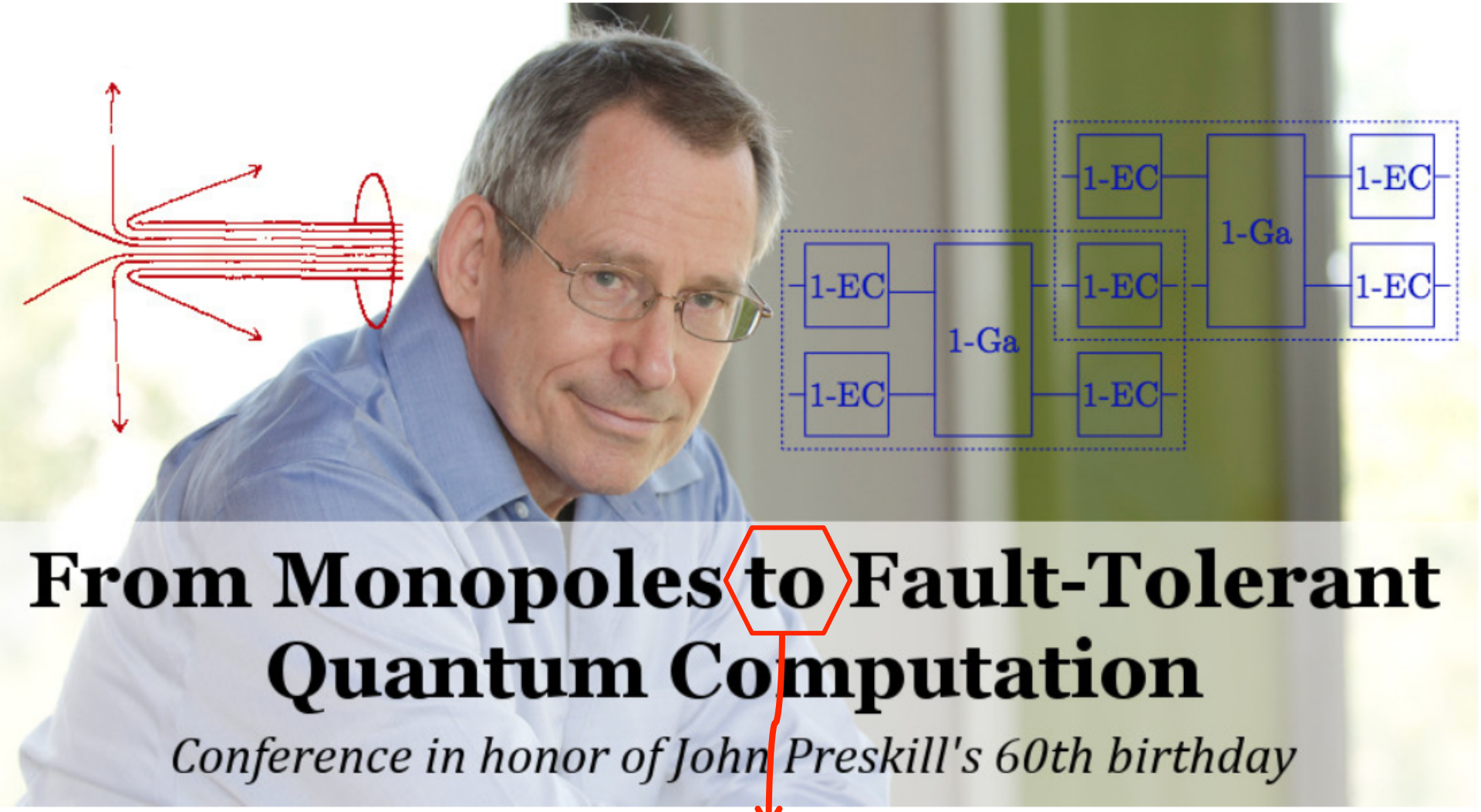

From Monopoles to Fault-Tolerant Quantum Computation

Conference in honor of John Preskill's 60th birthday

Strong Interactions of Single Atoms & Photons in 1 and 2-Dimensional Photonic Crystals

H. Jeff Kimble
California Institute of Technology, 14 March 2013

Quantum Information and Computation

Caltech - MIT - USC

DARPA
1995-2001

NSF
Institute for Quantum Information
John Preskill
09/01/00

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE (if not in response to a program announcement/solicitation enter NSF 00-2)
NSF 99-167 04/17/00

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0086038

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REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
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PI/PD DEPARTMENT
Physics

PI/PD FAX NUMBER
626-793-9506

PI/PD POSTAL ADDRESS
1201 East California Boulevard
Mail Code 12-33
Pasadena, CA 91125
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME H. J Kimble	PH.D.	1978	626-395-8342	hjkimble@ceo.caltech.edu
CO-PI/PD John Doyle	ph.d.	1979		
CO-PI/PD John P Preskill	Ph. D.	1980	626-395-6691	preskill@theory.caltech.edu
CO-PI/PD Michael L Roukes	Ph.D.	1985	626-395-2916	roukes@caltech.edu
CO-PI/PD Axel Scherer	Ph.D.	1985	626-395-4691	etcher@caltech.edu

IQI Institute for Quantum Information

John Preskill
Physics

Caltech Establishes IQI: Institute for Quantum Information

by John Preskill

Alexei Kitaev
Physics and
Computer Science

Leonard Schulman
Computer Science

"As with any revolutionary scientific insight, the long-term implications [of QIS] cannot be clearly anticipated, but we are confident that they will be profound. We also expect that the emergence of QIS will have an extensive eventual impact on how science is taught at the college and secondary level, and will bring a deeper understanding of quantum physics to a broad segment of the lay public."
—*John Preskill, Professor of Theoretical Physics*

Gil Refael
Physics

Jeff Kimble
Physics

IQI Alumni: Postdocs

Eddy Ardonne	Nordita	Debbie Leung	Waterloo
Salman Beigi	IPM	Netanel Lindner	Technion
Sougato Bose	UCL	Yi-Kai Liu	NIST
Sergey Bravyi	IBM	Ashwin Nayak	Waterloo
Darrick Chang	ICFO	Stefano Pironio	ULB
Andrew Childs	Waterloo	David Poulin	Sherbrooke
Andrew Doherty	Sydney	Robert Raussendorf	UBC
Luming Duan	Michigan	Ben Reichardt	USC
Lukasz Fidkowski	Stony Brook	Norbert Schuch	Aachen
Steve Flammia	Sydney	Yaoyun Shi	Michigan
Alexei Gorshkov	NIST	Kirill Shtengel	UCR
Sean Hallgren	Penn State	Barbara Terhal	Aachen
Patrick Hayden	McGill	Frank Verstraete	Vienna
Liang Jiang	Yale	Guifre Vidal	Perimeter
Stephen Jordan	NIST	Stephanie Wehner	Singapore
Liang Kong	New Hamp.	Pawel Wocjan	UCF
Robert König	Waterloo	Shengyu Zhang	Hong Kong

34 former IQI postdocs hold faculty positions (or the equivalent).

13 US, 8 Canada, 7 Europe, 2 Asia, 2 Australia, 2 Middle East

Also: Dave Bacon (Google), Robin Blume-Kohout (Sandia), Sergio Boixo (ISI), Jon Yard (Microsoft)

INSTITUTE FOR QUANTUM INFORMATION AND MATTER

An NSF Physics Frontiers Center with support from the
Gordon and Betty Moore Foundation

GORDON AND BETTY
MOORE
FOUNDATION

IQIM at the Entanglement Frontier

➔ *A quest for qualitatively new physics in the quantum realm*

Grand Challenges Spanning across the IQIM

1. Are all quantum systems in Nature computationally equivalent (i.e., is there a "Quantum Church-Turing" theorem)?

2. Is there an exhaustive classification of the quantum phases of matter? What are the topological properties of these phases?

3. How do we best discover highly entangled quantum states in Nature? Will fundamental insights in physics emerge?

4. Can we "build" exotic quantum systems? Will such systems be "useful" (e.g., to realize a *universal quantum simulator*, to enhance quantum metrology, …)?

5. How do we robustly measure entanglement in quantum many-body systems?

6. How do we best realize nonabelian anyons and confirm their exotic statistics?

7. What are the physical limitations on quantum computation?

IQIM Professorial Faculty and Vision
Caltech Institute for Quantum Information and Matter

Physics
Jason Alicea
Rana Adhikari
Yanbei Chen
James Eisenstein
Matthew Fisher (UCSB)
David Hsieh
Jeff Kimble
Alexei Kitaev (1/2)
Olexei Motrunich
Jerome Pine
John Preskill
Gil Refael
Michael Roukes
Nai-Chang Yeh

Applied Physics
Andrei Faraon
Oskar Painter
Keith Schwab
Kerry Vahala

Computer Science
Alexei Kitaev (1/2)
Leonard Schulman

IQIM Professorial Faculty – 19
≈ 30% of Caltech physics faculty

IQIM Vision

• The IQIM is driven by the belief that there is a rare convergence of theoretical insights and experimental capabilities that offers remarkable opportunities for discoveries of new principles and phenomena at the multidisciplinary interfaces of Physics and Quantum Information Science (QIS).

• We are merging analytic tools from the IQI with emerging laboratory capabilities in CMP, AMOP, and QMMS for the discovery of new exotic quantum states of matter and the advancement of core issues in physics.

IQIM Young Person's Seminar
Organized by and for Students & Postdocs

Friday afternoon,
4:30 –5:15pm
Afterwards 5:15 – ?:??pm
Refreshments
and social interactions

IQIM Postdocs - 34

IQIM Senior Research Fellows - 3

IQIM Graduate Students - 48

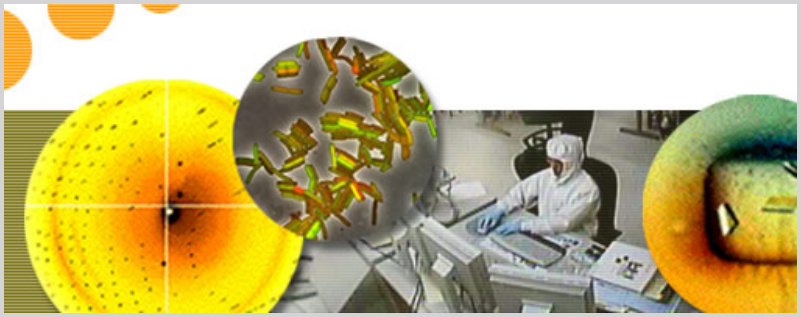
IQIM Undergraduates - 11

IQIM spans across Caltech with significant institute support

- Funding from the Gordon and Betty Moore Foundation (November, 2010)
  - Brings together the diverse Caltech communities who focus on Quantum Mechanics at the table-top scale. Expands and substantiates our IQIM programs.
- Permanent home for NSF-sponsored Institute for Quantum Information - IQI
  - Annenberg Center for Information Science and Technology

The infamous "3J" Gang:
Jim (eisenstein)
John (preskill)
Jeff (kimble)

- Kavli Nanoscience Institute – KNI
  - KNI's mission is to advance the state of the art in nanofabrication



- Renovation of historic Bridge Building for IQIM faculty
  - Has brought together in one building many of the researchers that form IQIM

CALIFORNIA INSTITUTE OF TECHNOLOGY

IQIM

Institute for
Quantum Information and Matter

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- Research
- Publications
- People
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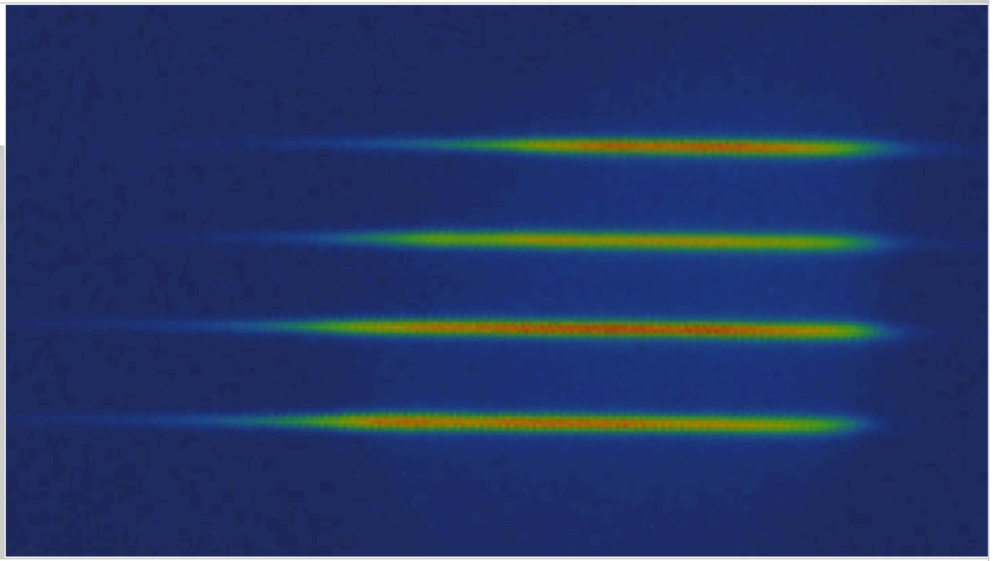


IQIM

Institute for
Quantum Information and Matter

http://iqim.caltech.edu/

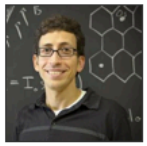
Welcome

The Institute for Quantum Information and Matter (IQIM) at Caltech is a Physics Frontiers Center supported by the National Science Foundation and the Gordon and Betty Moore Foundation. IQIM researchers study physical systems in which the weirdness of the quantum world becomes manifest on macroscopic scales. Our research programs span quantum information science, quantum many-body physics, quantum optics, and the quantum mechanics of mechanical systems.

IQIM Postodoctoral Fellowships

To apply, visit the IQIM Postdoctoral Fellowship web page

In the News



New Physics faculty, Jason Alicea, discusses his circuitous path to physicis and his current work toward developing the physics behind a quantum computer. Working with collaborators Gil Refael and Matthew Fisher, they look forward to "combining traditional conventional materials that are already available on people's shelves—to design a device that's capable of performing bona fide universal quantum computation without decoherence. We don't know how to do that, but we've made some small steps in that direction fairly recently. That's what I'm most excited about right now." [Read the full article introducing Jason Alicea] 12.18.12

Jeff Kimble, William L. Valentine Professor and Professor of Physics, is the 2013 recipient of the Herbert Walther Award, which is jointly made by the Deutsche Physikalische Gesellschaft (DPG) and the Optical Society of America (OSA). Kimble is being recognized *For pioneering experimental contributions to quantum optics, cavity quantum electrodynamics, and quantum information science.* [Read more of the press release here] 11.21.12

Calendar

IQIM Postdoctoral and Graduate Student Seminars

Institute for Quantum Information Science (IQI) Seminars

Condensed Matter Physics (CMP) Seminars

Physics Mathematics and Astronomy Seminars

Upcoming Visitors

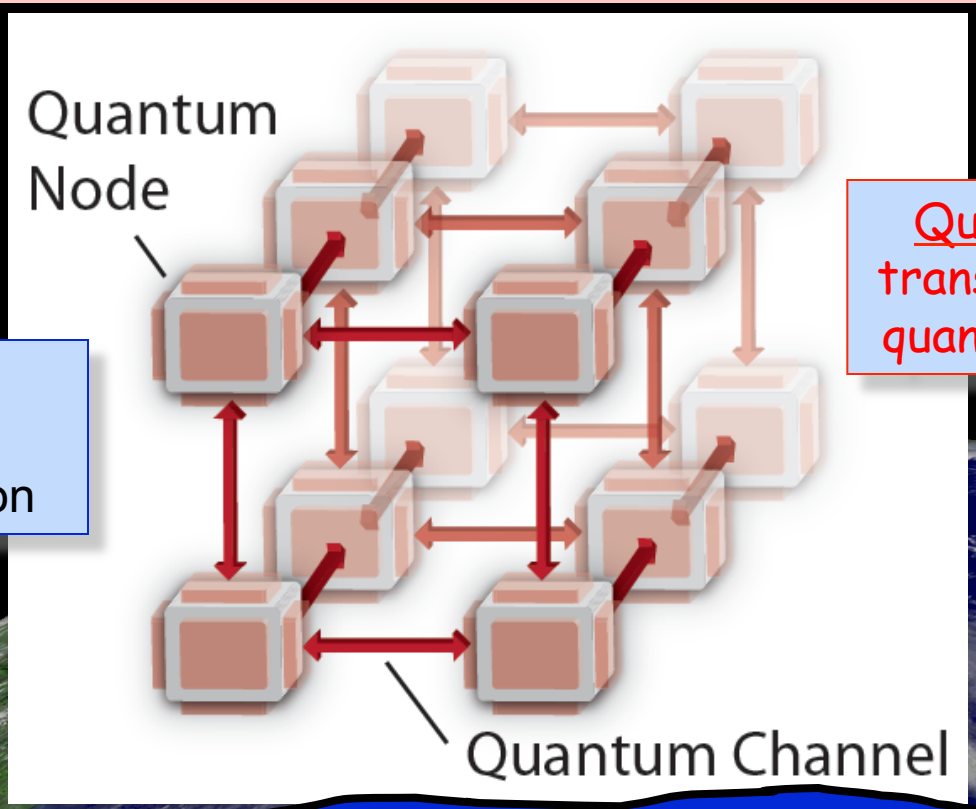
Keith Lee *Dec 31-Jan 18*
Stephen Jordan *Jan 6 - 19*
Stacey Jeffery *Jan 8-10*
Kejie Fang *Jan 10-11*
Steve Flammia *Jan 29*
Andrew Doherty *Jan 29*
Stephen Bartlett *Jan 29*
David Perez-Garcia *Feb 10-24*
Norbert Schuch *Feb 10-24*

Complete list of visitors here

Search:

Quantum Networks

➪ Fundamental Scientific Question and Diverse Technical Challenges



Quantum Node-
process / store
quantum information

Quantum Channel -
transport / distribute
quantum entanglement

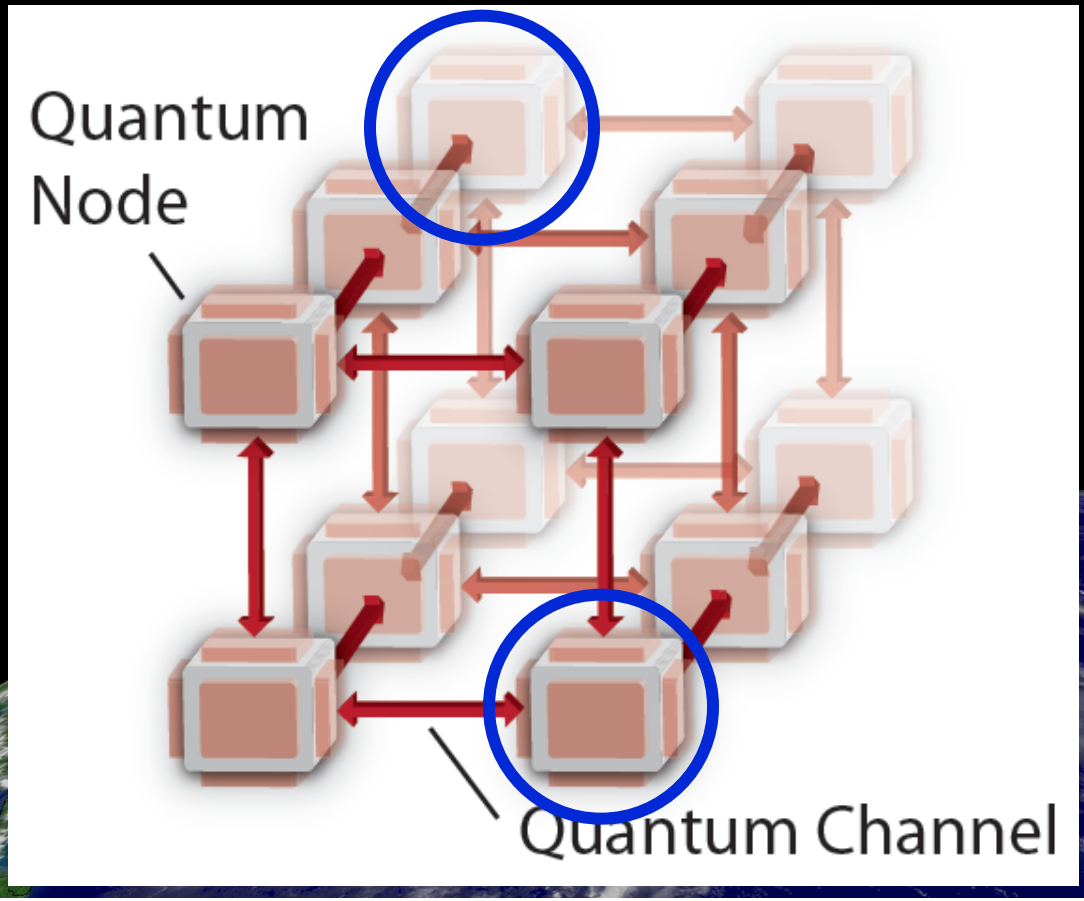
Theoretical issues

- Does it "work" – capabilities beyond *any* classical system
- Characterization of entangled states ➪ Computationally intractable?

Experimental implementation

- Physical processes for reliable generation, processing, & transport of quantum states

Distribution of Entanglement across Quantum Networks

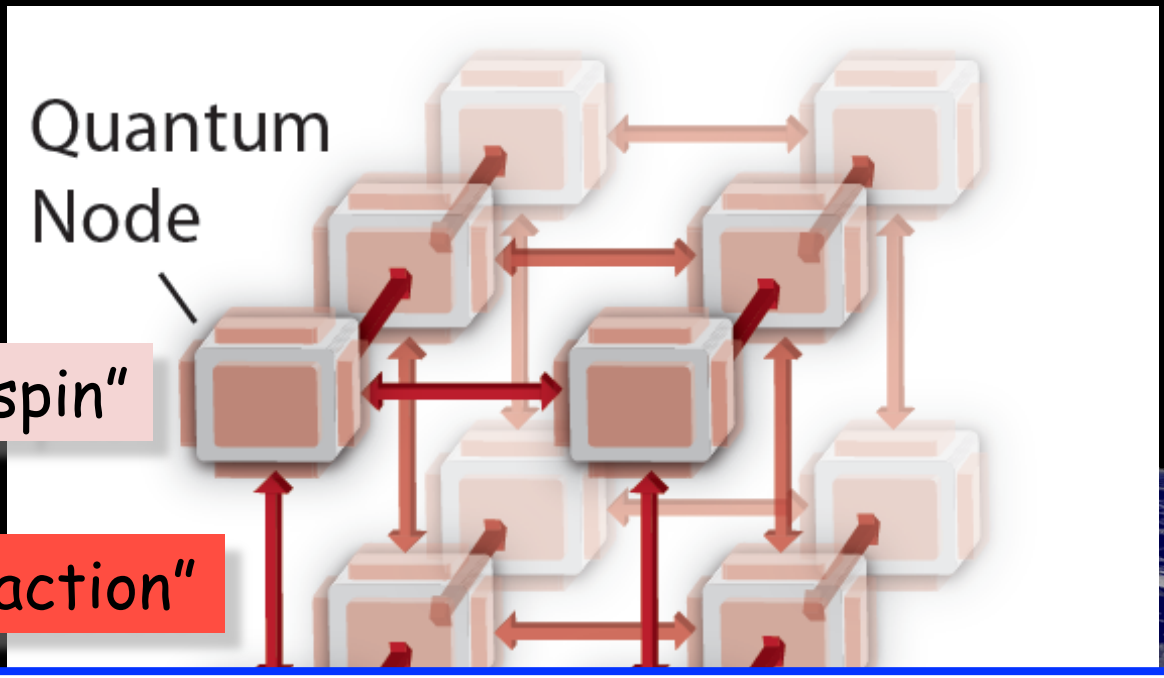


Entanglement percolation in quantum networks

nature physics | VOL 3 | APRIL 2007 | www.nature.com/naturephysics

ANTONIO ACÍN[1,2*], J. IGNACIO CIRAC[3*†] AND MACIEJ LEWENSTEIN[1,2*]

Quantum Networks for Quantum Simulation



Quantum many-body phenomena in coupled cavity arrays

Michael J. Hartmann [1,2,3,*], *Fernando G. S. L. Brandão* [2,3], *and Martin B. Plenio* [2,3]

Laser & Photon. Rev. **2**, No. 6, 527–556 (2008) / **DOI** 10.1002/lpor.200810046

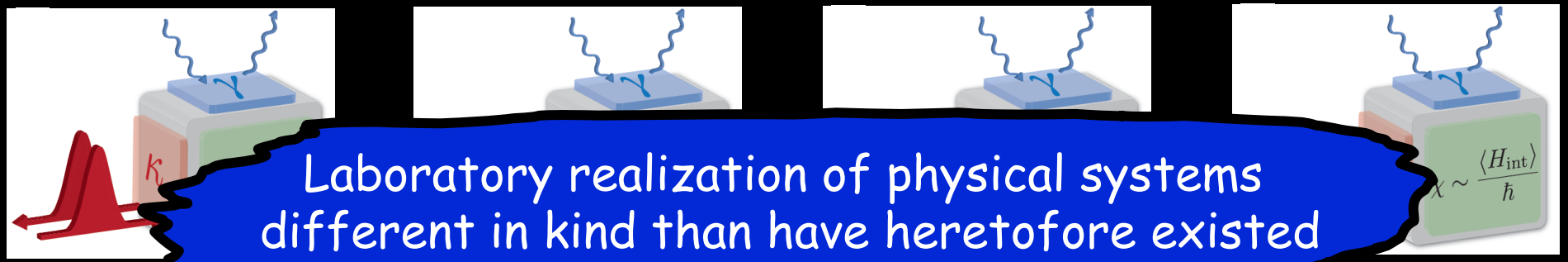
Laser & Photonics Reviews

L. Amico, R. Fazio, A. Osterloh, & V. Vedral, "Entanglement in many-body systems," Rev. Mod. Phys. **80**, 517 (2008)

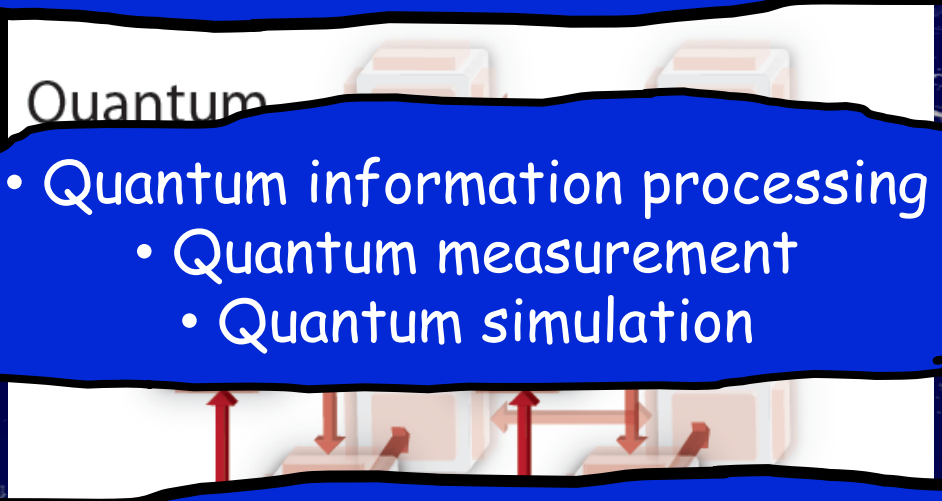
R. P. Feynman, "Simulating Physics with Computers," Intl. J. of Th. Physics **21**, 467 (1982)

Building Exotic Quantum Systems -

- "Lego blocks" for the realization of complex quantum systems
- Fundamental scientific question and diverse technical challenges



Laboratory realization of physical systems different in kind than have heretofore existed

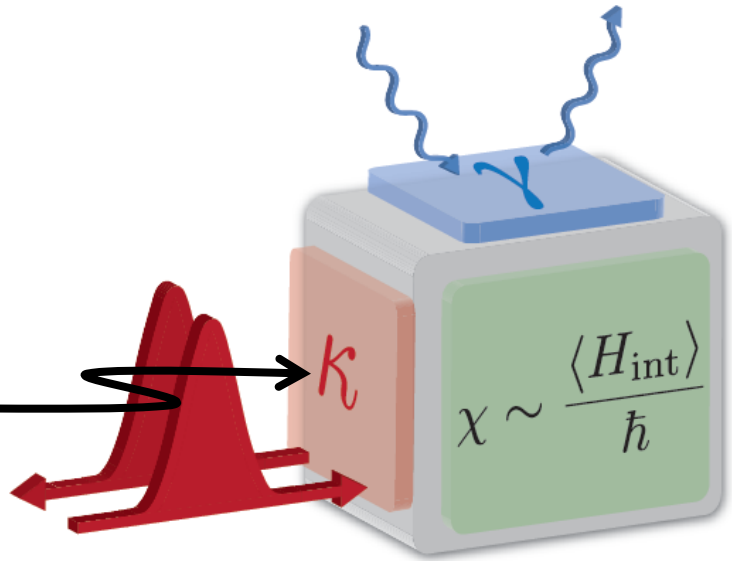


- Quantum information processing
- Quantum measurement
- Quantum simulation

Characterization and verification of entanglement for multipartite dystems -

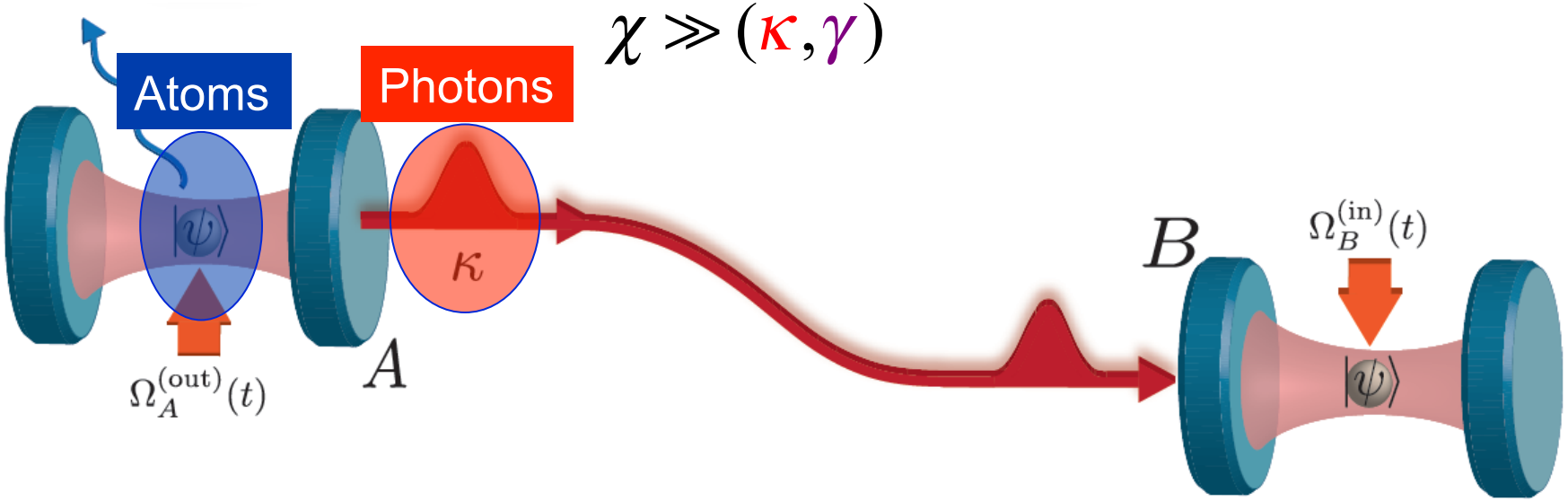
for N qubits, 2^{2N} elements of $\hat{\rho}$.

1) A Quantum Interface between Matter and Light



- Strongly coupled atom – photon via cavity QED

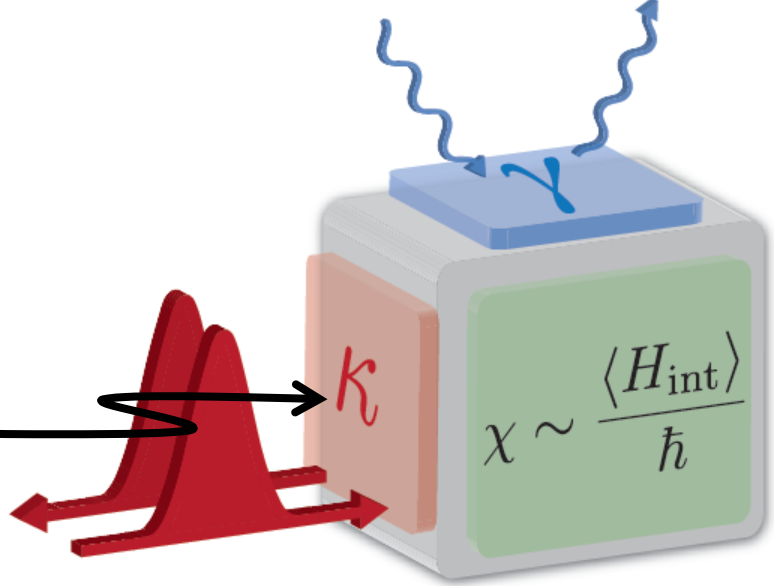
$$\chi \gg (\kappa, \gamma)$$



- Cirac, Zoller, Kimble & Mabuchi, **PRL** 78, 3221 (1997)

2) A Quantum Interface between Matter and Light

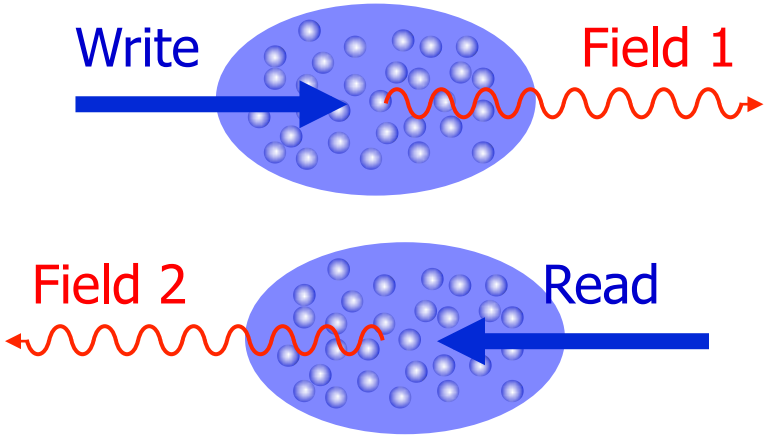
What's inside here?



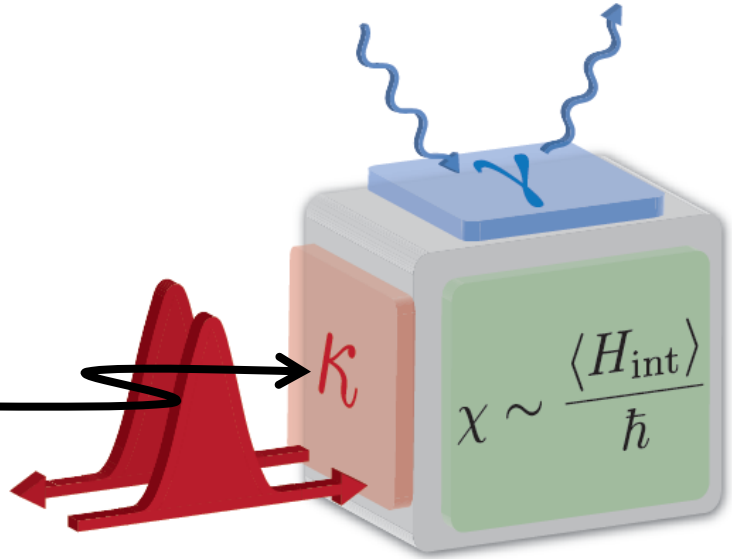
- Ensemble of ~ 10^5 atoms
- Strong interaction of single photons and collective spin excitations
- Raymer; Bigelow, Kuzmich, Mandel, Polzik; …., Fleischhauer, Lukin, …

- Duan, Cirac, Lukin & Zoller – *DLCZ*, Nature **414**, 413 (2001)

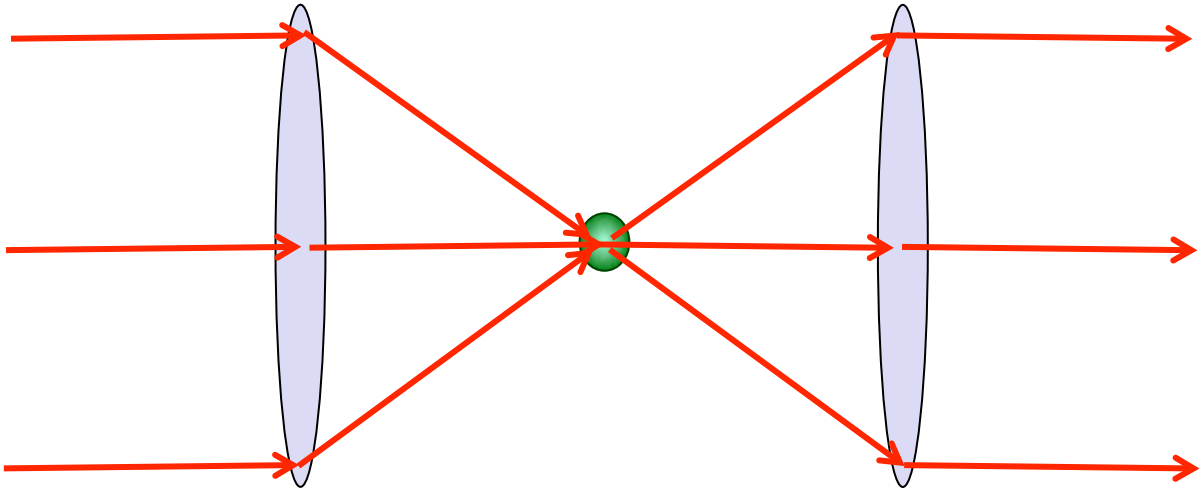
Writing and Reading single spin excitations via Raman processes



3) A Quantum Interface between Matter and Light



- Strong focusing of one photon onto a localized atom
- Efficient collection of atomic emission of single photons

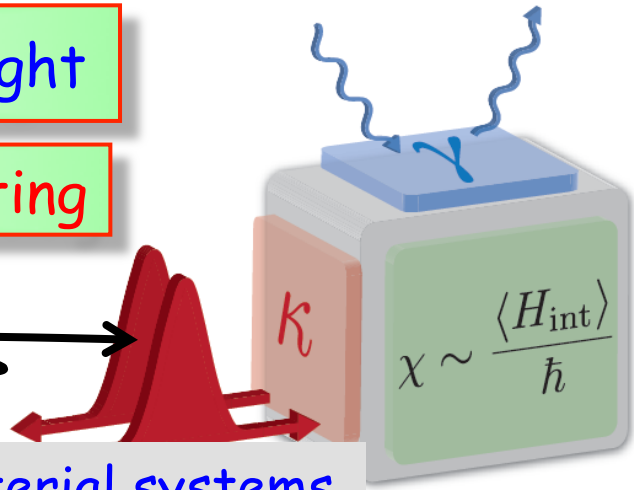


"Single atom in free space as a quantum aperture," van Enk & Kimble, PRL 61, 051802 (2000)

A Quantum Interface between Matter and Light

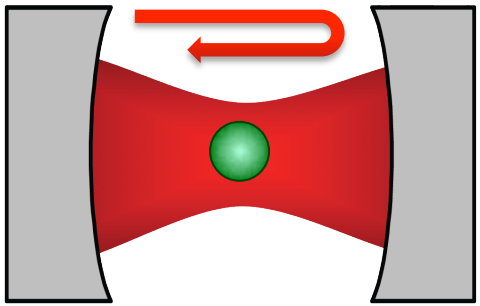
A new frontier to achieve 1), 2), 3) in one setting

What's inside here?

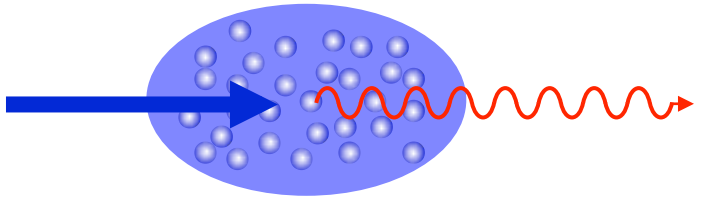


➢ Strong interactions of single photons with material systems

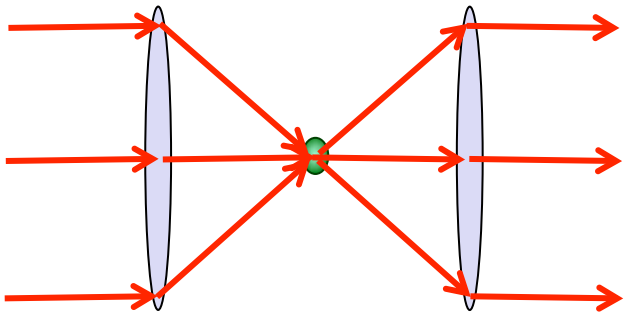
1. Multi-pass interactions and small mode volume in an optical cavity (cQED)



2. Large optical depth (e.g., atomic ensembles)

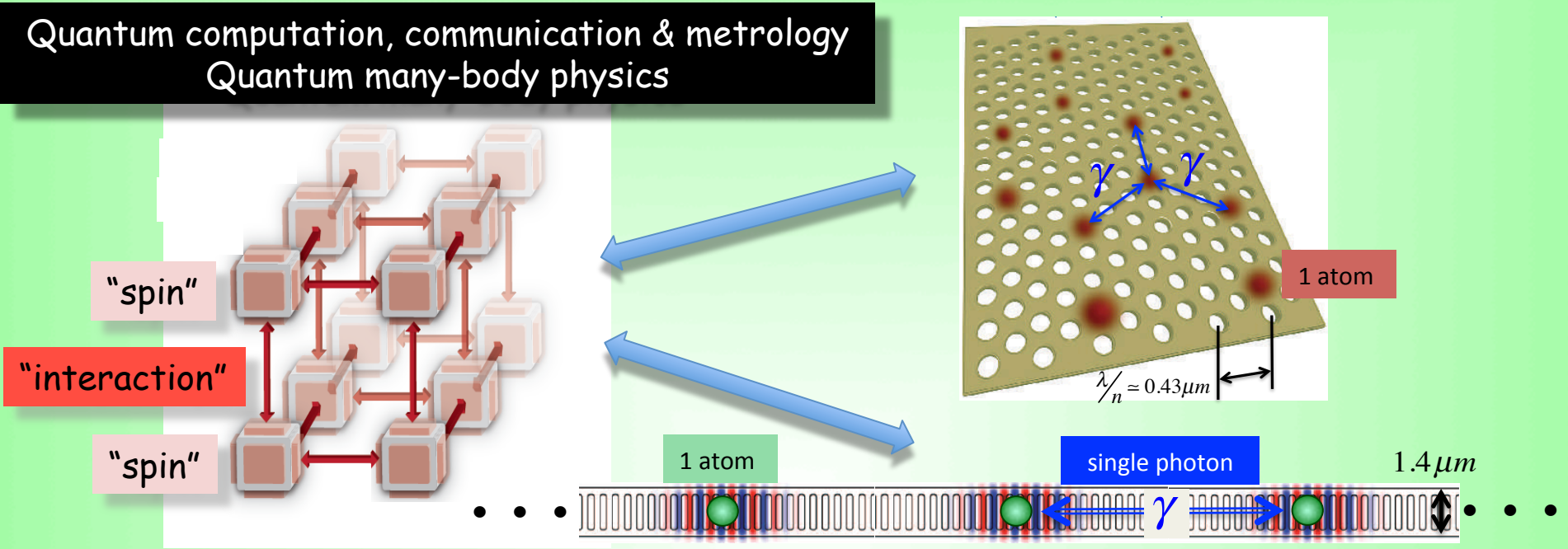


3. Strong focusing (localization) of light



Quantum Networks in Quantum Optics ⟺ CMP to IQI

Quantum computation, communication & metrology
Quantum many-body physics

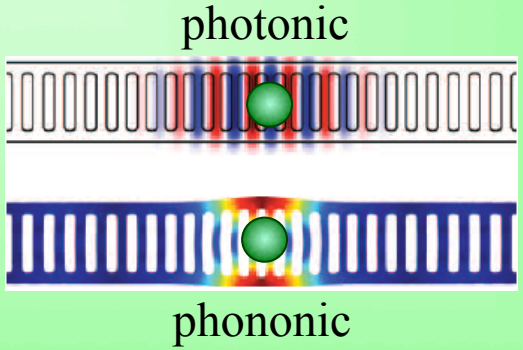


- How to realize such systems in the laboratory?
  - Strong collaboration between Physics and Applied Physics (Kimble, Painter, Vahala)

- What physics to anticipate from such systems?
  - Refael, QMBP in Condensed Matter; IQIM visitors: Chang, Cirac, van Enk

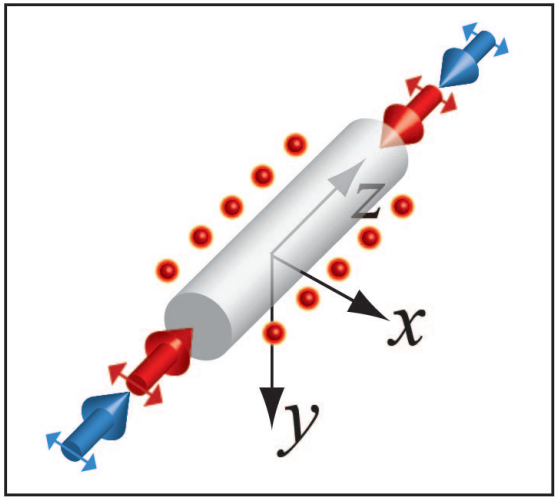
- Robust characterization of laboratory systems
  - IQI – Preskill & Refael, entanglement verification?
  - IQI & CMP – *physical* manifestations of entanglement?

- Strong interactions of single atoms, photons, & *phonons*
  - Painter & Vahala, opto-mechanical crystals

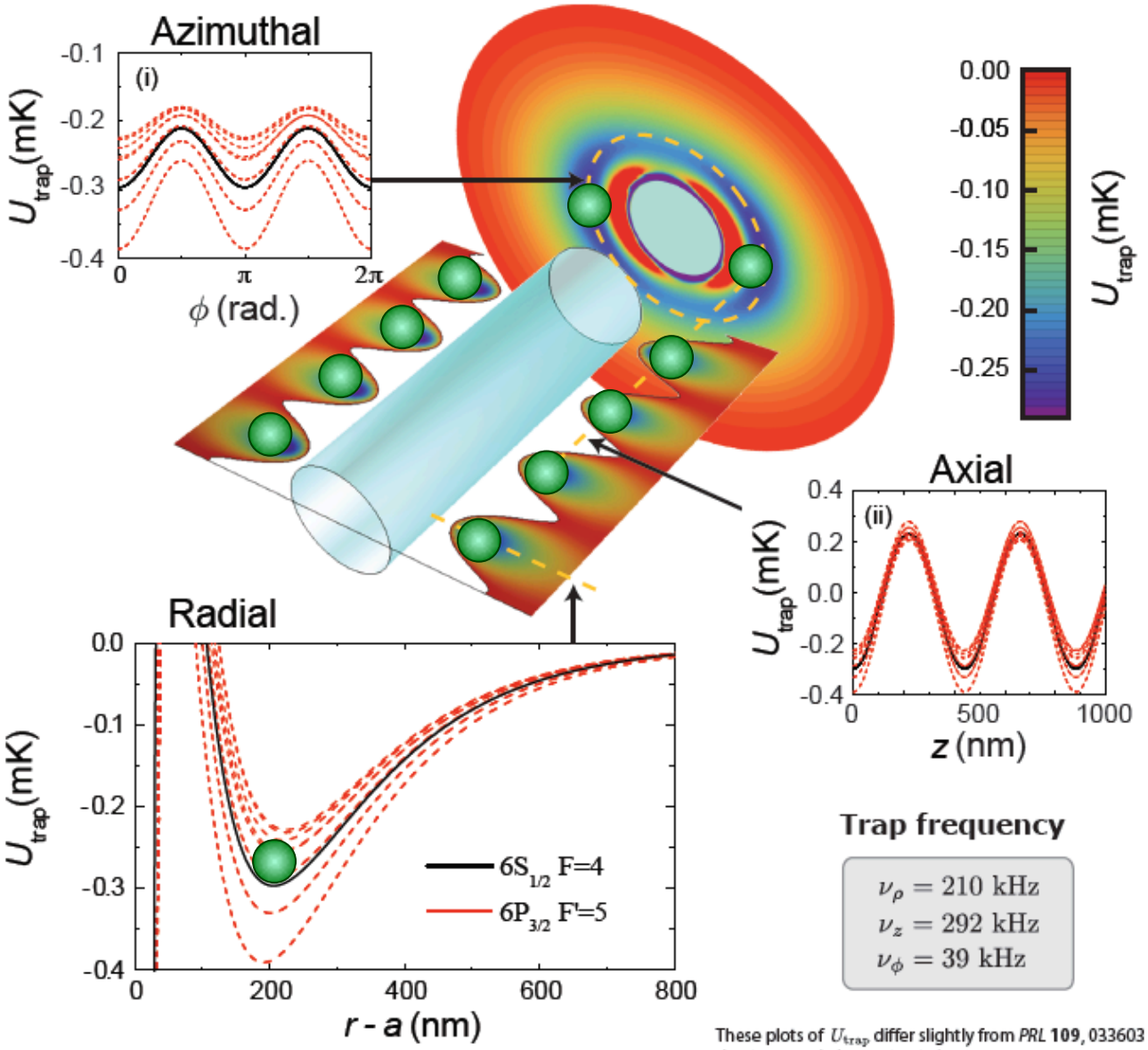


A State-Insensitive, Compensated Nanofiber Trap

C. Lacroute *et al.*, New J. Phys.14, 023056 (2012)



SiO_2 nano-fiber
diameter = 430nm



Trap parameters

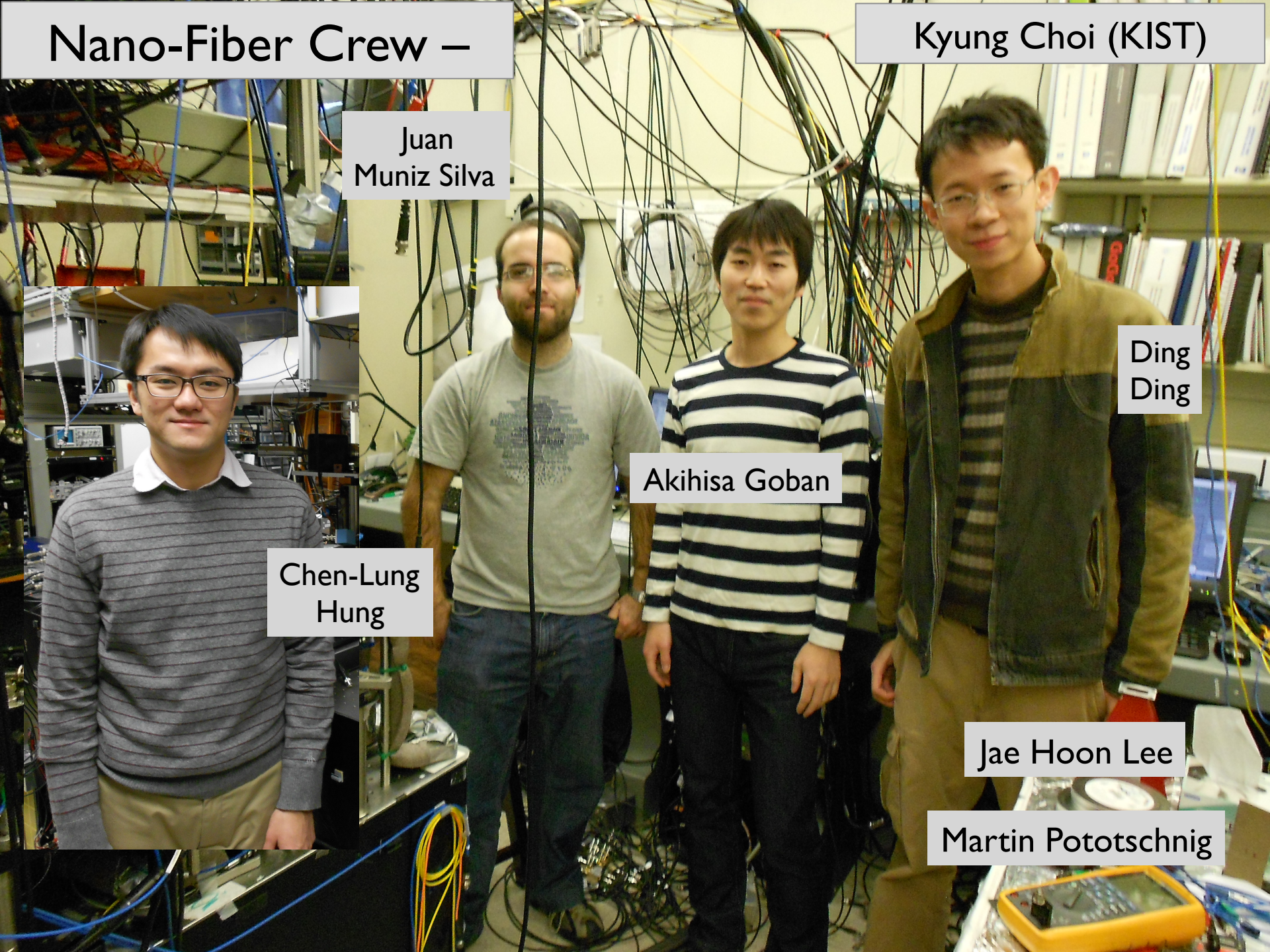
$\lambda_{red} = 935$ nm
$P_{red} = 2$ x 0.4 mW
$\lambda_{blue} = 687$ nm
$P_{blue} = 2$ x 5 mW
$f_r = 216$ kHz
$f_z = 294$ kHz
$f_\phi = 41$ kHz

Trap frequency

$\nu_\rho = 210$ kHz
$\nu_z = 292$ kHz
$\nu_\phi = 39$ kHz

These plots of U_{trap} differ slightly from *PRL* **109**, 033603 due to errors in Lacroute *et al.**

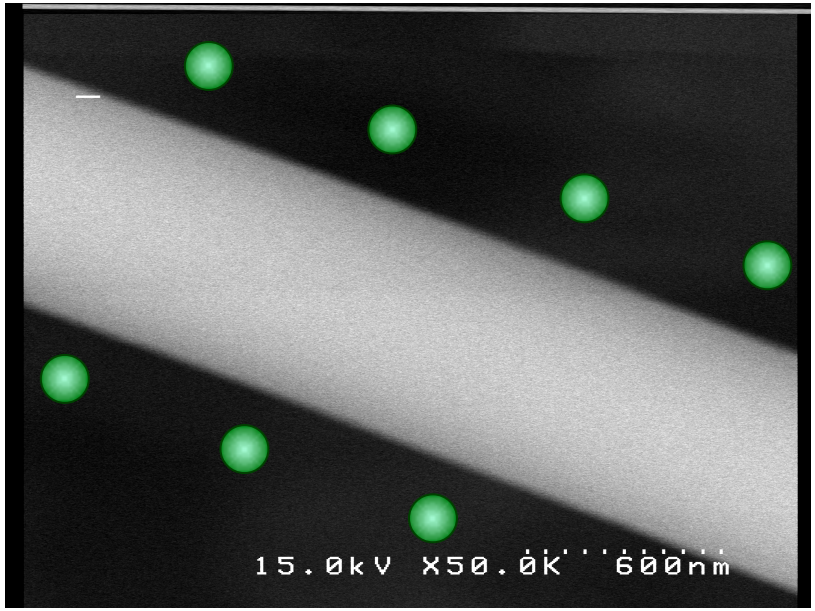
Nano-Fiber Crew –

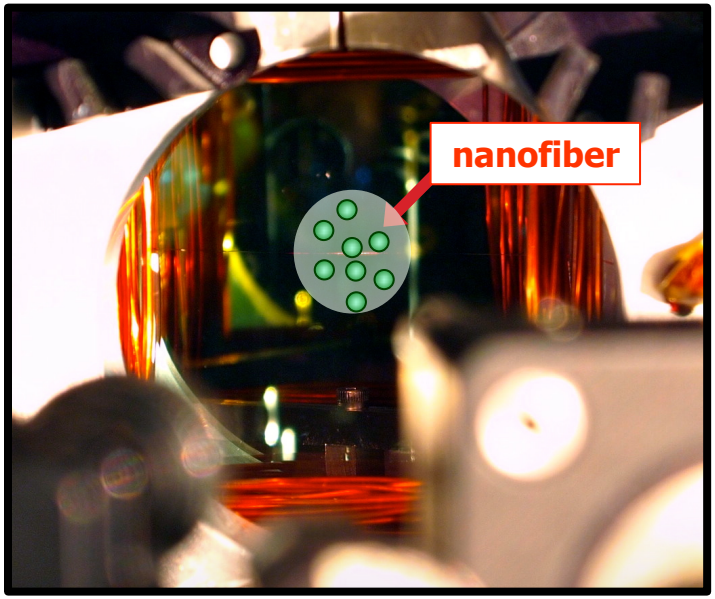


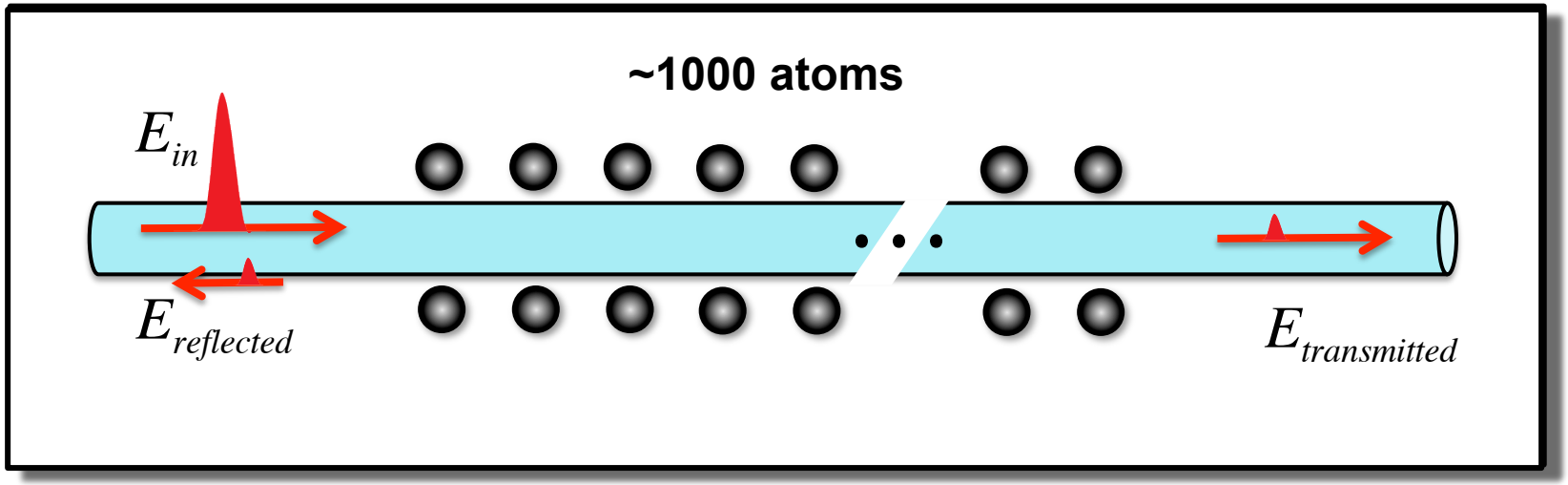
Demonstration of a State-Insensitive Nanofiber Trap

A. Goban *et al.*, Phys. Rev. Lett. **109**, 033603 (2012); arXiv:1203.5108v1

Nano-fiber



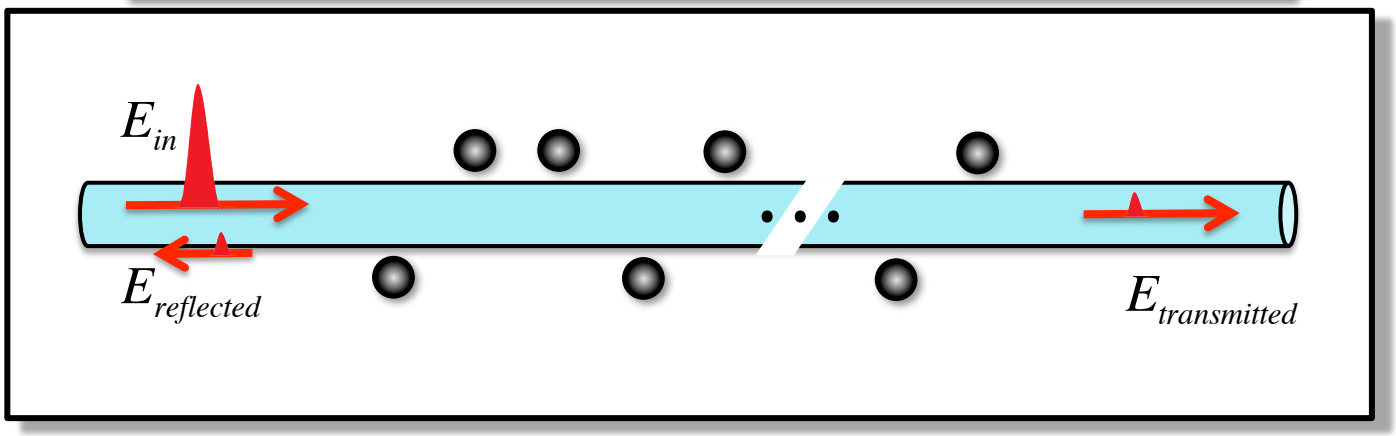




Absorption Spectroscopy for a Nano-Fiber Trap

Goban *et al.*, Phys. Rev. Lett. **109**, 033603 (2012); arXiv:1203.5108v1

$N_A \approx 800$ trapped atoms; $f \approx 0.2$ fraction of sites occupied



$$T(\delta) = \frac{|E_{in}|^2}{|E_{transmitted}|^2}$$

(trap at $\tau \approx 300$ ms)

Linewidth = 5.7 ± 0.1 MHz

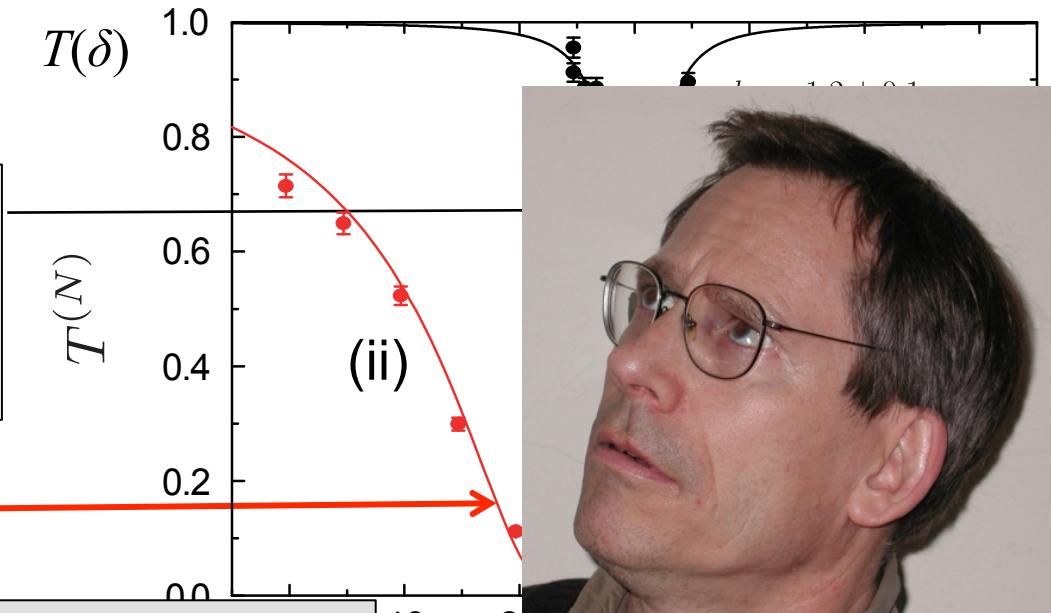
(4.94 + 0.32) MHz ~ 5.26 MHz

Frequency shift < 0.5 MHz

(trap at $\tau \approx 1$ ms)

Optical depth ≈ 66 ± 17

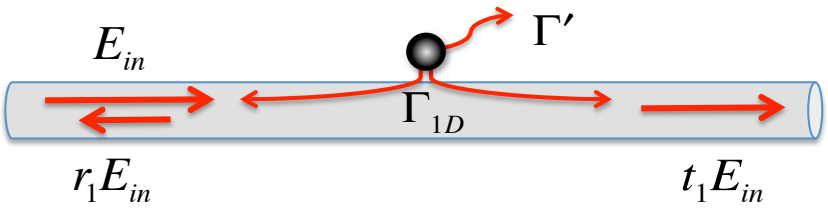
OD/atom ~ 8%



Recall Vetsch *et al.* (2010)
OD/atom ~ 0.65%

An Atomic Chain Coupled to a Nano-Fiber Waveguide

Single atom coupling

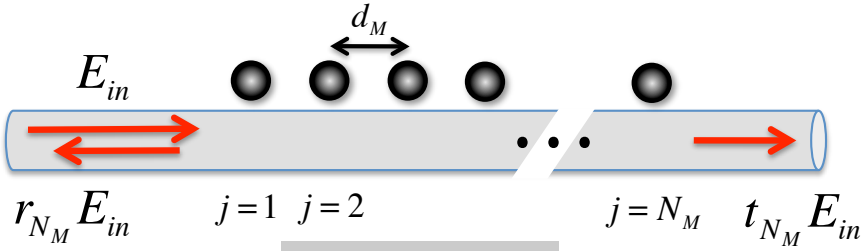


$$r_1 = \frac{\Gamma_{1D}}{\Gamma' + \Gamma_{1D}} = 0.2$$

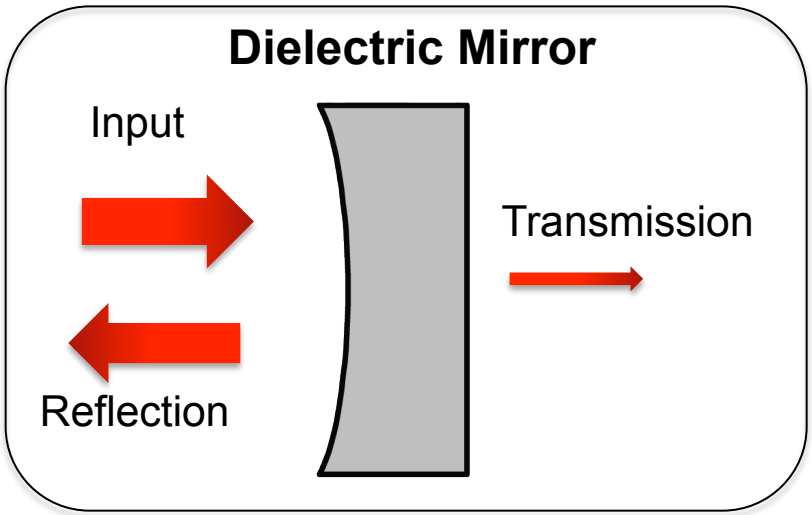
Current experiment - $r_1 \simeq 0.07$

Projected - $r_1 \simeq 0.9$

Atomic Bragg mirror with N_M atoms

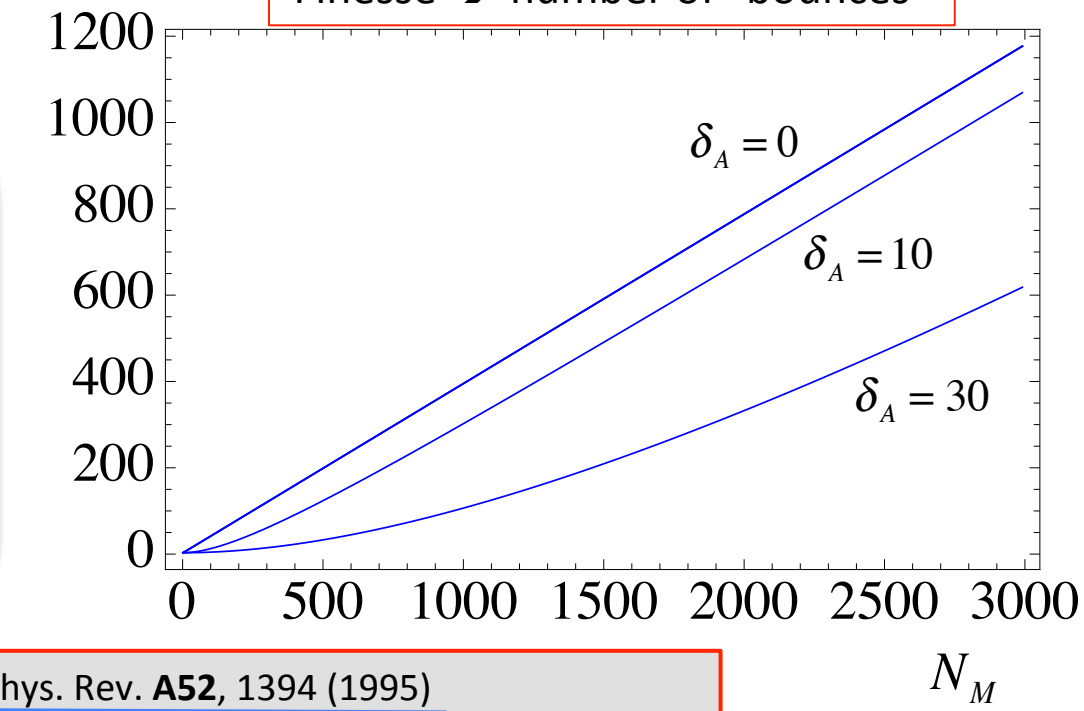


$$k_{probe} \times d_M = \pi$$



Atomic Mirror

Finesse ➔ number of "bounces"

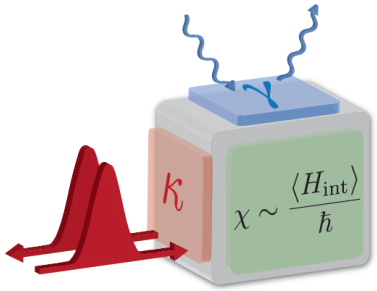


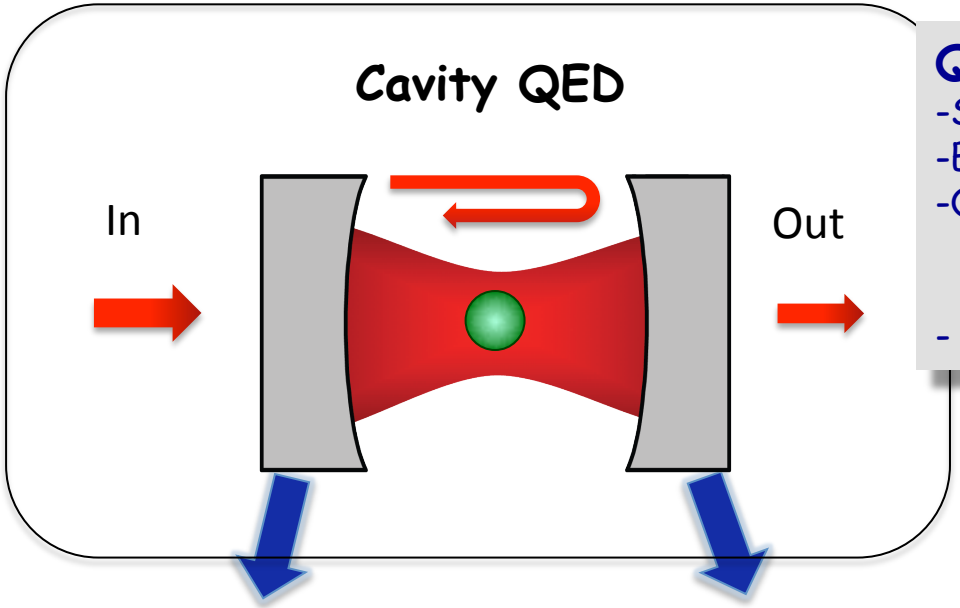
I. Deutsch, R. Spreeuw, S. Rolston & W. Phillips, Phys. Rev. **A52**, 1394 (1995)

Y. Chang, Z. R. Gong & C. P. Sun, Phys. Rev. **A83,** 013825 (2011); A. Schilke, C. Zimmermann, P. W. Courteille and W. Guerin, Phys. Rev. Lett. 106 223903 (2011); …

Cavity QED with Atomic Mirrors

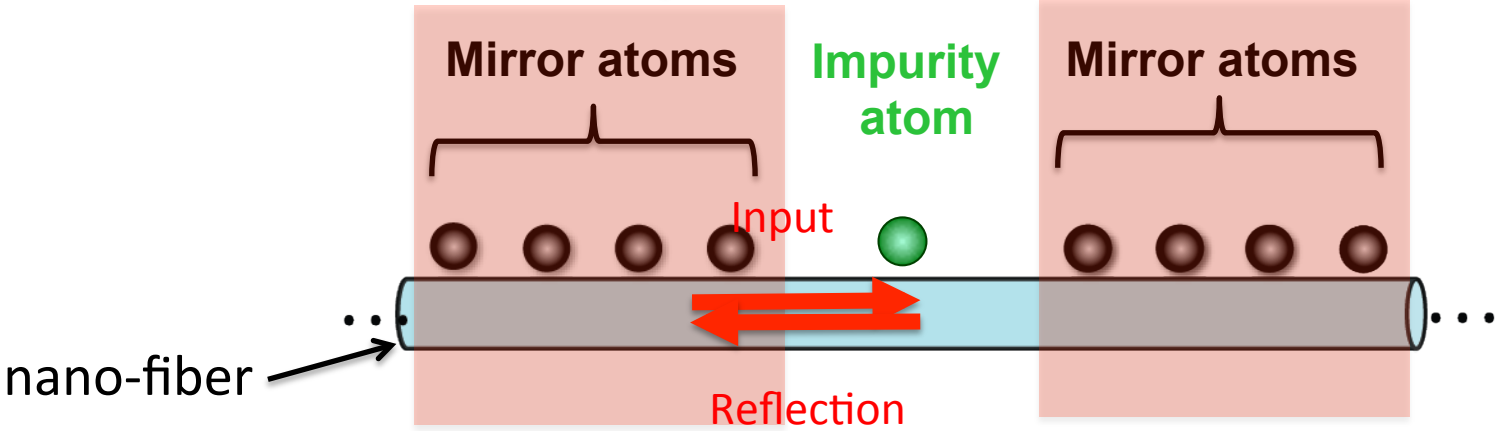
D. Chang, L. Jiang, A. Gorshkov & H.J. Kimble, N. J. Phys. **14** 063003 (2012); arXiv:1201.0643





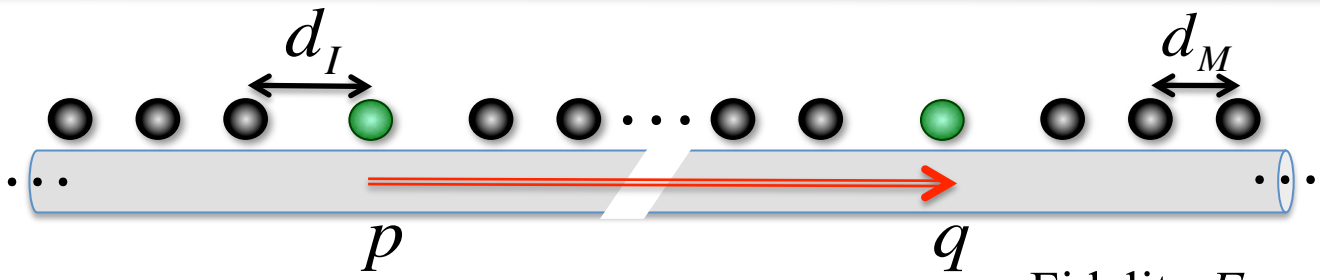
Quantum protocols

-Single photon generation
-Entanglement distribution
-Quantum logic
  - atoms
  - photons
- ...



Mirrors as coherent quantum memories strongly coupled to single impurity atom

Building Blocks for Scalable Quantum Information Processing*



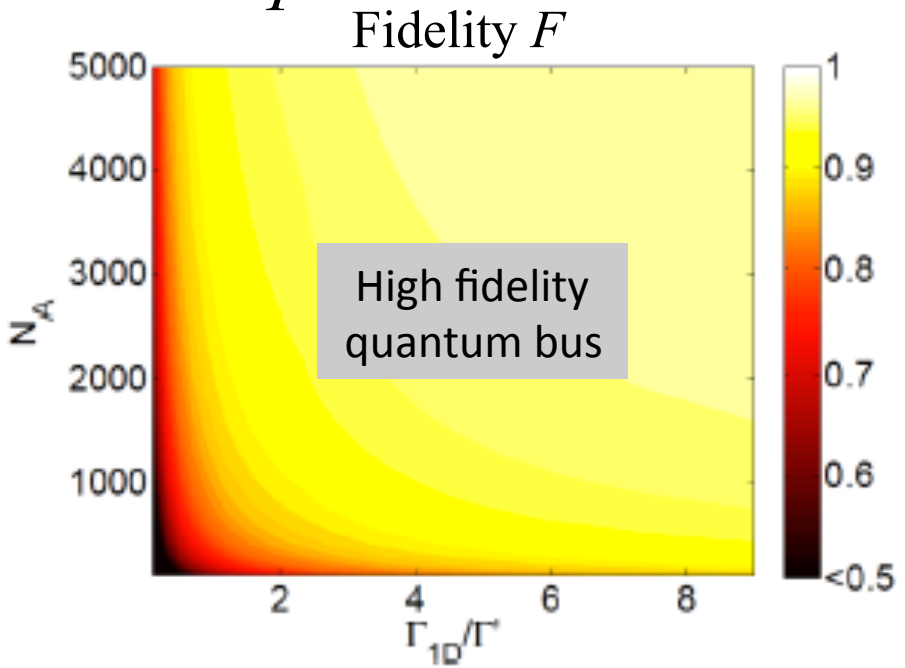
Example –

Quantum state transfer from atom *p* to atom *q*

$$\left(c_1\left|s_p\right\rangle + c_2\left|g_p\right\rangle\right)\otimes\left|g_q\right\rangle$$

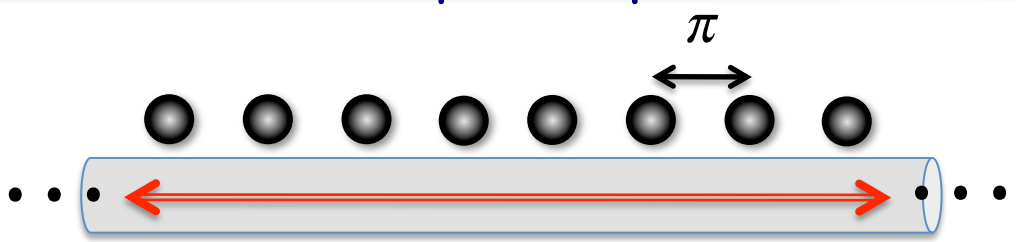
$$\downarrow$$

$$\left|g_p\right\rangle\otimes\left(c_1\left|s_q\right\rangle + c_2\left|g_q\right\rangle\right)$$



*D. Chang, L. Jiang, A. Gorshkov & H.J. Kimble, New J. Phys. **14** 063003 (2012); arXiv:1201.0643

Photon-Mediated Dipole-Dipole Interactions*



Master equation for the atomic density matrix ρ

$$\dot{\rho} = -i[H_{dd}, \rho] + \mathcal{L}_{dd}[\rho],$$

where

$$H_{dd} = (\Gamma_{1D}/2)\sum_{j,k} \sin k_A |z_j - z_k| \sigma_{eg}^j \sigma_{ge}^k$$

and

$$\mathcal{L}_{dd}[\rho] = -(\Gamma_{1D}/2)\sum_{j,k} \cos k_A |z_j - z_k| \left(\sigma_{eg}^j \sigma_{ge}^k \rho + \rho \sigma_{eg}^j \sigma_{ge}^k - 2\sigma_{ge}^k \rho \sigma_{eg}^j\right)$$

H_{dd} - coherent dipole-dipole coupling between atoms j, k

$\mathcal{L}_{dd}$ - cooperative atomic emission (e.g., super- and sub-radiance)

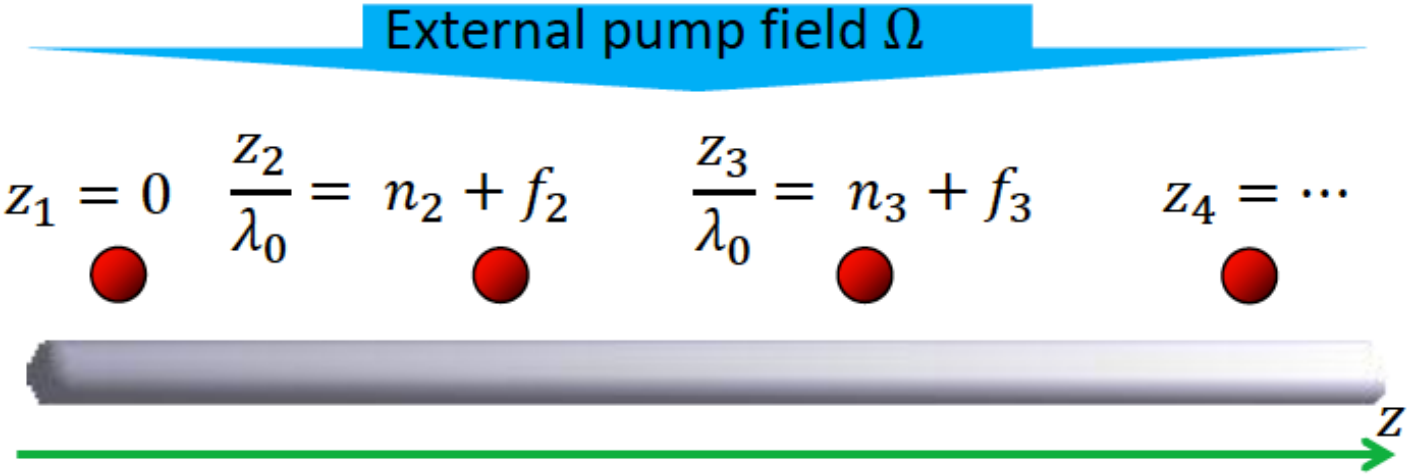
➔ "Infinite" range spin-spin interactions with sinusoidal coupling set by Γ_{1D}

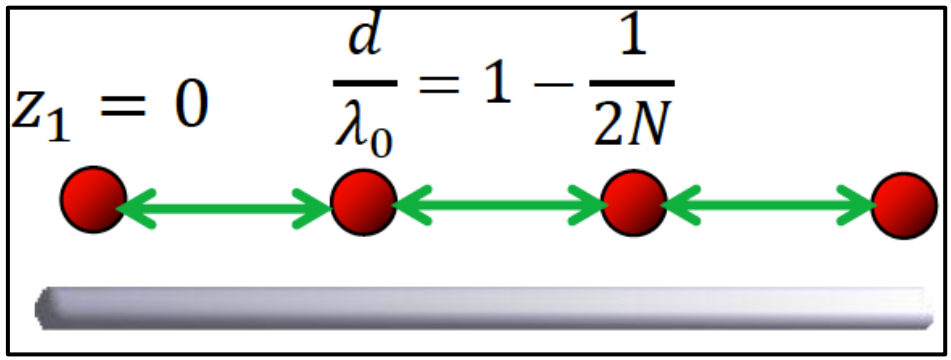
*D. Chang, L. Jiang, A. Gorshkov & H.J. Kimble, N. J. Phys. 14 063003 (2012)

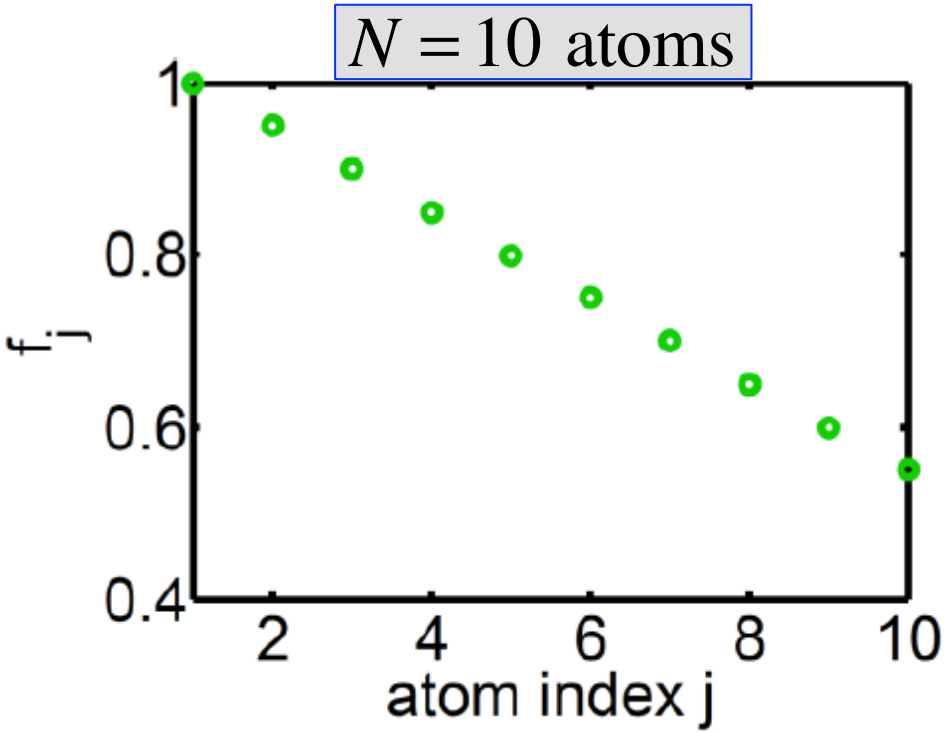
Le Kien F, Dutta Gupta S, Nayak K P and Hakuta K, Phys. Rev. A **72** 063815 (2005)
Shen J T and Fan S 2005, *Opt. Lett.* **30** 2001 (2005)
Zoubi H and Ritsch H, New J. Phys. **12** 103014 (2010)
Dzsotjan AS, Sørensen, and Fleischhauer, Phys. Rev. B **82**, 075427 (2010)

Self Organization of Atoms along a 1-D Waveguide

D. Chang, I. Cirac, & H.J. Kimble, arXiv1211.5660v1 (2012); PRL (2013)

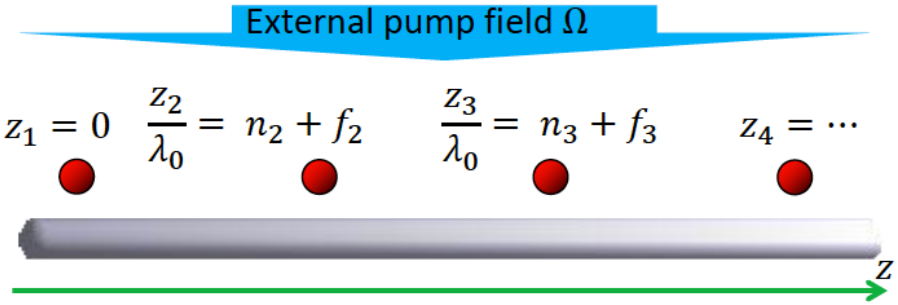






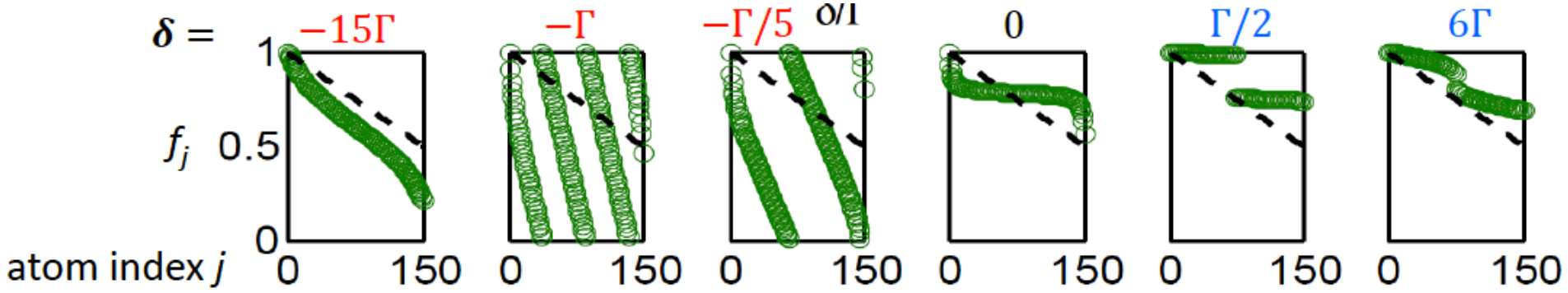
Self Organization of Atoms along a 1-D Waveguide

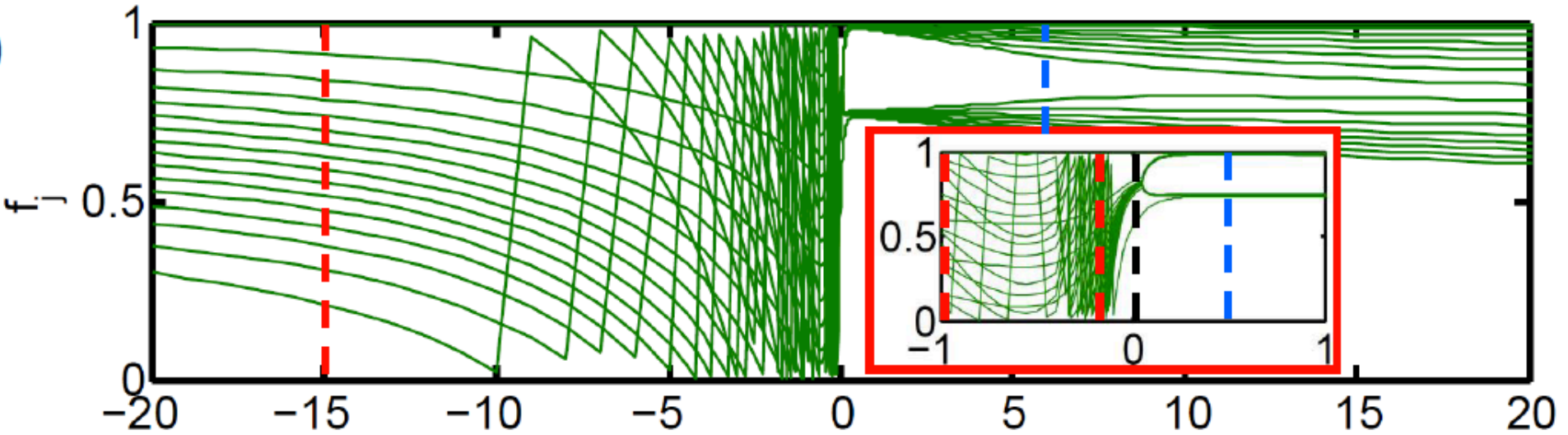
D. Chang, I. Cirac, & H.J. Kimble, arXiv1211.5660v1 (2012); PRL (2013)



$N = 150$ atoms

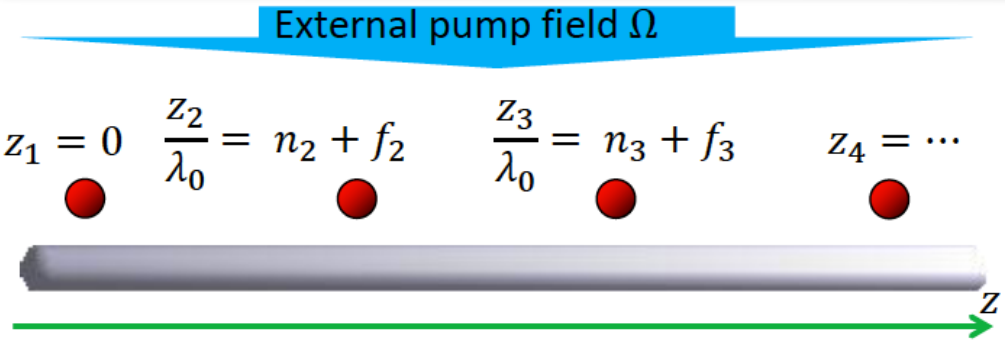
$$\Gamma_{1D}/\Gamma' = 0.25 \rightarrow r_1 = \frac{\Gamma_{1D}}{\Gamma' + \Gamma_{1D}} = 0.2$$





Self Organization of Atoms along a 1-D Waveguide

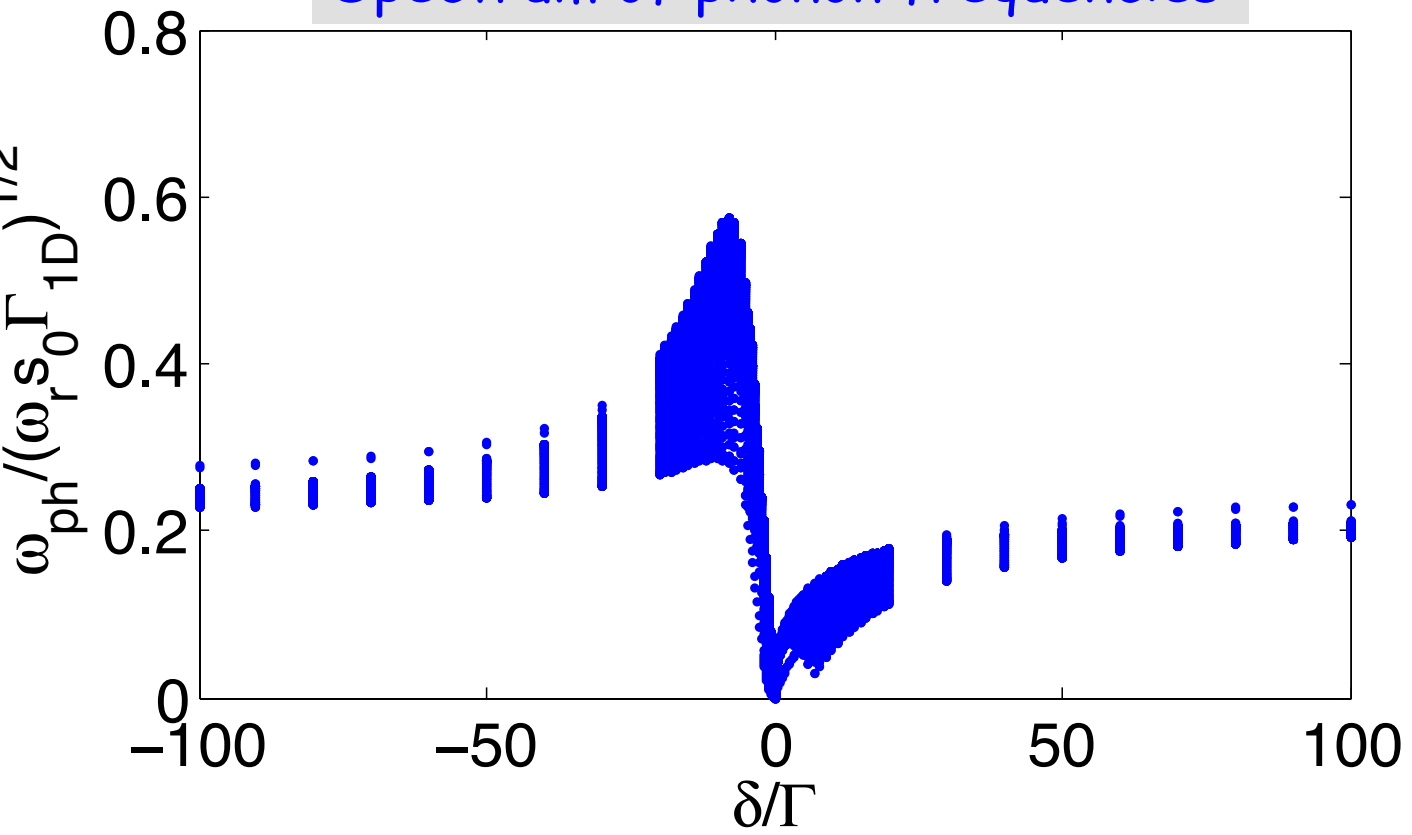
D. Chang, I. Cirac, & H.J. Kimble, arXiv1211.5660v1 (2012); PRL (2013)



$$N = 150 \text{ atoms}$$

$$\Gamma_{1D}/\Gamma' = 0.25 \rightarrow r_1 = \frac{\Gamma_{1D}}{\Gamma' + \Gamma_{1D}} = 0.2$$

Spectrum of phonon frequencies



Self Organization of Atoms along a 1-D Waveguide

D. Chang, I. Cirac, & H.J. Kimble, , arXiv1211.5660v1 (2012); PRL (2013)

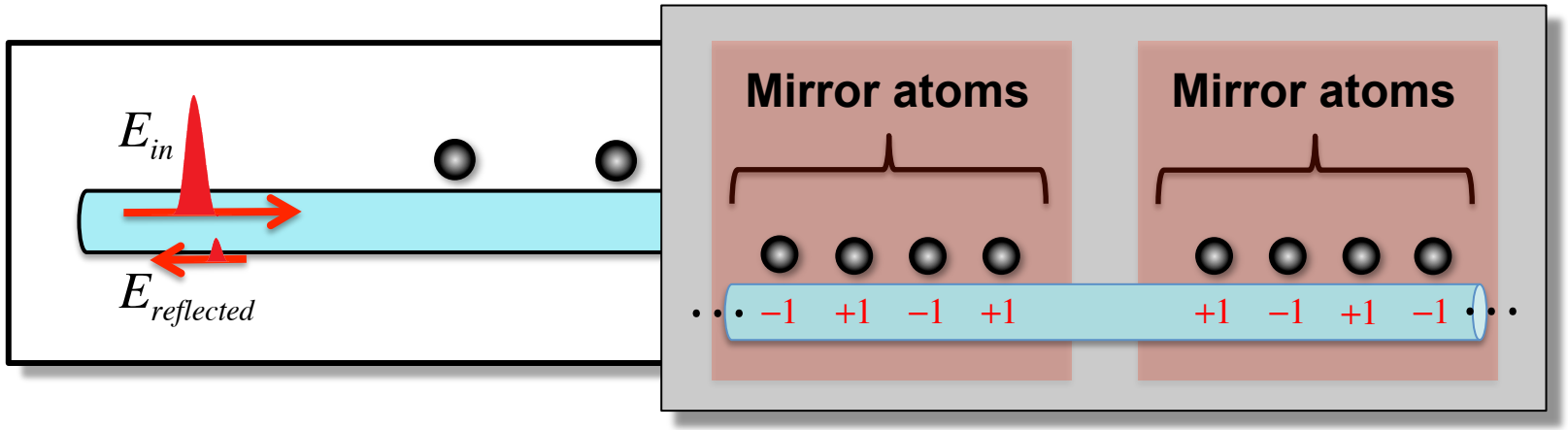
Probing 1-d self-organized "lattices"

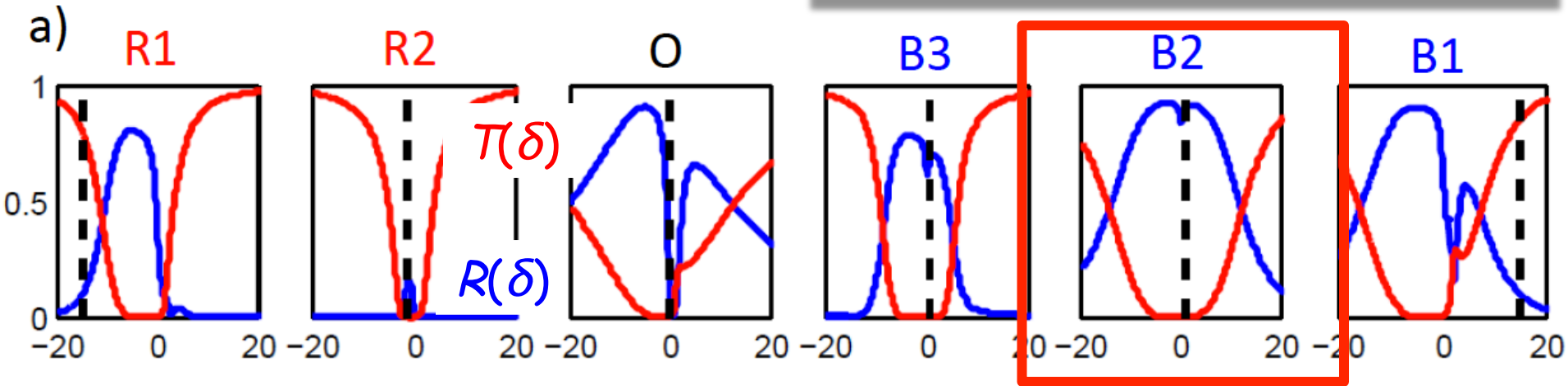
Reflection spectra $R(\delta)$

Transmission spectra $T(\delta)$

$$N = 150 \text{ atoms}$$

$$\Gamma_{1D}/\Gamma' = 0.25 \rightarrow r_1 = \frac{\Gamma_{1D}}{\Gamma' + \Gamma_{1D}} = 0.2$$

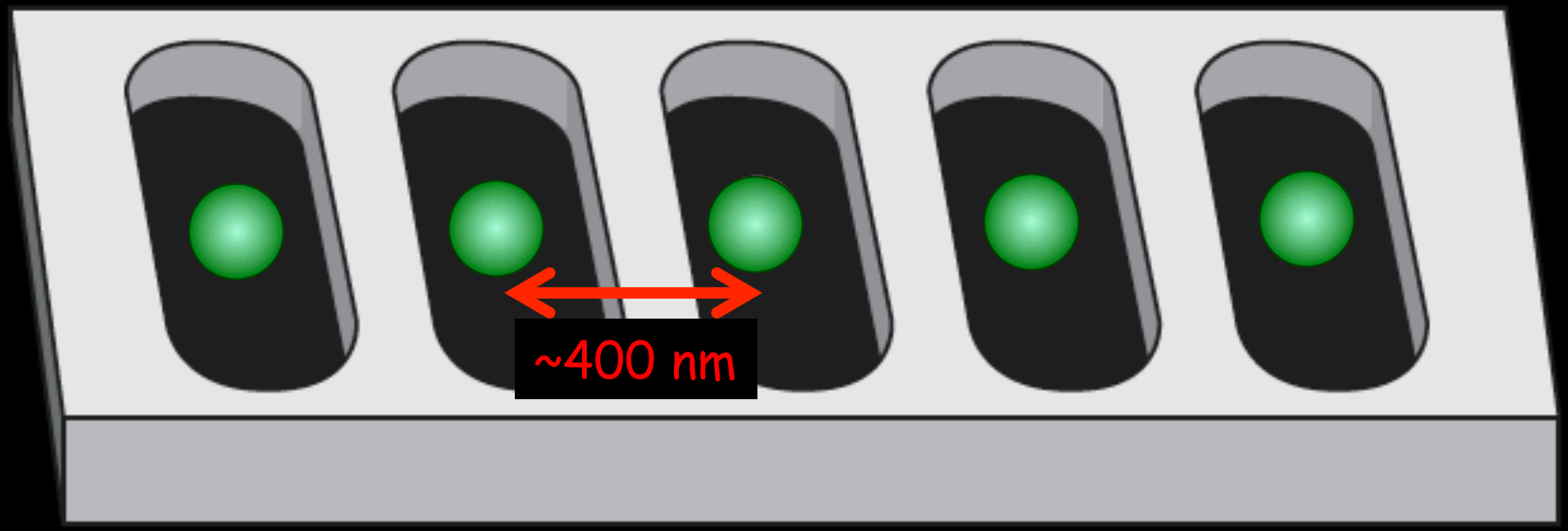




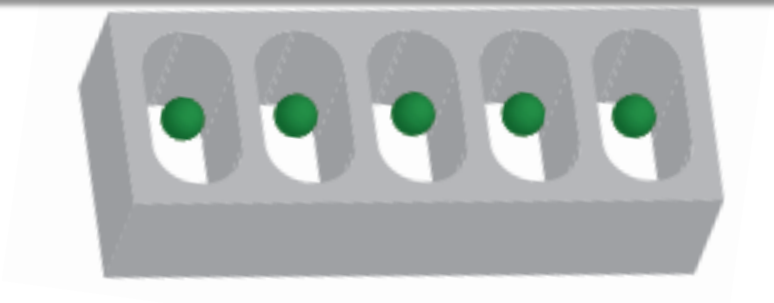
A Exciting Way Forward -
Quantum Optics and Atomic Physics with 1-D and 2-D Photonic Bandgap Structures

Oskar Painter
Caltech

Kimble – Painter at Caltech
D. Chang at ICFO
I. Cirac at MPQ
K. Choi at KIST



Quantum Optics with 1-d Photonic Structures



- Large atom-photon interaction

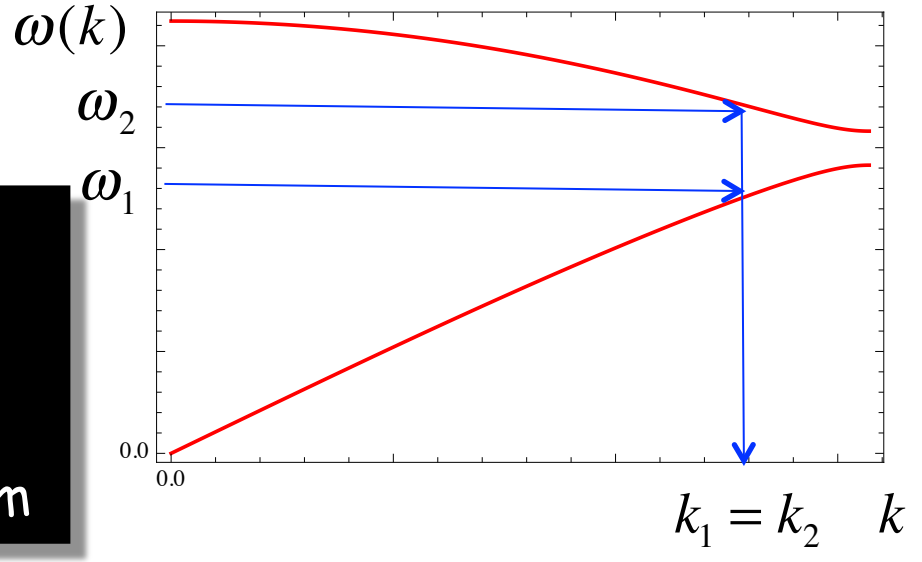
$$\frac{\Gamma_{1D}}{\Gamma'} \simeq 20 \rightarrow r_1 = \frac{\Gamma_{1D}}{\Gamma' + \Gamma_{1D}} \simeq 0.95$$

- Strong coupling in cQED

Single-photon Rabi frequency $\Omega_1 \gtrsim 1$ GHz

Critical photon number $n_0 \lesssim 10^{-6}$ photons

- Wave-vector "engineering"

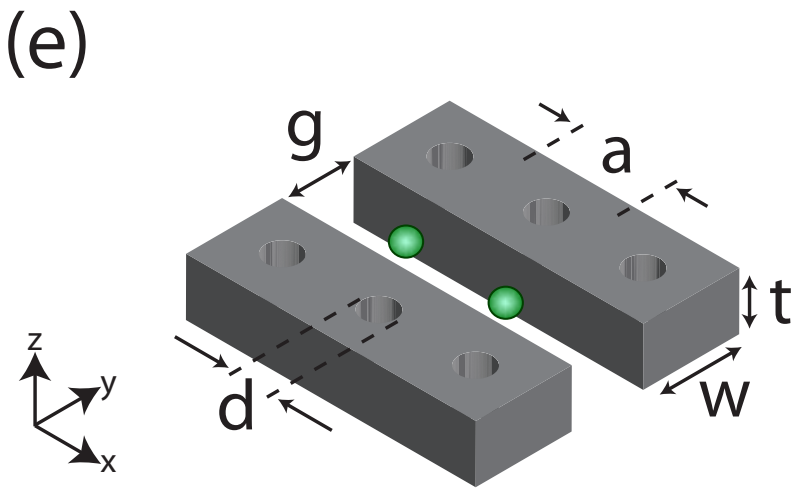


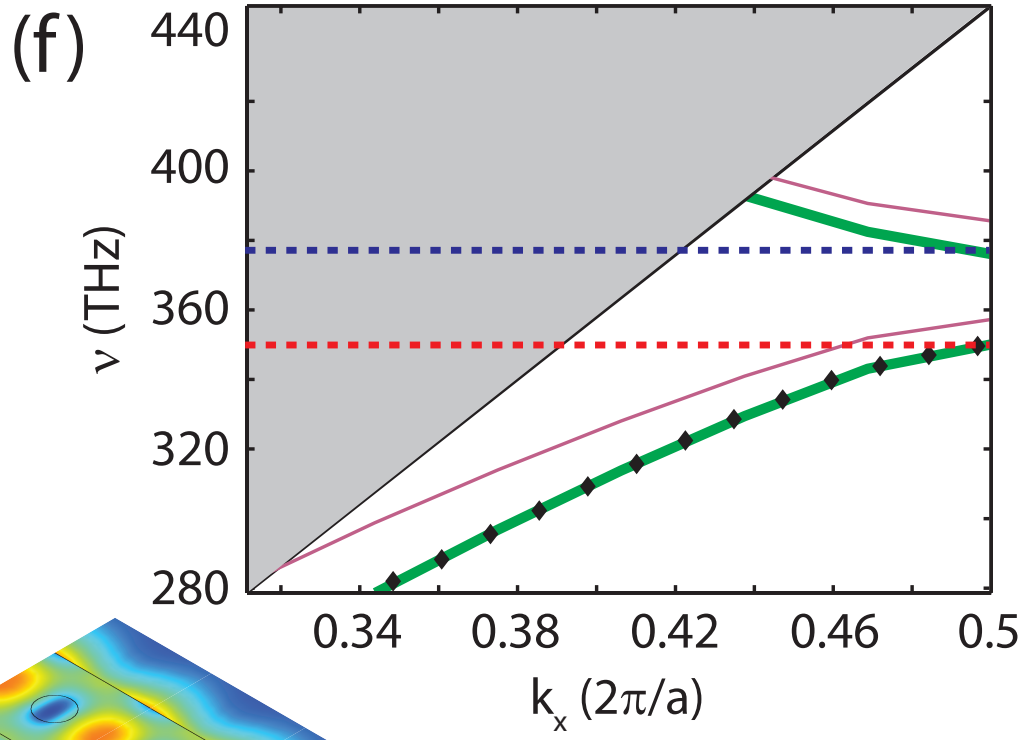
Long-range atom-atom interactions mediated by single photons

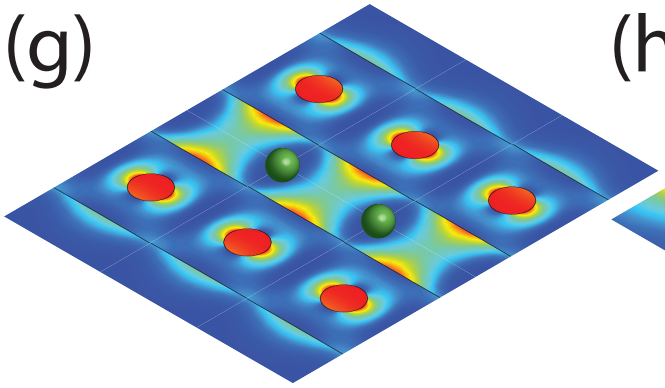
Quantum many-body physics for internal & external degrees of freedom

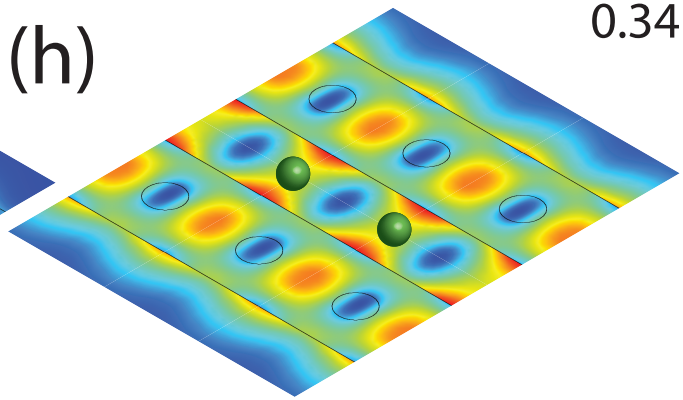
Magic Wavelength Optical Trap at 792nm for Atomic Cesium

C.-L. Lung Hung, S. Meenehan, D. Chang, O. Painter, J. Kimble, arXiv:1301.5252





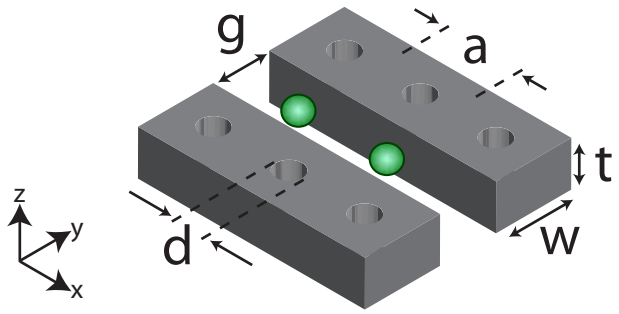




Magic Wavelength Optical Trap at 792nm for Atomic Cesium – Hybrid trap from optical and vacuum forces

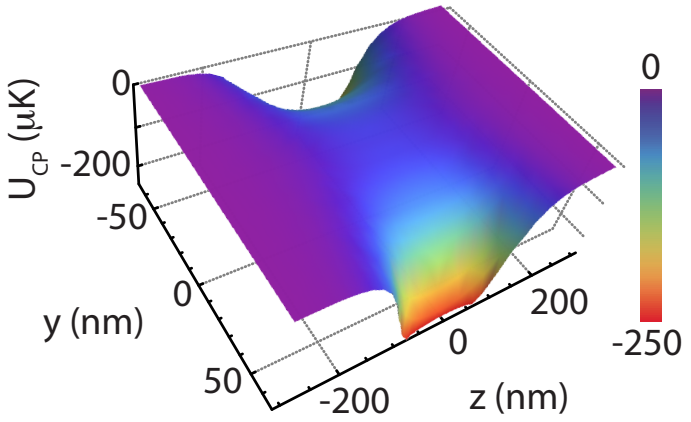
C.-L. Hung, S. Meenehan, D. Chang, O. Painter, J. Kimble, arXiv:1301.5252

(e)

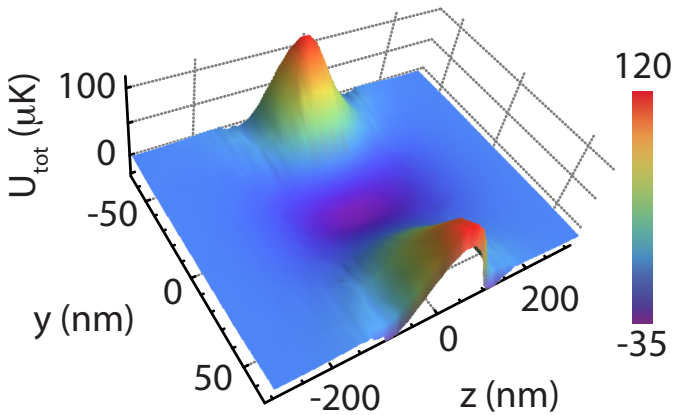


z direction trapped by Casimir-Polder forces

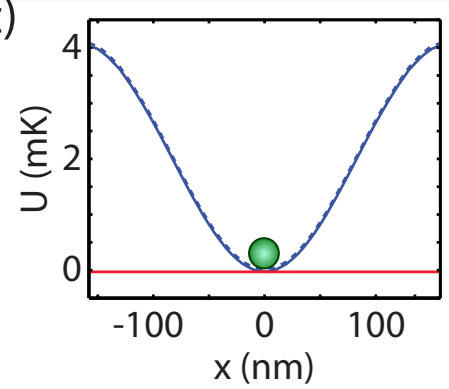
(a)



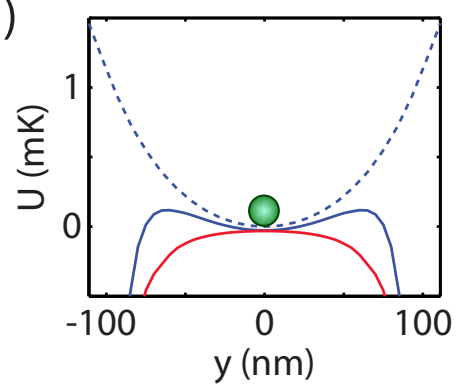
(b)



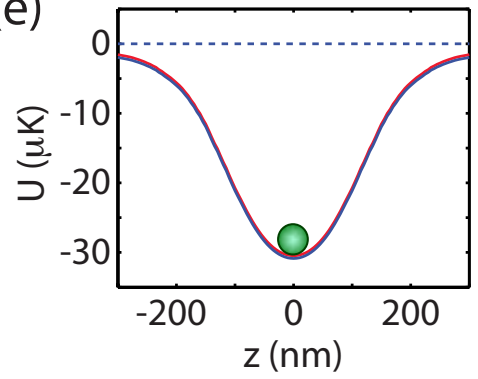
(c)



(d)



(e)

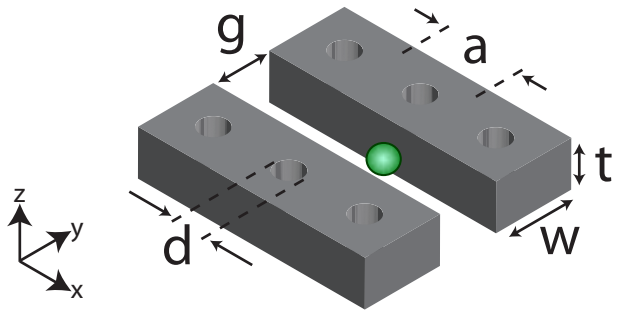


Total spontaneous decay rate γ_{tot} for 1 atom in a 1-D photonic crystal

Cesium $6P_{3/2}, F = 5 \rightarrow 6S_{1/2}, F = 4$

C.-L. Hung, S. Meenehan, D. Chang,
O. Painter, J. Kimble, arXiv:1301.5252

(e)



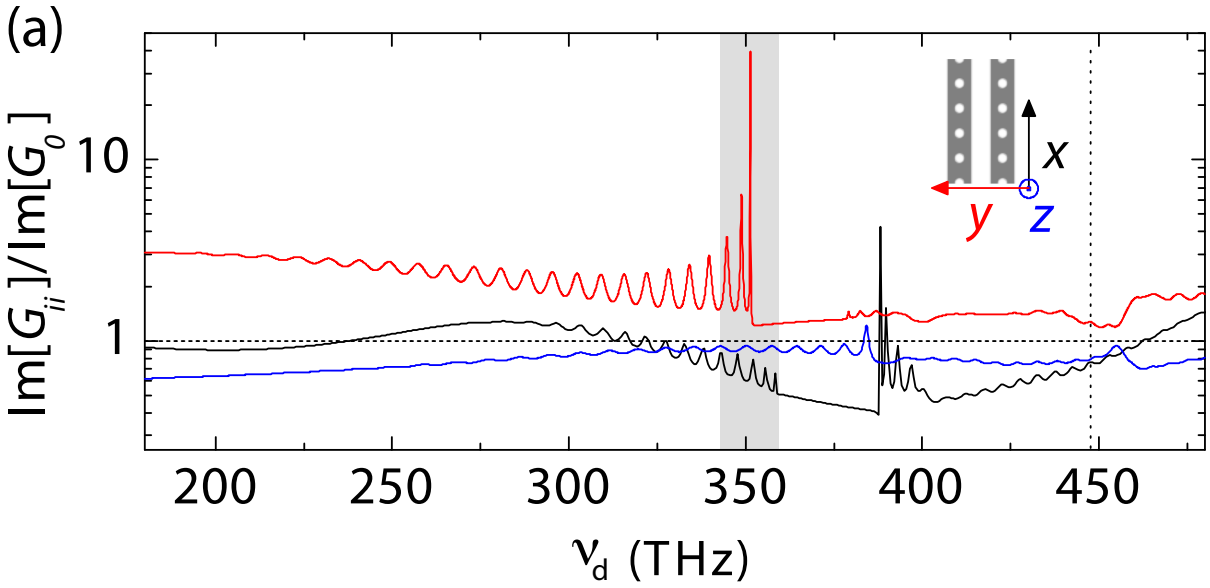
1-atom refection:

$$r_1 = \frac{\gamma_{1-d}}{\gamma_{1-d} + \gamma'} \simeq 0.95$$

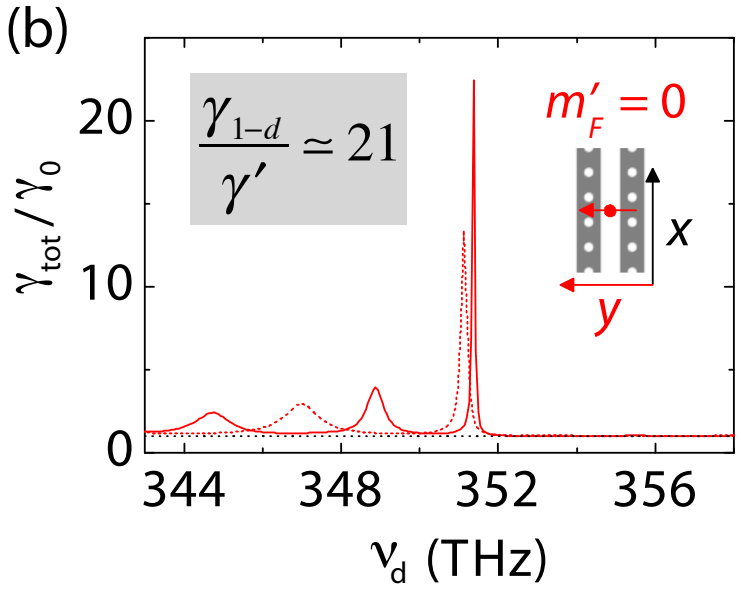
1-atom transmission:

$$T = (1 - r_1)^2 \simeq 0.003$$

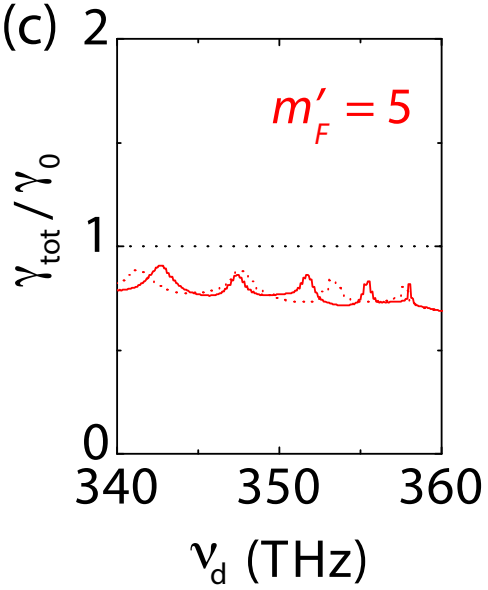
(a)



(b)

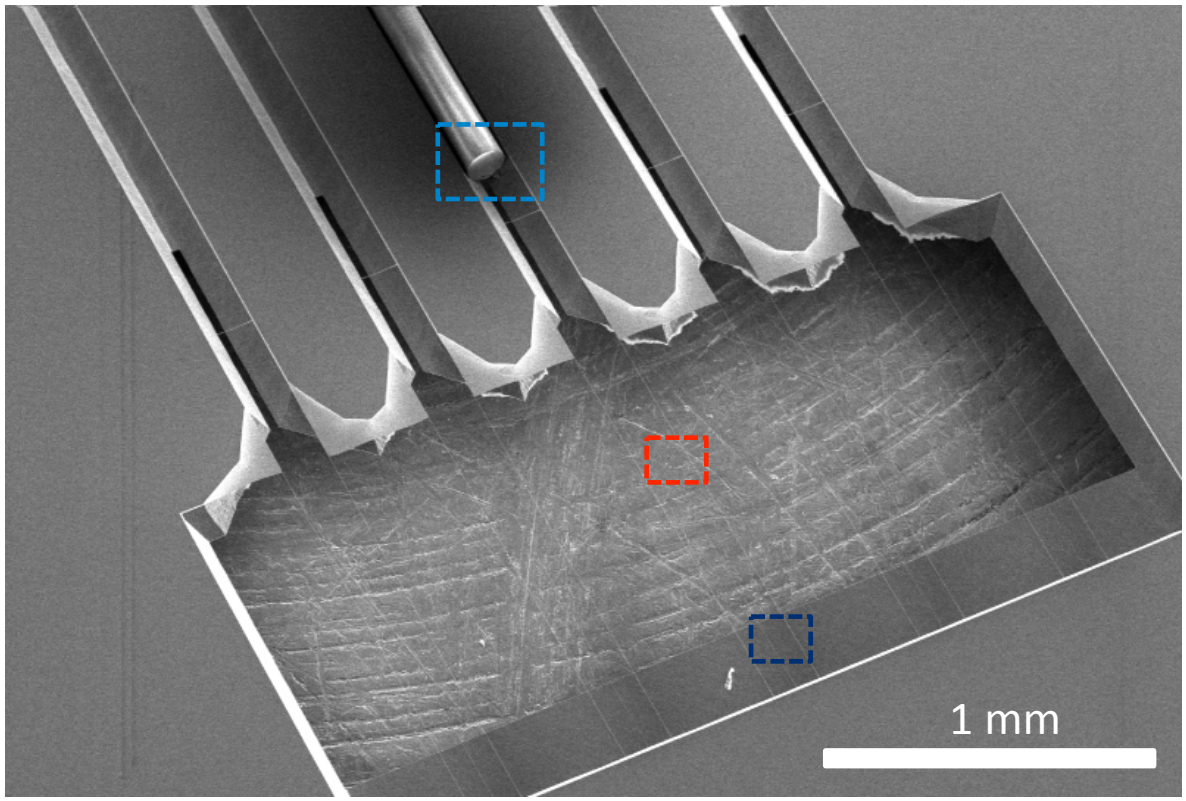


(c)

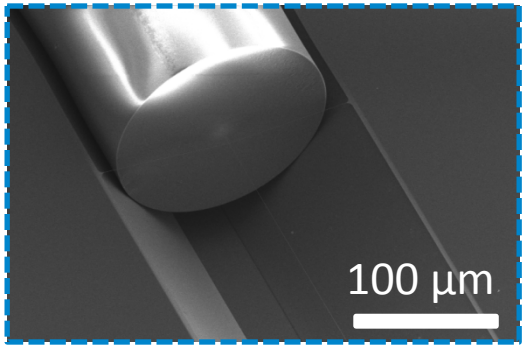


Device Design and Fabrication
1-d photonic waveguide butt coupled to conventional optical fiber

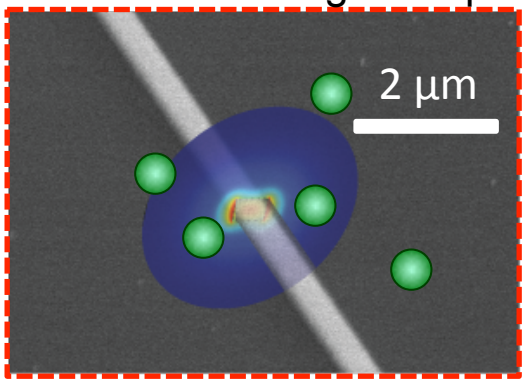
- Efficient "on chip" quantum connectivity provided by photons over integrated optical networks.



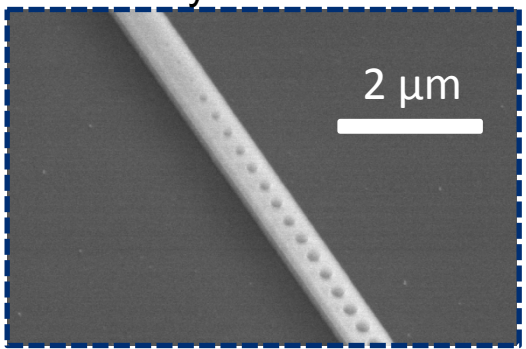
Efficient butt-coupled fiber



Evanescent atom-light coupling

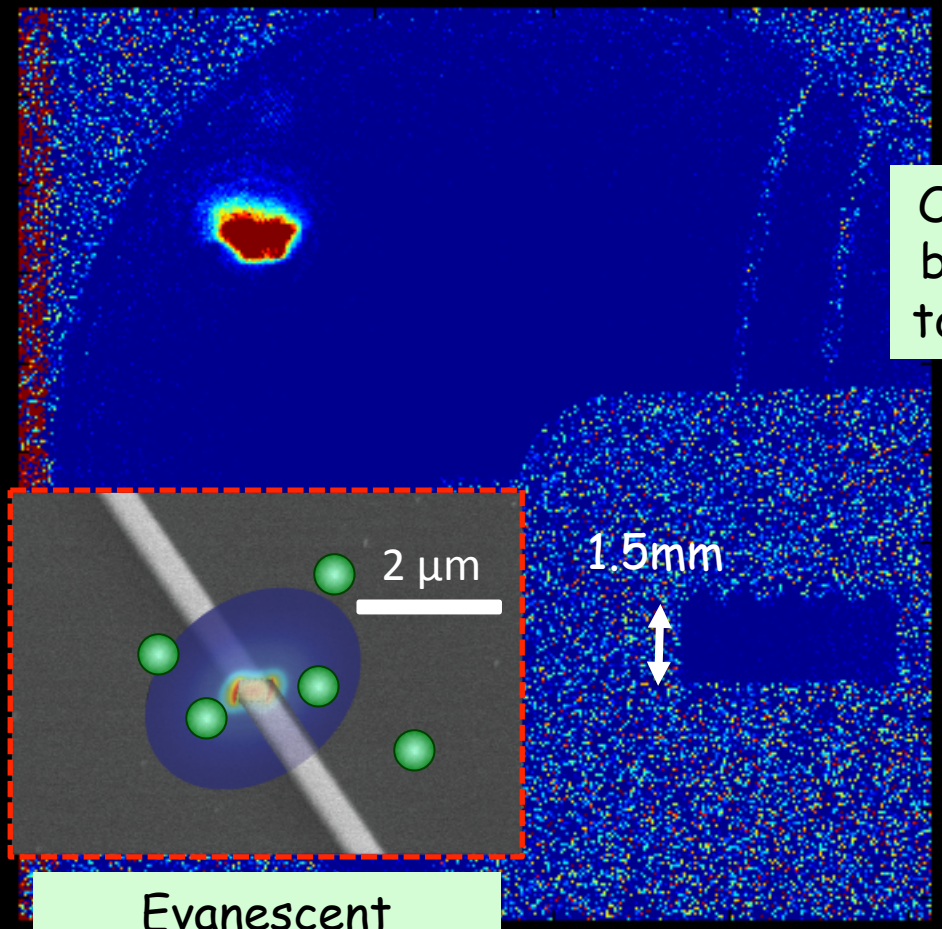


Photonic crystal mirrors/cavities



Progress in the Laboratory – Kimble[1] & Painter[2] Groups

$N_i \sim 10^7$ Cs atoms
at $\rho \sim 10^{12}/cm^3$
T ~ 10μK



Optical fiber butt-coupled to SiN device

SiN device – ~ 300nm x 200nm waveguide terminated by 1-d mirror

$N_f \sim 10^6$ Cs atoms
at $\rho \sim 10^{11}/cm^3$
T ~ 100μK

Evanescent atom-light coupling

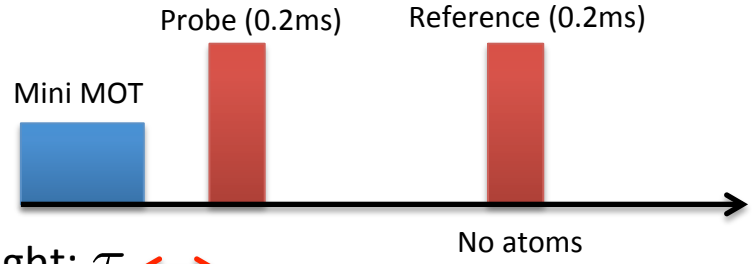
1c) Daniel Alton
Pol Forn Diaz
Andrew McClung
Martin Pototschnig

1b) Ding Ding
Jae Lee
Juan Muniz

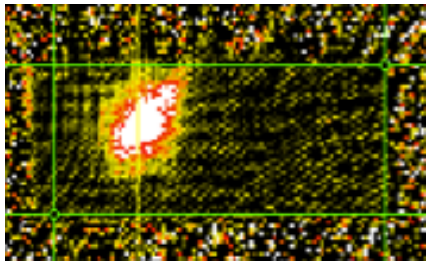
1a) Aki Goban
Chen-Lung Hung
Jonathan Hood
Su-Peng Yu

2. Sean Meenehan
Justin Cohen
Richard Norte

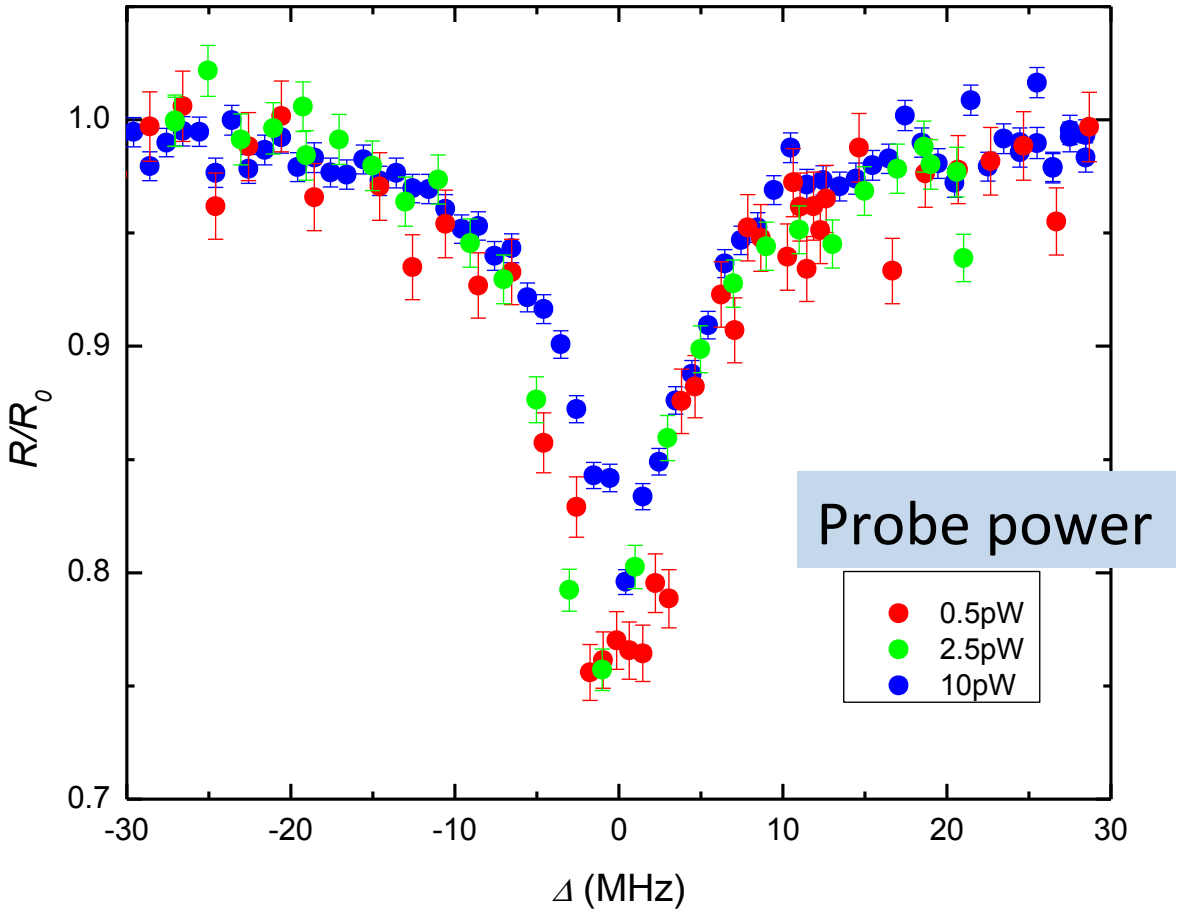
Recent lab progress – Reflection measurement: power dependence



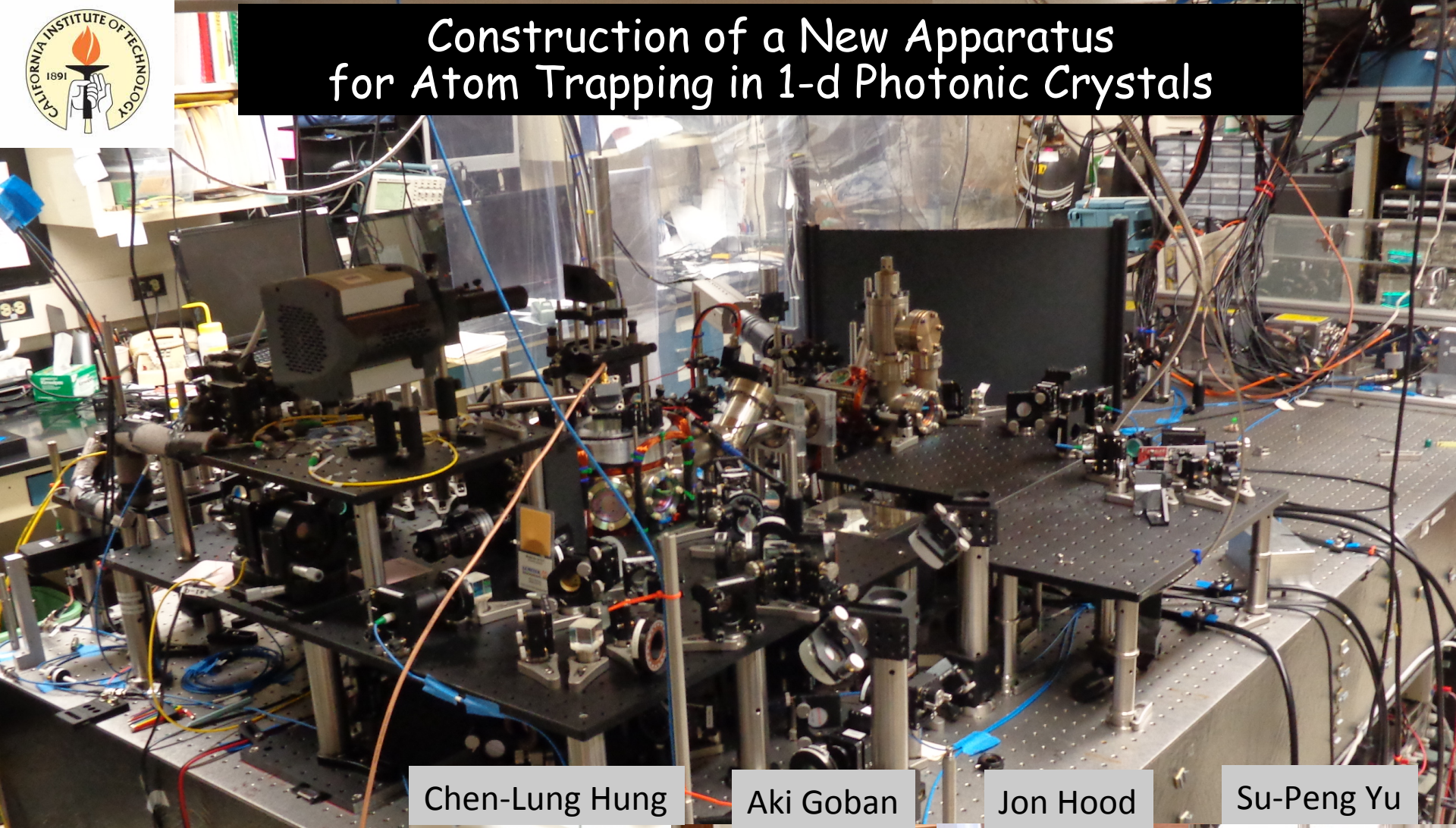
Time of flight: τ ⟷



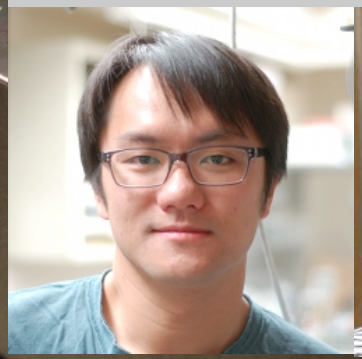
$$\frac{R}{R_0} = \frac{P_{\text{probe}}}{P_{\text{Reference}}}$$



Construction of a New Apparatus for Atom Trapping in 1-d Photonic Crystals



Chen-Lung Hung

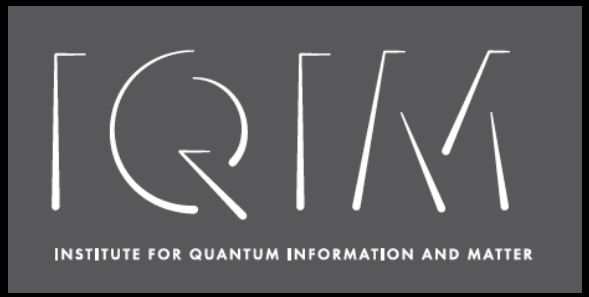


Aki Goban

Jon Hood

Su-Peng Yu

IQIM video available at
http://iqim.caltech.edu/outreach/index.html



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