

UNIVERSITY OF ALBERTA

EDMONTON, ALBERTA, CANADA

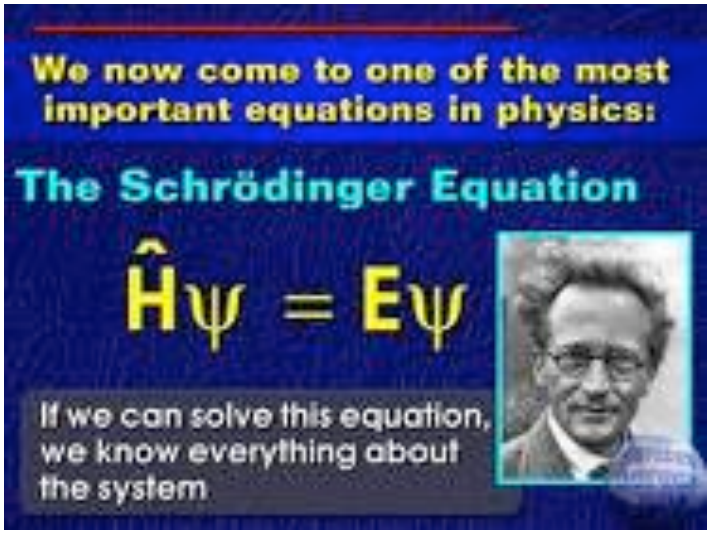
Alberta Quantum-Nano Workshop: Research at University of Alberta

Frank Marsiglio,
University of Alberta, Edmonton

July 6, 2011 Red Deer, AB

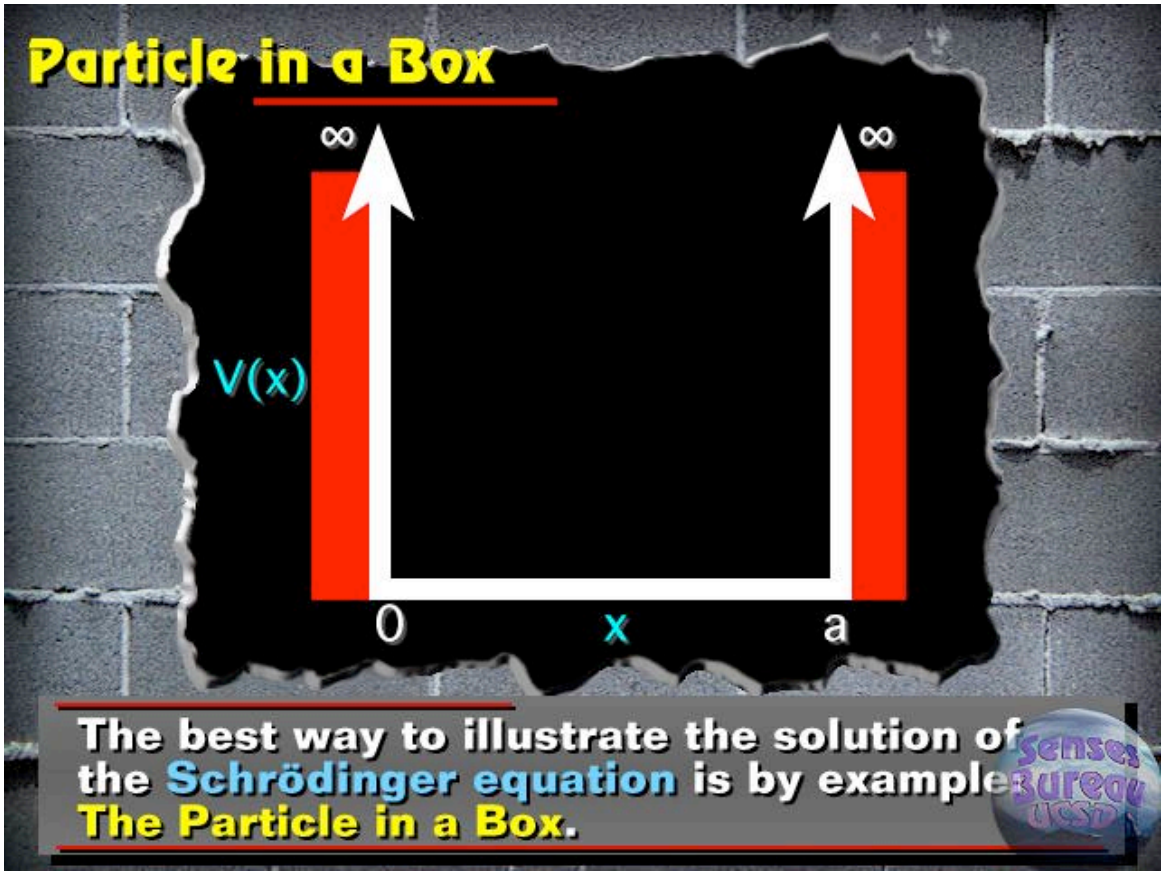
“Quantum”

Schrodinger Equation:



$$i\hbar\frac{\partial}{\partial t}\psi = -\frac{\hbar^2}{2m}\nabla^2\psi + V\psi$$

http://www.chemistry.ucsc.edu/teaching/switkes/CHEM163A/Fall02/KWILSON/qm/schrsolving.html

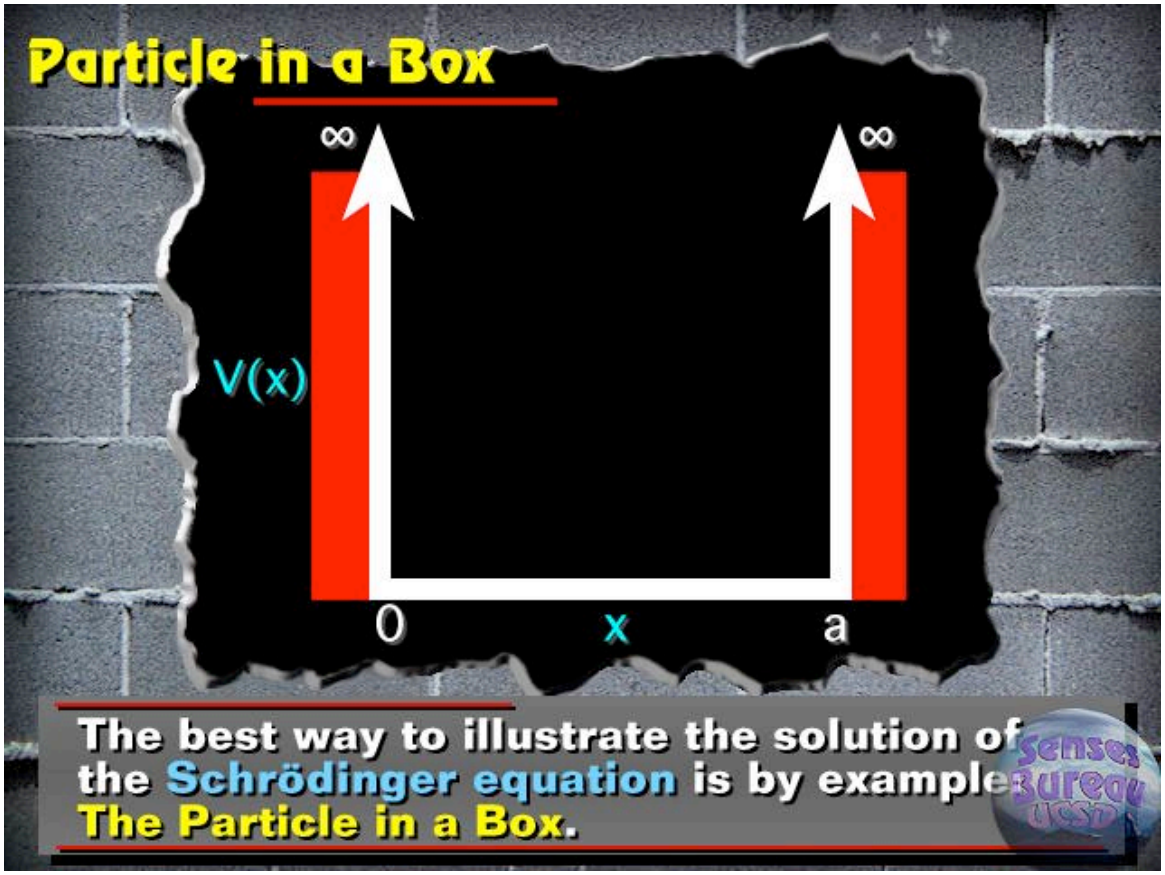


1. Zero point motion
2. "Quantum Pressure"
3. Energy Discretization
4. Indistinguishability

$$E_n = \frac{\pi^2 \hbar^2 n^2}{2ma^2}$$

http://www.chemistry.ucsc.edu/teaching/switkes/CHEM163A/Fall02/KWILSON/qm/schrsolving.html


浮いた 土佐ノ海
TOSANOUMI
(Sumo Wrestler)
Height of Tosanoumi 186cm
Weight of Tosanoumi 142kg
Weight of disk 60kg
Total weight 202kg
As of February '95



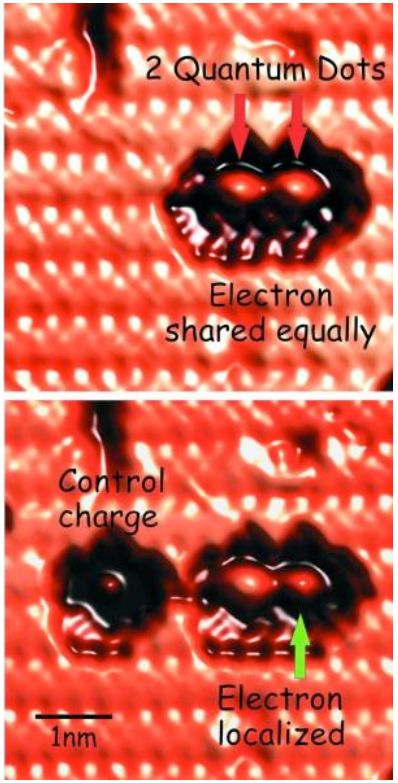
$$E_0 = \frac{3.8 \times 10^{-15}}{a^2} \text{ meV with } a \text{ in cm}$$

$$E_0 = \frac{.38}{a^2} \text{ meV with } a \text{ in nm}$$

$$\frac{\pi^2 \hbar^2}{2ma^2}$$

http://www.chemistry.ucsc.edu/teaching/switkes/CHEM163A/Fall02/KWILSON/qm/schrsolving.html

"Nano"



Smallest Quantum Dots Ever Created

Bob Wolkow group

ScienceDaily (Jan. 28, 2009) — Single atom quantum dots created by researchers at Canada's

Bob sends his regrets, he is at a business meeting



Movie suggests 2 electrons, in cells formed of 4 Q dots, can electrostatically couple to like cells, to transmit information without use of conventional current. Other groupings of cells can achieve logic operations. Such cells have been realized with silicon atoms. The same approach can define entities of interest from a qcomp point of view.

Quantum Defects and Supersolidity in Helium

John Beamish

Science (2004)

Observation of Superflow in Solid Helium

E. Kim and M. H. W. Chan*

Solidified helium appears to flow without any resistance. How that happens is anything but crystal clear

Flowing Crystals Flummox Physicists

UNIVERSITY PARK, PENNSYLVANIA—The gizmo could be mistaken for an artifact from a science museum or a custom-made part for your old VW Beetle. An aluminum cylinder 13 millimeters wide and 5 millimeters tall sits atop a slender post of beryllium copper. From its sides, two flaps protrude like large ears on a small boy's head, and fine wires festoon the top of the can. As Eunseong Kim, a postdoc here at Pennsylvania State University (Penn State), cradles it in his palm, the device hardly looks like the heart of a breakthrough physics experiment. Yet it produced perhaps the weirdest stuff ever made.

Last year, while Kim was a graduate student, he and physicist Moses Chan used the can to squeeze ultracold helium into a crystalline solid that appears to flow without resistance—like a liquid with no viscosity. For decades physicists had mused about such a bizarre "supersolid," and others had searched for and failed to find it. So Kim and Chan's results have touched off a flurry of activity among experimenters and a debate among theorists as to whether it's even possible for a perfect crystal to flow. They are rejuvenating helium physics, a small field that has played a large role in shaping modern physics (see sidebar, p. 39).

Kim and Chan had previously seen signs of such "superfluid" flow in solid helium crammed into the pores of a spongelike glass. But on 3 January 2004 they saw the first clear evidence that it could occur in a pure crystal. "That was an exciting moment," the soft-spoken Kim recalls as he sits at his desk in the subbasement of Osmond Hall. "That morning Moses came into my lab and I said to him, 'Maybe you'll strongly against such a phase," says Leggett in a phone interview from his office. "It looks like the experiments will make me rethink that."

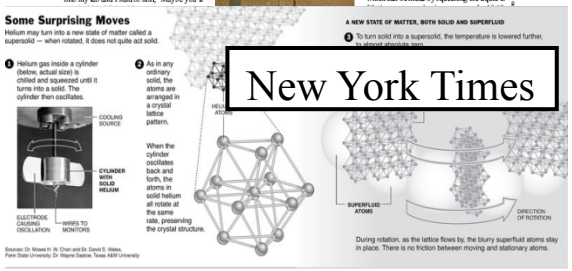
researchers are tackling new experiments that should challenge even helium physicists, who enjoy a reputation as expert tinkerers who can squeeze every drop of information out of a thimbleful of helium.

Letting go

Prone to burst into effusive laughter, Moses Chan talks fast and forcefully. But when discussing solid helium, he chooses his words carefully. "I think it's safe to say we've done all the possible control experiments," he says. "And though it sounds weird, I think the simplest explanation is that we see superfluidity in a solid." It's a big claim. Chan is saying that a material structurally similar to rock salt oozes through itself unimpeded. Yet other physicists agree with his assessment of the situation. Of course, they're used to the perversity of helium.

Since it was first liquefied nearly a century ago, physicists have puzzled over ultracold helium. Every other element freezes at some temperature, but unpressurized helium remains a liquid all the way down to absolute zero. Below 2.17 kelvin, however, the most common helium isotope, helium-4, undergoes a stranger transformation: It becomes a superfluid that flows without any resistance. That happens because, compared with other atoms, light and lively helium atoms act a bit less like billiard balls and a bit more like quantum waves. At low enough temperatures, many collapse into a single quantum wave that resists disturbances, in a process known as Bose-Einstein condensation.

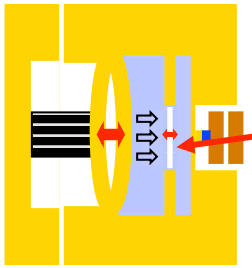
Theorists have long speculated that something similar might happen in solid helium-4, which can be made by squeezing the liquid to

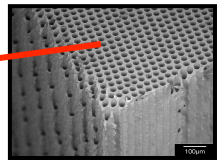


New York Times

Kim and Chan at Penn State

but:

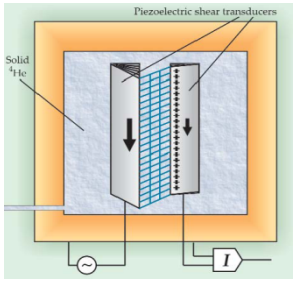




it does **NOT** flow through micron sized holes

PHYSICAL REVIEW LETTERS

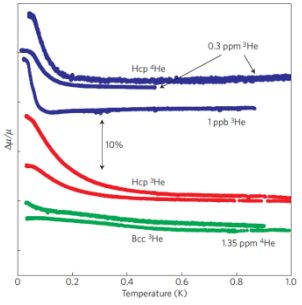
and:



it gets elastically **STIFFER** in the "supersolid" phase

nature

and:



quantum **STATISTICS** matter: boson (^{4}He) or fermion (^{3}He)

nature physics

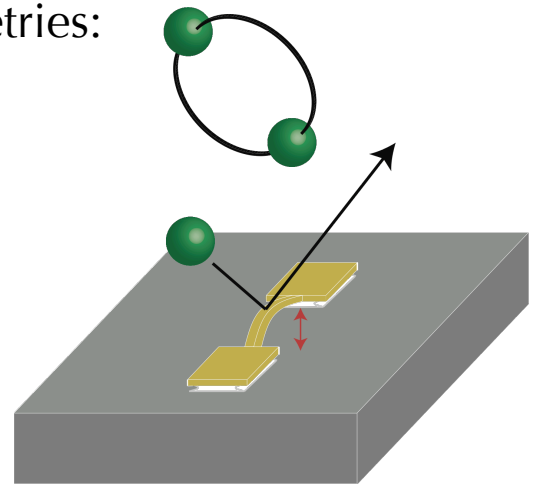
Is it supersolidity or perhaps "superplasticity"?

How do microstructure and nanostructure affect quantum defects?

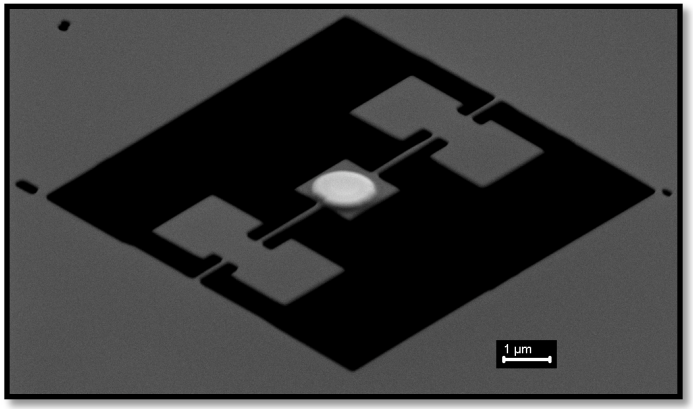
The Davis Lab:
Low-Temperature Quantum Nanoscience

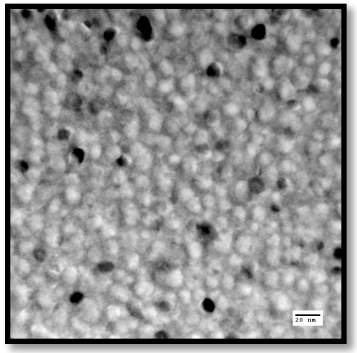
- Are there new superfluid phases in confined geometries / reduced dimensions?
- Why do nanoscale (granular) superconductors have enhanced transition temperatures?
- How large can an object be, and still be quantum mechanical?

Nanomechanical Measurements of Quantum Fluids in Confined Geometries:



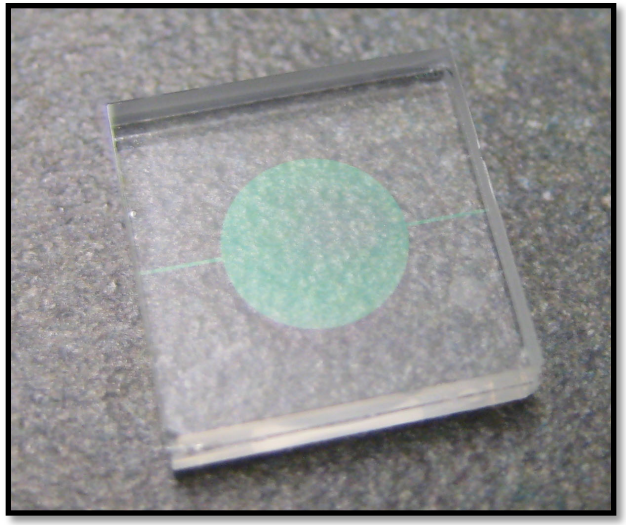
Nanomechanical Measurements of Mesoscopic and Granular Superconductors:





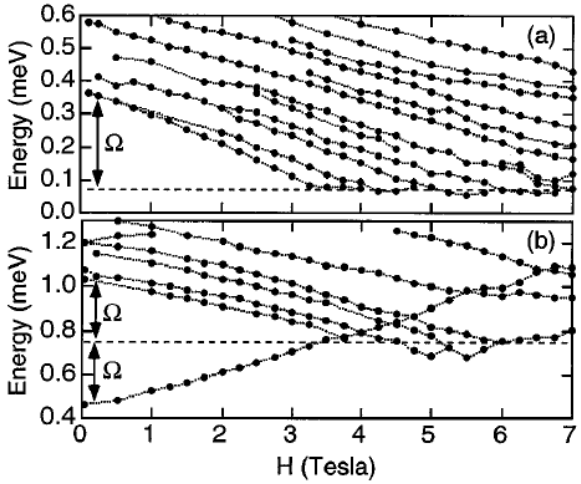
1 μm diameter Nb disk on a torsional resonator
(left)Al nanocrystals in a Ge matrix (right)

1 μm chamber for superfluids (below)



Nanoscale Superconductivity

Phil Anderson (1959): What happens to superconductivity as you make the sample smaller?



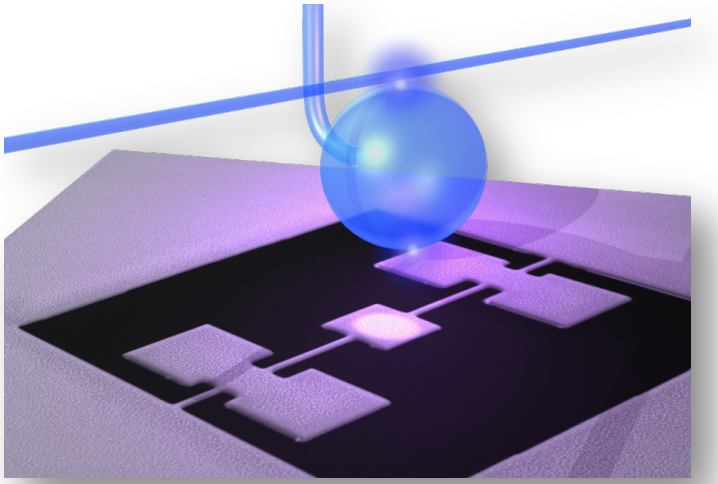
PHYSICAL REVIEW B VOLUME 60, NUMBER 5 1 AUGUST 1999-I

Even-odd and super-even effects in the attractive Hubbard model

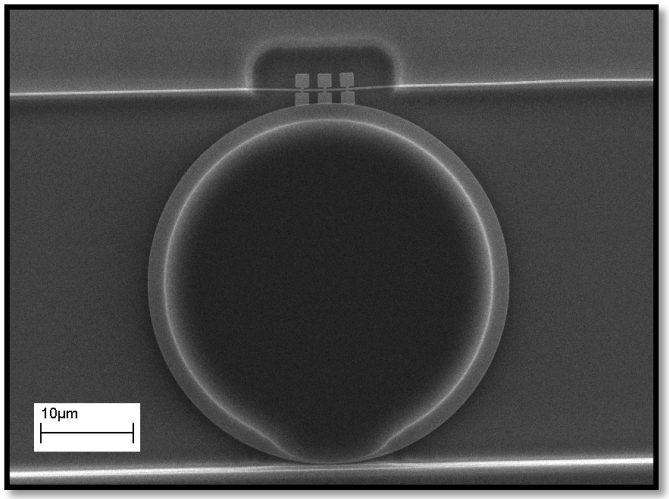
K. Tanaka and F. Marsiglio
Department of Physics, University of Alberta, Edmonton, Alberta, Canada T6G 2J1
(Received 10 February 1999)

The Davis Lab:
Low-Temperature Quantum Nanoscience

To explore the quantum properties of nanomechanical devices at ultra-low temperatures (as well as our other scientific goals) we must increase our detection capabilities and have turned to optomechanics and photonics.

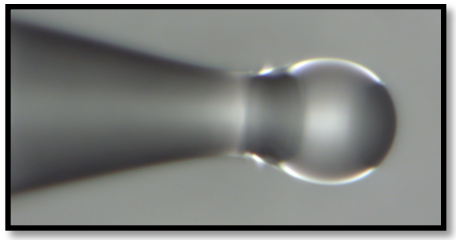


Optomechanical detection using a WGM resonator (above)

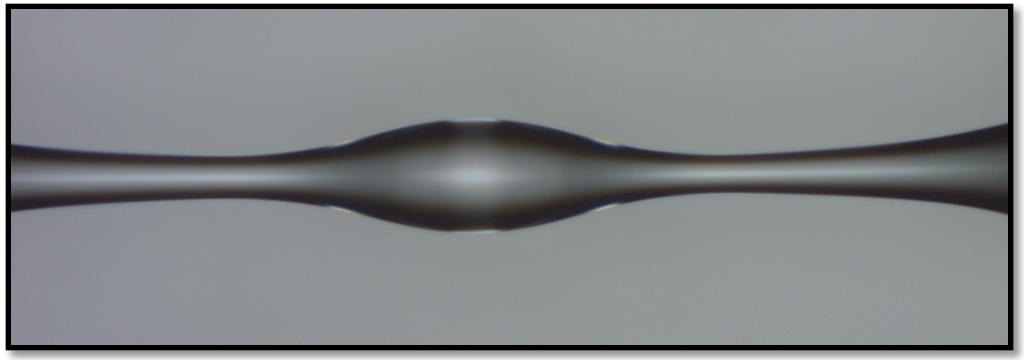


On-chip WGM device (above)

45 μm diameter optical microsphere (below)



60 μm diameter bottle resonator (below)



Find out more at our poster and: www.ualberta.ca/~jdavis

Quantum Dot Microfluidic Optical Resonators

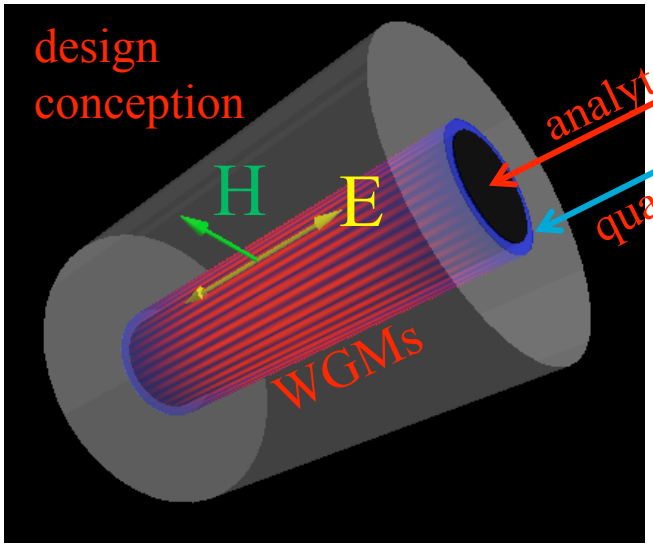
Optical microcavities have many intriguing sensor properties, including:

a) Ability to sample nanoliters of picoliters of fluid volume.
b) Mass sensitivity down to the level of femtograms.
c) Biocompatible and non-toxic.
d) Lab-on-a-Chip operation.
e) ICT compatible.
f) Disposable, re-usable, and parallelizable.
g) Future applications expected in biochemistry, medicine, environment.

However,

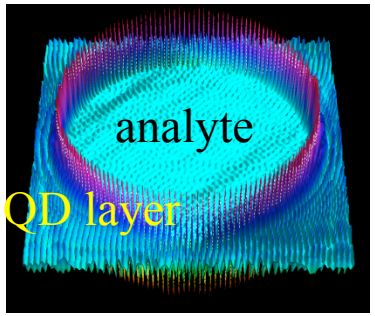
So far they're expensive, fragile, and require complex apparatus for analysis.

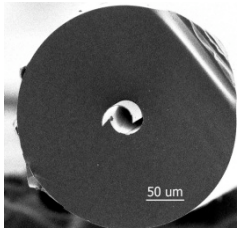
The objective: Develop a robust, inexpensive fluorescence-based microcavity sensor.



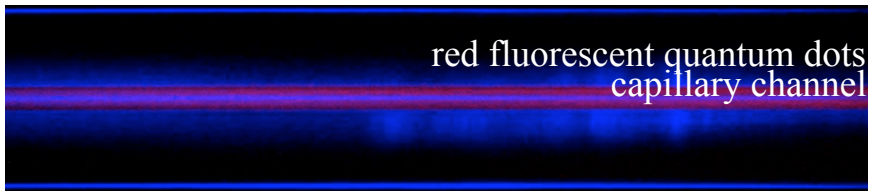
A "fluorescent core microcavity" capable of sustaining electric field resonances that sample analyte passing through the channel.

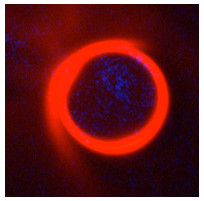
Simulated E-field profile





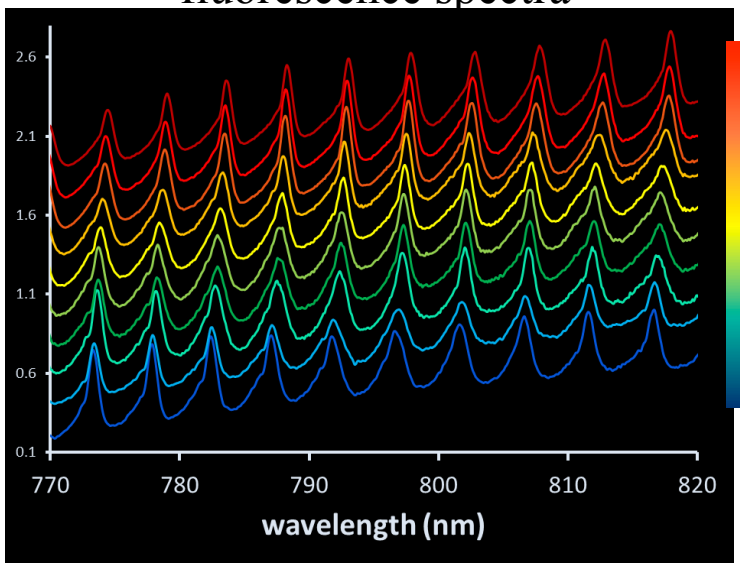
Experimental realization





Performance Analysis and Objectives

fluorescence spectra

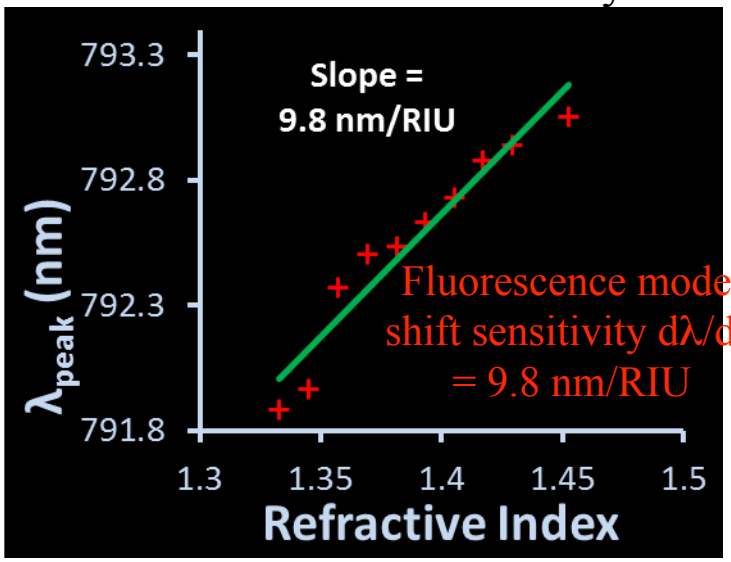


0.85 g/L
n = 1.453

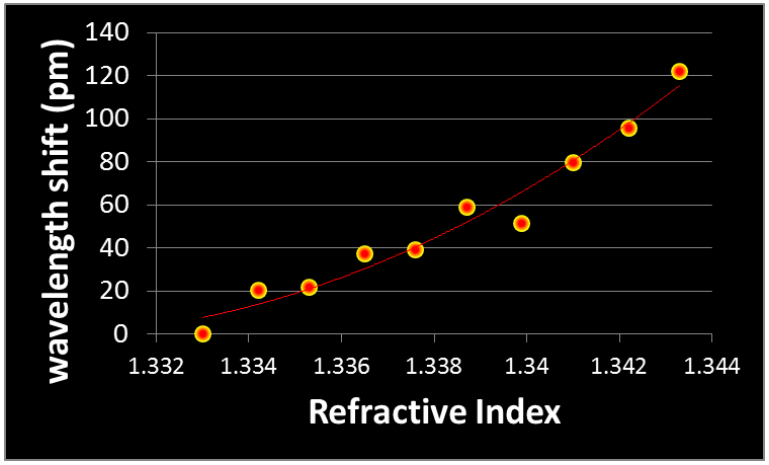
sucrose concentration

0 g/L
n = 1.333

device sensitivity



Detection limits for an inexpensive low-resolution spectrometer:



We can obtain a 3σ deviation of 24 *picometers* with an inexpensive 0.24 nm resolution spectrometer!

These devices have many advantages, including low cost (no laser necessary) and remarkable robustness – can even be handled with bare hands. Next objectives:

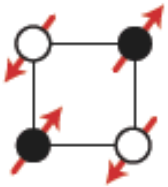
i) Demonstration of biosensing with biotin-streptavidin system.
ii) Functionalization for analysis of penicillin in milk products (with Scimed Technologies).
iii) Increase shift detection limits down to ~1 pm.

Kevin Beach

C. Graves, A. Raghavan, B. Ritter, X. Zhang, F. Zschocke
University of Alberta

- Theory and numerics for simple models of quantum particles
  - electrons in solids, ^{3}He films, cold atoms in a trap, ...
  - what are the effects of strong Coulomb repulsion, competing exchange interactions, disorder, or particle filling?
  - what interesting quantum phases can we stabilize in bulk?
  - what useful quantum behaviours emerge in small assemblies?
  - how to understand magnetism, Kondo and Mott insulator physics, the interplay between itinerancy and localization?
- Numerical tools
  - exact methods (quantum Monte Carlo, diagonalization) and systematic approx. (cluster Dynamical mean field theory)
  - rigorous characterization of phases and transitions
  - computing response functions and real-time dynamics
  - new algorithm development

Example: magnetic frustration

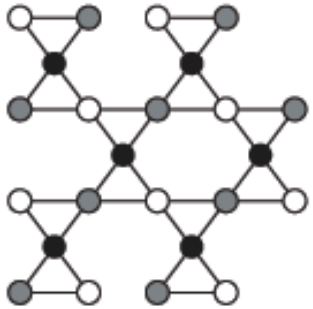


conventional antiferromagnetic order on a bipartite structure

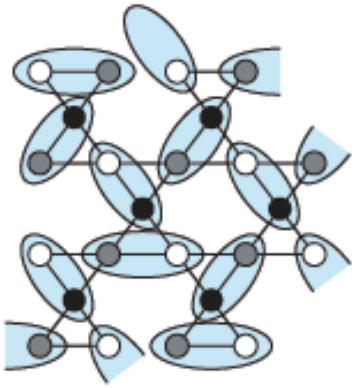


no unambiguous spin-up / spin-down labelling; the classical long-range magnetic order is said to be "frustrated"

lattices with triangular units, such as the Kagome, are intrinsically frustrated

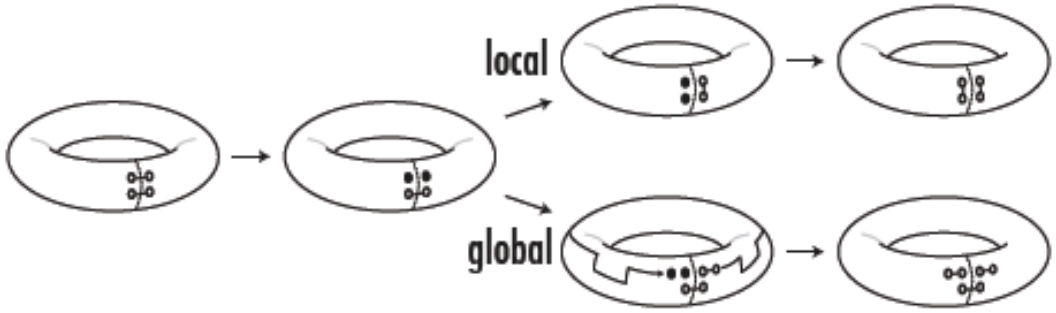


may support a spin liquid state: fluctuating soup of short-ranged singlet bonding that has no classical analogue



whether such a ground state is stable has to be settled with large-scale simulations; tricky because of large Hilbert space and the qmc sign problem.

purely short-ranged magnetic states are topologically protected against local perturbations (technologically useful for quantum devices?)

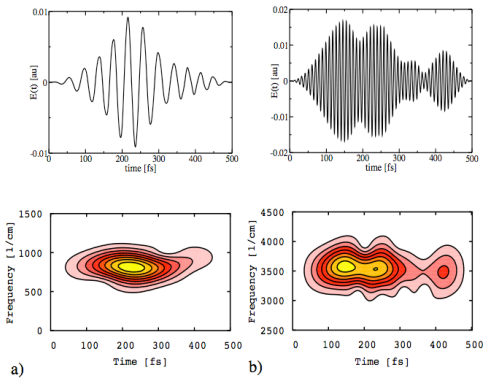


Professor Alex Brown, University of Alberta

www.chem.ualberta.ca/~abrown

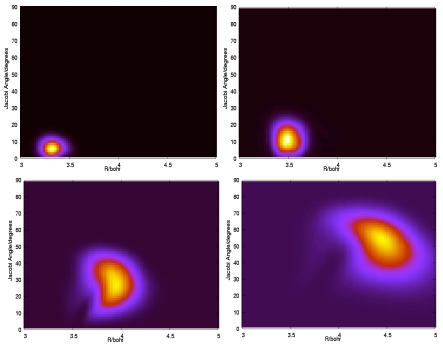
Theoretical/computational chemistry for understanding and controlling photochemistry

Laser Control & Quantum Computing



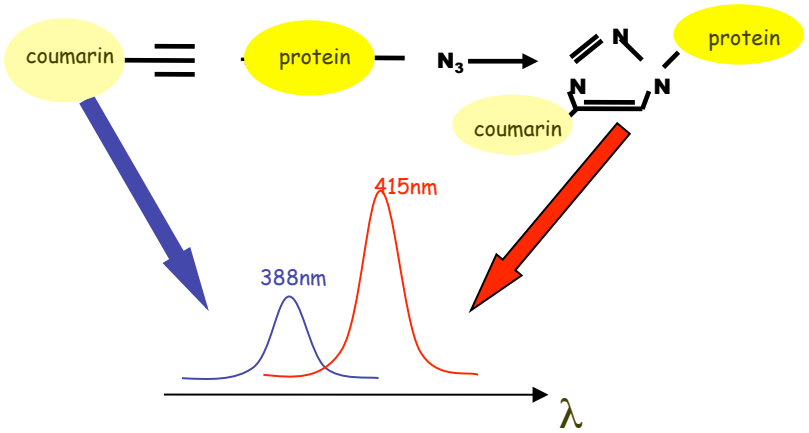
Design of tailored laser fields (in the mid-IR and UV) to control photochemistry and to perform molecular quantum computing

Quantum dynamics



Development and application of quantum and semi-classical dynamics methods for understanding photochemistry in large molecules

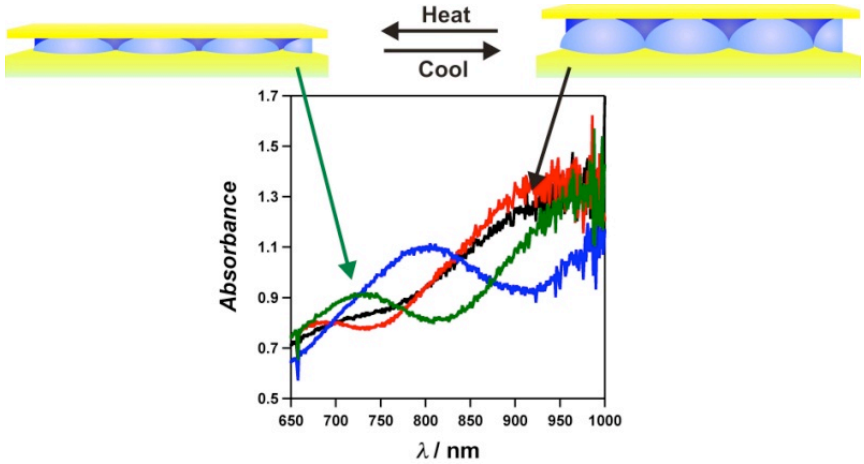
Fluorogenic Probes



Use of ab initio electronic structure theory to design rationally new fluorescent molecules for biological labeling

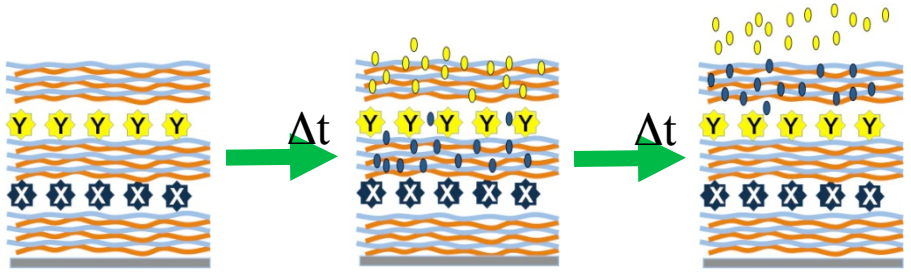
Research in the Serpe Group

Color Tunable Materials



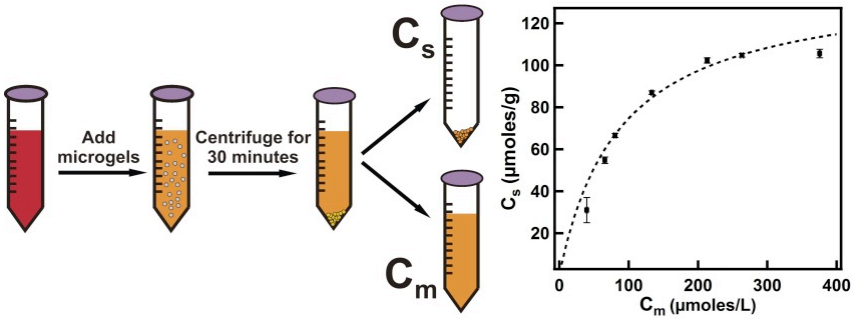
Sorrell, C.D.; Carter, M.C.D.; Serpe, M.J. ACS Appl. Mater. Interfaces, **2011**, 3, 1140-1147.
Sorrell, C.D.; Carter, M.C.D.; Serpe, M.J. Adv. Funct. Mater., **2011,** 21, 425-433.
Sorrell, C.D.; Serpe, M.J. Adv. Mater., **Submitted**.

Layer-by-Layer Assembled Microgel Films for Drug Delivery



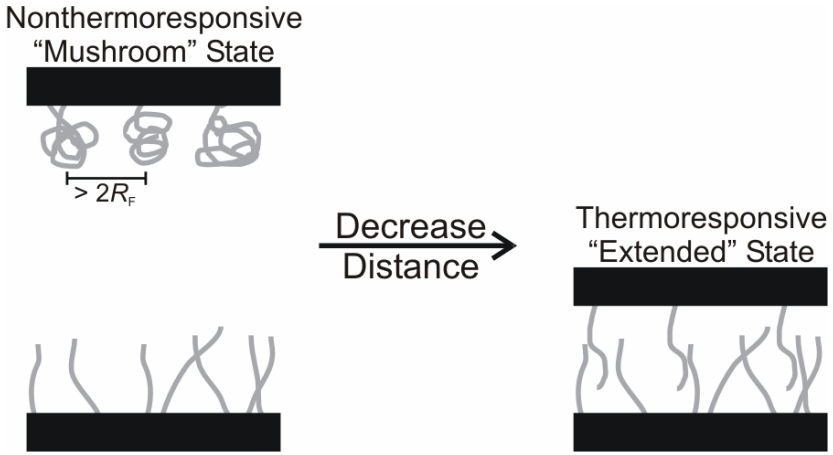
Zavgorodnya, O.; Serpe, M.J. Colloid Polym. Sci., **2011**, 289, 591-602.

Microgels for Water Remediation



Parasuraman, D.; Serpe, M.J. ACS Appl. Mater. Interfaces, **Accepted**..

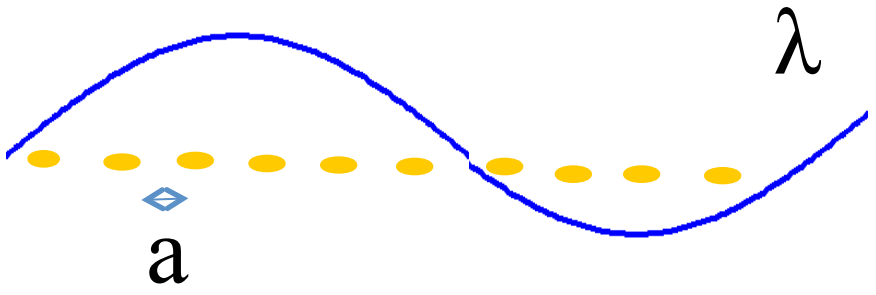
Confinement Effects on Polymer Conformation



Quantum Nanophotonics with |metamaterials⟩

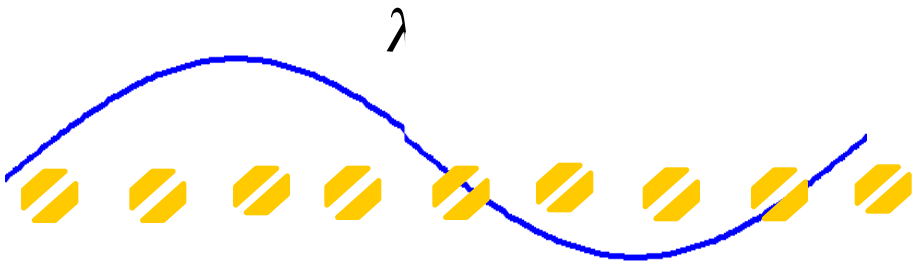
Prof. Zubin Jacob
ECE Department,
University of Alberta

Normal Materials



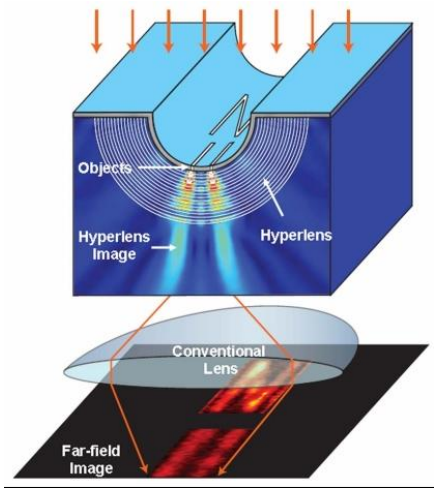
Metamaterials

- Tailor the electromagnetic constants
- Unprecedented control over light



Nano-inclusions/meta-atoms ~ 10 nm

Initial Applications





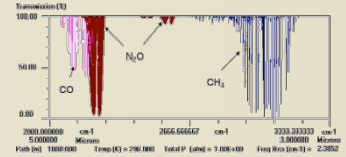
Subwavelength imaging: Hyperlens

Invisibility (cloaking)

Unique direction for field of Metamaterials
www.ece.ualberta.ca/~zjacob

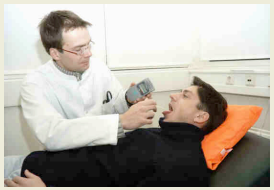
- Quantum nanophotonics : Engineer density of states by engineering ε,μ
- Metamaterial with broadband singularity in the density of states for various quantum optical applications

Jäger Group: Infra-red laser-based trace gas sensing





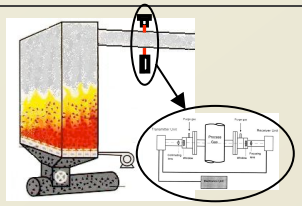
Open path sensing



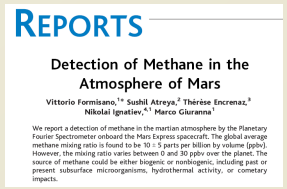
Medical Diagnostics



Point sensing



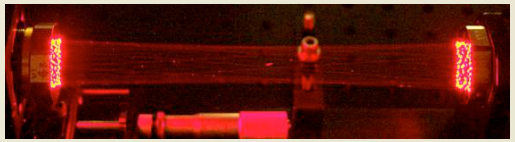
Industrial Applications



Planetary Atmospheres

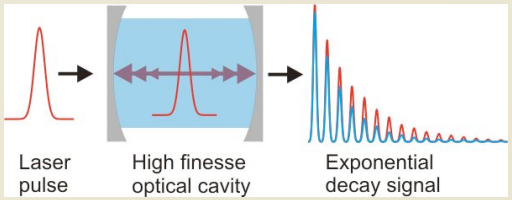
Method Development:

Absorption modulation spectroscopy
Fast scan spectroscopy



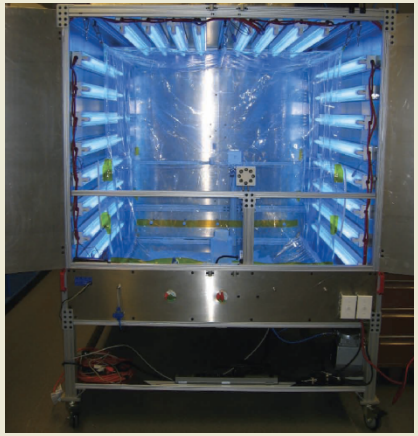
Multi-Pass Cell

Cavity ring-down spectroscopy



Cavity Ring-Down Principle

Studies of (nano-)Aerosol Formation:

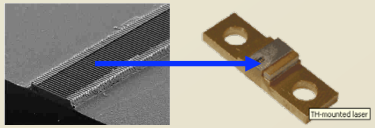


Spectroscopic detection of aerosol precursors (e.g. BTEX, benzene, toluene, ethylbenzene, xylene) and reaction intermediates in real time.

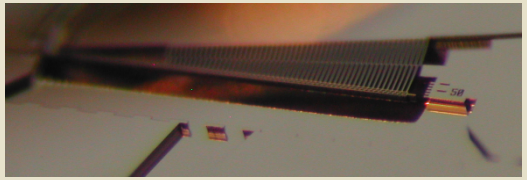
Photo-Reaction (Smog) Chamber

Laser Development

Design and implementation of external cavity for mid-IR quantum cascade laser. The resulting increased tuning range will allow for, for example, multi-species detection.



Quantum Cascade Laser

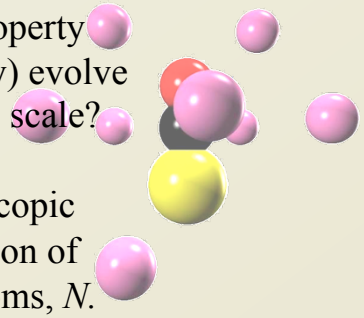


MEMS Rotary Comb Actuator (see poster by Quamrul Huda)

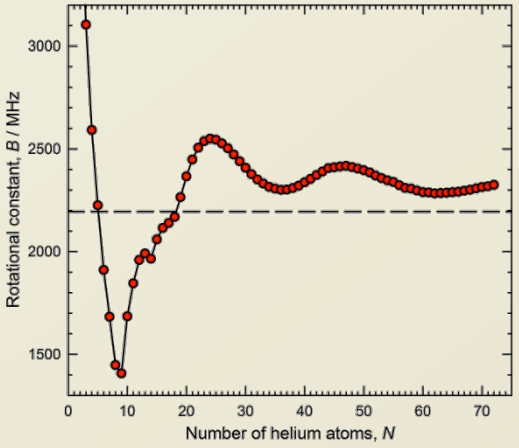
Jäger Group: Cluster and Helium Nanodroplet Spectroscopy

Spectroscopy of Doped Helium Clusters:

How does a bulk property (example: superfluidity) evolve from the microscopic scale?



Determine spectroscopic parameters as function of number of helium atoms, *N*.



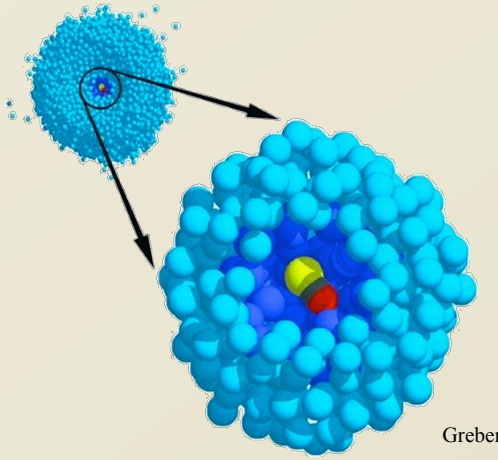
"Turn-around" in rotational constant, *B*, indicates decoupling of helium density from rotational motion of probe molecule.

→Onset of "microscopic superfluidity"

Corresponding experiments on doped *para*H_2 clusters [(*para*H_2)$_N$-CO] have provided evidence for the existence of a molecular superfluid.

Helium Nanodroplet:

1000 to several 100,000 helium atoms
Temperature: 0.38 K
Superfluid
Helium atom binding energy: ~ 5 cm^{-1}



Molecules can be embedded into the nanodroplets.

Experiments yield rotationally resolved spectra.

Grebenev *et al.*, *Science* **279**, 2083 (1998).

The dopant molecules can be used to probe properties of the helium nanodroplets, which are models of finite size quantum systems.

The nanodroplets can be used as "nano-cryostats" to capture, stabilize, and study transient species. Even chemical reactions can be initiated in the helium nanodroplet. **(See the poster by Paul Raston.)**

ultrafast microscopy group & collaborators

we study: "nonequilibrium physics of nanostructures"



ultrafast microscopy group & collaborators

we study: "nonequilibrium physics of nanostructures"

translation: strike things and listen to them ring

why: you can tell a lot more about a bell by listening to it that just looking at it

magnetic nanostructures

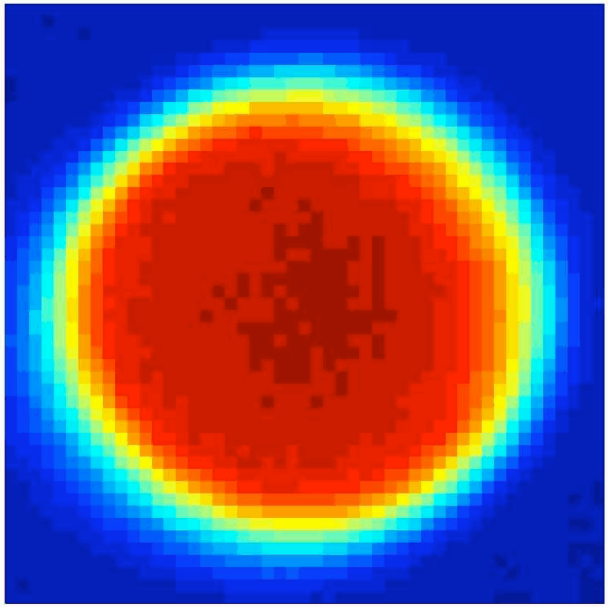
not just small,
also different.

great scope for hybrid magnetic/electric/mechanical/optical nanodevices

example*: magnetic resonance imaging and spectroscopy of individual nanomagnets*



jupiterimages.ca, with perm.



frequencies typically in the GHz range

Nanoscale superconductivity; magnetism: Marsiglio group

Superconductivity

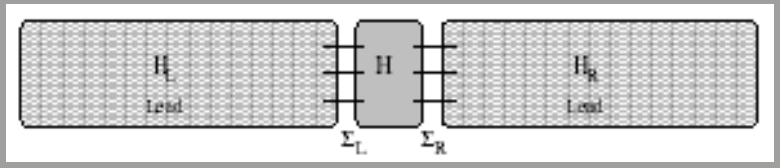


High Tc: what is the mechanism ?

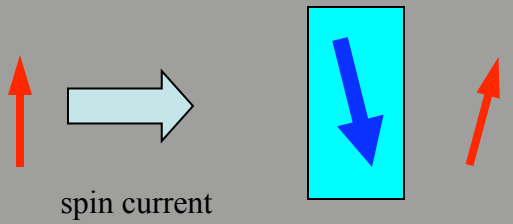
Hints come from a variety of properties:

- Bulk (photoemission, scanning tunneling microscopy (STM))
- Junctions (proximity effect)
- Reaction to defects, pressure, etc.

Example: proximity junctions:



Kinetics of Spin Flip



How does the magnetic moment in a thin film "flip" under the presence of an applied spin current ?

We are investigating quantum mechanical effects:

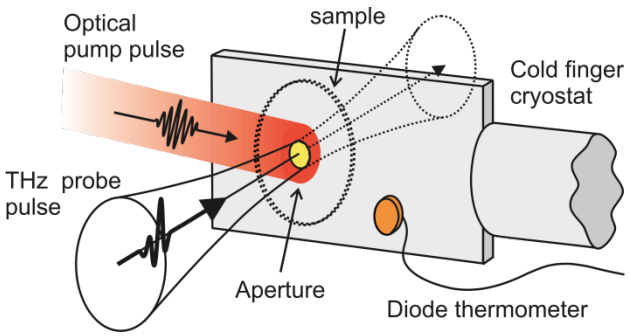
- Interference effects
- Spin Resonance
- Quantum correlations

Theoretical Physics Institute
TPI
University of Alberta

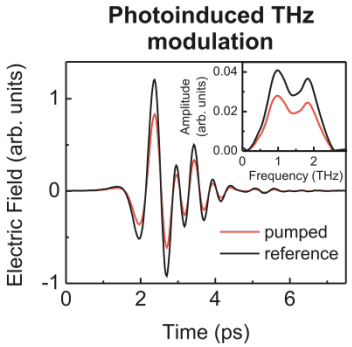
Frank Hegmann

Ultrafast terahertz spectroscopy

A non-contact probe of transient conductivity on the nanoscale



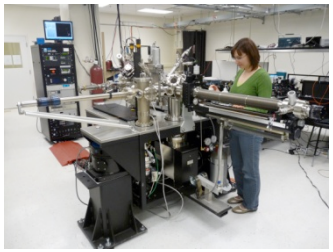


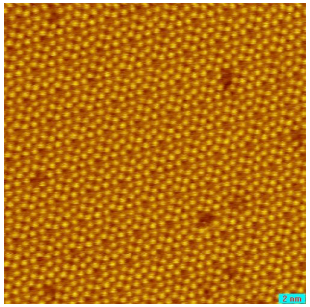


+

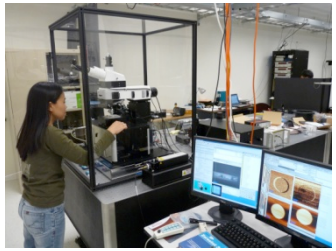
Nanoscale imaging techniques

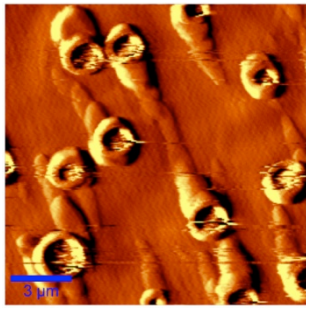
STM





AFM, NSOM



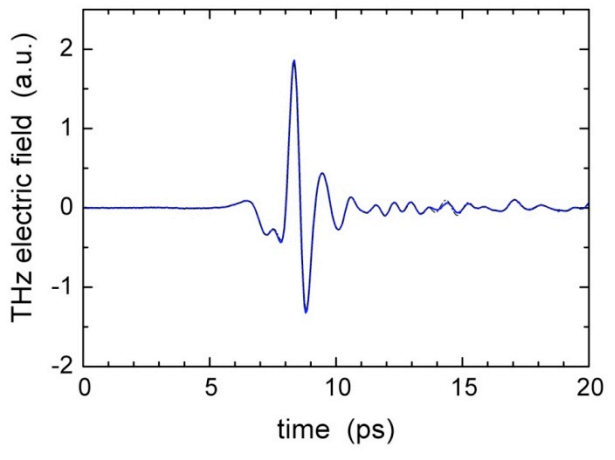


In the new ultrafast nanotools laboratory, we are working to combine ultrafast and nanoscale imagining techniques to create new and powerful tools.

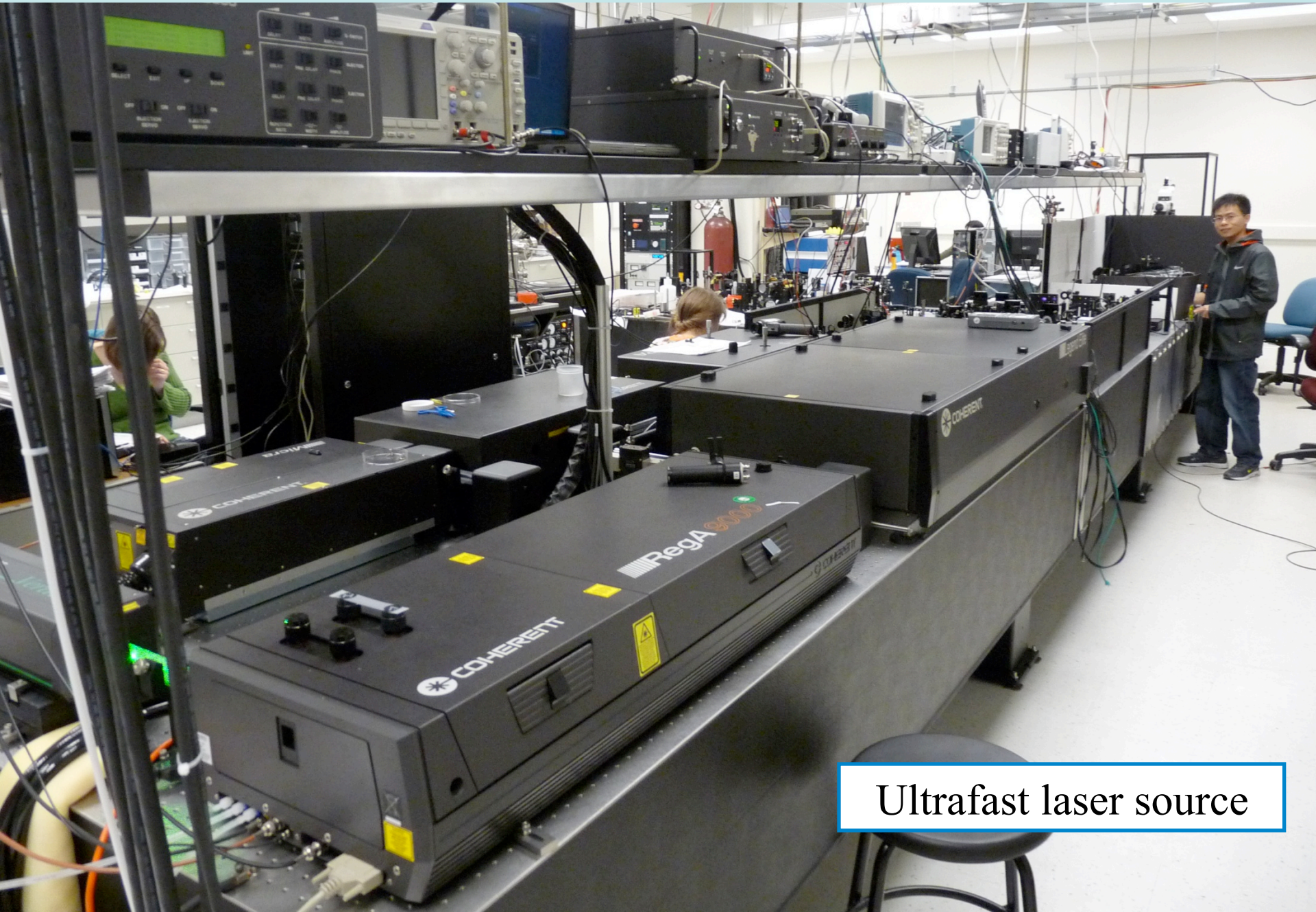
The Ultrafast Spectroscopy Lab (Hegmann)

Ultrafast Ti:sapphire amplifier laser source

Terahertz (THz) pulses and time-resolved THz spectroscopy

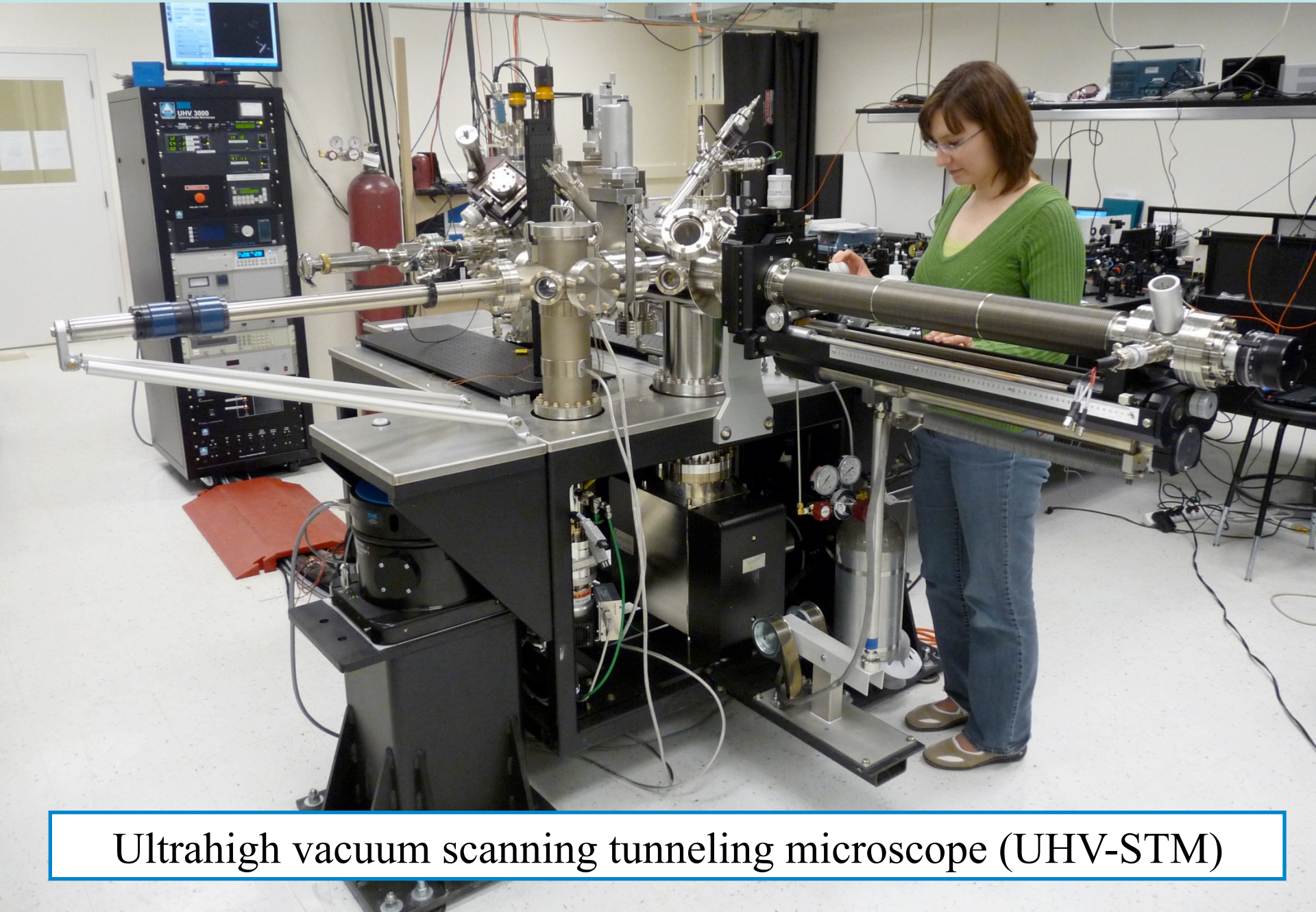


The Ultrafast Nanotools Lab (Hegmann)



Ultrafast laser source

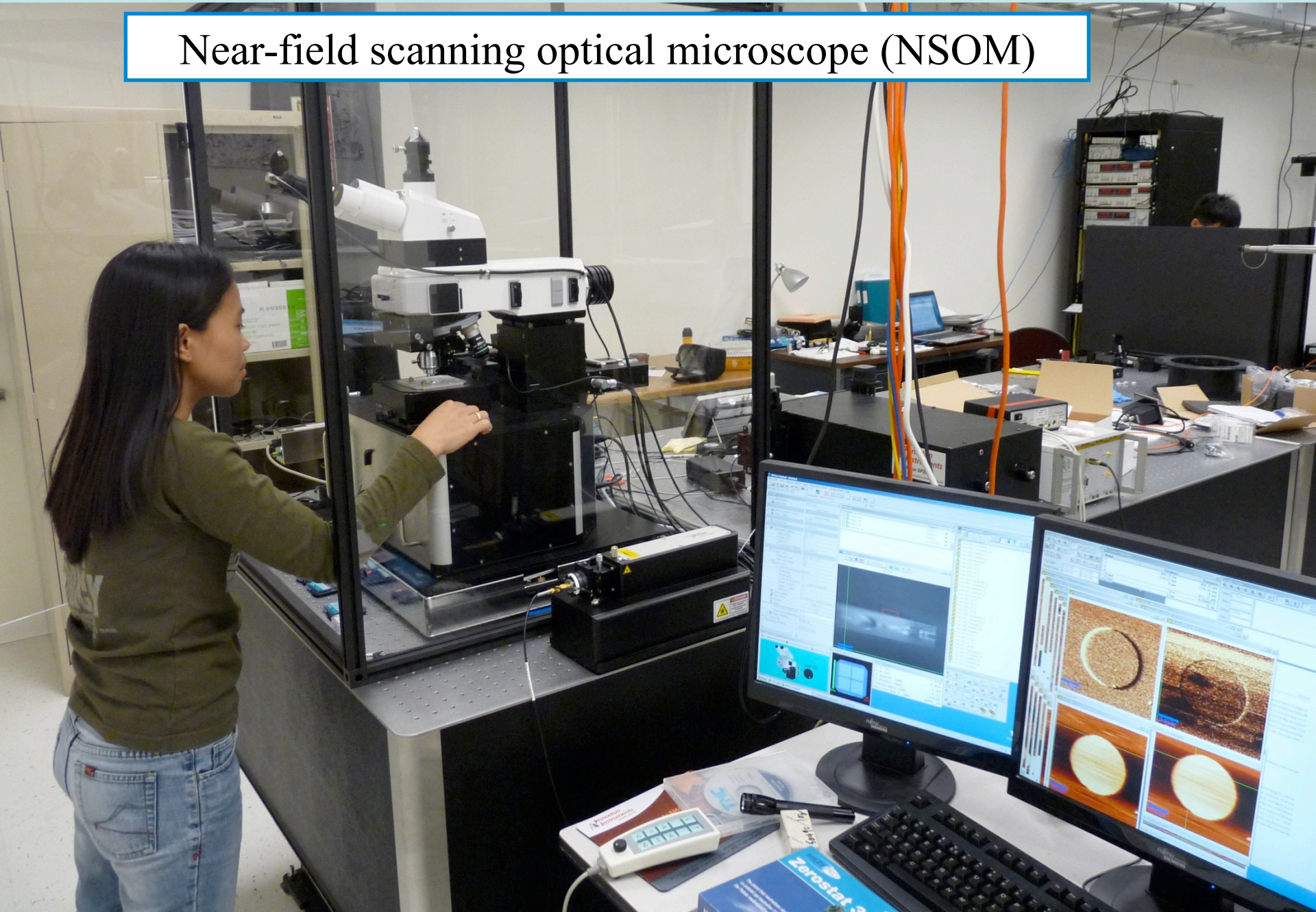
The Ultrafast Nanotools Lab (Hegmann)



Ultrahigh vacuum scanning tunneling microscope (UHV-STM)

The Ultrafast Nanotools Lab (Hegmann)

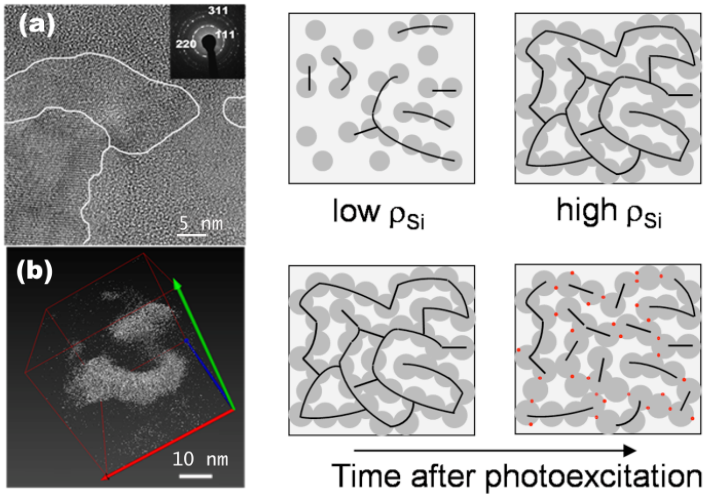
Near-field scanning optical microscope (NSOM)



Exploring nanoscale conductivity using THz spectroscopy

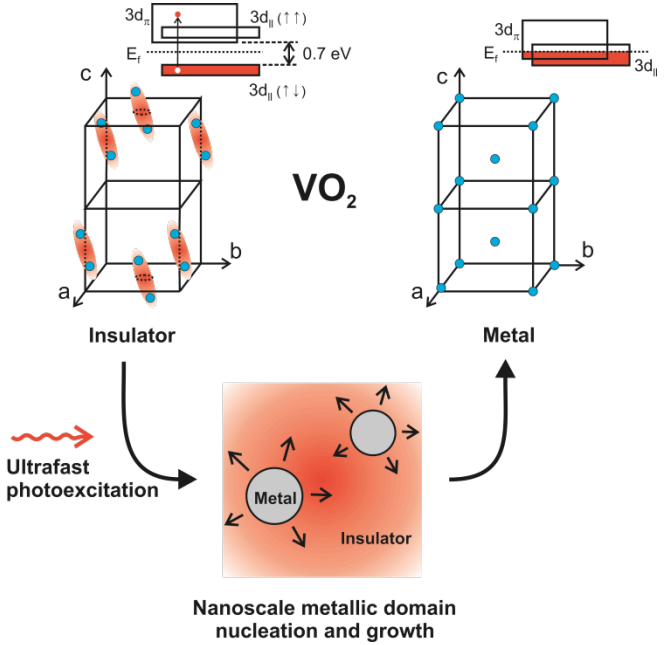
Silicon nanocrystals

Understanding nanoscale carrier dynamics is vital for potential solar cell design



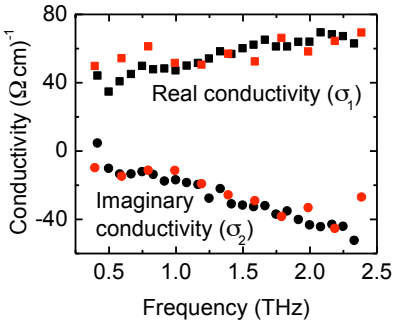
Vanadium dioxide

A model system for insulator-metal phase transitions in materials



Monte Carlo simulations

Modelling the THz response of mesoscopically confined carriers provides physical insight into their nanoscale behaviour



- Silicon nanocrystal data
- Monte Carlo simulation

University of Alberta

Beach	theoretical physics
Beamish	experimental physics
Brown	theoretical chemistry
Freeman	experimental physics
Davis	experimental physics
Hegmann	experimental physics
Jäger	experimental chemistry
Jacob	experimental engineering
Marsiglio	theoretical physics
Meldrum	experimental physics
Serpe	experimental chemistry
Wolkow	experimental physics