The Development of Quantum Optics & Quantum Information

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EPSNA Virtual Summer School (VSS)
(August 6, 2021 - August 8,2021)

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The Ethiopian Physics Society in North America

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Outline

- *Introduction*
- *First Quantum Revolution View*
- *Second Quantum Revolution: QIP*
- *Optomechanical Systems*
- *Future Research Direction*

Part-I: Presentation !

Introduce on the *basic theory of Classical Mechanics and devt. of quantum physics….*

Introduction

- *Classical Mechanics* was used to predict the dynamics of material bodies, and Maxwell's electromagnetism provided the proper framework to study Radiation. Thus, matter & Radiation were described in terms of Particles and Waves, respectively.

- However, at the turn of the twentieth century the classical physics, which had been quite unassailable, **was seriously challenged on two major fronts:**

I. **Relativistic domain**: Einstein's 1905 theory of relativity showed that the validity of Newtonian mechanics ceases at very high speeds (i.e., ***at speeds comparable to that of light***).

II. **Microscopic domain**: As soon as *new experimental techniques* were developed to the point of probing atomic and subatomic structures, it turned out that classical physics fails miserably in providing the proper explanation for several newly discovered phenomena.

- The failure of classical physics was to explain several **Microscopic Phenomena;**

✓Blackbody Radiation

✓Photoelectric Effect

✓Atomic Stability

✓Atomic Spectroscopy

- All matter (particles) has wave-like properties
  - so-called particle-wave *duality*
- Particle-waves are described in a probabilistic manner
  - electron doesn’t expert around the nucleus, it has a probability distribution describing where it might be found
  - allows for seemingly impossible “quantum tunneling”
- Some properties come in dual packages: can’t know both simultaneously to arbitrary precision
  - called the Heisenberg Uncertainty Principle
  - position/momentum and energy/time are example pairs
- The act of “measurement” fundamentally alters the system
  - called entanglement: information exchange alters a particle’s state

- Theories of break through due to Planck, Einstein, Bohr, and Compton—gave both the theoretical foundations as well as experimental confirmation for the *particle aspect of waves*….***material particles*** themselves ***display wave-like behavior.***

- Such theory had put an end to twenty five years (1900–1925) of patchwork which was dominated by the ideas of Planck and Bohr and which later became **known as the old Quantum Theory.**

- Historically, there were two independent formulations of quantum mechanics. The first formulation, called Matrix Mechanics, was developed by Heisenberg (1925) to describe atomic structure starting from the observed spectral lines.

- The second formulation, called Wave Mechanics, was due to Schrödinger (1926); it is a generalization of the de Broglie postulate. This method, more intuitive than matrix mechanics, describes the dynamics of microscopic matter by means of a wave equation, called the Schrödinger Equation

Quantum Mechanics: A 20th century revolution in physics:

- Why doesn’t the electron collapse onto the nucleus of an atom?
- Why are there thermodynamic anomalies in materials at low temperature?
- Why is light emitted at discrete colors?
- . . . .

Albert Einstein (1879-1955)

Werner Heisenberg (1901-1976)

Erwin Schrödinger (1887-1961)

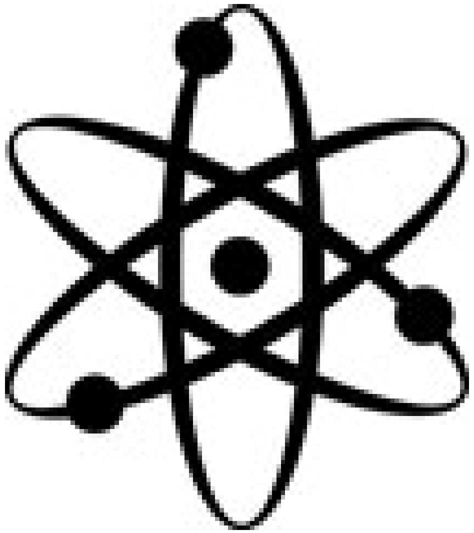
The First Quantum Revolution

Observation and Macroscopic Manifestation Of Quantum Principles

Most of 20th Century Quantum Physics *concerned with;*

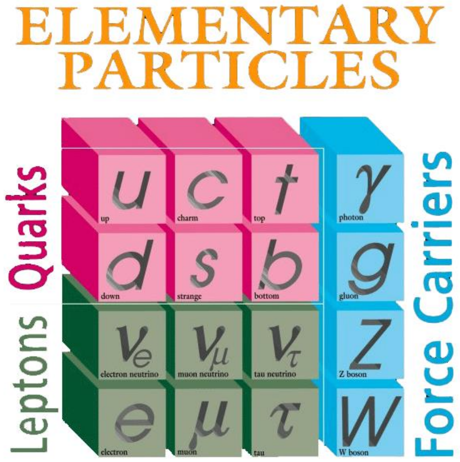
- Wave mechanics
- Quantized energy

$$\hat{H}[\Psi] = -i\hbar \frac{\partial[\Psi]}{\partial t}$$

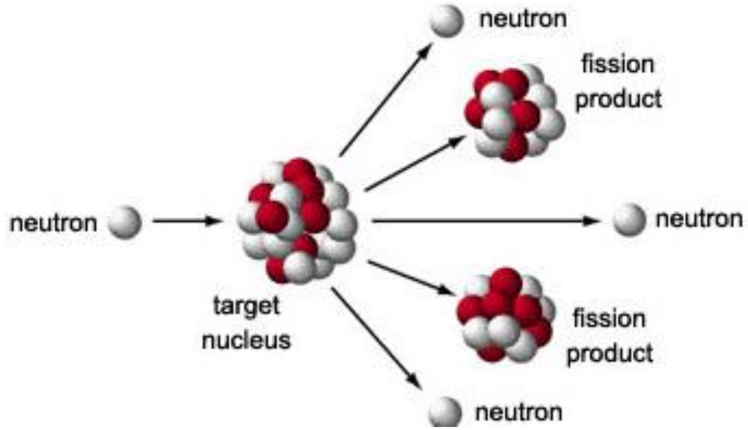


- Low temperature phenomena
  e.g., Super fluidity, BEC
- Quantum Electrodynamics (QED)

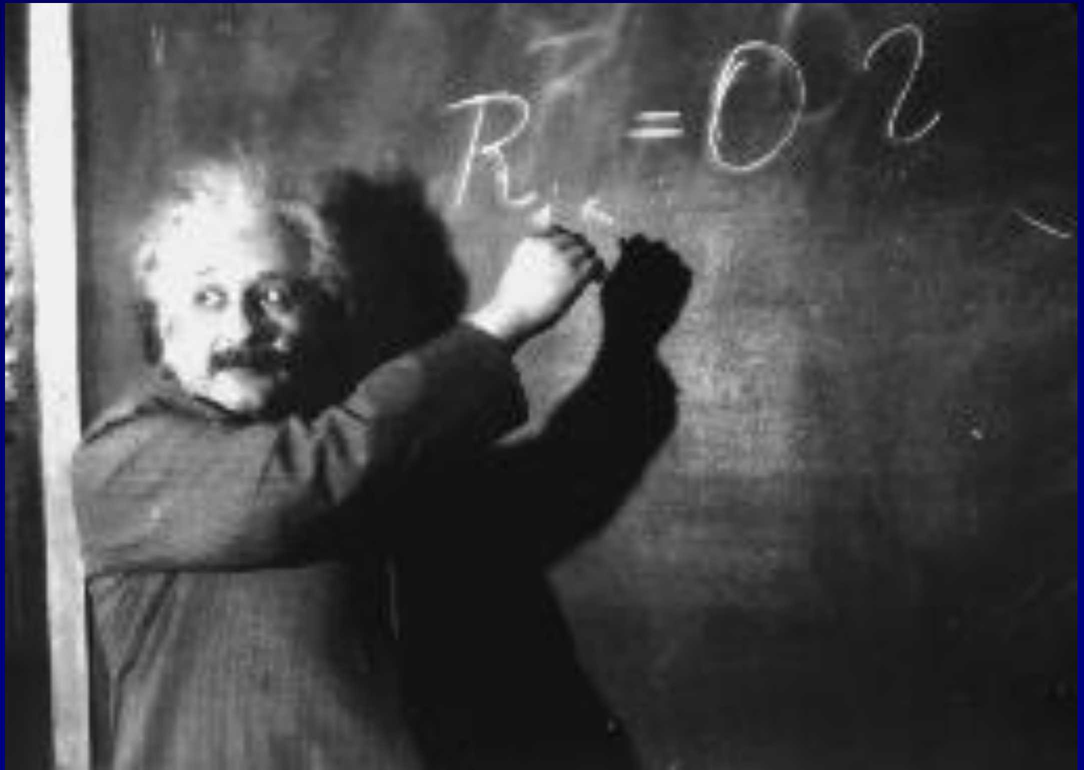
e.g., magnetism of the electron:
g_e = 2.00231930439 (agrees w/ theory to 12 digits)



- Nuclear physics
- Particle physics



"Things should be made as simple as possible, but not any simpler."



What I do…

Unravel the mysteries
of the universe…

Quantum Optics

↓ ???

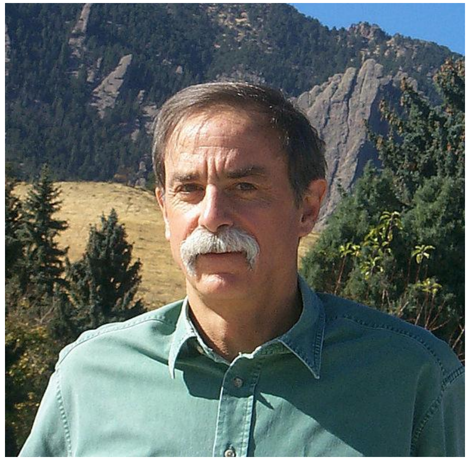
↓ Light

- In 2012 award, France (Serge Haroche) with the US (David Wineland) Award on the grounds that;

" discover breaking experimental method to *measure and manipulate individual quantum systems*"

✓ (*6th the Nobel Prize for Physics in quantum optics).*

Serge Haroche



David Wineland

✓ Provide a channel for realization of quantum information

- Quantum optics is the subject that deals with optical phenomena that can be explained by treating light as a stream of photons rather than as electromagnetic waves

- In principle, the subject is as old as quantum theory itself, but in practice, it is a relatively new one, and has really only come to the fore during the last quarter of the twentieth century.

1905: Einstein made a 'quantum leap' and proposed that light was really made of particles with tiny energy given by

$$E = h\,f = h\,c/\lambda$$

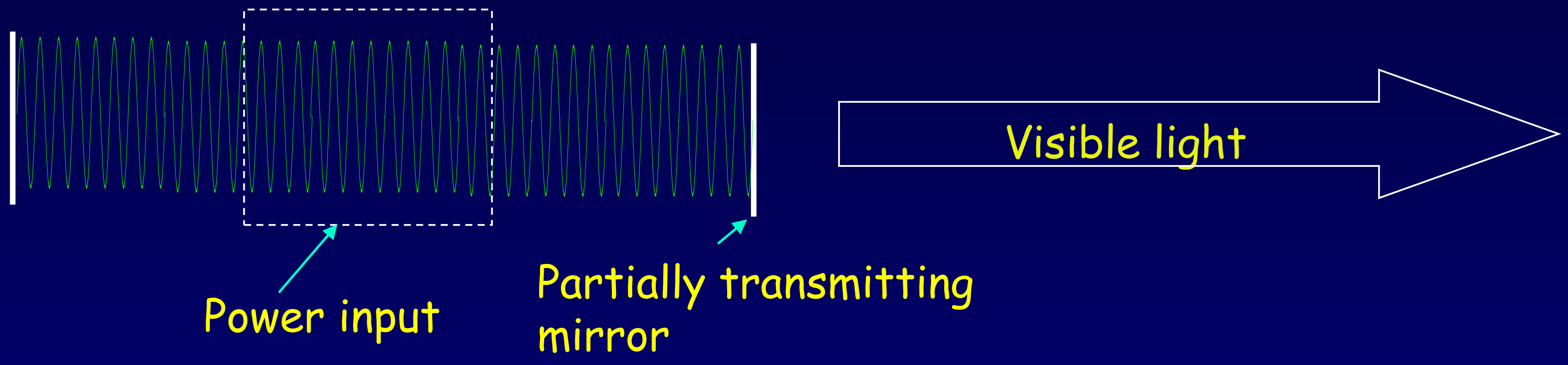
h → 6.6×10^{-34} J-s

f → frequency

λ → wavelength

Example: "Counting photons"

How do we reconcile this notion that light comes in 'packets' with our view of an electromagnetic wave, e.g., from a laser??



How many photons per second are emitted from a 1-mW laser (λ=635nm)?

$$E_{photon} = \frac{hc}{\lambda} = \frac{1240\,\text{eV-nm}}{635\text{ nm}} \approx 2\,\text{eV}$$

Power output: P = (# photons/sec) x E_{photon}

$$(\#\text{ photons/sec}) = \frac{P}{E_{photon}} = \frac{10^{-3}\text{ J}}{\text{s}} \times \frac{1\text{eV}}{1.6\times10^{-19}\text{J}} \times \frac{1\text{photon}}{2\,\text{eV}} = 3.1\times10^{15}\text{s}^{-1}$$

1 mW red laser

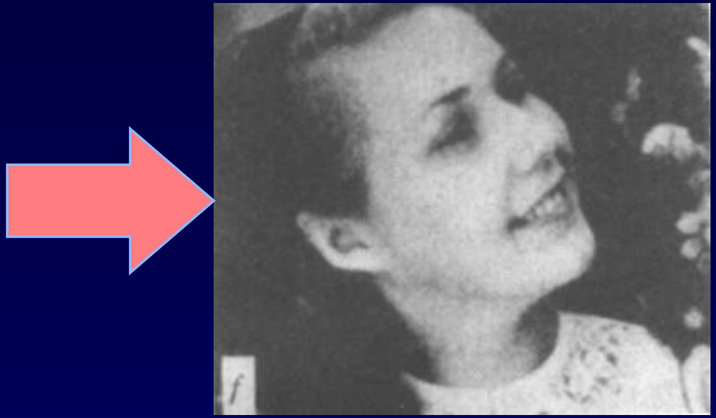
3×10^{15} photons/sec =

3,000,000,000,000,000/sec

This is an incredibly huge number – your eye basically cannot resolve this many individual photons (though the rods can detect single photons!). And you MAY be able to see just one photon!!

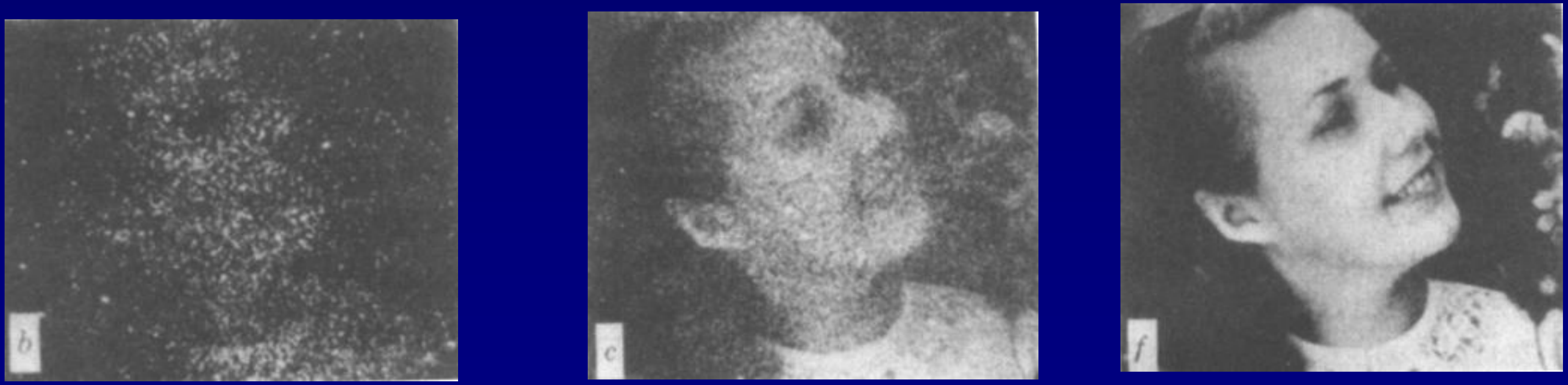
Formation of Optical Images

- For large light intensities, image formation by an optical system can be described by classical optics.



- However, for very low light intensities, one can see the statistical and random nature of image formation.
  - Use an extremely sensitive CCD camera that can detect single photons.

A. Rose, J. Opt. Sci. Am. 43, 715 (1953)

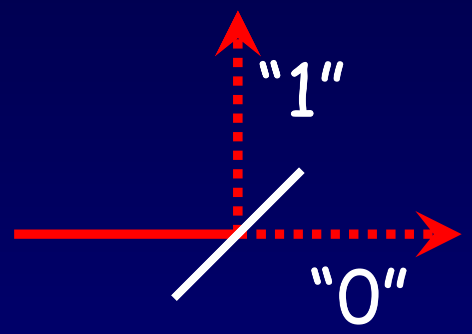


Exposure time

CCD amera

But how do we *know* there's only ONE photon…

A beamsplitter…



Photon only detected in one output. Equally likely to be transmitted or reflected – cannot tell which.

Quantum random-number generator!

- completely unpredictable
- patented
- commercially available

"The important thing is not to stop questioning."

-A. Einstein

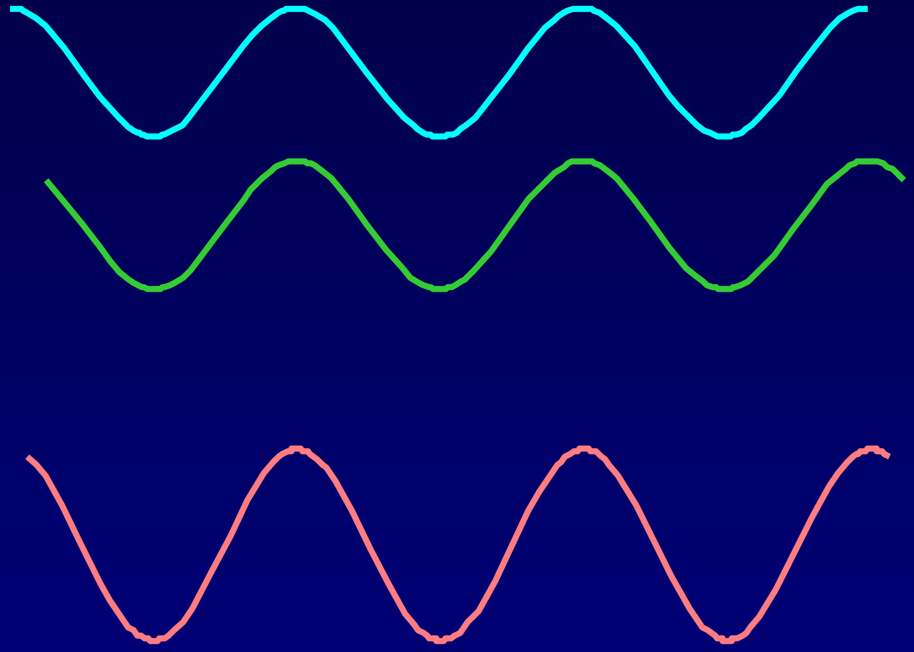
Qu. WHY was Einstein's 1905 proposal that light was made of particles such a profound leap that *almost no one believed him?*

Because everyone KNEW that light was really waves.

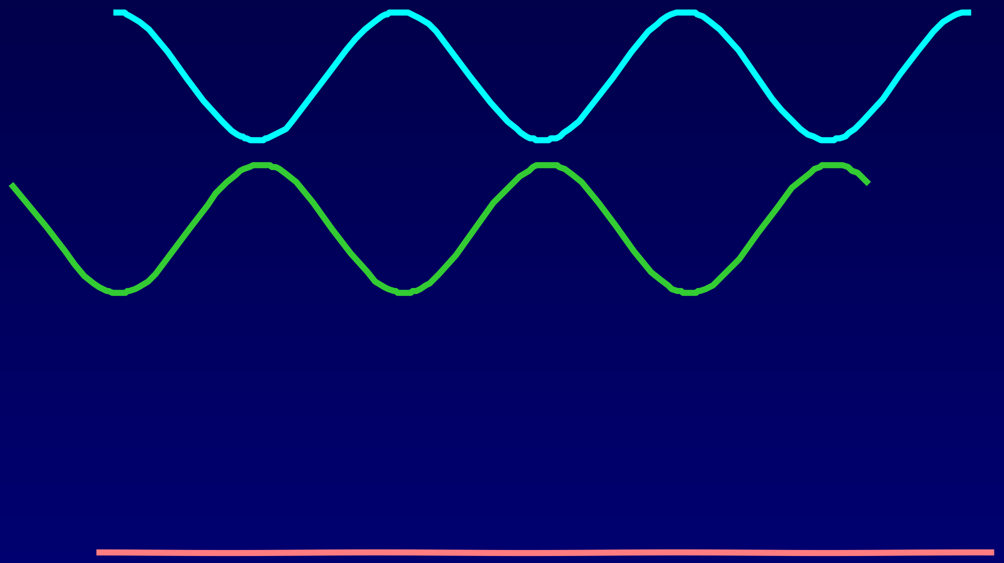
One of the strangest features of QM: all particles can behave like waves…

Interference of waves (e.g., water, sound, …)

Superposition (adding together) of waves



Waves add up:
"Constructive interference"



Waves cancel:
"Destructive interference"

Light: Particle or Wave?

1675: Newton "proved" the light was made of "corpuscles"

1818: French Academy science contest

Fresnel proposed interference of light.

- Judge Poisson knew light was made of particles: "Fresnel's ideas ridiculous" If Fresnel ideas were correct, one would see a bright spot in the middle of the shadow of a disk.

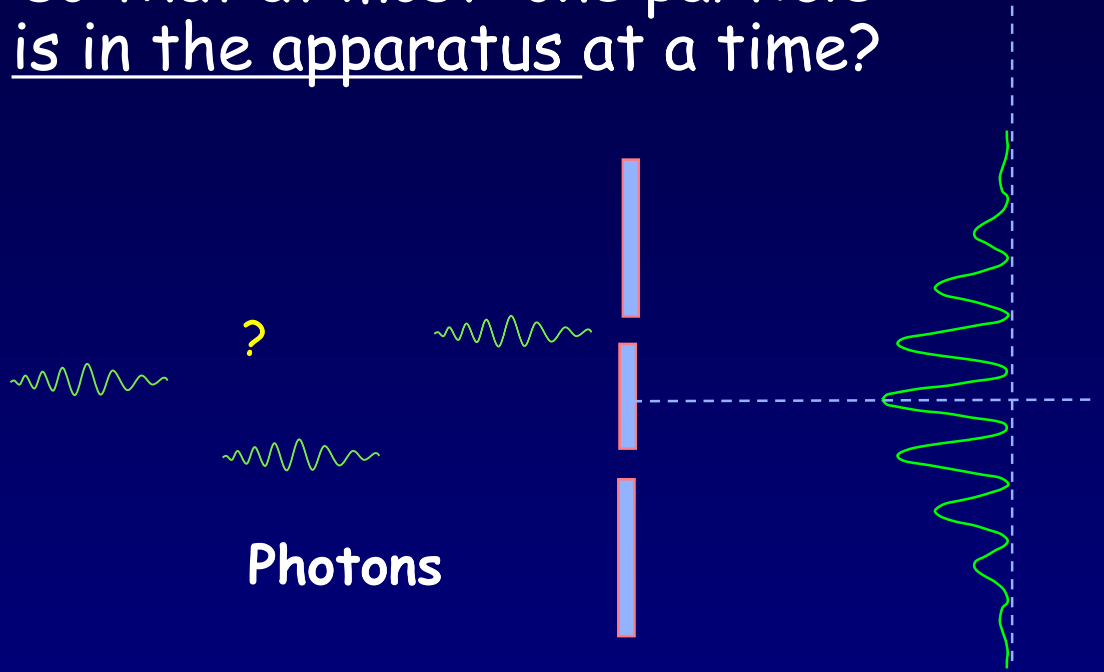
Judge Arago decided to actually do the experiment…

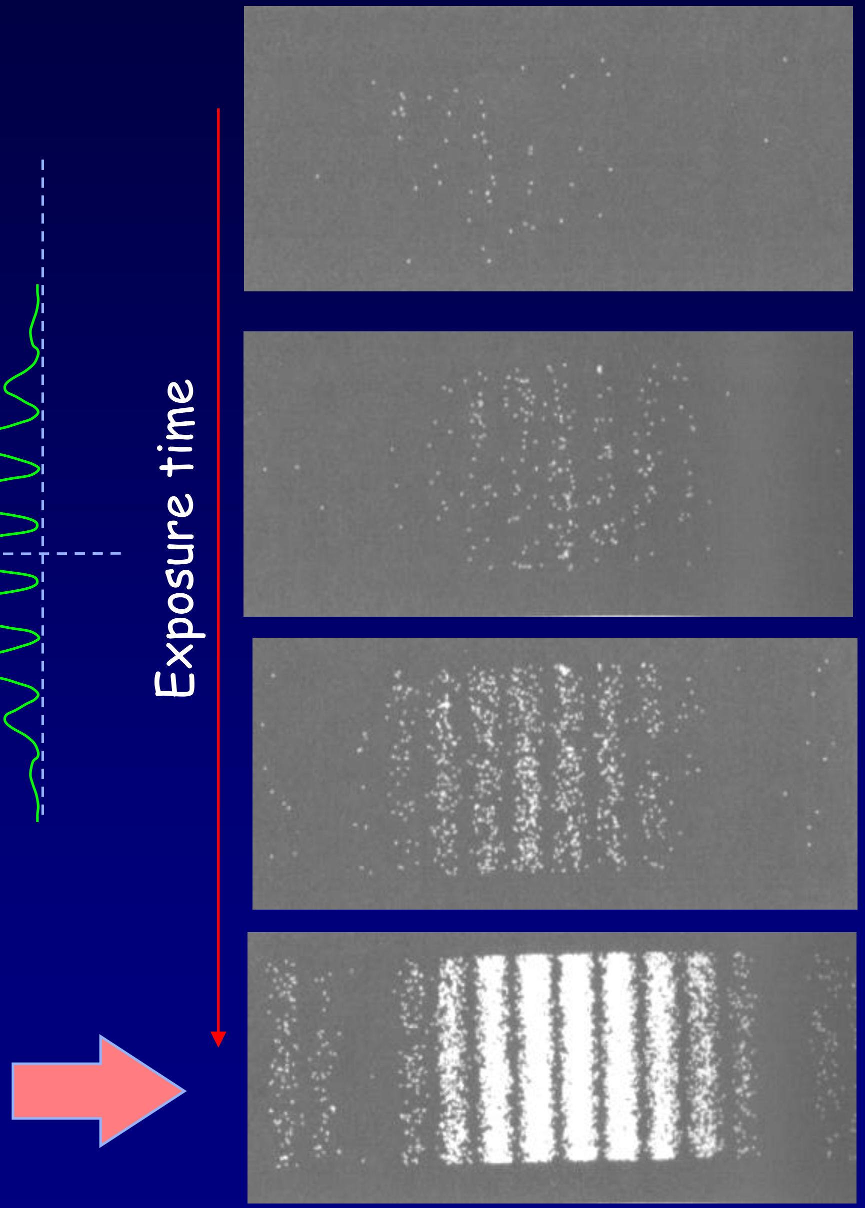
Conclusion (at the time): Light must be a wave, since particles don't interfere!

Only, now we know that they must!

Single-Photon Interference:

- Question: what if we reduce the source intensity so that at most one particle (photon) is in the apparatus at a time?



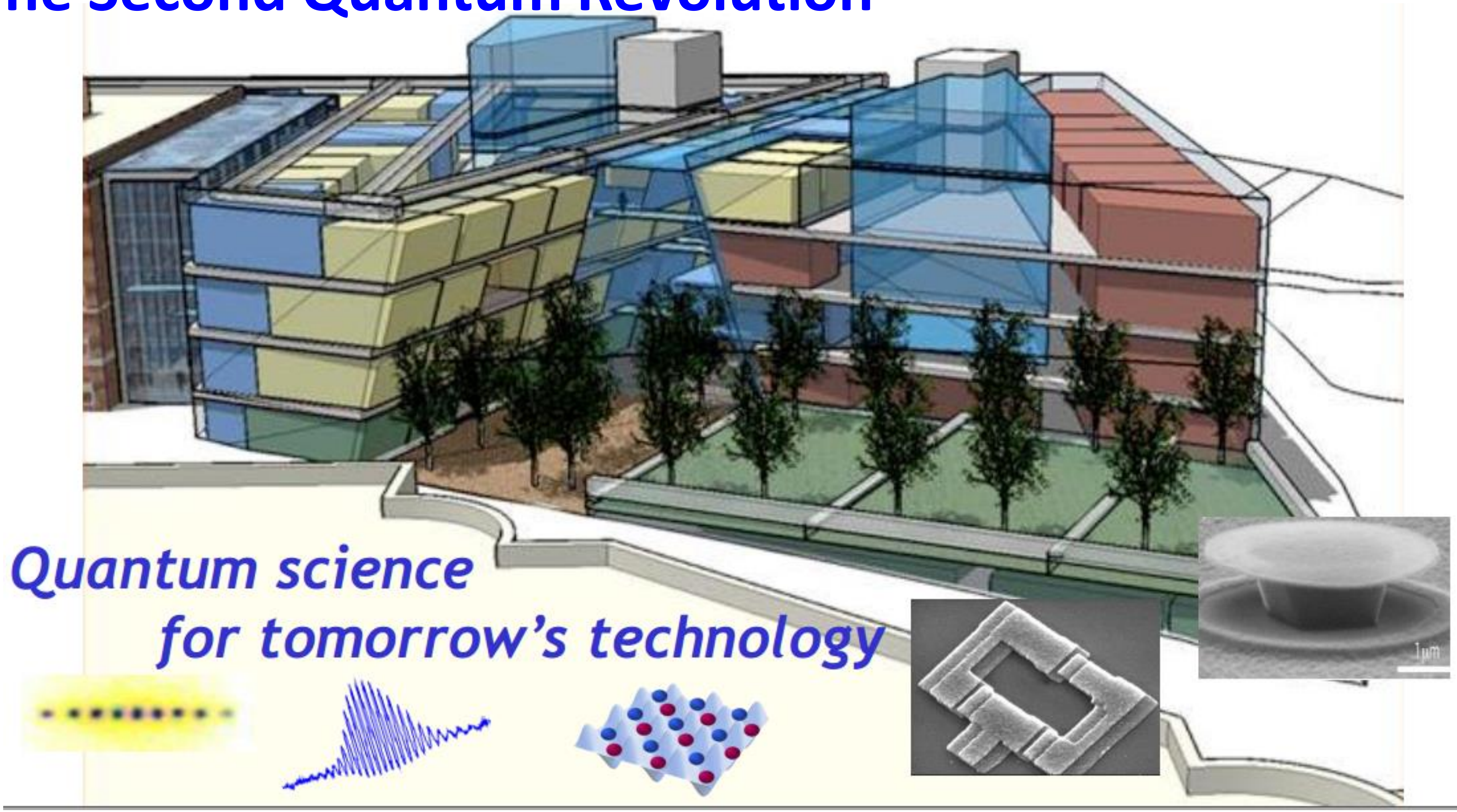


- Answer: Just like in the "optical image formation", given enough time, the classical interference pattern will gradually build up from a huge # of seemingly random "events"!

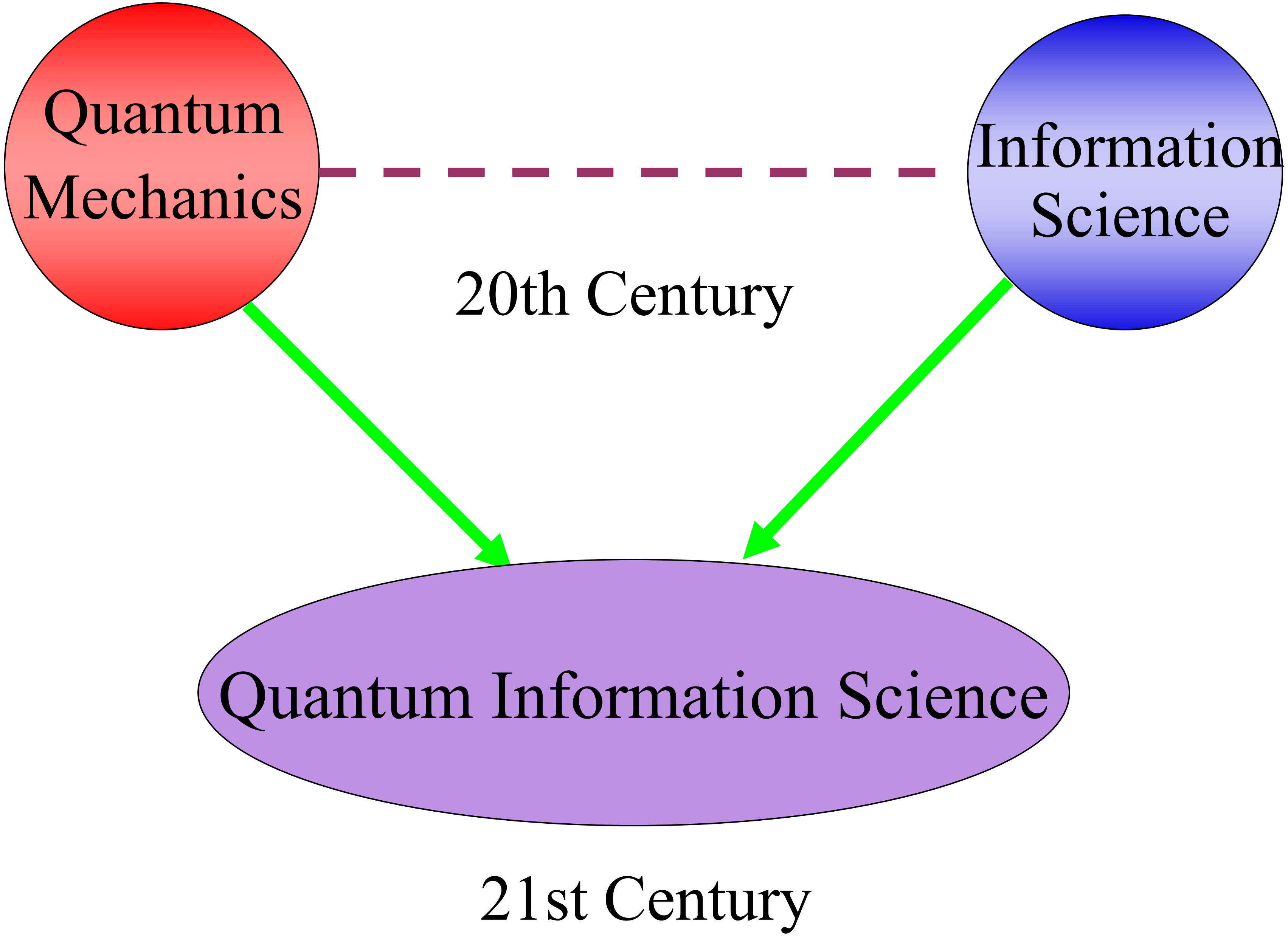
Part-II: Presentation !

- The current research topics, and applications of quantum optics and Optomechanics…. QIP

The Second Quantum Revolution



A New Science!



Quantum Information Processing

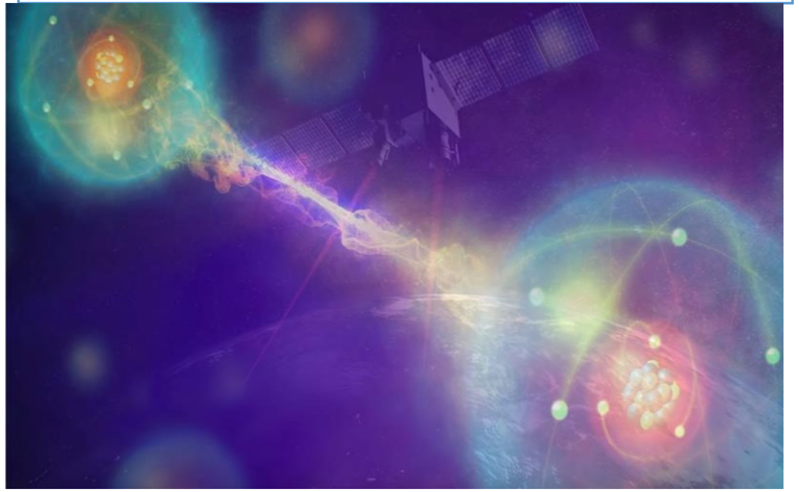
- *QIP: is* the transfer and process of a given amount of information using quantum systems as carriers of information

- Quantum entanglement is the currency within the world of quantum information science

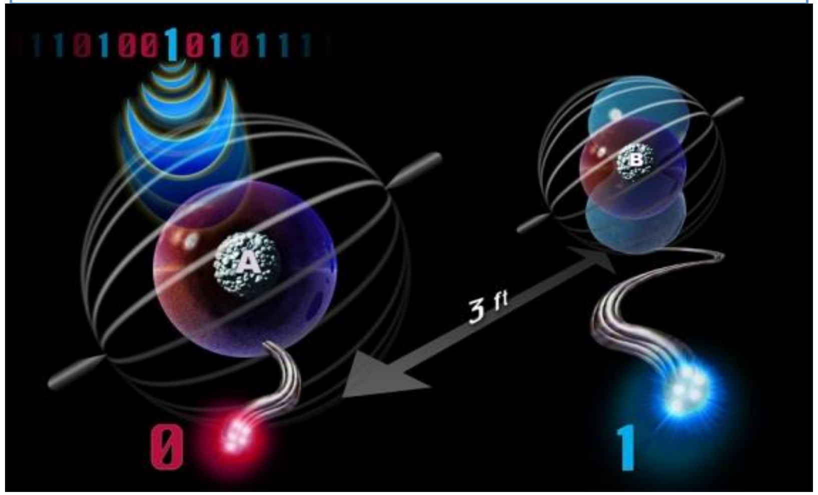
- Essentially various quantum-mechanical phenomena such:

Results in Physics 7 (2017) 3773–3777

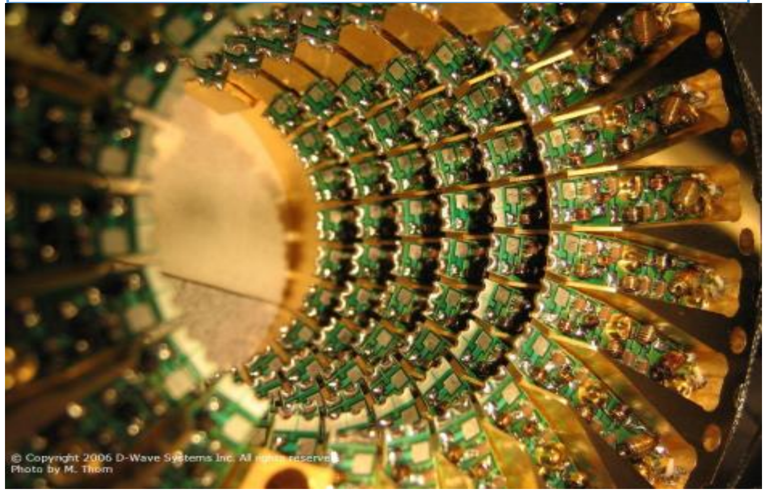
- ✓ **Quantum Communication**



- ✓ **Quantum Teleportation**



- ✓ **Quantum Computation**



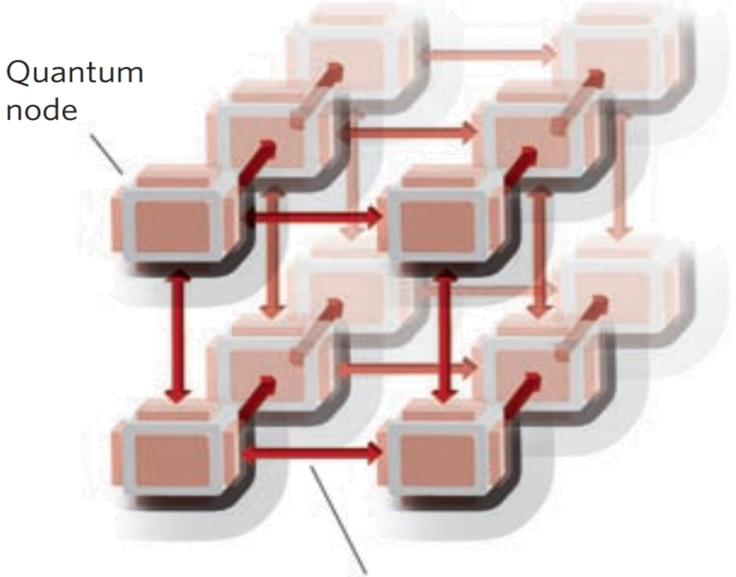
Cont.

- QIP presents many charming properties, since it employs quantum coherence

Quantum Internet

Nature 453, 1023 -1030 (2008)

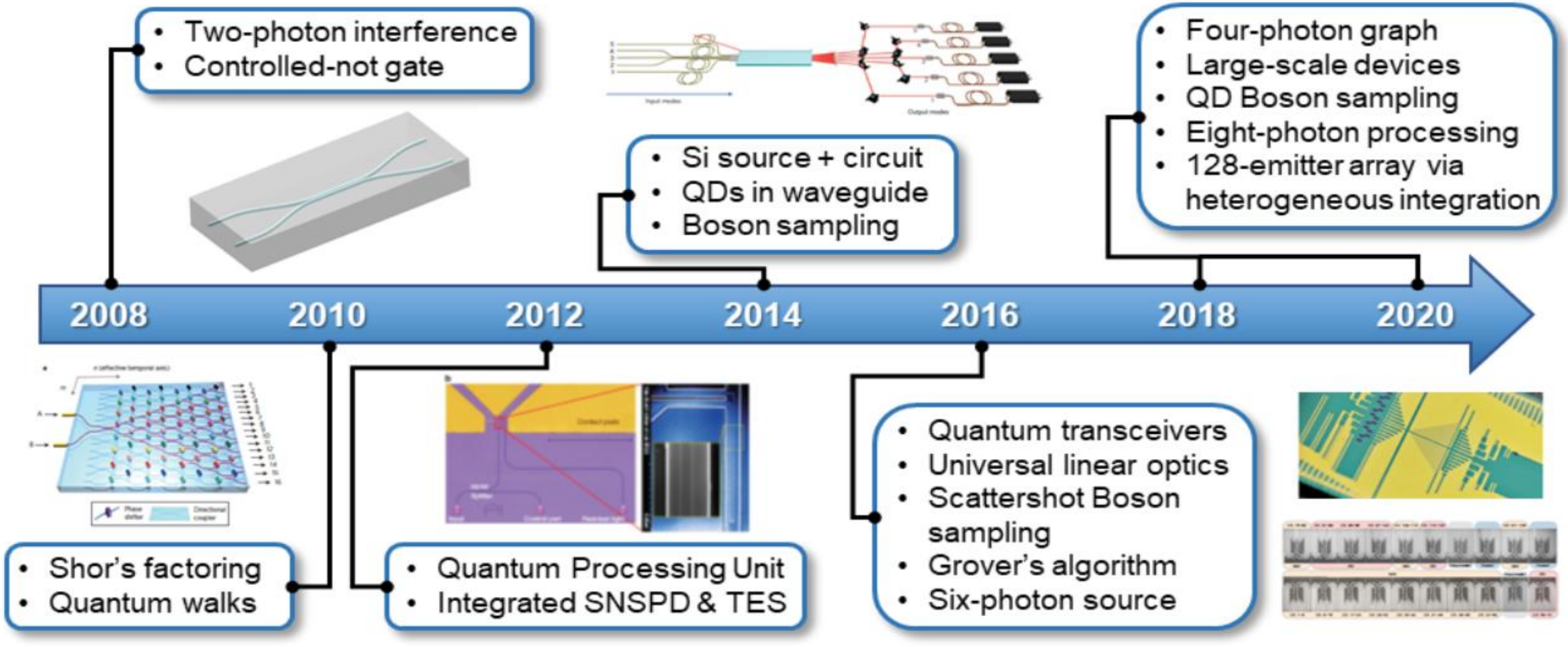
Quantum Networks



- This requires new scientific capabilities for the generation and characterization of **quantum coherence** and **entanglement.**

Roadmap on Integrated Quantum Photonics

❑ Key milestones in integrated quantum photonics in the past decade to 2020



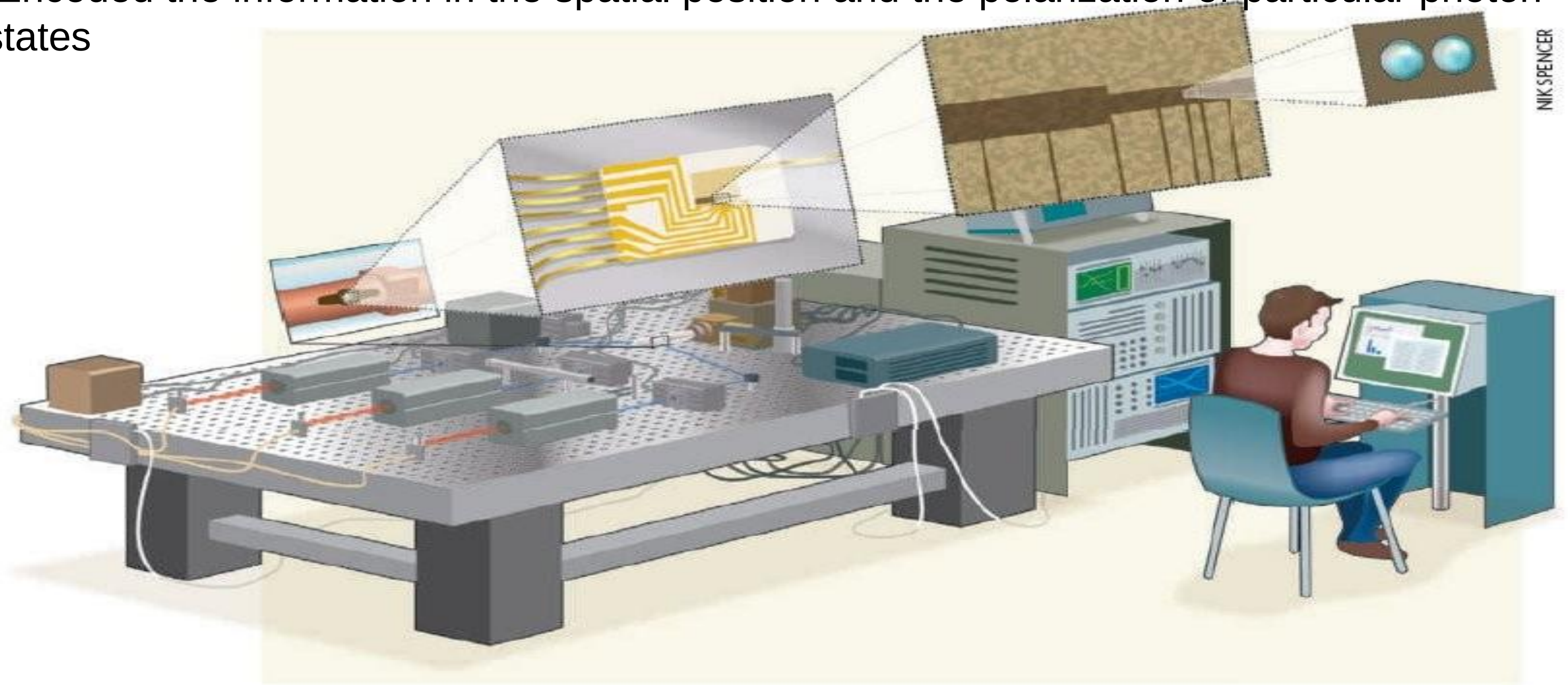
❑ Beginning two-photon interference and fundamental quantum gates prior to 2008 to probabilistic quantum light sources on a single chip in 2020.

Journal of Physics: Photonics (2021)

Expt: the Quantum Processor

Quantum Computing

Encoded the information in the spatial position and the polarization of particular photon states



Artist's impression of an ion-trap quantum computing laboratory

Figure from E. Knill, *Nature* **463** 441-443 (2010)

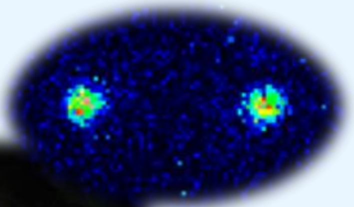
Higher gate fidelities

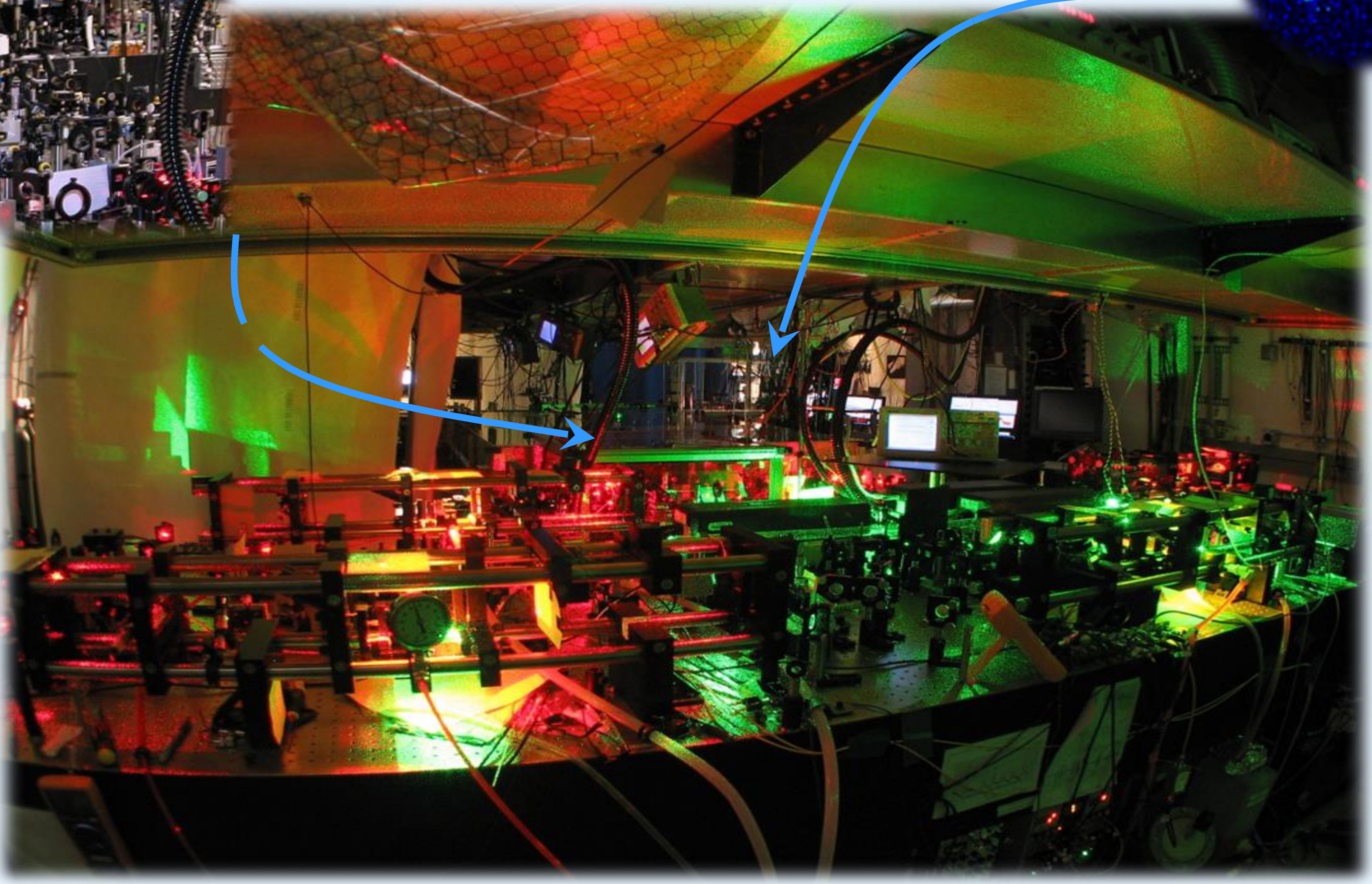
Need ~ 99.99%!!

Lab for Quantum Processor

the optics forest

ions live here





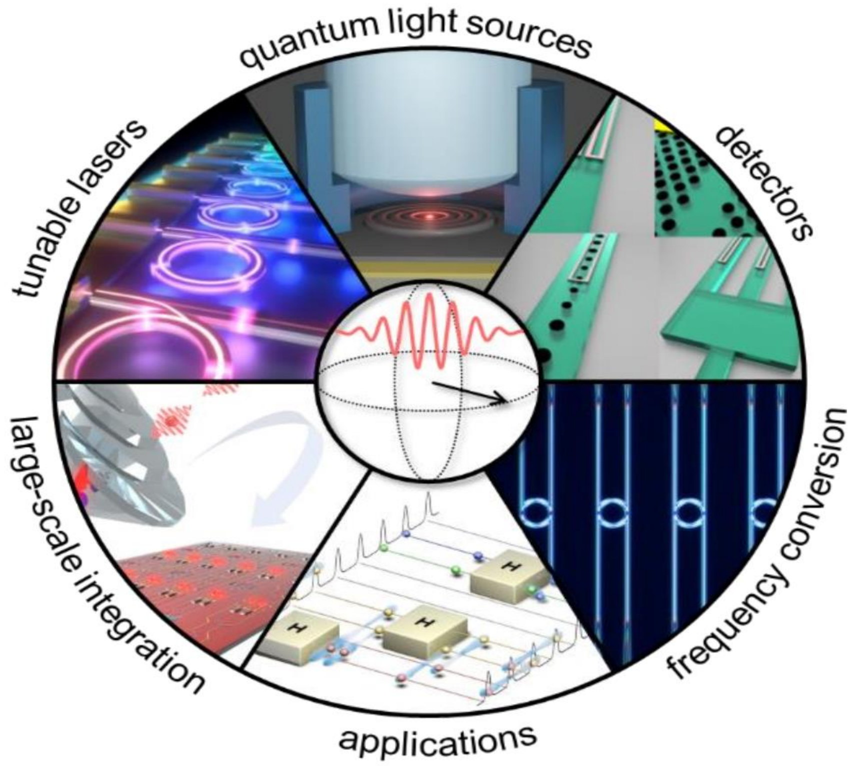
@ Lab of ICTP, Italy (2020)

Cont

- Today, quantum scientists and engineers are facing similar integration challenges with solid-state, atomic, and photonic quantum systems for **computing**, communications, and sensing

  - In the next decade, with sustained research, development, and investment in the **quantum photonic ecosystem**

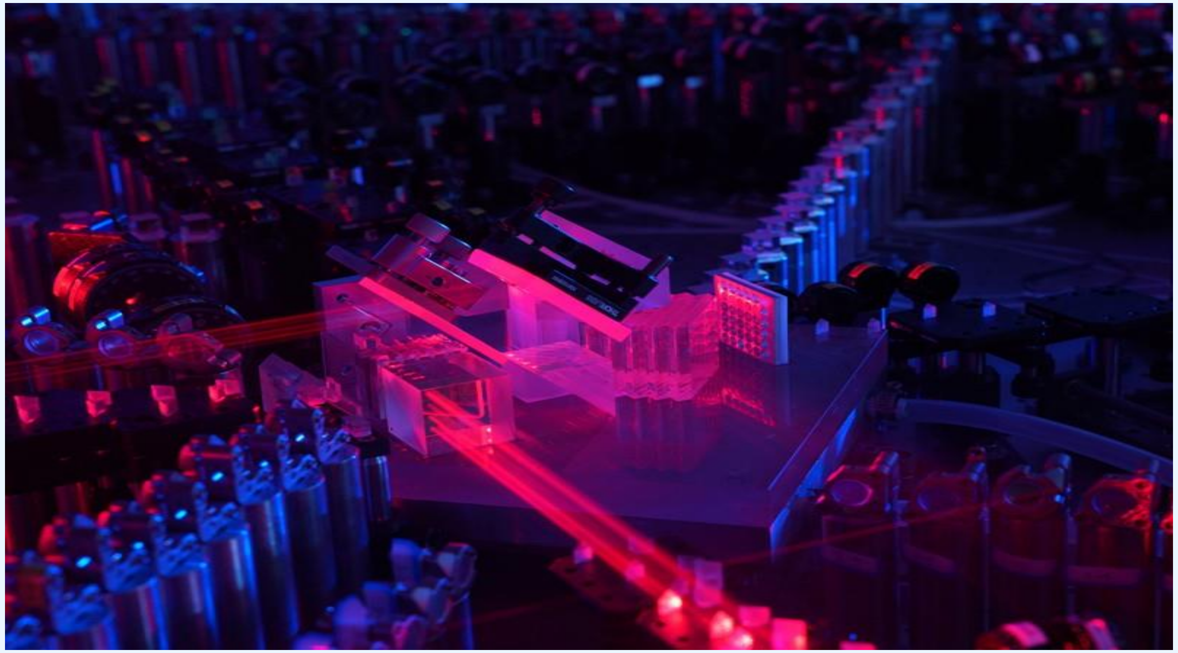
    - Quantum light sources detectors,
    - Frequency conversion & transduction
    - Photonic material platforms
    - Applications in computing, communications, and sensing



Physicists In China Challenge Google's 'Quantum Advantage,
03 December 2020

- Photon-based quantum computer does a calculation that ordinary computers might never be able to do?

- They used beams of laser light to perform a computation which had been mathematically proven to be practically impossible on normal computers



Nature, 588 (7838), 380 (2020).

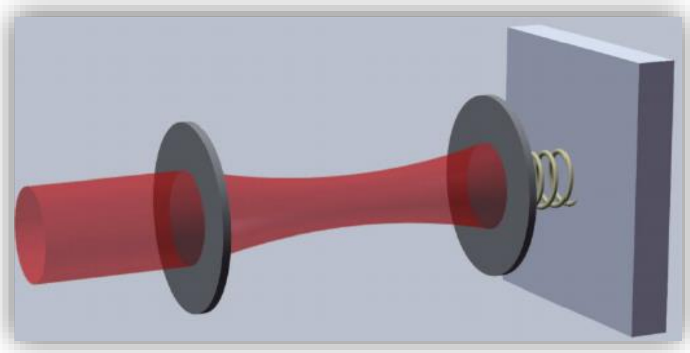
Higher gate Fidelities
~ 99.99%!!

- This photonic computer performed in **200 seconds** a calculation that on an ordinary supercomputer would take **2.5 billion years to complete**.

Optomechanical Systems (OMS)

- ❑ Is rapidly growing research field and considered as an excellent candidate to coupled the electromagnetic modes to mechanical modes through radiation pressure

- ❑ It is the combination of the Mechanical and Optical modes



Motivations that drive the rapid interest in OMS;

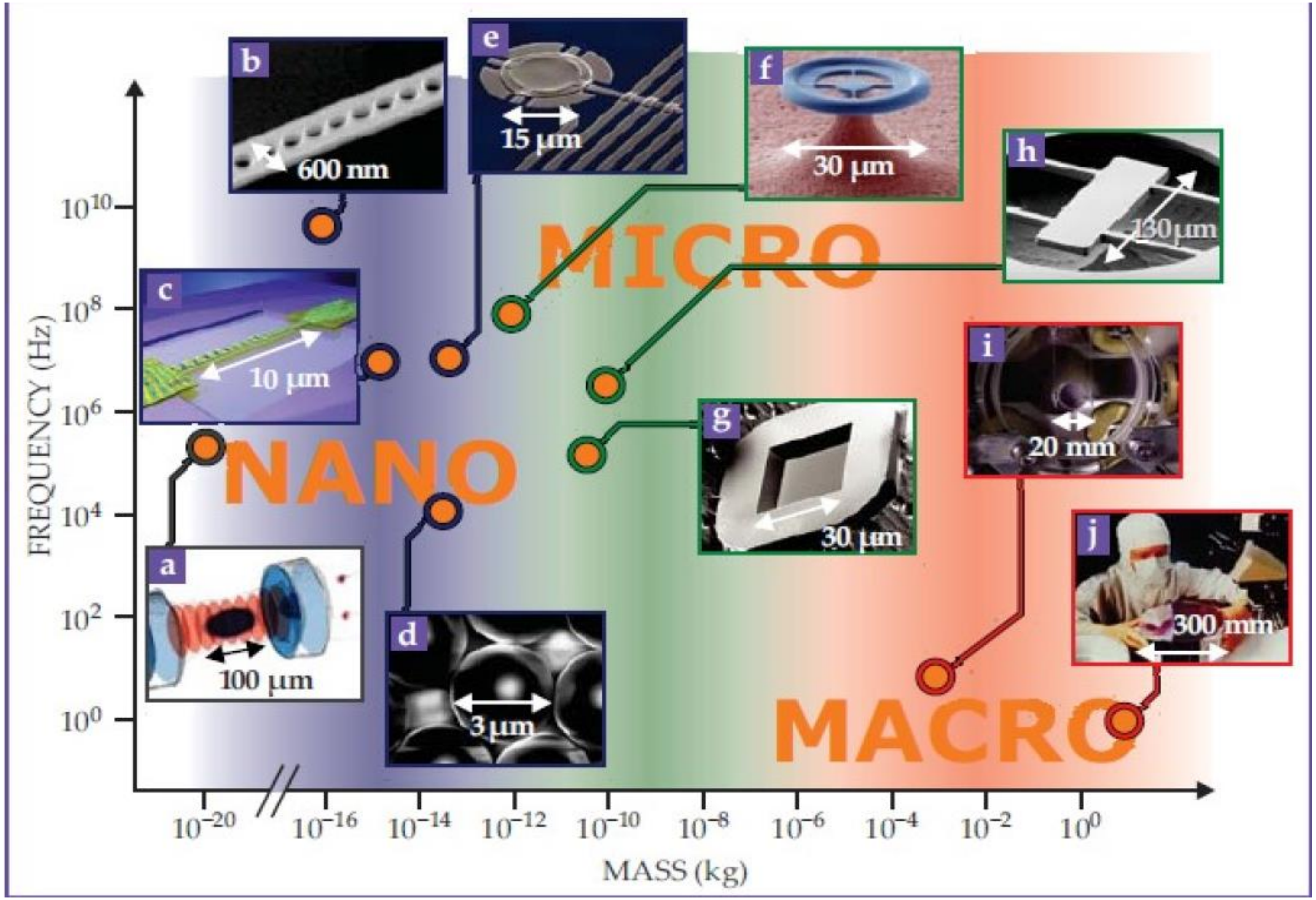
Promising

Physical resource

- **high-precision measurements**
- **manipulate mechanical motion in the quantum regime using light**
- transform information processing and communication technology

Rev. Mod. Phys. 86, 1391 (2014)   Ann. Phys. (Berlin) 525, 215 (2013)   Chin. Phys. B. 11, 114213 (2013)

OMS @ Macro, Micro and Nano-Scale



(a) Micro-Cavity with Ultracold atoms

(b,c) Nano-Scale Waveguides

(d) Microsphere

(e) Superconducting membranes

(f) Micro-toroidal waveguide

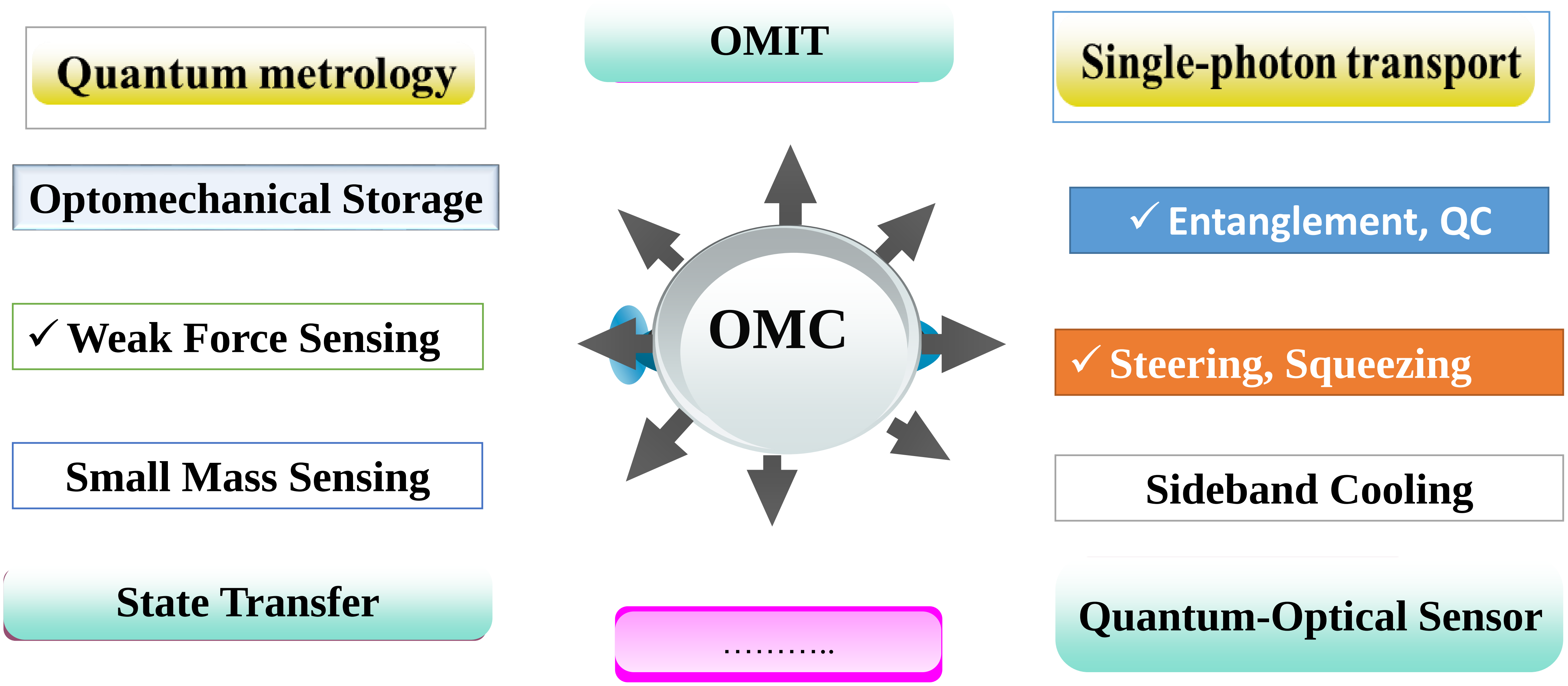
(g) Micromembranes

(h,i,j) Mirrors from Microscopic to Macroscopic

Optics Express, 15 (25),17172 (2007)

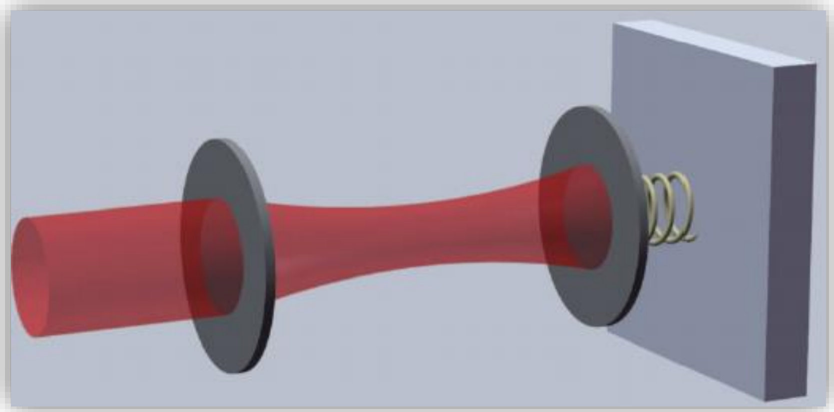
Physics Today, 2012, 65(7): 29-35

Optomechanical Systems and its Application



Rev. Mod. Phys. 86, 1391 (2014)

Hamiltonian Formulation of OMS



Optomechanical system (Fabry-Perot cavity)

$$\omega = \frac{c\pi}{L} = \frac{c\pi}{L_0 - x} \sim \omega_0\left(1 - \frac{x}{L_0}\right)$$

$$H = \omega a^\dagger a = \omega_0 a^\dagger a - H_{int}$$

$$F = -\frac{d\hat{H}_{int}}{dx} = \hbar G_0 \hat{a}^\dagger \hat{a} = \hbar \frac{g_0}{x_{ZPF}} \hat{a}^\dagger \hat{a}.$$

Total Hamiltonian of the system

$$\hat{H} = -\hbar\Delta \hat{a}^\dagger \hat{a} + \hbar\Omega_m \hat{b}^\dagger \hat{b} - \hbar g_0 \hat{a}^\dagger \hat{a}(\hat{b} + \hat{b}^\dagger).$$

$$\hat{H}_{int} = -\hbar g_0 \hat{a}^\dagger \hat{a}(\hat{b} + \hat{b}^\dagger)$$

$$\Delta = \omega_L - \omega_{cav}$$

Lloyd S. Science, 2008, 321(5895): 1463-1465. (2008)

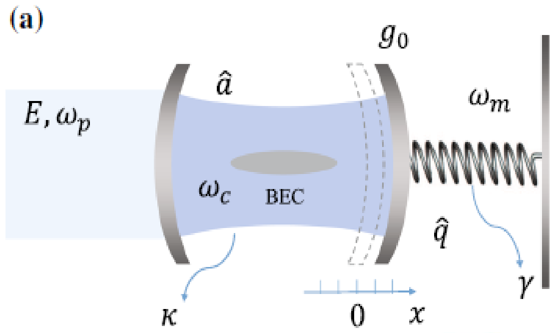
Si-Hui Tan, et al., PhysRevLett.101.253601 (2008)

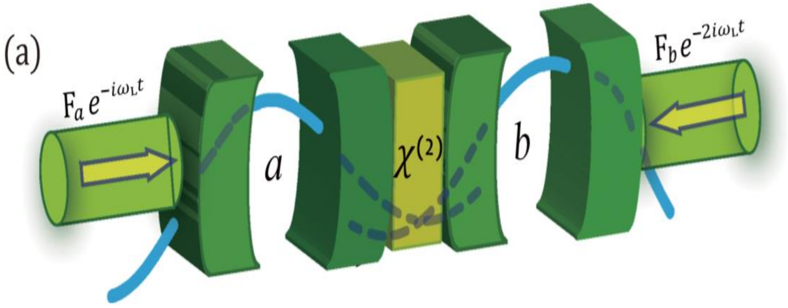
Rev. Mod. Phys. 86, 1391 (2014)

OMS with diverse Mechanical Modes

- Mechanical mode connects very different systems – Hybrid system

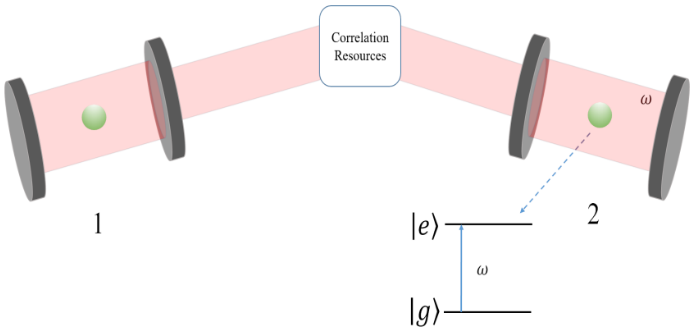
Commun. Theor. Phys. 68 (2017) 661–666

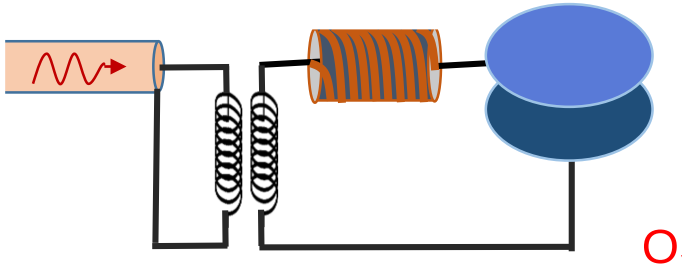


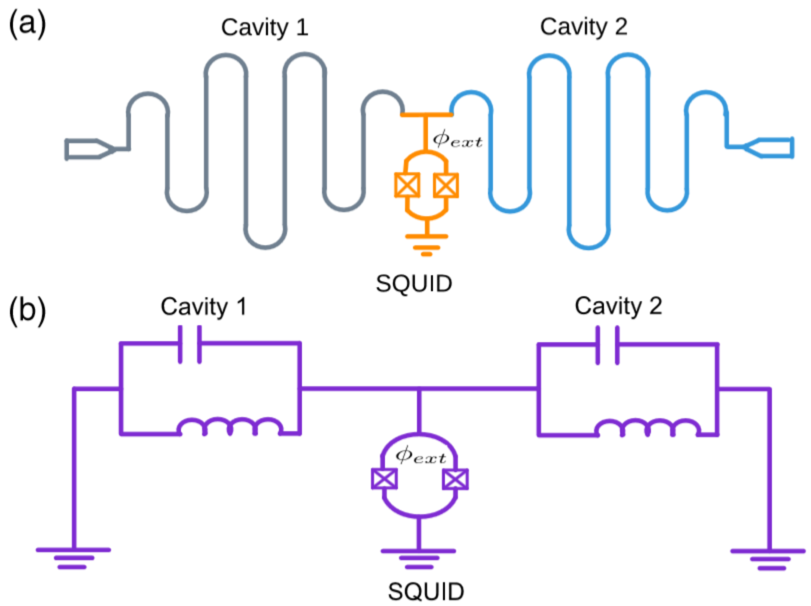


JOSA B 36, 168-177 (2019)

Results in Physics 7 (2017) 3773–3777







OSA B 35, 2334-2341 (2018)

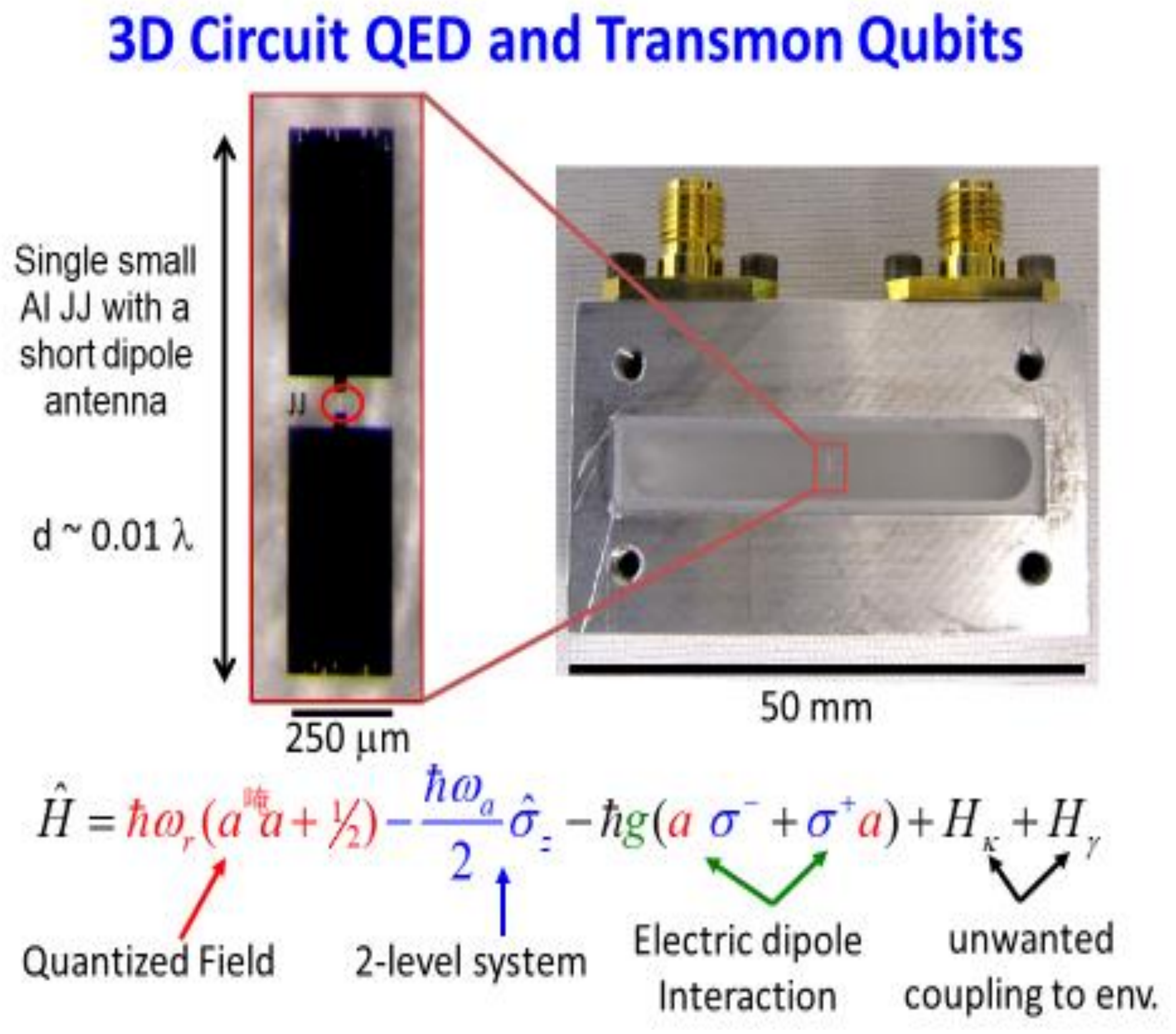
Experimental Parameters for OMS

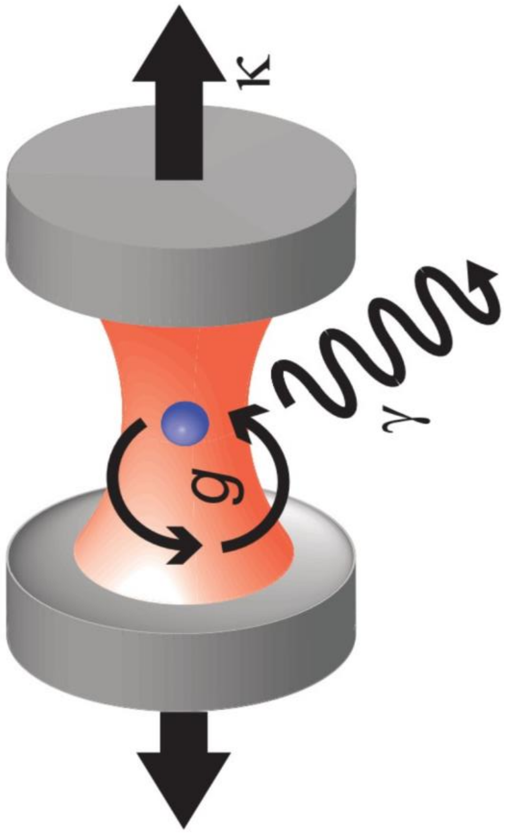
Reference	$\omega_m/2\pi$[Hz]	m [kg]	$\Gamma_m/2\pi$[Hz]	$Q \cdot f$ [Hz]	$\kappa/2\pi$[Hz]	$g_0/2\pi$[Hz]
Murch [139]	4.2×10^4	1×10^{-22}	1×10^3	1.7×10^6	6.6×10^5	6×10^5
Chan [51]	3.9×10^9	3.1×10^{-16}	3.9×10^4	3.9×10^{14}	5×10^8	9×10^5
Teufel [140]	1.1×10^7	4.8×10^{-14}	32	3.5×10^{12}	2×10^5	2×10^2
Verhagen [141]	7.8×10^7	1.9×10^{-12}	3.4×10^3	1.8×10^{12}	7.1×10^6	3.4×10^3
Thompson [142]	1.3×10^5	4×10^{-11}	0.12	1.5×10^{11}	5×10^5	5×10^1
Kleckner [143]	9.7×10^3	1.1×10^{-10}	1.3×10^{-2}	9×10^9	4.7×10^5	2.2×10^1
Gröblacher [144]	9.5×10^5	1.4×10^{-10}	1.4×10^2	6.3×10^9	2×10^5	3.9
Arcizet [21]	8.14×10^5	1.9×10^{-7}	81	8.1×10^9	1×10^6	1.2
Cuthbertson [145]	10^3	1.85	2.5×10^{-6}	4.1×10^{10}	275	1.2×10^{-3}

Rev. Mod. Phys., 86 (4):1391, (2014)

Cont.

Principles of Coupling Strengths





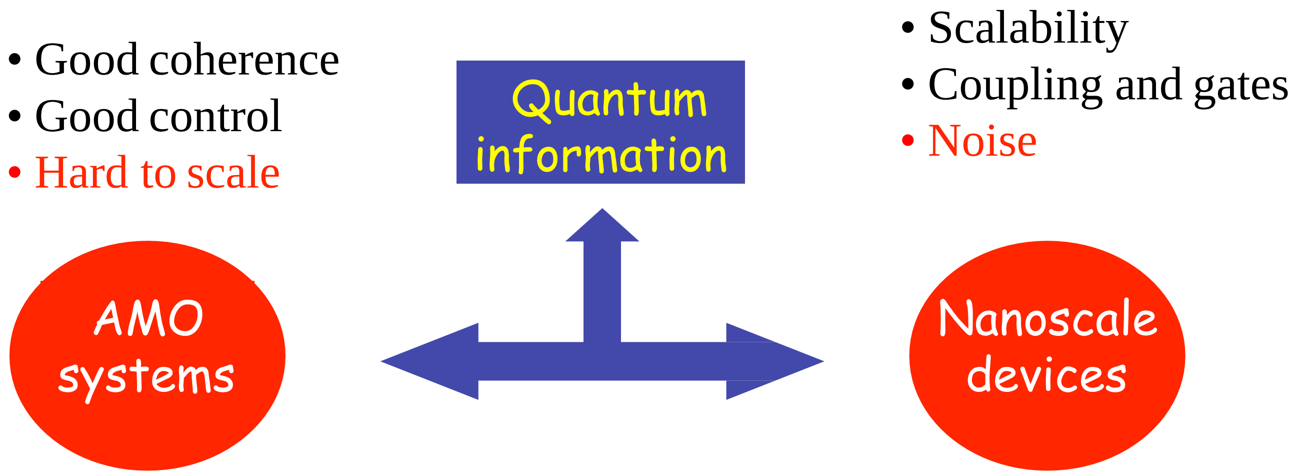
Johnson B.R. et al. Nature Phys. 6, 663-667 (2010)

Kirchmair G. et al. Nature 495 205-209 (2013)

B. Vlastakis et al. Science 342, 6158 (2013)

Hybrid Quantum Sstems

1. Challenge of building scalable quantum devices: decoherence, information transfer, perform gate operations, memory element
2. Combining merits of AMO and Condensed Matter Systems



3. Different systems can work in different frequencies

Tian, Rabl, Blatt & Zoller, PRL (2004)
Daniilidis, Gorman, Tian, Haeffner, NJP 15, 073017 (2013)

Atomic, Molecular, and Optical (AMO)

Research Article

Vol. 37, No. 11 / November 2020 / *Journal of the Optical Society of America B* **A245**

Journal of the Optical Society of America B

OPTICAL PHYSICS

Generation of the bipartite entanglement and correlations in an optomechanical array

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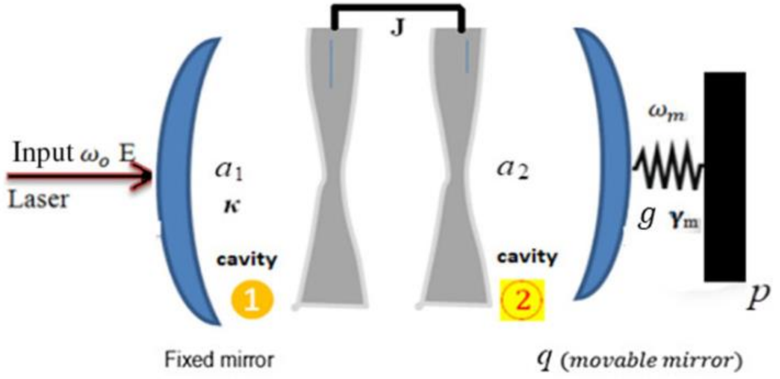
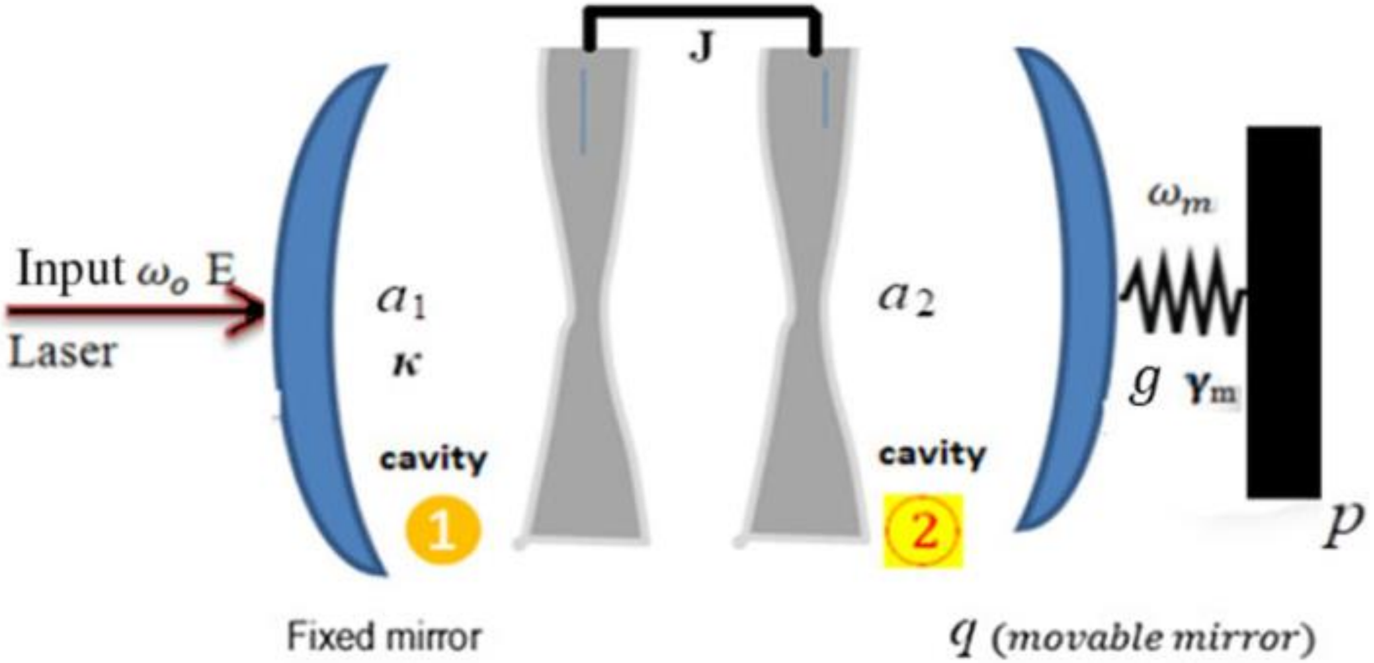
Goal

- *We consider an optomechanical array consisting of an optical cavity array coupled with one oscillating end-mirror via optical coupling strength.*
- *Cavity1 is driven by a pump field, and cavity2 is an oscillating mirror at one end, serving as a mechanical harmonic oscillator.*
- We generate the Ent. and correlation between two CV correlations, i.e., cavity1–mirror, cavity2–oscillating mirror, and cavity1–cavity2.



Bipartite Entanglement via Optical Micro Cavity



$$H = \hbar\Delta_1 a_1^\dagger a_1 + \hbar\Delta_2 a_2^\dagger a_2 + \hbar J\left(a_1^\dagger a_2 + a_2^\dagger a_1\right) + \frac{\hbar\omega_m}{2}\left(p^2 + q^2\right) - \hbar g a_2^\dagger a_2 q + i\hbar E\left(a_1^\dagger - a_1\right).$$

$$\Delta_1 = \omega_1 - \omega_0$$

$$\Delta_2 = \omega_2 - \omega_0$$

Con't

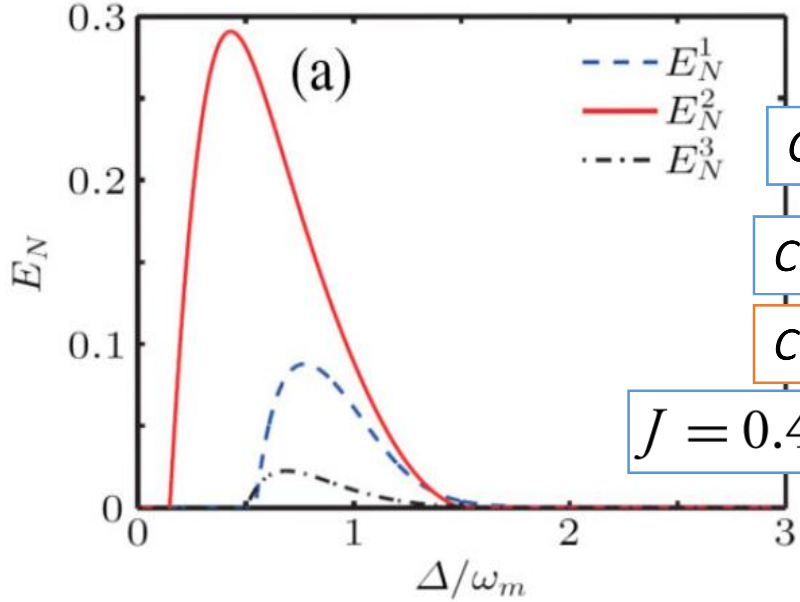
- Accordingly, we extract the drift matrix A as

$$\dot{\mathbb{U}}(t) = A\mathbb{U}(t) + \mathbb{N}(t),$$

$$\begin{pmatrix} \delta\dot{p} \\ \delta\dot{q} \\ \delta\dot{x}_1 \\ \delta\dot{y}_1 \\ \delta\dot{x}_2 \\ \delta\dot{y}_2 \end{pmatrix} = \begin{pmatrix} 0 & \omega_m & 0 & 0 & 0 & 0 \\ -\omega_m & -\gamma_m & 0 & 0 & \sqrt{2}G_1 & 0 \\ 0 & 0 & -\kappa_1 & \Delta_1 & 0 & J \\ 0 & 0 & -\Delta_1 & -\kappa_1 & -J & 0 \\ 0 & 0 & 0 & J & \kappa_2 & \Delta_2 \\ \sqrt{2}G_1 & 0 & J & 0 & \Delta'_2 & \kappa_2 \end{pmatrix} \begin{pmatrix} \delta p \\ \delta q \\ \delta x_1 \\ \delta y_1 \\ \delta x_2 \\ \delta y_2 \end{pmatrix} + \begin{pmatrix} 0 \\ \zeta \\ \sqrt{2\kappa}x_1^{\text{in}} \\ \sqrt{2\kappa}y_1^{\text{in}} \\ \sqrt{2\kappa}x_2^{\text{in}} \\ \sqrt{2\kappa}y_2^{\text{in}} \end{pmatrix},$$

$$\mathbb{V}_t = \begin{pmatrix} V_\Phi & V_{m\Phi} \\ V_{m\Phi}^T & V_m \end{pmatrix},$$

Results: Bipartite Entanglement

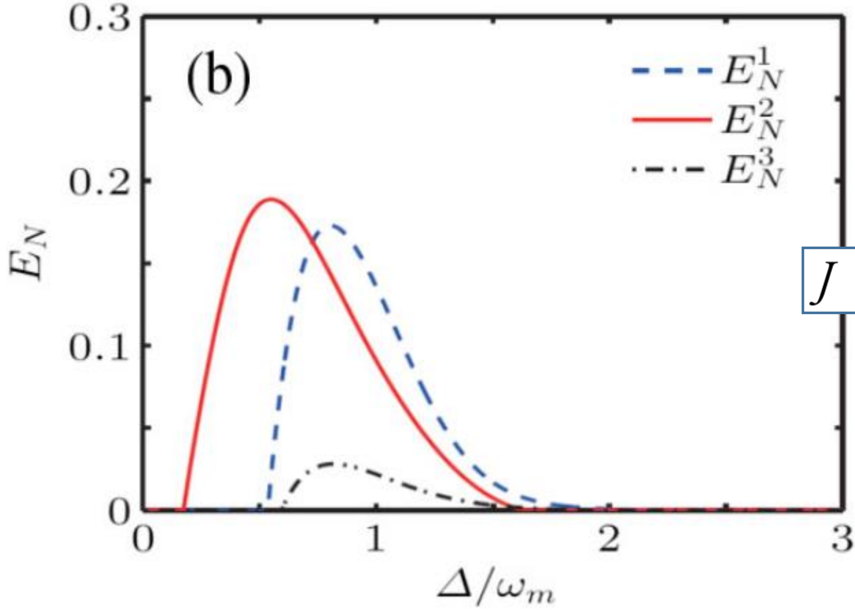


Cavity1–Oscillating mirror

Cavity2–Oscillating Mirror

Cavity1 – Cavity2

$J = 0.4\omega_m$,



$J = 0.6\omega_m$

Experimental Parameters

$\omega_m/2\pi = 200\,\mathrm{mHz}$, $\lambda = 810\,\mathrm{nm}$

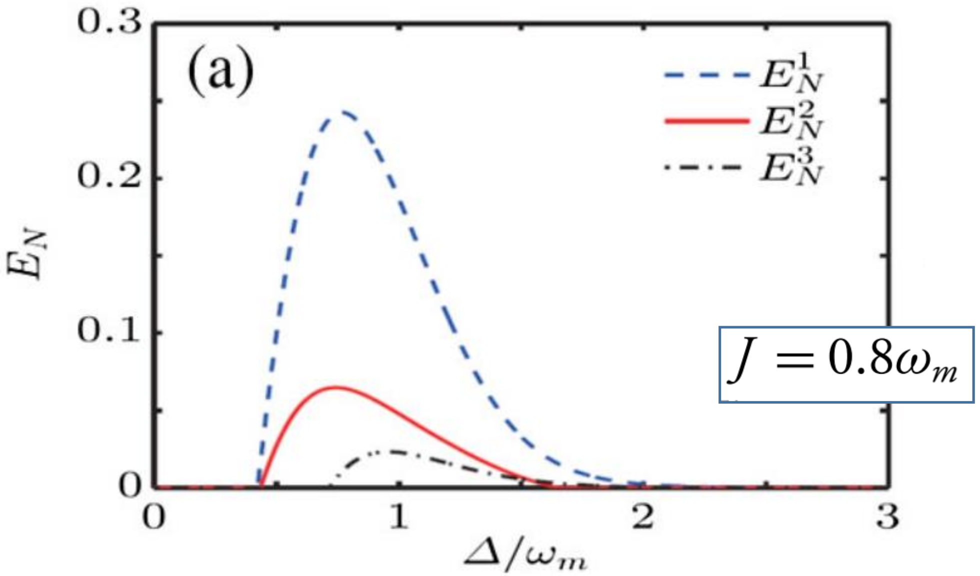
$m = 5\,\mathrm{ng}$ $P = 50\,\mathrm{mW}$, $Q = 10^5$

$\gamma_m/2\pi = 200$ $\kappa = 34\,\mathrm{MHz}$,

$T = 400\,\mathrm{mK}$.

- *Cavity1–mirror is enhanced and wider,*
- Cavity1–cavity2 is almost consistent

Con’t



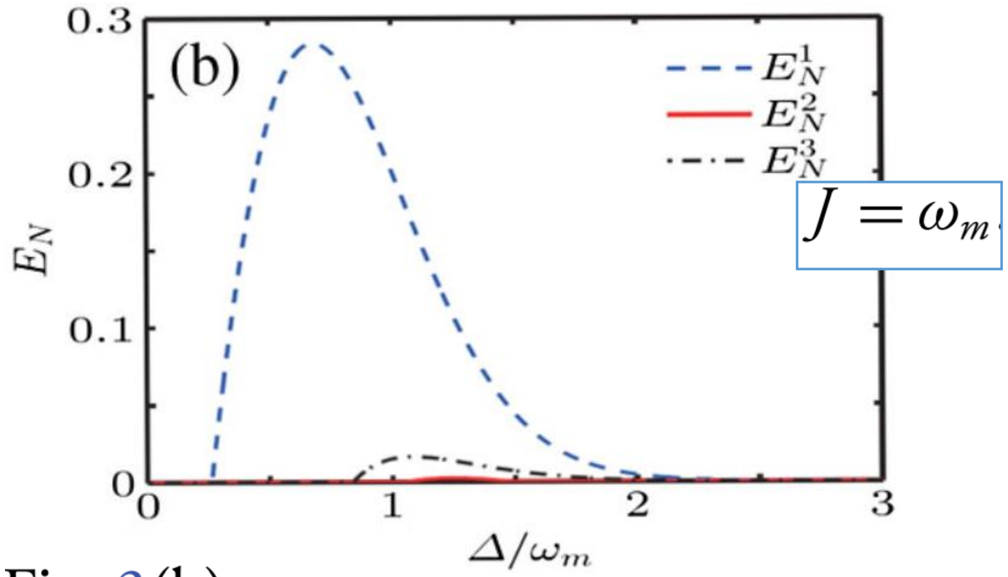


Fig. 3(b)

E_N^1 increases at the expense E_N^2

E_N^1 **is broader**

$\Delta/\omega_m \in [0.4,\ 1.5]$ in Fig. 2(a)

to $\Delta/\omega_m \in [0.3,\ 2]$ in Fig. 3(b).

the broader effective detuning can observed… *Ent. Ext released*

- The entanglement between cavity2–oscillating mirror is decreased,
- The Ent. cavity1–cavity2 is almost unchanged
- the adjacent cavity2 can serve as an *entanglement transmitter*

We assume that $\Delta_2' = \Delta_2 - g q_s$ and $-\Delta_1 = \Delta_2' = \Delta$

Summary

- *Understanding the quantum nature of the system and its effects in cavity optomechanics has a numerous important on the research field of nonlinear quantum optical system*

- *Optomechanical coupling via radiation pressure is a promising resource to prepare and manipulate quantum states of mechanical motion, and as a fundamental resource for several protocols in quantum information*

Future Research Direction

- Therefore, I recommended to all the students and researchers to read more & extended to innovative platform of Cavity Optomechanics, and Cavity-Magno-mechanics, which is nowadays active research for studying many interesting quantum nonlinearity phenomena such as;

  - Magnon-Photon-Phonon Entanglement
  - *Entanglement induced by Coulomb interaction in OMS*
  - *Optomechanically Induced Transparency (OMIT)*
  - *Machine Learning and Quantum Devices*
  - *Optomechanical Quantum Interface*

Publications

1. Tesfay Gebremariam, Wenlin Li, Chong Li. Dynamics of quantum correlation of four qubitssystem. **Physica A: Statistical Mechanics and its Applications, 457: 437-442 (2017).**

2. Tesfay Gebremariam, Yexiong Zeng, Chong Li. Dynamics of quantum correlations for two mode entangled coherent fields. Results in Physics,**, 7:** 3773–3777, **(2017).**

3. **Tesfay Gebremariam**, YeXiong Zeng, Xin-Yu Chen, and Chong Li. Observation and Measures of Robust Correlations for Continuous Variable System. **Commun. Theor. Phys., 68: 661–666, (2017).**

4. Tesfay Gebremariam, Mojtaba Mazaheri, Yexiong Zeng, Ming-Song Ding, Chong Li. Dynamical quantum steering in electro-optomechanical system. **J**. Opt. Soc. Am. B, Vol. 36, No. 2, **(2019).**

5. Tesfay Gebremariam, Yexiong Zeng, Mojtaba Mazaheri, Chong Li. Sensing optical forces achieved by using cooling processes and coherent quantum noise cancellation in hybrid optomechanical system. SCIENCE CHINA Physics, Mechanics & Astronomy. *China Phys. Mech. Astron.* 63, 210311 **(2020**).

6. Tesfay Gebremariam, Chong Li, Heshan Song. Synchronization effect for uncertain quantum networks. Physica A: Statistical Mechanics and its Applications,, 465: 621–627**, (2017).**

7. Tesfay Gebremariam, Ming-Song Ding, Chong Li. Quantum optical diode based on Lyapunov control in a superconducting system. J. Opt. Soc. Am. B, 35: 2334–2341, **(2018).**

8. Tesfay Gebremariam, Ming-Song Ding, Chong Li. The Influence of Non-Markovian Characters on Quantum Adiabatic Evolution**.** Ann. Phys.(Berlin) ,1800234 **(2018).**

Cont

9. Tesfay Gebremariam, Steady-State Quantum Correlation Measurement in Hybrid Optomechanical Systems" Submission, International Journal of Quantum Information (DOI: 10.1142/S021974992050046X) **(2020).**

10. Tesfay Gebremariam, "Generation of the bipartite entanglement and correlations in an optomechanical array" J. Opt. Soc. Am. B Vol. 37, Issue 11, pp. A245-A252 **(2020).**

11. Tesfay Gebremariam "Quantum control based on machine learning in an open quantum system**".** Physics Letters, A 384, 126886 **(2020).**

12 . Tesfay Gebremariam "Quantum force sensing using backaction noise suppression in optomechanical system.**"** Journal of Optics, 1-11**. (2020).**

13. Tesfay Gebremariam. et.al. "Application of machine learning for predicting strong phonon blockade." *Applied Physics Letters* **118.16 (2021): 164003**.

14. Tesfay Gebremariam, "Stationary Entanglement Dynamics in a Hybrid Opto-Electro-Mechanical System" Romanian Journal of Physics**, 16-Jan -2021.**

15. Tesfay Gebremariam "Enhanced Optomechanically Induced Transparency via Atomic Ensemble in Optomechanical System". QINP-D-20-00524 **(2021).**

16. Tesfay Gebremariam. et.al. "Optimal Teleportation via A Non-Maximally Entangled Channel in Qutrits System." *International Journal of Theoretical Physics* **(2021): 1-12**.

Cont

Books:

1.Tesfay Gebremariam, "An Introduction to Modern Physics " Publisher: LAP LAMBERT Academic Publishing (December 5, **2016**). https://www.amazon.com/Introduction-Modern-Physics-Tesfay Gebremariam/dp/3330015292

2.Tesfay Gebremariam, "Dirac Equation For Different Potential" Publisher: LAP LAMBERT Academic Publishing (May 17, **2016** https://www.amazon.com/Equation-Different-Potential-Tesfay-Gebremariam/dp/3659889938

List of International Conference /Workshops

- **September 23, 2016** "The Conference on northeast China quantum physics frontier and progress", Dalian University of Technology, Dalian, China.
- **September 15–17, 2017** "The Conference on Northeastern Quantum Physics Frontier and Progress", Changchun, Jilin Engineering Normal University, Changchun, Endomysia.
- **May 25–28, 2018** "The 9th International Workshop on Solid-State Quantum Computing", Hangzhou, Normal University Hangzhou, China.
- **September 13, 2018** "International Workshop on Micro-Cavity Photonics", Dalian University of Technology, Dalian, Japan.
- **September 13–16, 2018** "CPS (Chinese Physical Society) Fall meeting", Dalian University of Technology, Dalian, China.
- **February 3-7/ 2020** “Preparatory School on Optics: Quantum Photonics and Information”; Abdus Salam International Centre for Theoretical physics, Italy.
- **February 10-21/ 2020** “Winter College on Optics: Quantum Photonics and Information’’ Abdus Salam International Centre for Theoretical physics, Italy.
- **February 10-21/ 2020; Poster Presenter;** “Enhancing Optomechanical Force Sensing Via Precooling and Quantum Noise Cancellation” Abdus Salam International Centre for Theoretical physics, Italy

Cont.

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- **February 10-21/ 2020** “Winter College on Optics: Quantum Photonics and Information’’ Abdus Salam International Centre for Theoretical physics, Italy.
- **April 15-24 2012** ”Short- term training on SAS and SPSS Softwar”, Arbaminch University, Ethiopia
- **April 24 - 26 2013** ”Short- term training on module preparation”, Arbaminch University, Ethiopia
- **Febrary 20 to March 27, 2012** ”Short- term training on Software and Networking application” Arbaminch University, Ethiopia
- ***June 16–18, 2016*** “The 4th International Workshop on Frontiers in Quantum Optics and Quantum Information; “Optomechanics meets circuit QED", Beijing Computational Science Research Center, Beijing China.
- **May 23 –28, 2016** "The 3rd International Conference on Phoonics and Thermal Energy Science (PTES 2016) ", Xian Jiaotong University Xian, Japan.

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Collaborators

Acknowledgements

To all committees

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