular orbit:
Perpetual free fall with potential varying as:

$$\Phi_g(t) = -\frac{GM}{r(t)}$$

$$r(t) = \frac{r_p + r_a}{2} + \frac{r_p - r_a}{2}\cos(\Omega t) \equiv A + B\cos(\Omega t)$$

$$\Phi_g(t) \approx -\frac{GM}{A}\left[1 - \frac{B}{A}\cos(\Omega t)\right]$$

Mass of quantum system is critical

$$i\hbar\frac{\partial\psi}{\partial t} = H\psi = (H_0 + m\Phi_g(t))\psi$$

$$-m\Phi_g + i\hbar\frac{1}{T}\frac{dT}{dt} = \frac{1}{X}H_0 X$$

$$\psi_i(\mathbf{r}, t)$$

$$= \Psi_i(\mathbf{r})\sum_{n=-\infty}^{\infty}(-1)^n J_n(\alpha)\exp(in\Omega t)\exp\left(-\frac{i(E_i + \frac{GmM}{A})t}{\hbar}\right)$$

$$= \Psi_i(\mathbf{r})\sum_{n=-\infty}^{\infty}(-1)^n J_n(\alpha)\exp\left(-\frac{i(E_i + \frac{GmM}{A} - n\hbar\Omega)t}{\hbar}\right).$$

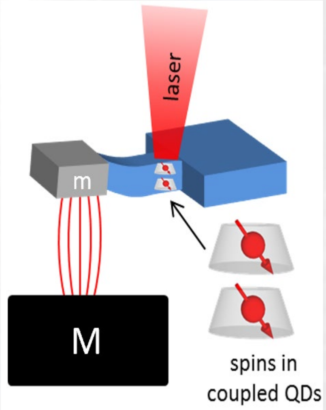
$$E_i^{(n)} = E_i + \frac{GmM}{A} \pm n\hbar\Omega \equiv \tilde{E}_i \pm n\hbar\Omega,$$

$$\alpha \equiv \frac{GmMB}{\hbar\Omega A^2}$$ with $n_{max} \approx \alpha$

R. Y. Chiao et al., *PRD, 109, 064073 (2024)*

Related Projects & Programs

Quantum-enhanced motion sensing using entangled spins in quantum dots (UCM, NRL, (VT); DTRA)



GraSP: Gravity- Spin-Probe

Semiconductor quantum emitters for probing gravitational signatures at the quantum scale (UCM, CSUF, UWA, UNSW, UCF, NETL)

Gravitational Aharonov-Bohm effect, Chiao, *et al.*, Phys. Rev D 109, 064073 (2024)
https://doi.org/10.1103/PhysRevD.109.064073
Energy-level shift of quantum systems via the scalar electric Aharonov-Bohm effect, Chiao, *et al.*, Phys. Rev A 107, 042209 (2023).
https://doi.org/10.1103/PhysRevA.107.042209

CONDESA
CONVERGENCE OF NANO-ENGINEERED DEVICES FOR ENVIRONMENTAL AND SUSTAINABLE APPLICATIONS

National Research & Training Grant (NRT)
(UCM, LLNL; NSF)

Thrust 3: Advanced Quantum Sensing for Geoenvironments.

Quantum-enhanced inertial sensing:

- Mass density distributions
- Motion (water flows)
- Magnetic properties of soil (clays)

VISION
Venture for Innovation in Self-assembly and Integration of Optoelectronic Nanostructures

NSF Award-#: 2425230

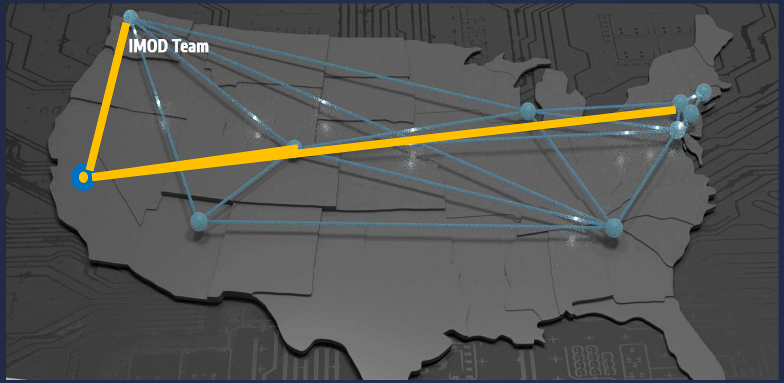
A (Seed) Partnership for Research & Education in Materials (PREM)
(UCM, IMOD-STC; NSF)

- RT-1: Quantum Dot Meta-Structures
- RT-2: Atomic Emitters in 2D
- RT-3: Composite Optoelectronic Structures

VISIONPREM.UCM

Michael Scheibner | Reagan Chan | William Saldana | Jesse Martinez | Alexander Grishko | (Israel Galeana) | (Bamidele Onipede)

Alexander Glasgo | Kazem Akbarnataj | Mason Foster | Hayley Hoang | Bruce Barrios | Muzzakkir Amin | Joseph Spinuzzi | Asmitha Mekala



VISION-PREM

Venture for Innovation in Self-assembly and Integration of Optoelectronic Nanostructures (VISION)

A Seed Partnership for Research & Education in Materials| UC Merced – IMOD-STC

Materials and Biomaterials Science & Engineering, Physics, Chemistry, Mechanical Engineering, Human Biology

https://visionprem.ucmerced.edu/

NSF Award-#: 2425230

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Hui Cai (Co-PI, RT-3 Lead, UG-lead)
Tao Ye (RT-1 Lead, Grad-Lead)
Mehmet Baykara (RT-2 Lead)

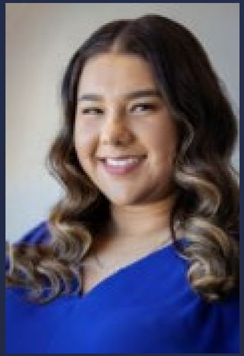
Leads @ IMOD
David Ginger (Co-PI)
Lisa Neshyba (Co-PI)







Staff @ UCM
Korynn Maravilla

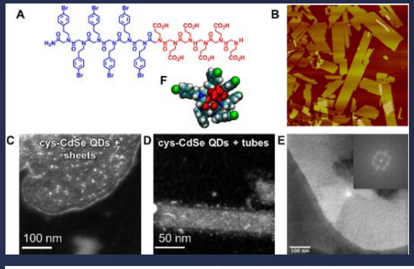


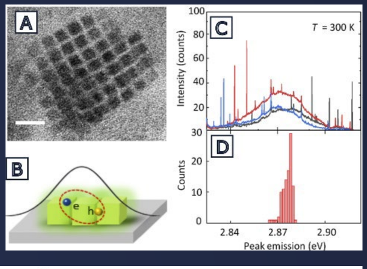
Staff @ IMOD
Denise Bale

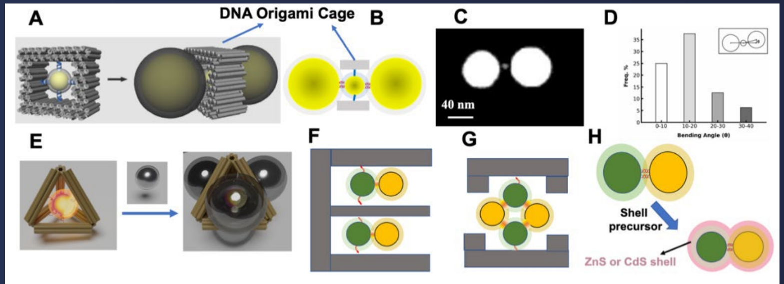
Research Topics

RT-1: Quantum Dot Meta-Structures

1.1: Molecular templated nano-assemblies of colloidal quantum dots
1.2: Structural and optoelectronic characterization
1.3: Single and Cooperative Photon Emitters

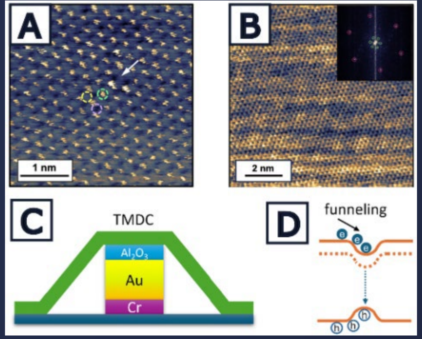






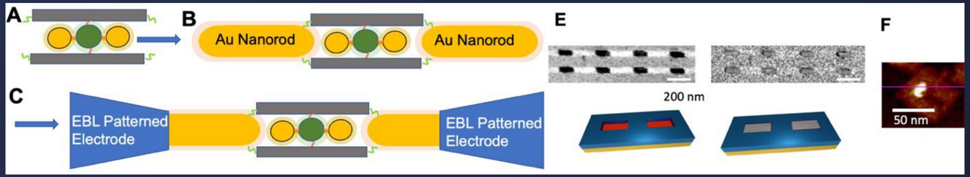
RT-2: 2D-hosted atom-like structures

2.1: Optoelectronic properties of atoms and molecules in 2D materials
2.2: Strain and defect-engineered atom-like emitters in 2D materials

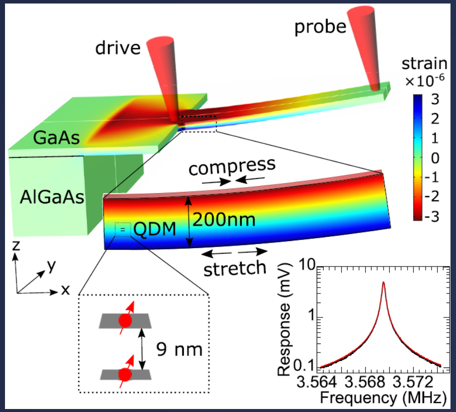


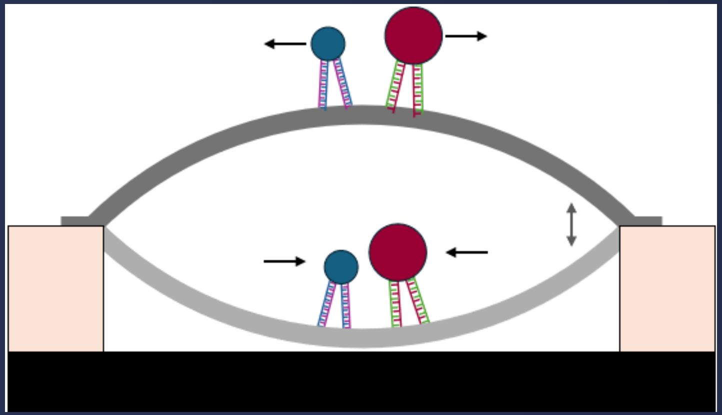
RT-3: Composite Optoelectronic Structures

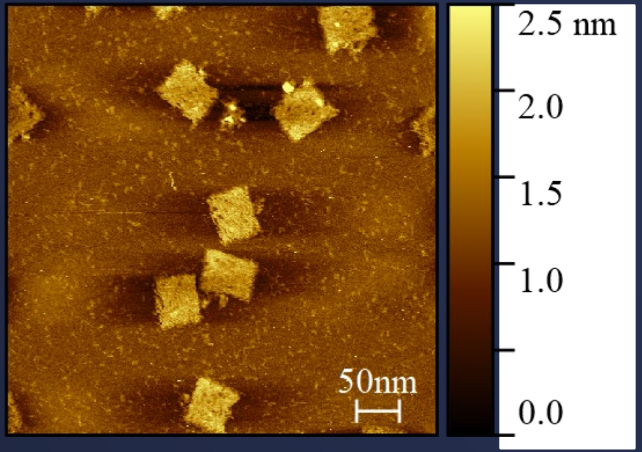
3.1: Hierarchical integration of solid-state atomistic assemblies
3.2: Light-matter interaction by design through spatial arrangement and photonic integration



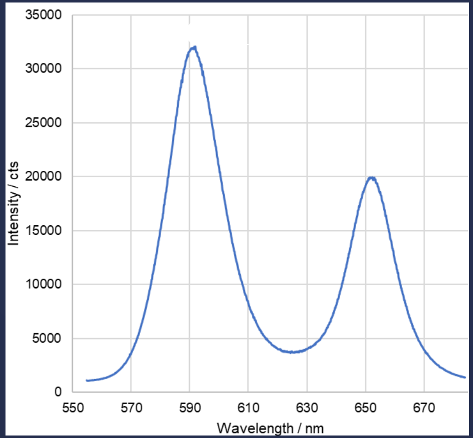
DNA-templated CQDs

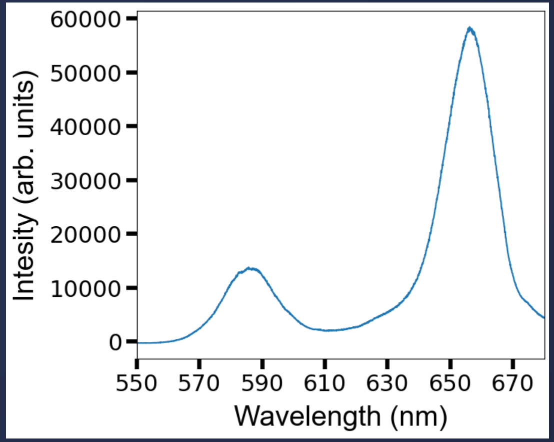






AFM image of DNA origami tiles, Yichen Li, Prof. Tao Ye Group





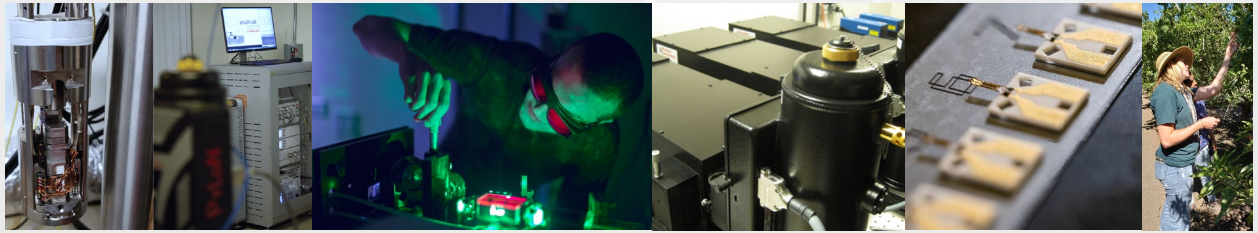
PL spectra of two QD wavelengths, 600 & 645nm: measurement taken at 295K

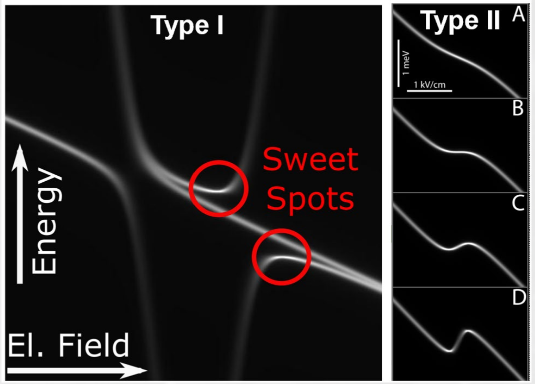
work in progress…

Partnership & Collaboration

Condensed Matter Quantum Systems for

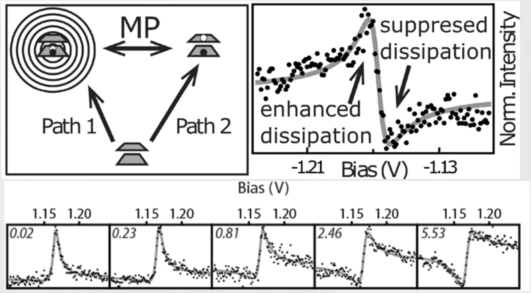
- *Fundamental Physics*
- *Life- & Environmental Systems*
    - *Natural Resources Localization & Tracking*
    - *Structural Health Monitoring*
    - *Geological Structure and Process Monitoring*
    - *Medical Imaging and Diagnostics*
    - *Energy*
- *Looking for partners for*
    - *Materials & Nanofabrication*
    - *Additive manufacturing & Prototyping*
    - *Quantum programming*
    - *Reciprocal, Experiential Education & Workforce Development Pathways*





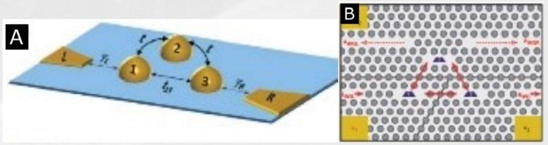
Quantum Molecular Energy Dispersion Engineering

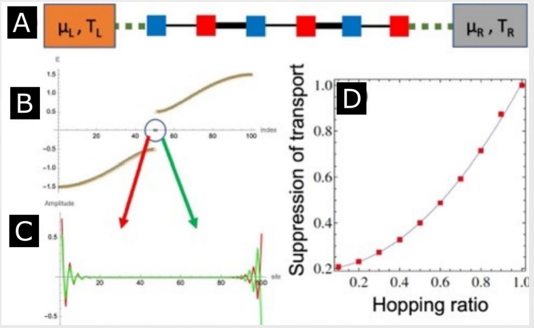
- Generate zero-dispersion points
- Quantum state stabilization
- Patent pending



Quantum Interference Dissipation Engineering

- Fano-type Quantum interference
- Molecular Polaron
- Kerfoot *et al.*, Nat. Com. (2014)
- Patent: US 9,705,081 B2





Topological Structures

- Geometrical arrangement & controlled coupling
- C.-Y. Lai, M. Di Ventra, M. Scheibner, C.-C. Chien, EPL (2018)
- P. Dugar, M. Scheibner, & C.-C. Chien, PRA (2020)
- Y. He, C.C. Chien PLA (2023)

Summary

- Coupled dots/quantum emitters provide a rich basis for fundamental physics and functionalization.
- Enable control over charge, spin-spin, and other interactions
- Make phonons behave non-dissipative and coherent, enabling optophononics applications and fundamental physics tests.
- Promising system for sensing—strain, motion, acceleration, gravity. Couple mechanical motion to quantum mechanical spin states.

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Collaborators

NRL: Allan Bracker, Dan Gammon, Sam Carter
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AFRL: Stefan Badescu

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Ray Chiao, Jay Sharping, & many more

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IMOD: David Ginger, Lisa Neshyba, & many more

UCF: Michael Leuenberger

NETL: Hari Paudel

UNSW: Stephen Bremner
UWA: Michael Tobar

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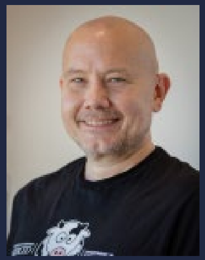
DoD HBCU/MI

Quantum Matter Group

Thank you for your attention!



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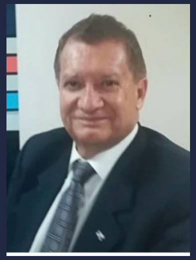

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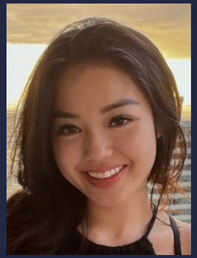

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