Second Youth of Quantum Mechanics

Technologies, Ideas, Frontiers

Quantum theory reveals that the world is much denser than anybody imagined before -

- not in mass, but in structure and information.

Consider, for example, how we describe the state of two particles.

$$\psi(x_1, x_2)$$

Quantum: “any” complex function

Classical: sum of two delta functions

Or how we describe the state of a 3-bit register:

$$
\begin{aligned}
s_1 &= 000 \\
s_2 &= 001 \\
s_3 &= 010 \\
s_4 &= 011 \\
s_5 &= 100 \\
s_6 &= 101 \\
s_7 &= 110 \\
s_8 &= 111
\end{aligned}
$$

Classical: a choice among 8 points.

Quantum: a point on a sphere in 16 dimensions.

The pioneers of quantum theory inferred this wealth of structure from rather indirect clues.

Many of them thought it was a provisional description.

Few if any of them thought that we'd be able to access it directly, much less control it in powerful ways.

But the quantum world seems here to stay, and we're starting to master it.

Technologies

Several technologies, working synergistically, have rejuvenated work in quantum mechanics:

Technology	Practical Applications	Scientific Tools
Microelectronics	computers, communications nodes, smart appliances, …	computation, miniaturization, materials processing
Lasers	illumination, communication, industrial processes, …	quantum optics, precision spectroscopy, precision measurement
Trapping and cooling	atomic clocks, gravitometers	precision timing, clean quantum access, quantum simulation
Placement	surface characterization and sculpting	STM and related “microscopes”, NV centers
Superconductivity and superfluidity	powerful electromagnets, Josephson devices	cryogenics, precision magnetometry

Ideas

New ideas have played a role too:

The idea that quantum systems embody information

The idea that we can identify - and construct - emergent entities and phenomena in quantum systems, that are connected with geometry *in Hilbert space*

The idea that we *can* do quantum engineering …

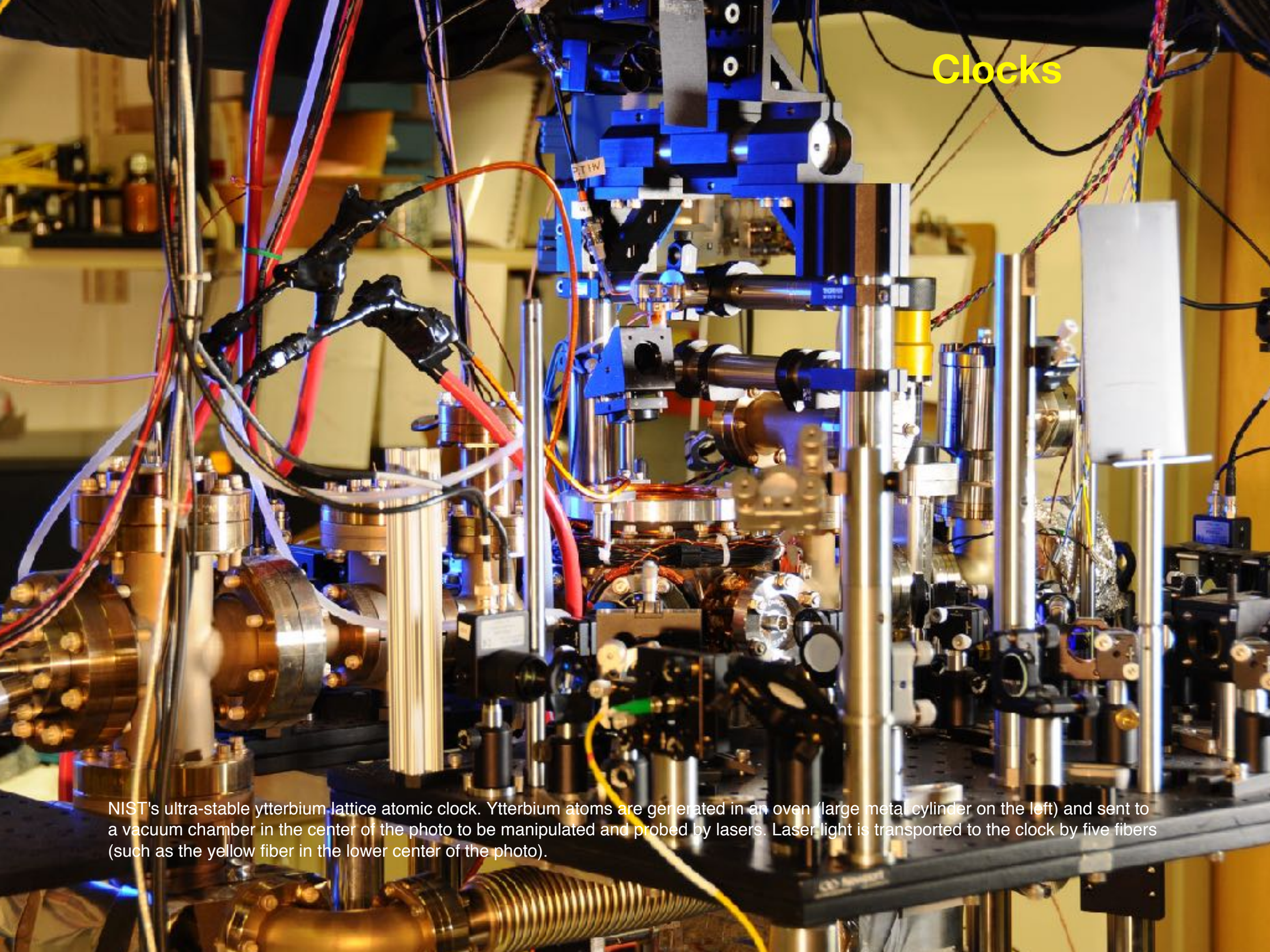
P. A. M. Dirac, 1929:

The fundamental laws necessary for the mathematical treatment of a large part of physics and the whole of chemistry are thus completely known,

and the difficulty lies only in the fact that application of the laws leads to equations that are too complex to be solved.

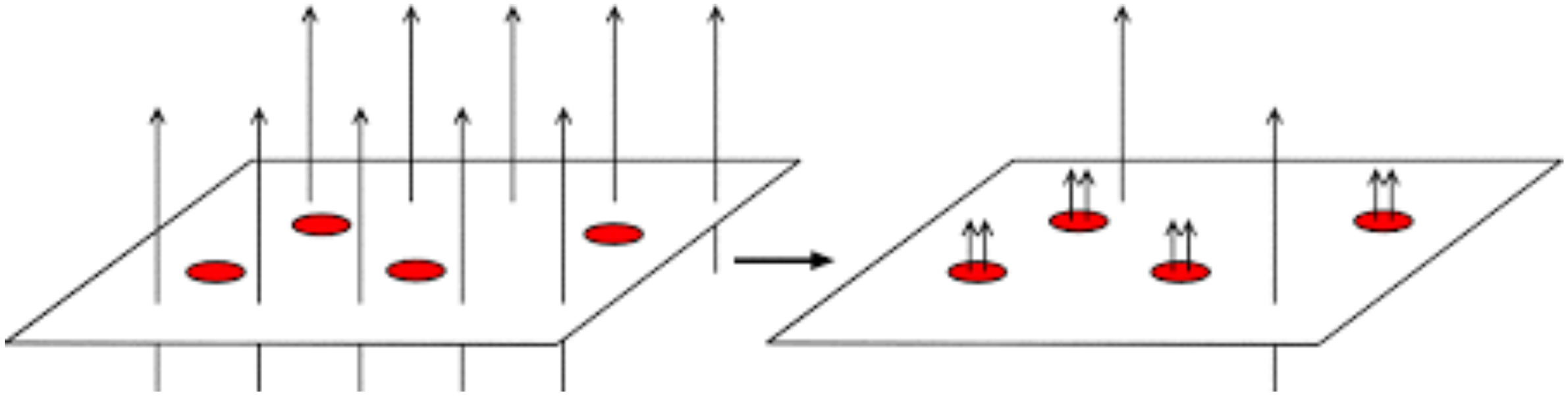
Frontiers

Clocks



NIST's ultra-stable ytterbium lattice atomic clock. Ytterbium atoms are generated in an oven (large metal cylinder on the left) and sent to a vacuum chamber in the center of the photo to be manipulated and probed by lasers. Laser light is transported to the clock by five fibers (such as the yellow fiber in the lower center of the photo).

New States of Matter



PHYSICS

DARPA Is Funding Time Crystal Research

Gizmodo



Ryan F. Mandelbaum

3/14/18 5:00pm • Filed to: TIME CRYSTALS

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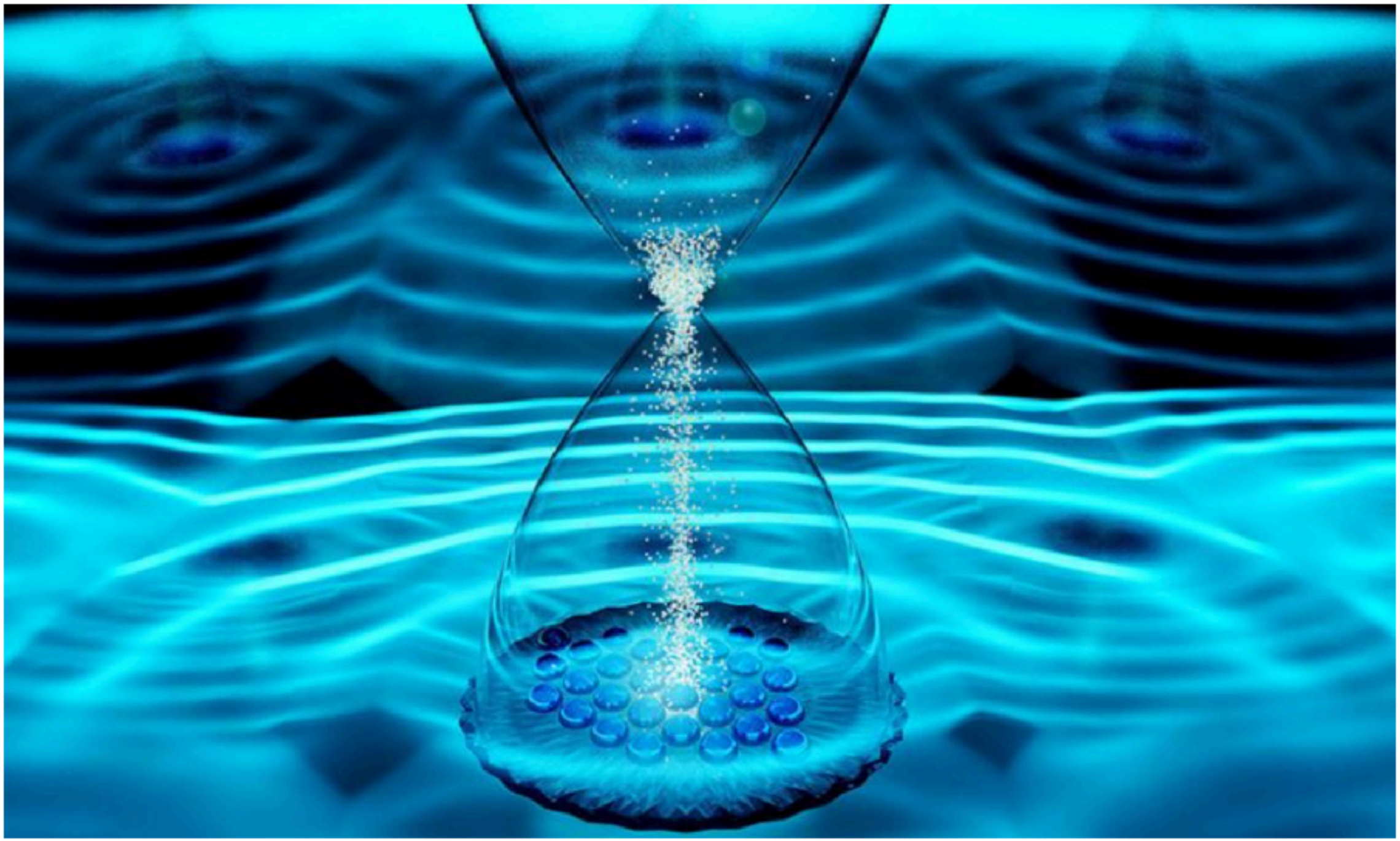
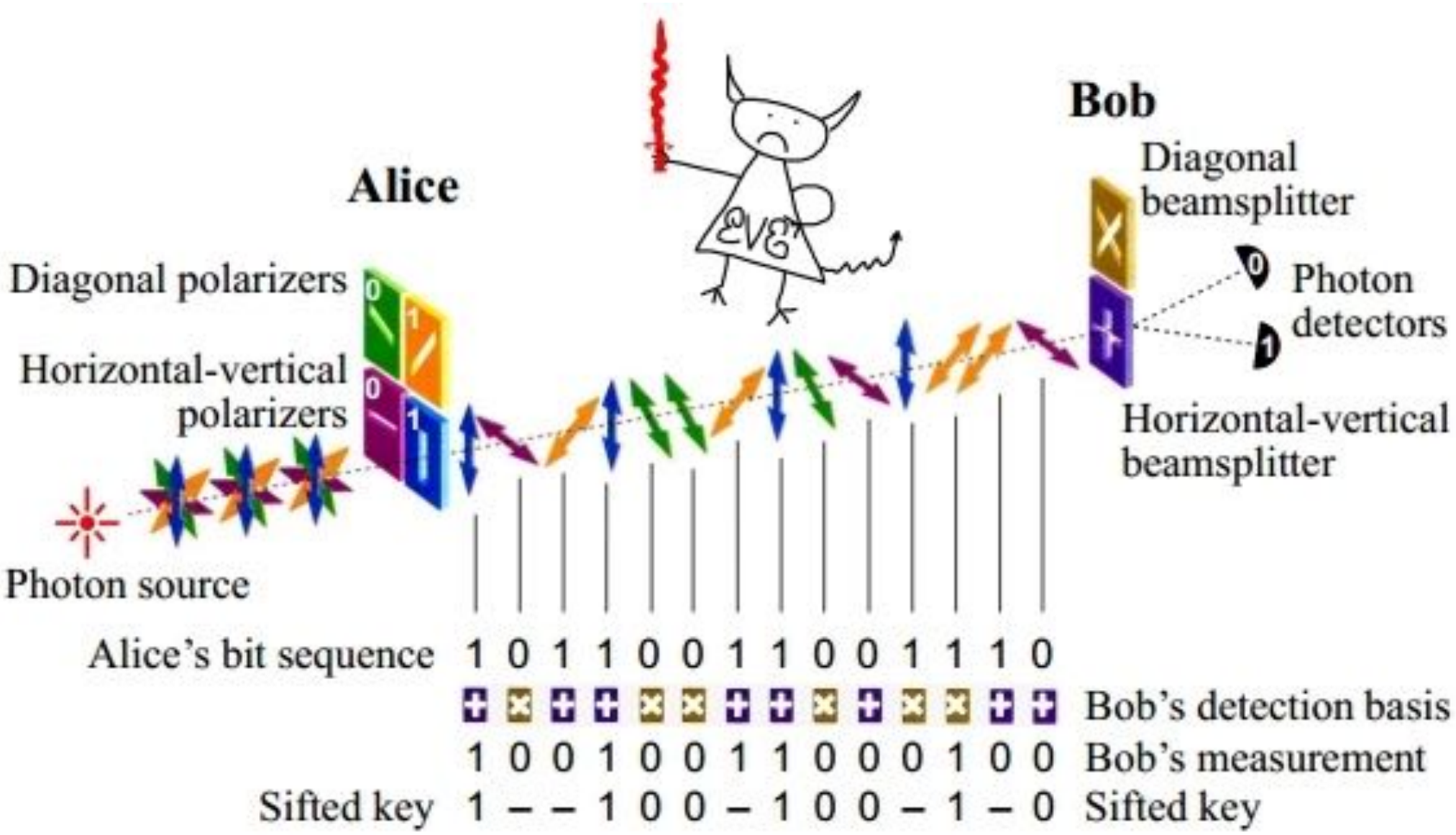


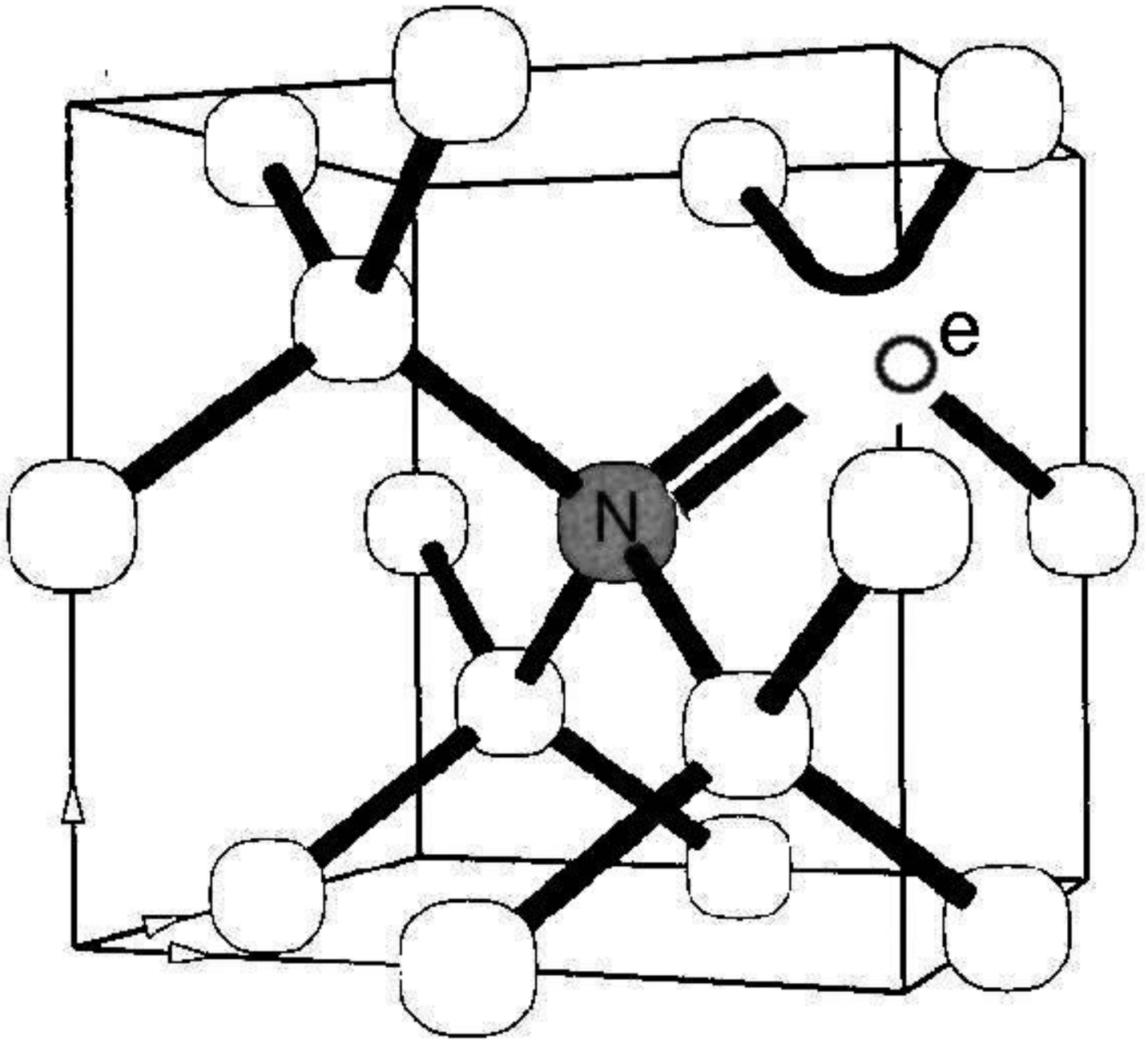
Illustration: Emily Edwards/IQI

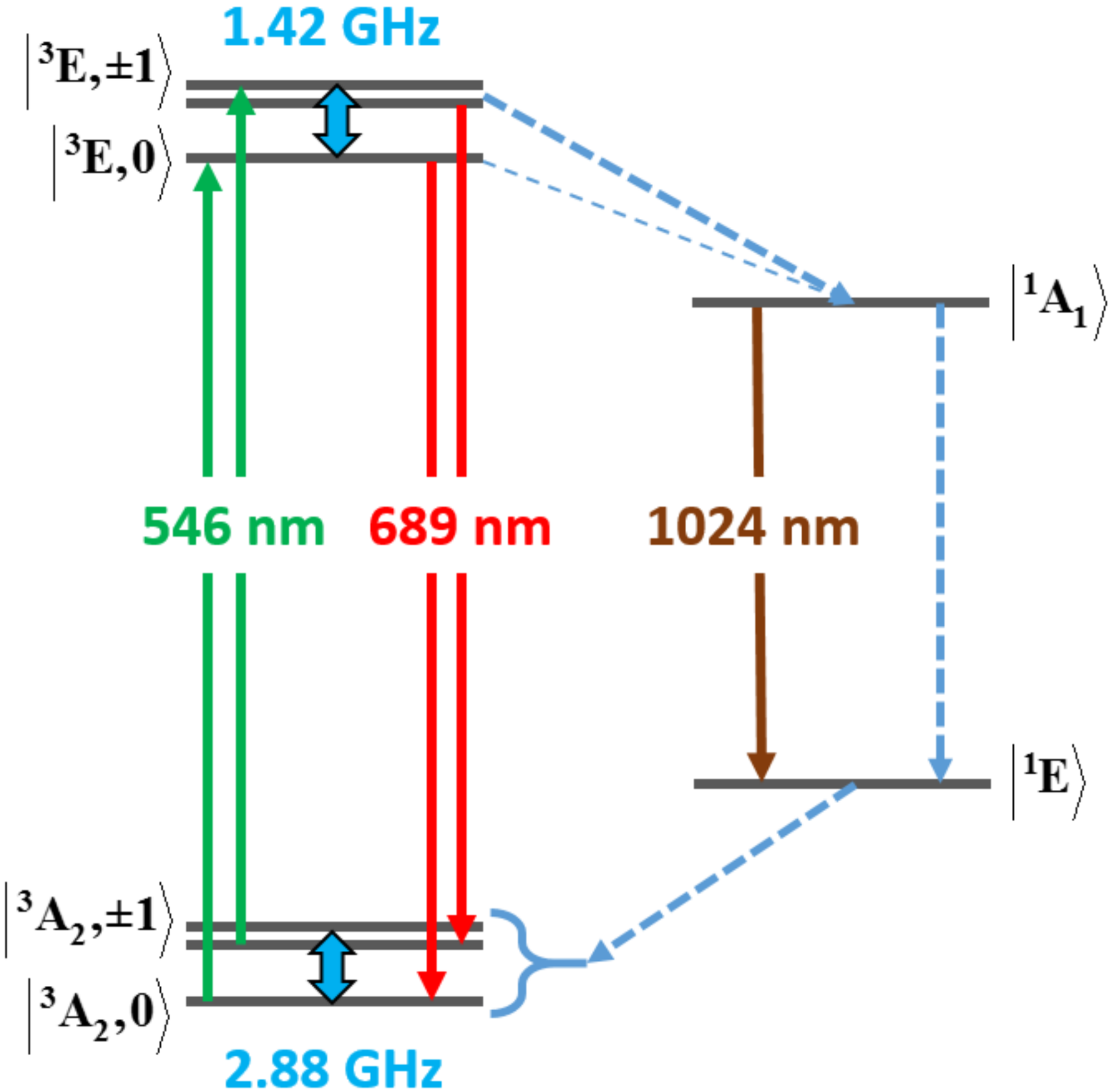
Quantum Cryptography

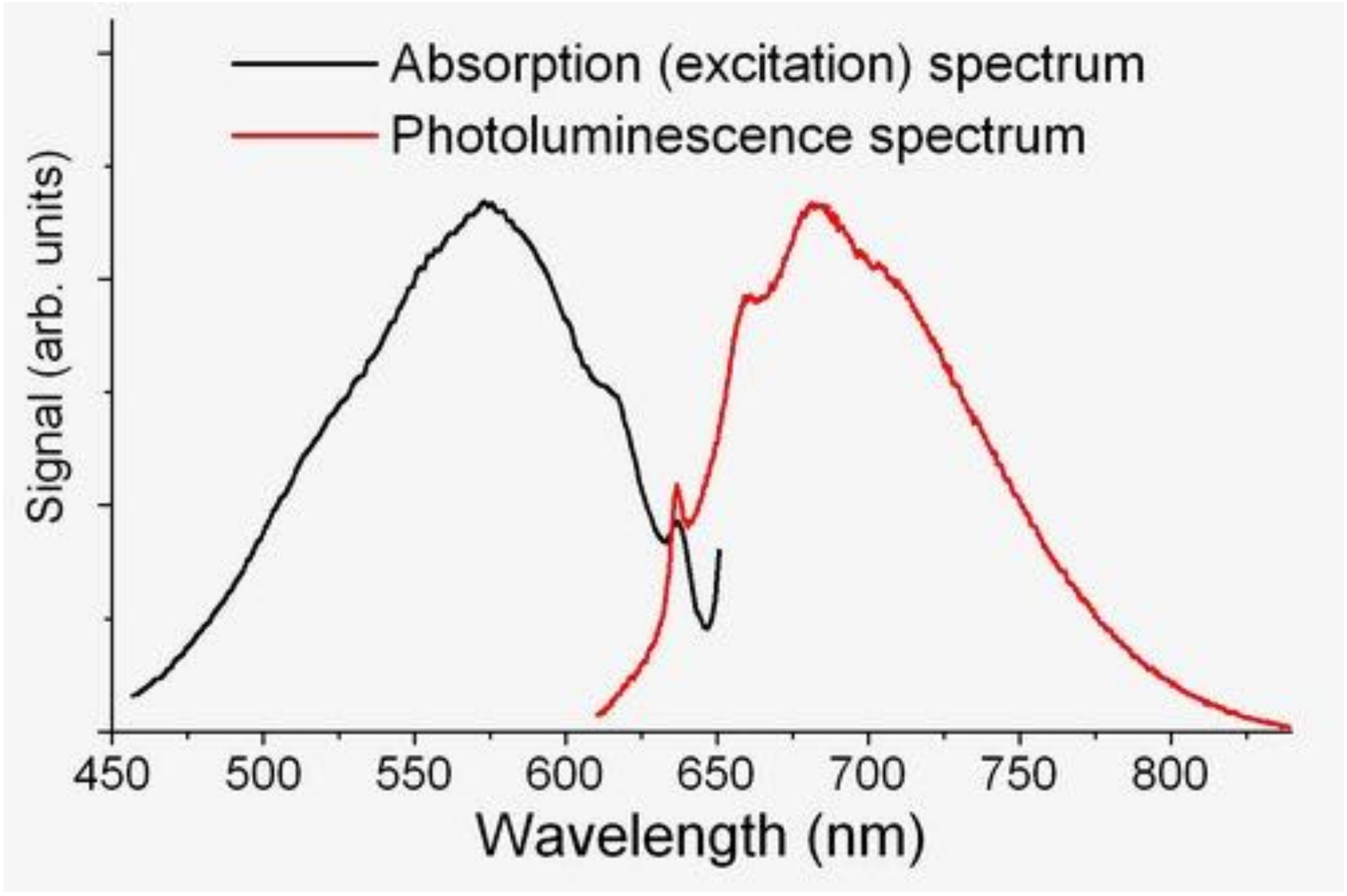


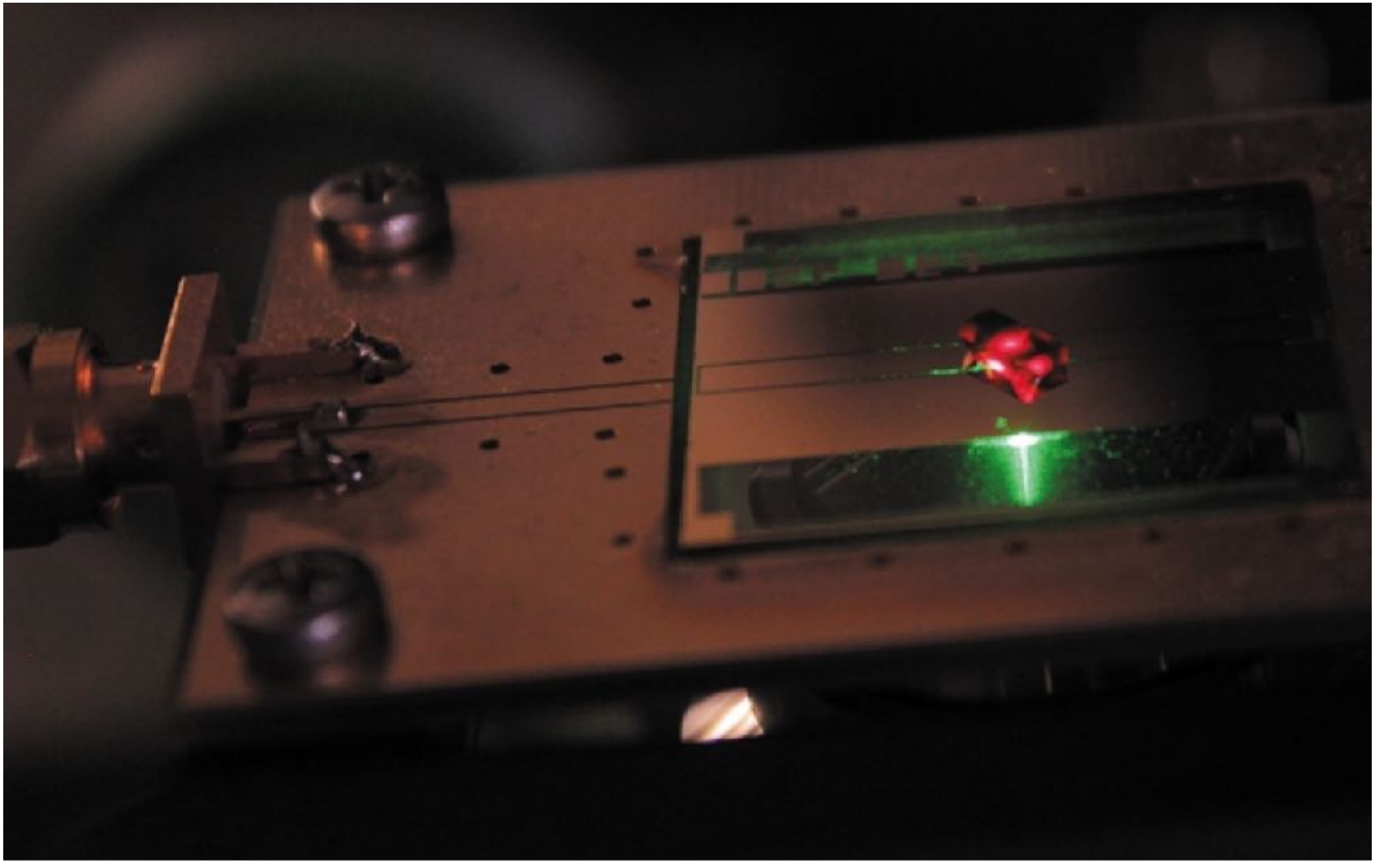
A Case Study:

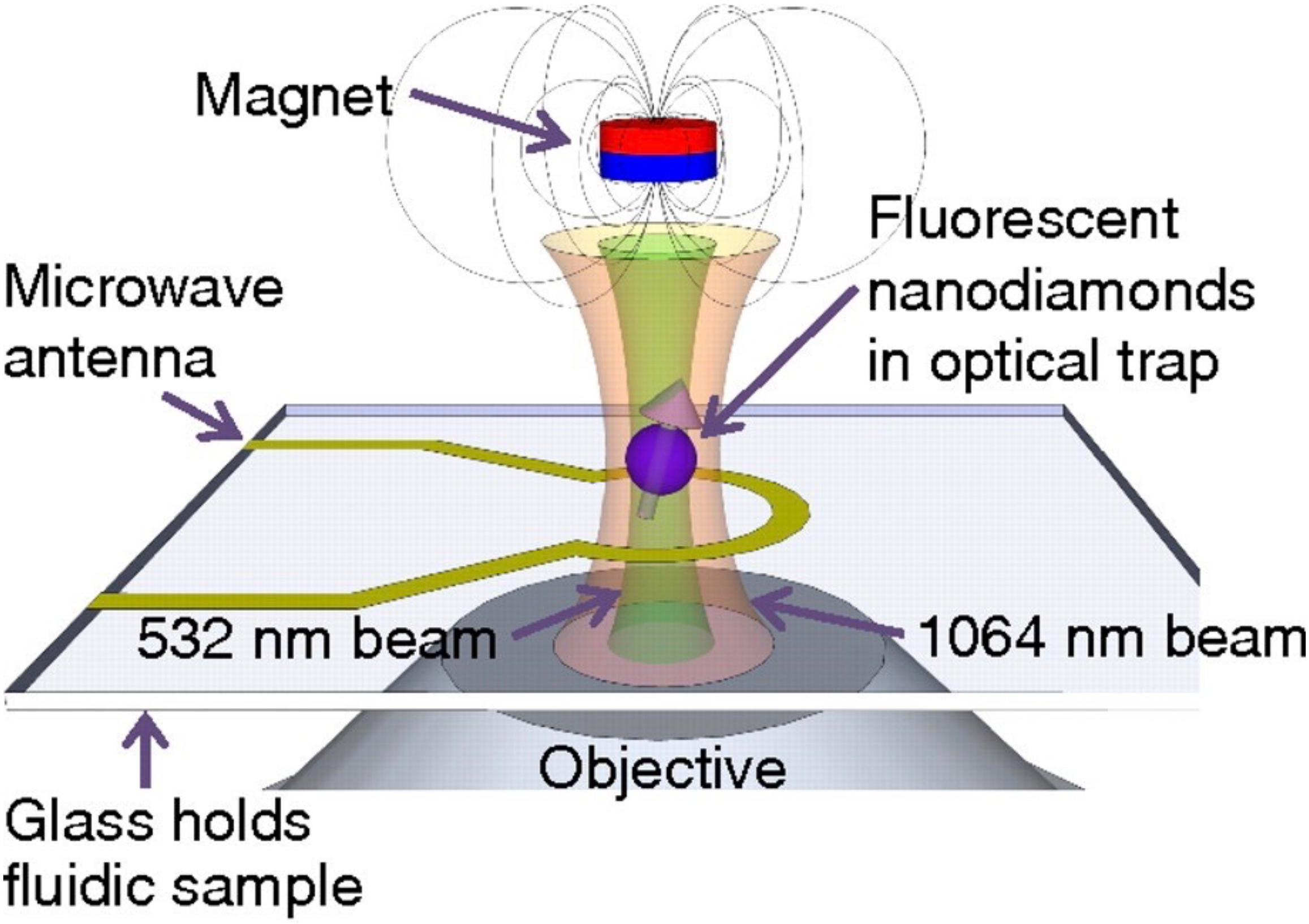
NV Centers


e
N


1.42 GHz
$|^3E,\pm1\rangle$
$|^3E,0\rangle$
$|^1A_1\rangle$
546 nm
689 nm
1024 nm
$|^1E\rangle$
$|^3A_2,\pm1\rangle$
$|^3A_2,0\rangle$
2.88 GHz

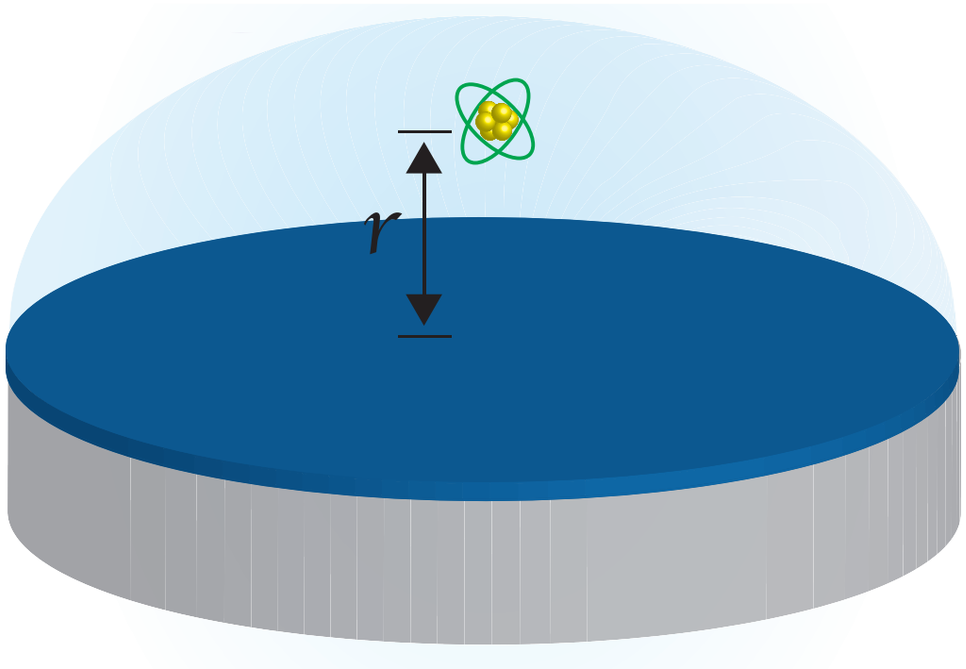

Absorption (excitation) spectrum
Photoluminescence spectrum
Signal (arb. units)
450
500
550
600
650
700
750
800
Wavelength (nm)




Magnet
Microwave antenna
Fluorescent nanodiamonds in optical trap
532 nm beam
1064 nm beam
Objective
Glass holds fluidic sample

Sampling Quantum Atmospheres

(a)



(b)

