Wave particle Duality: Some exciting experiments with ultracold matter

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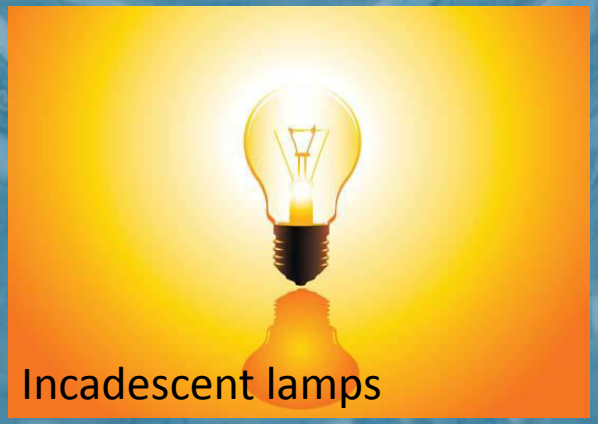
Light


Sun


Incadescent lamps


Laser

LED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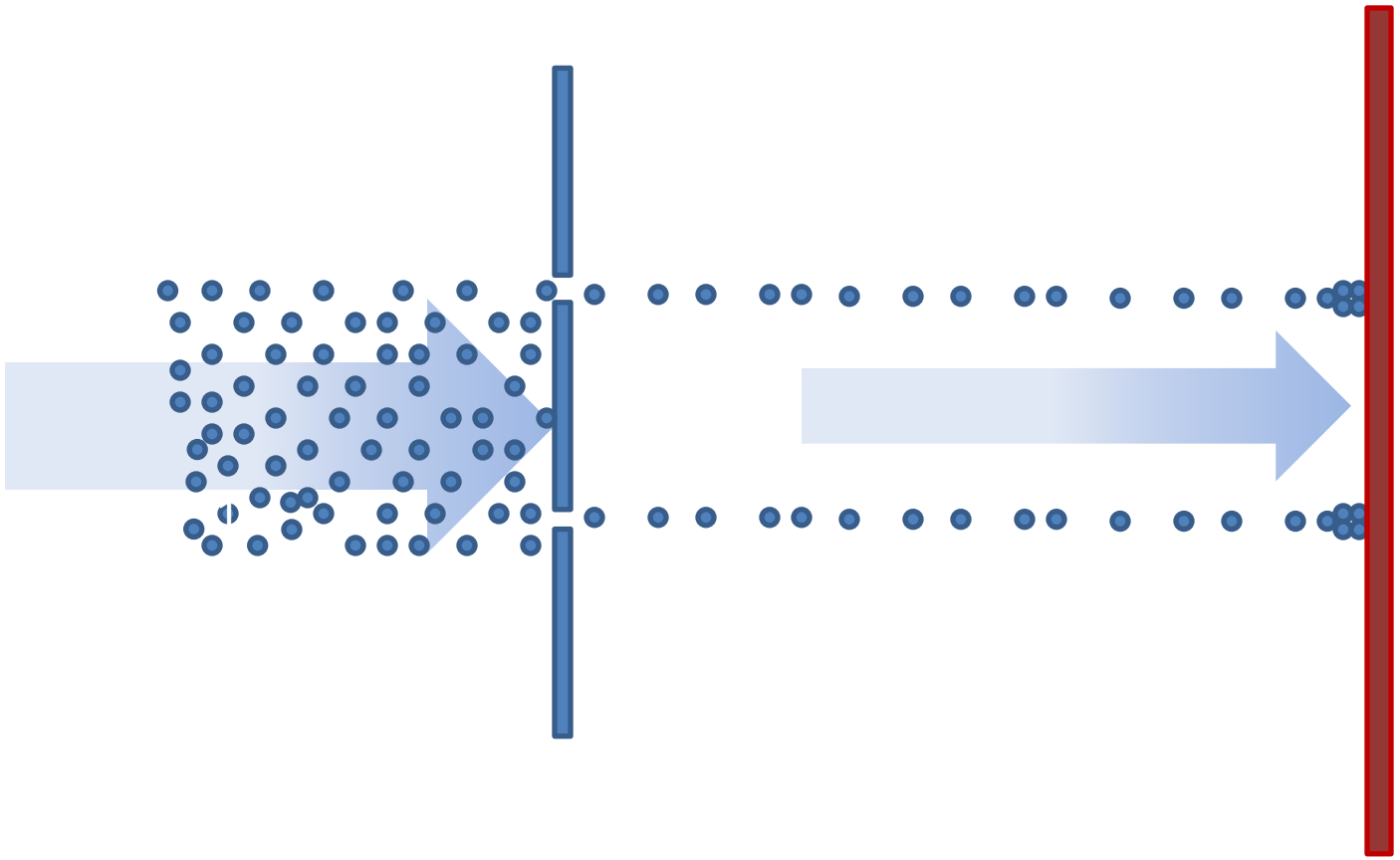
www.shutterstock.com · 547131553

What is light

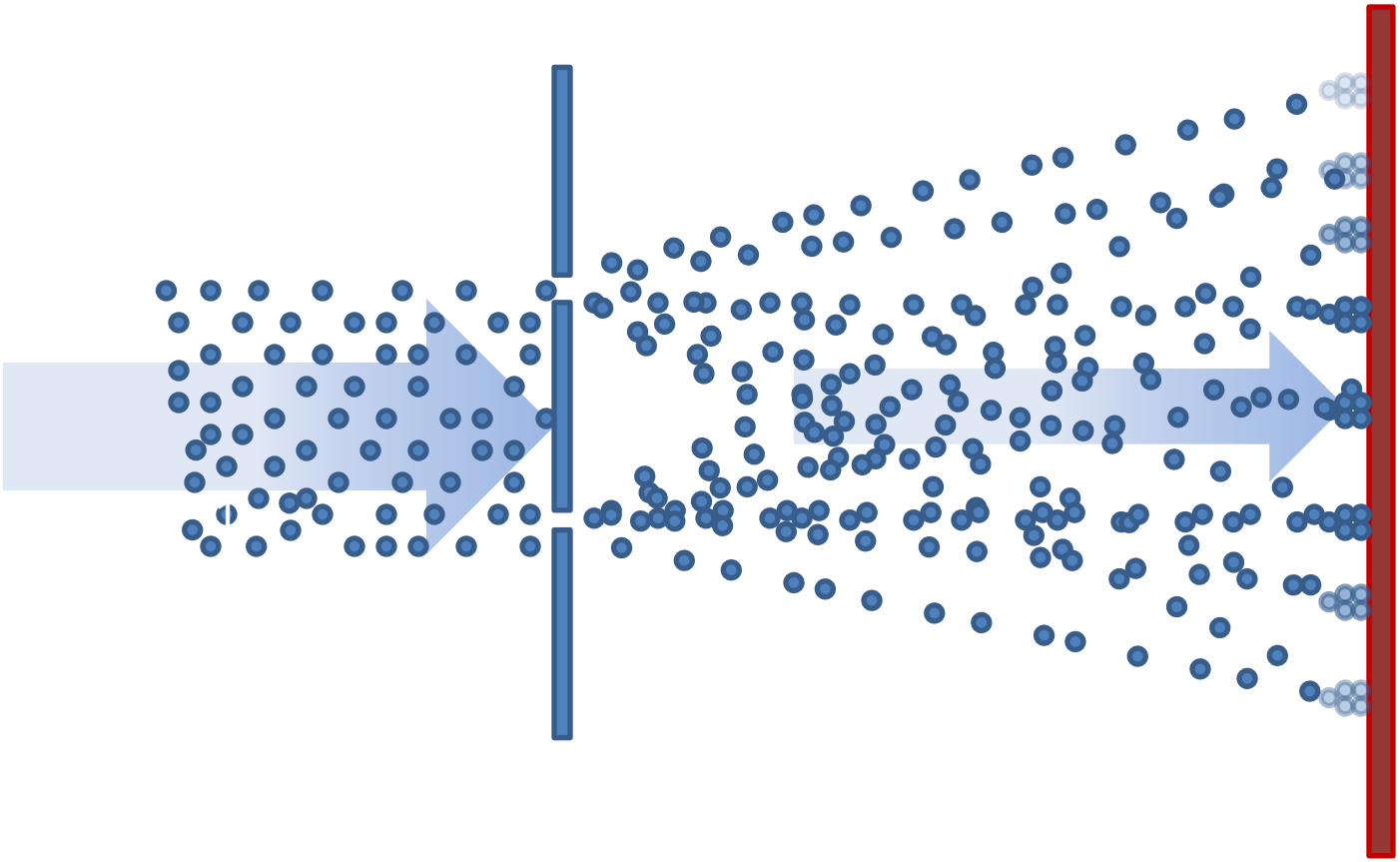
- **Rays of energy??**
- **Fluid medium?**
- **Disturbance in space?**
- **Waves?**
- **Particles?**
-
-

Young's Double slit experiment: Particles



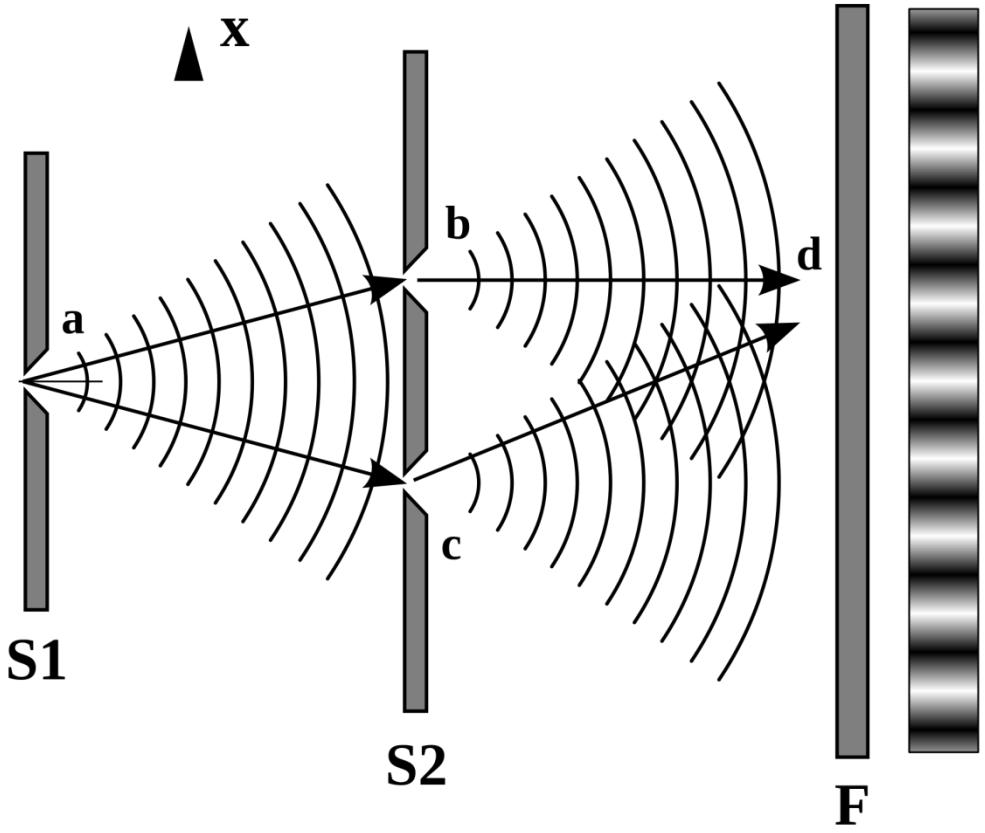
What you expect naively….

Young's Double slit experiment: Particles

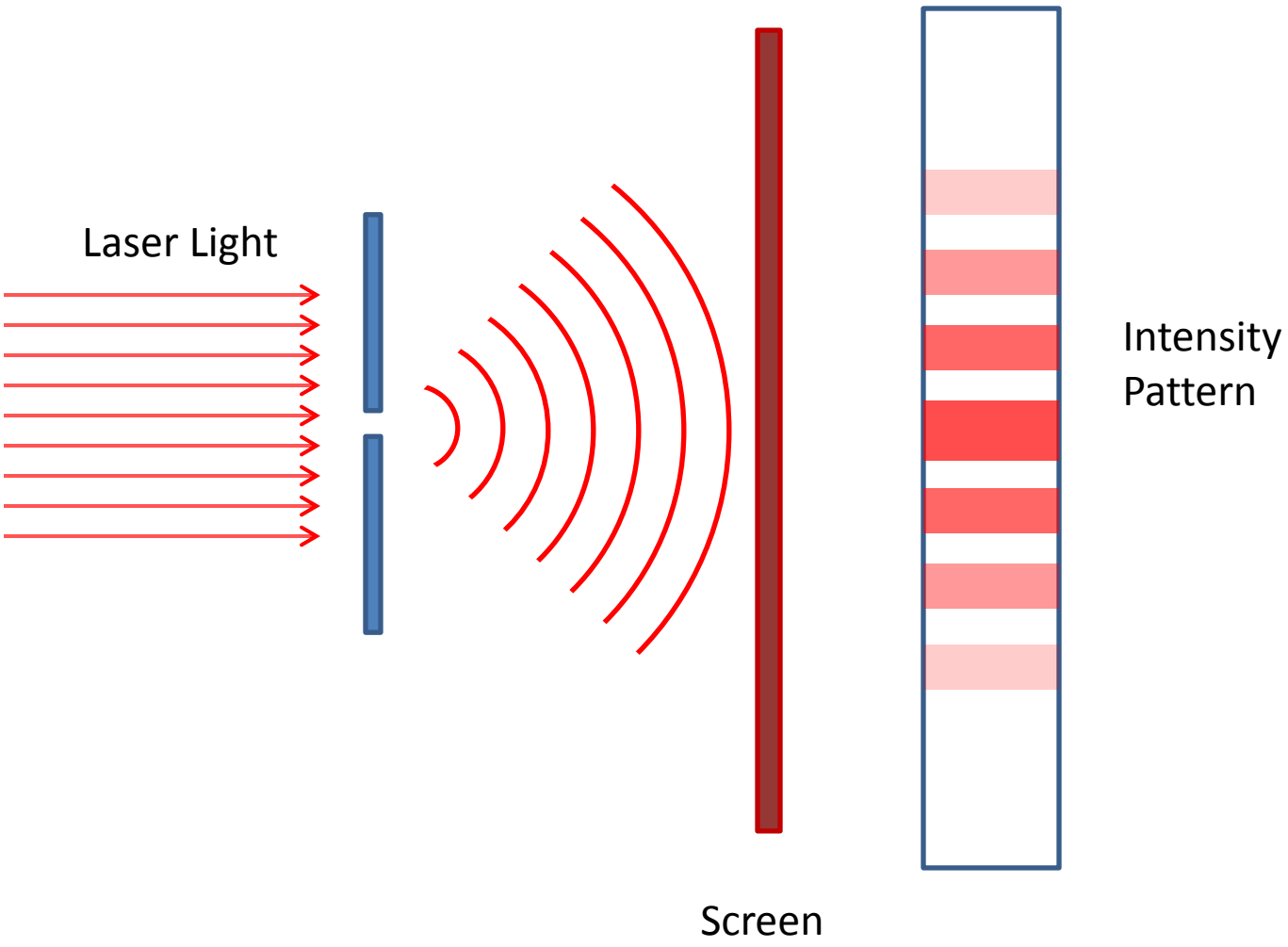


What you actually see…

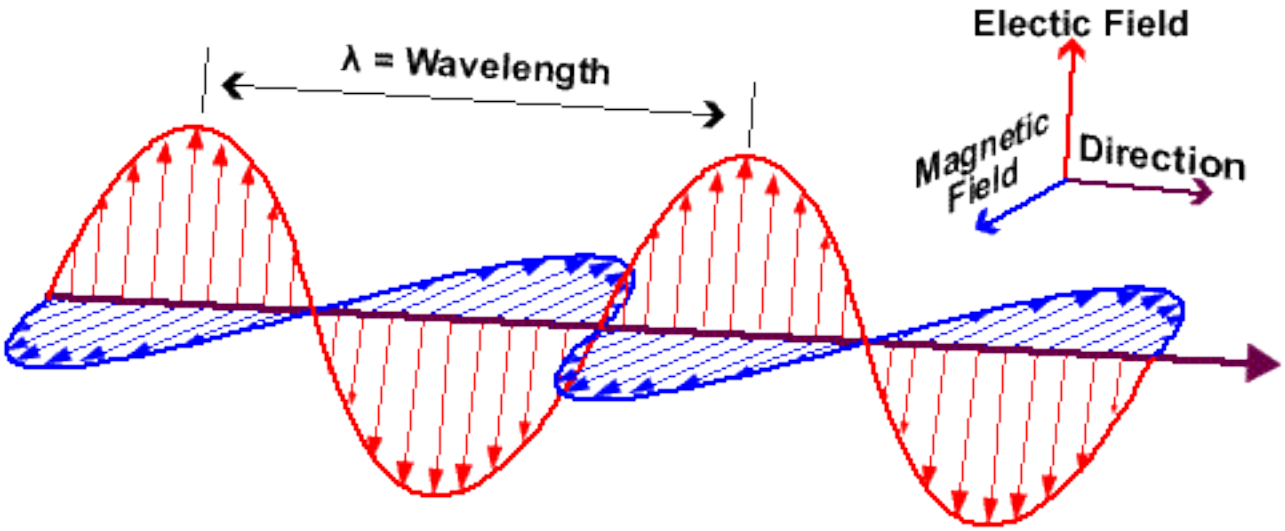
Young's Double slit experiment: Particles



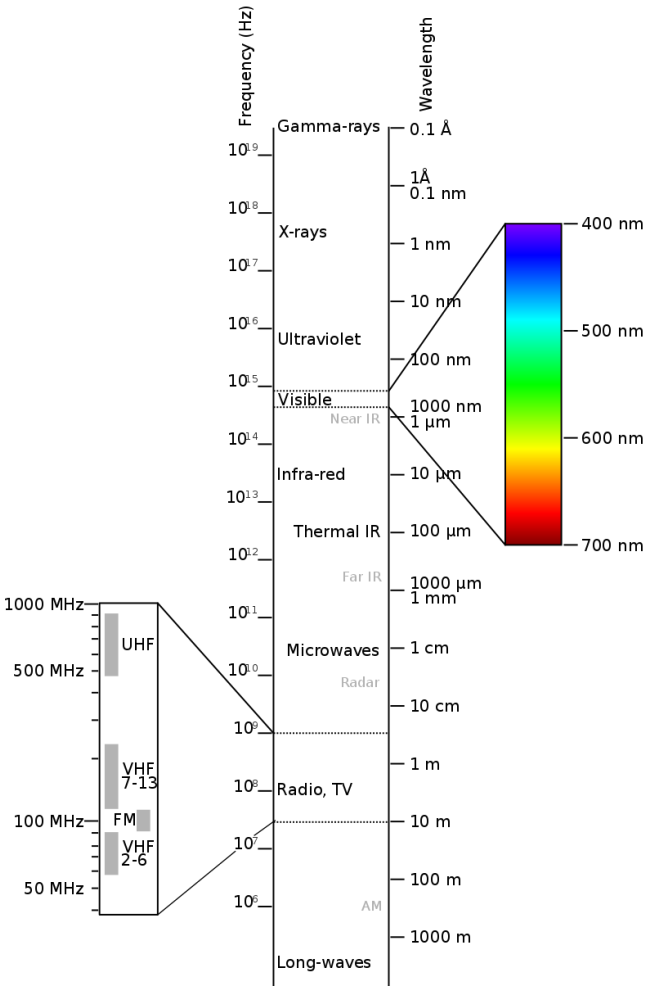
Single slit Diffraction

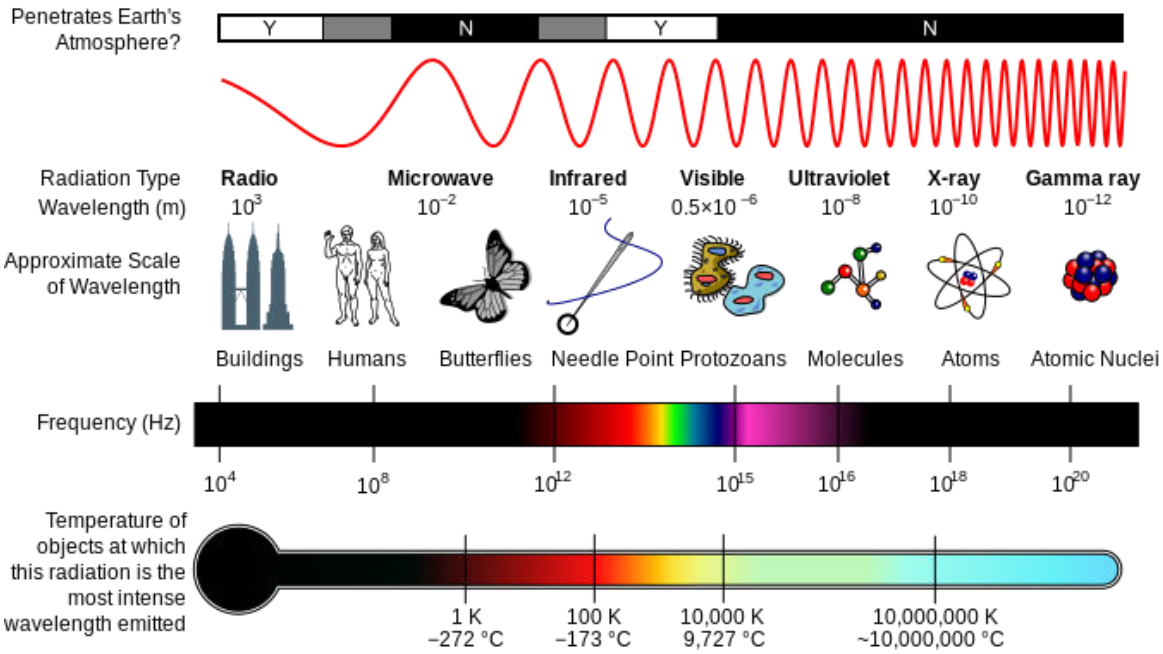


Light: oscillating Electromagnetic field

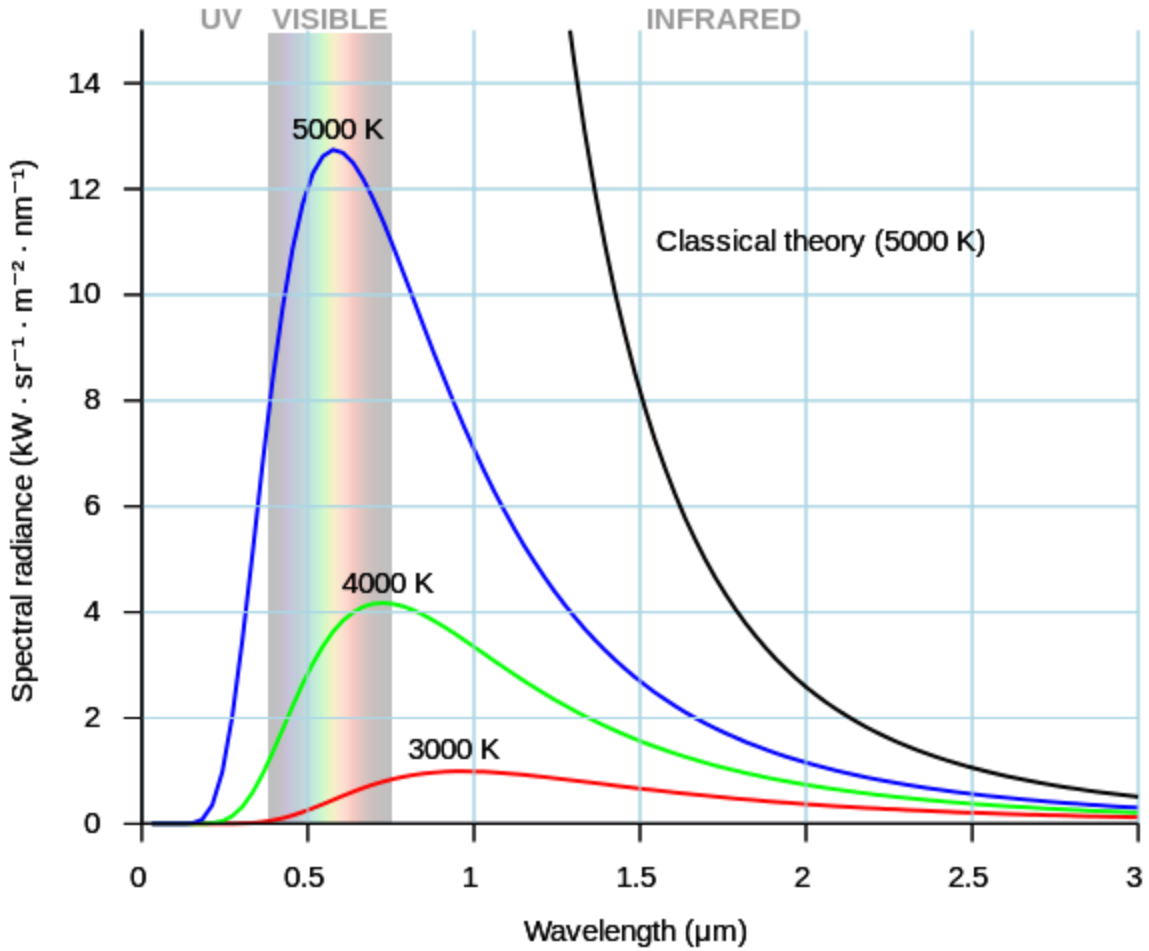


Electromagnetic Spectrum



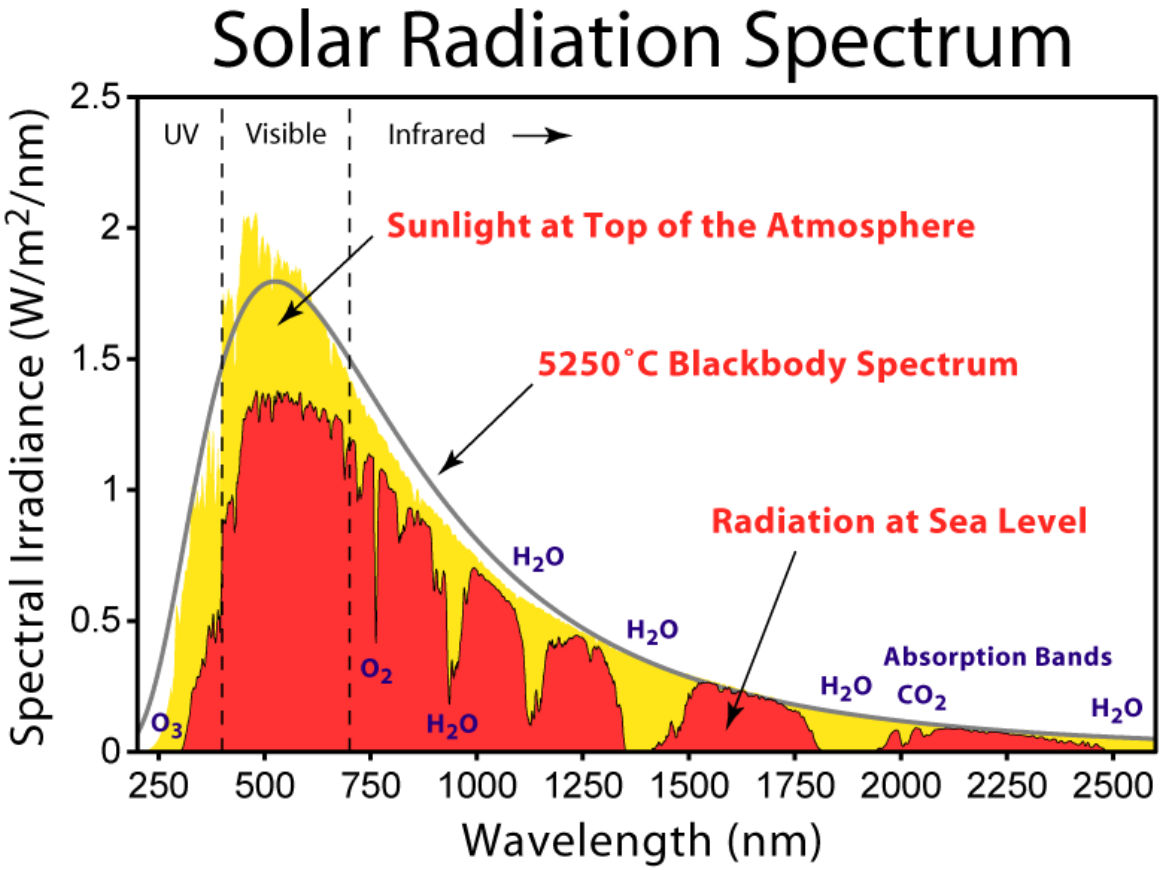


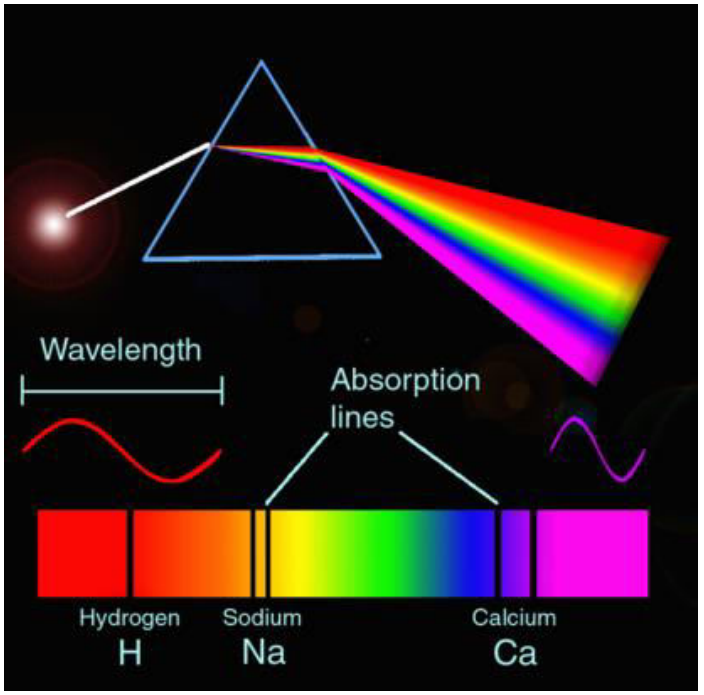
Black body radiation and Plancks law



Source: Wikipedia

Sun as a blackbody





https://physics.stackexchange.com

Light packets

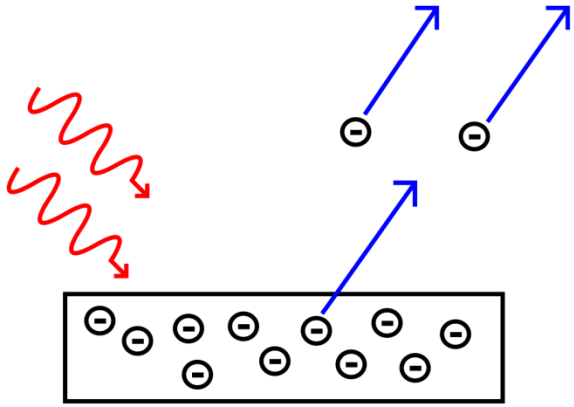
Max Planck

The Nobel Prize in Physics 1918:

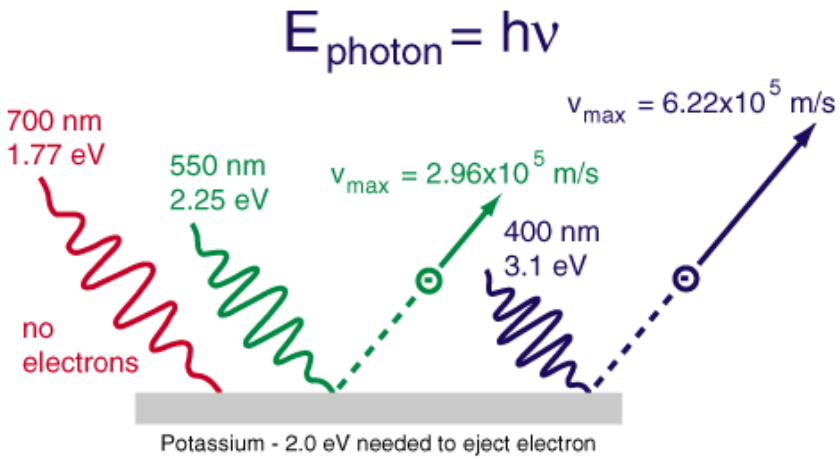
"in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta".

https://www.nobelprize.org

Photoelectric effect



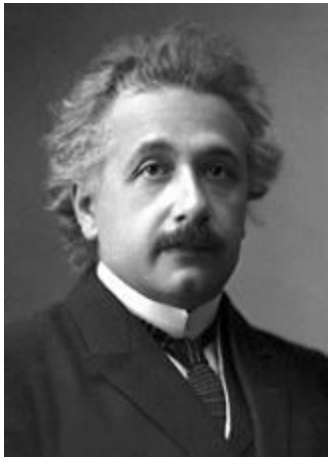
wikipedia



https://physics.stackexchange.com

Maximum Kinetic Energy = Energy of photon – Binding energy of electron in the metal

Photoelectric effect



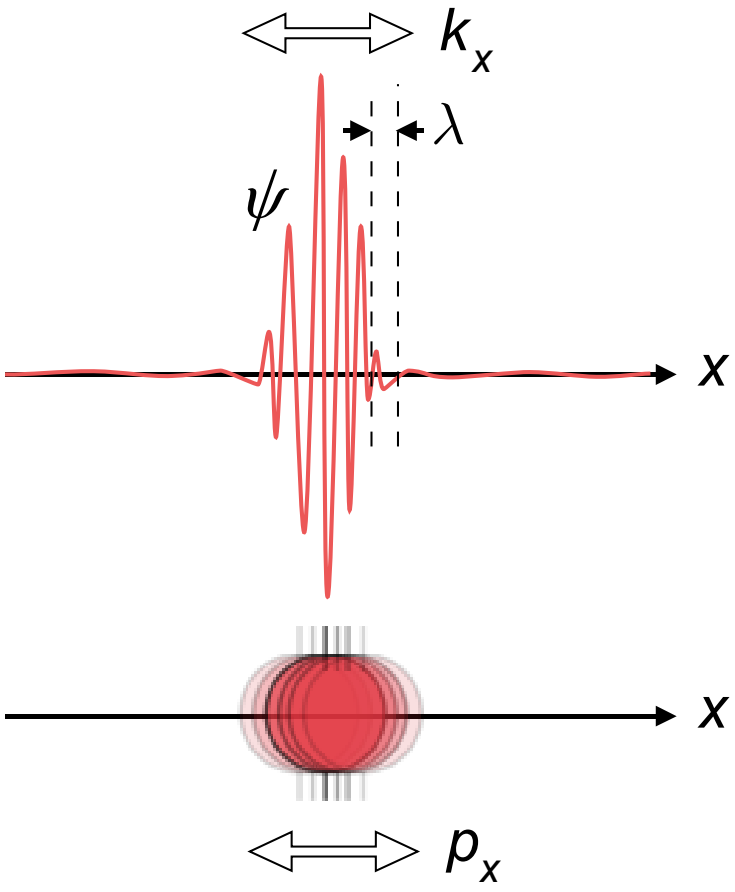
Albert Einstein

The Nobel Prize in Physics 1921:

"for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect".

https://www.nobelprize.org

Particles as waves: deBroglie hypothesis



de Broglie wavelength

$$\lambda = \frac{h}{p}$$

Planck's Constant

Momentum of the particle

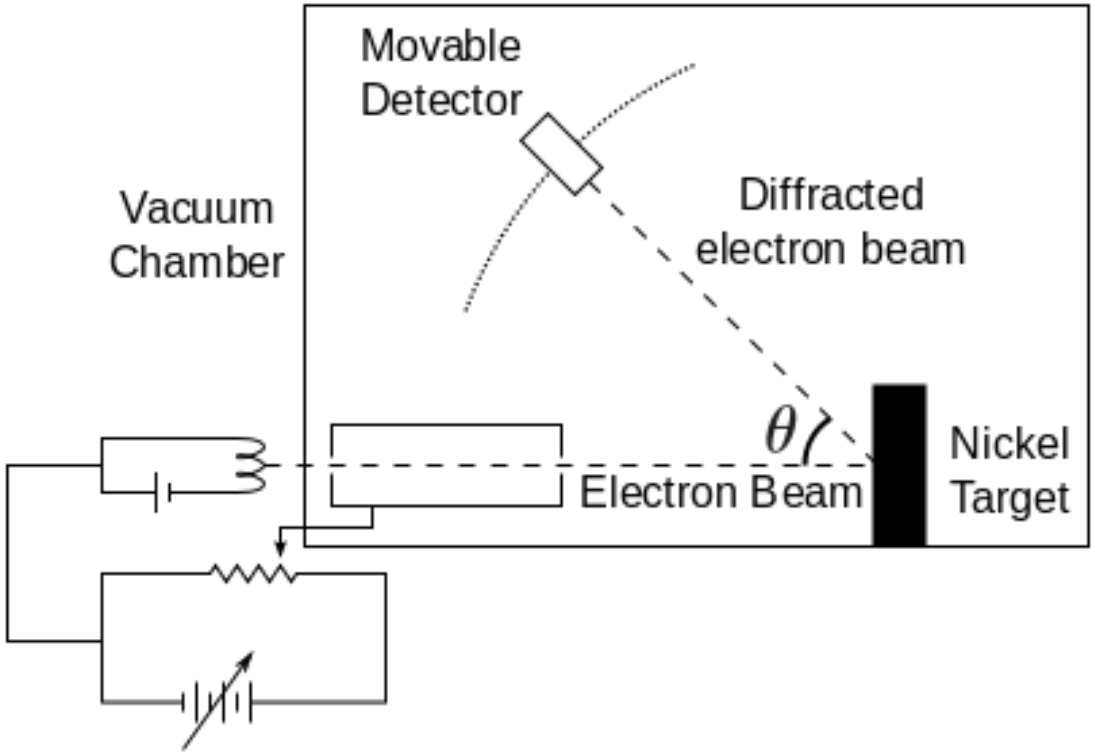
wavelength

Humans: 3.4 x 10^{-36} meters for 70 Kg person at 10 Km/hr speed

Electrons: 262 Micro meters !!!!

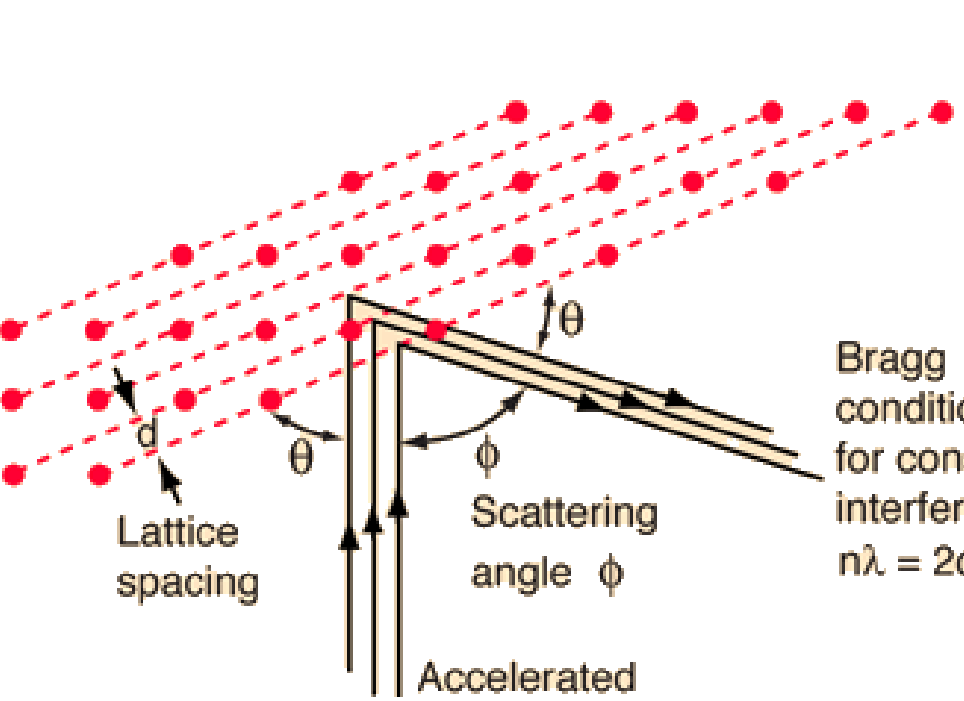
Electron Diffraction

The Davisson-Germer Experiment:

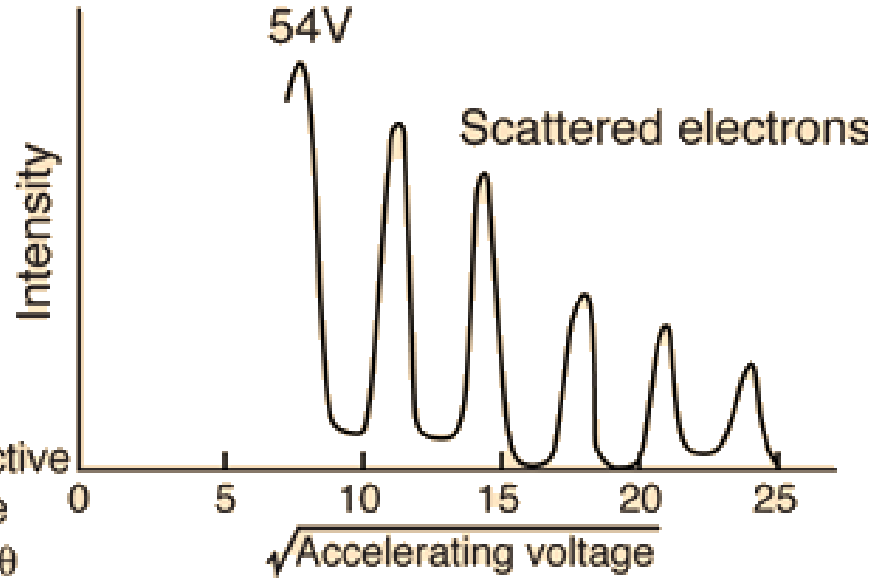


Electron Diffraction

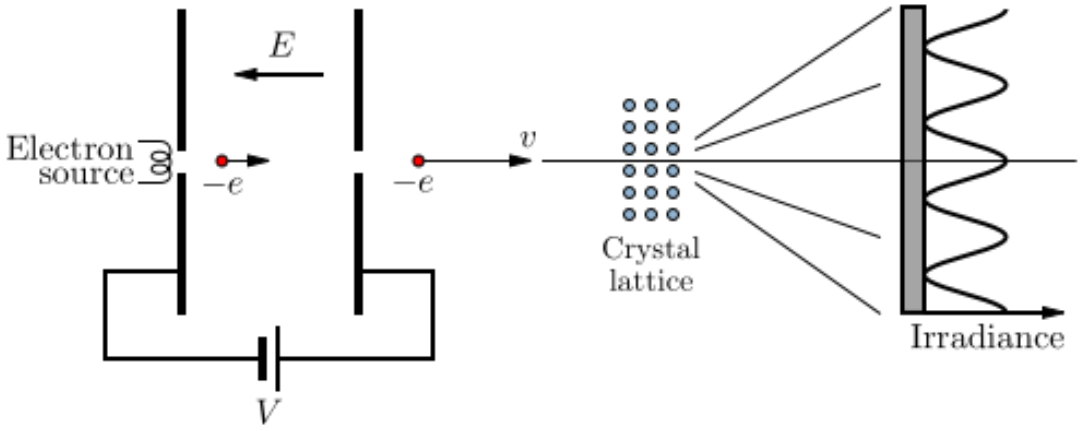
The Davisson-Germer Experiment:

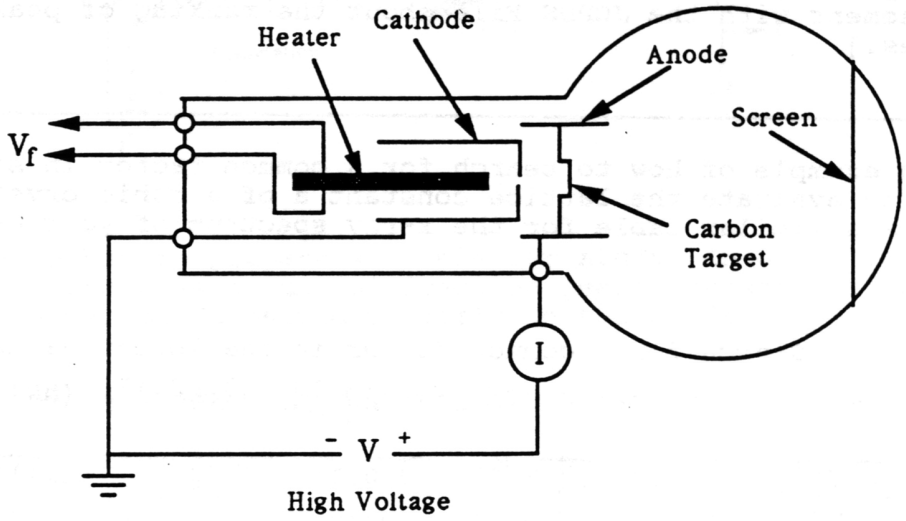


Bragg condition for constructive interference $n\lambda = 2d\sin\theta$



Electron Diffraction





de Broglie Hypothesis

Prince Louis-Victor Pierre Raymond de Broglie

The Nobel Prize in Physics 1929:

"for his discovery of the wave nature of electrons".

https://www.nobelprize.org

Wave nature of electrons

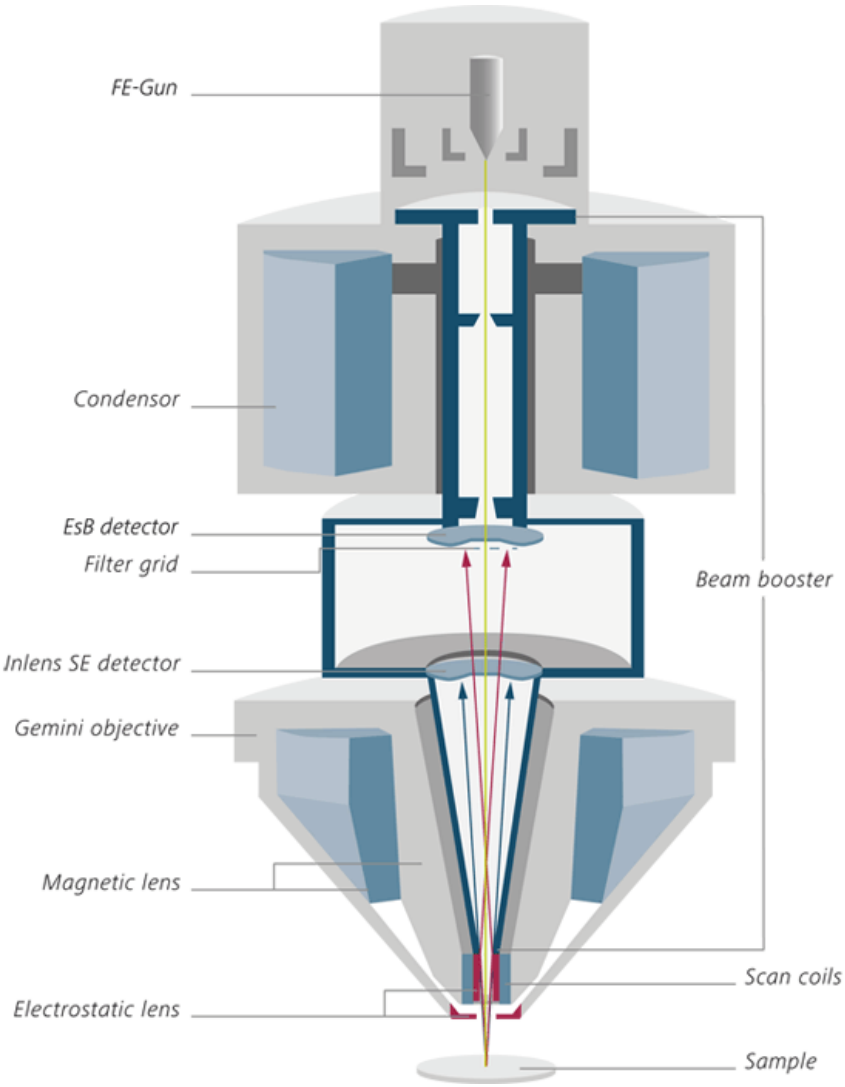
Clinton Joseph Davisson

George Paget Thomson

The Nobel Prize in Physics 1937: "for their experimental discovery of the diffraction of electrons by crystals"

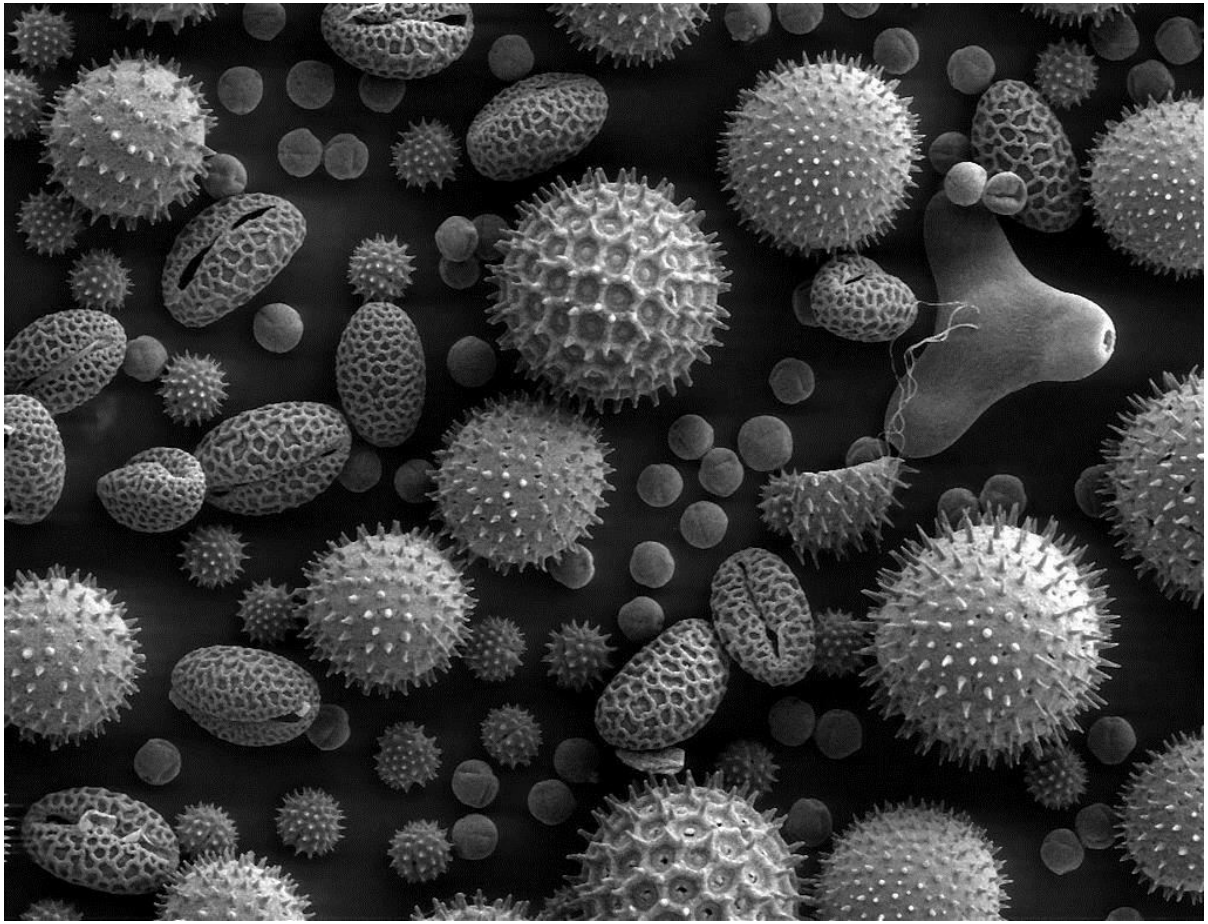
https://www.nobelprize.org

Electron beams for imaging: SEM



Electron beams for imaging: SEM

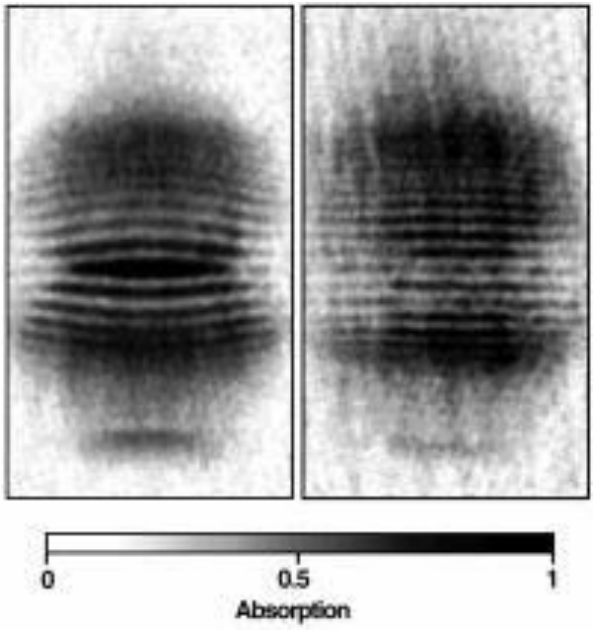
Electron beams for imaging: SEM



Pollen from a variety of common plants: sunflower (*Helianthus annuus*), morning glory *Ipomoea purpurea*, hollyhock (*Sildalcea malviflora*), lily (*Lilium auratum*), primrose (*Oenothera fruticosa*) and castor bean (*Ricinus communis*). The image is magnified some x500, so the bean shaped grain in the bottom left corner is about 50 µm long. :Source: Wikipedia

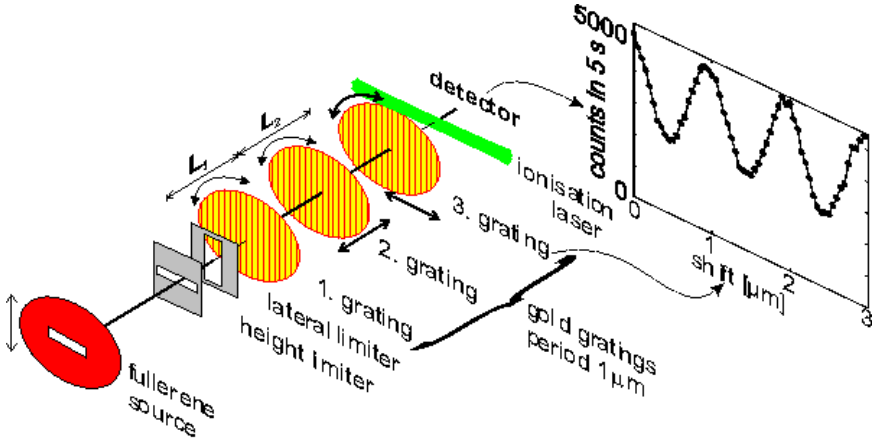
Wave nature of Atoms and Molecules

Interference of two BECs



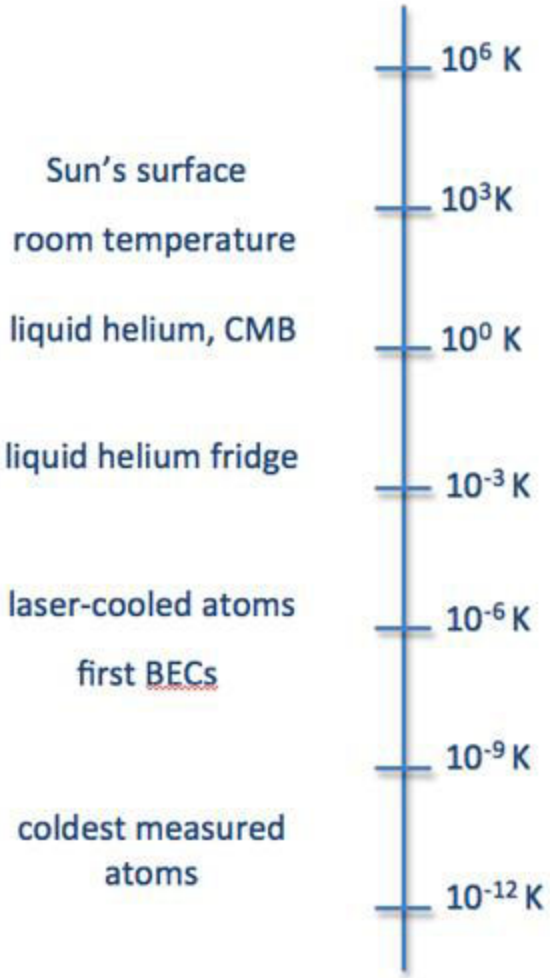
W. Ketterle: RLE Lab, MIT

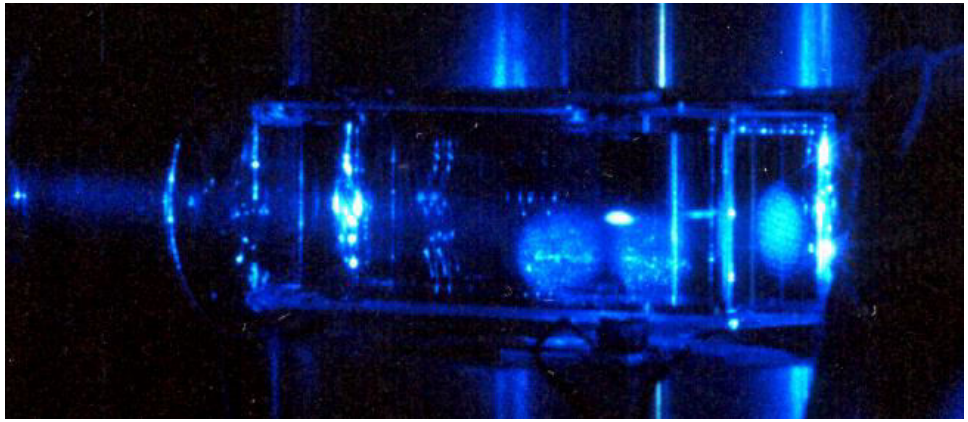
Diffraction of Fullerene molecules



https://www.univie.ac.at/qfp/research/matterwave/talbotlau/index.html

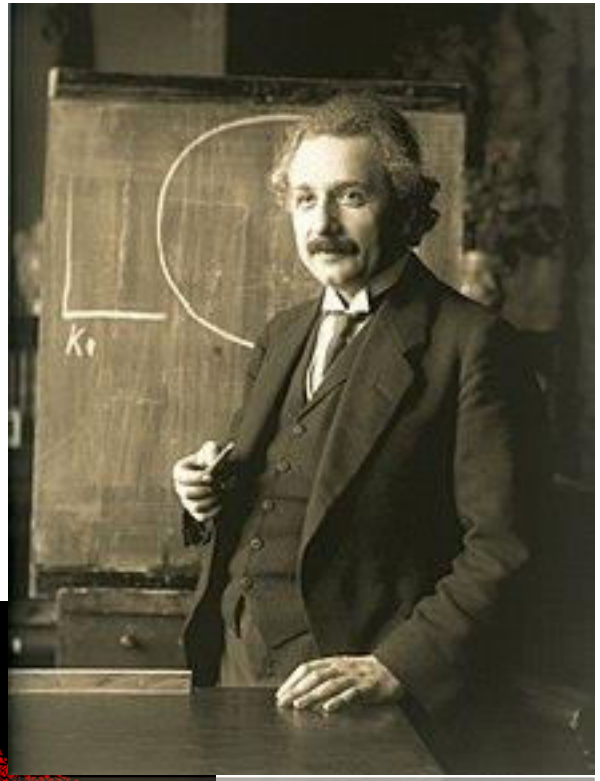
Ultracold atoms

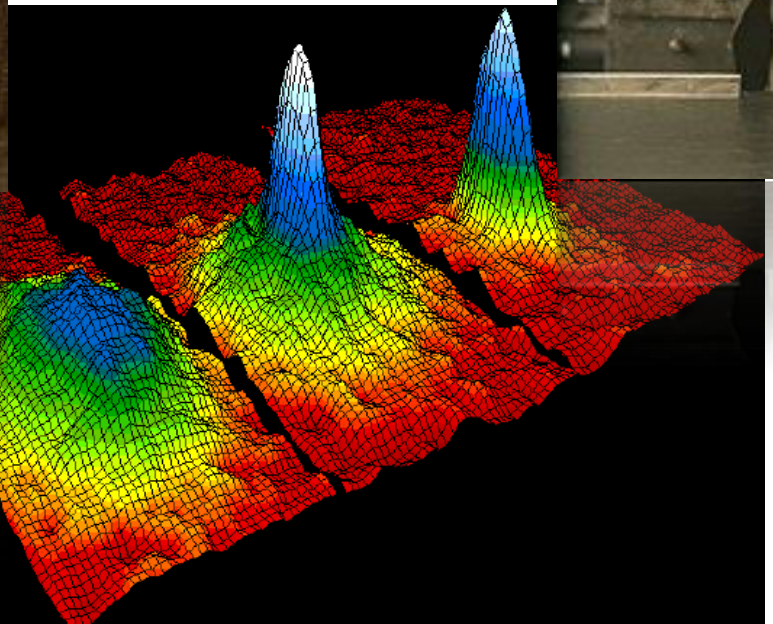




Cold Ytterbium atoms

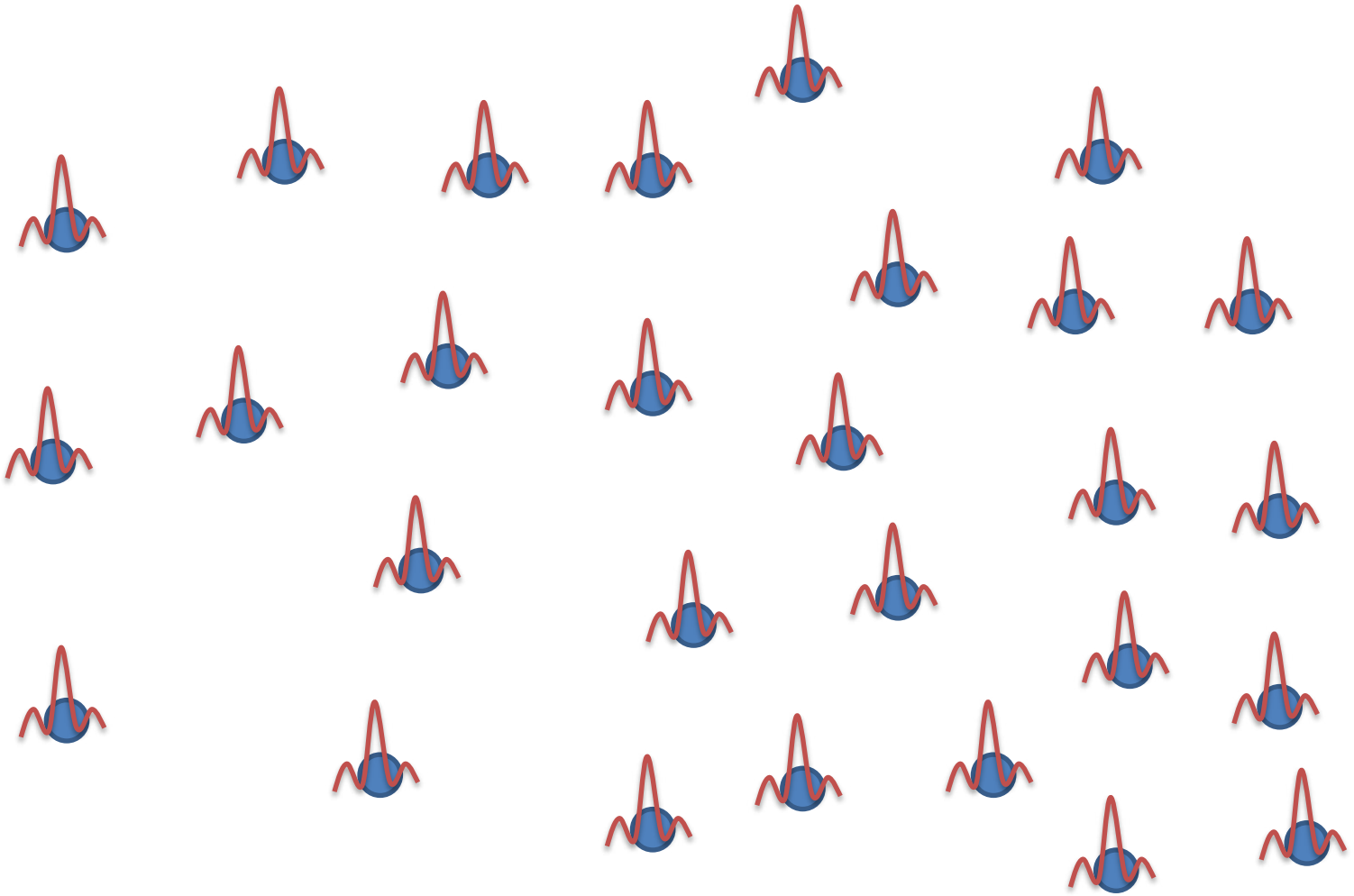
Bose-Einstein Condensation





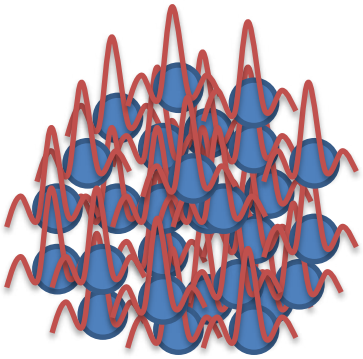
Source: Wikipedia

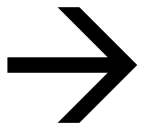
Bose-Einstein Condensation (BEC)

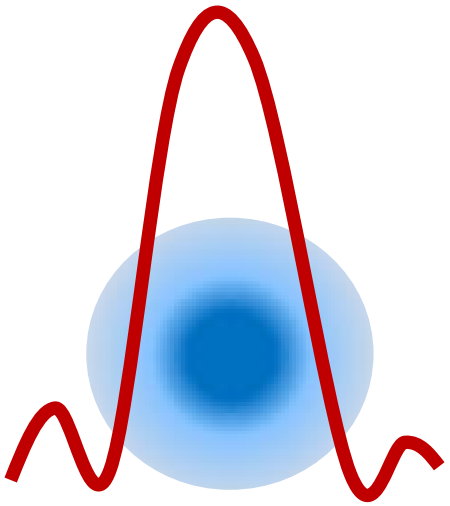


At room temperatures the de-Broglie waves do not overlap.

BEC





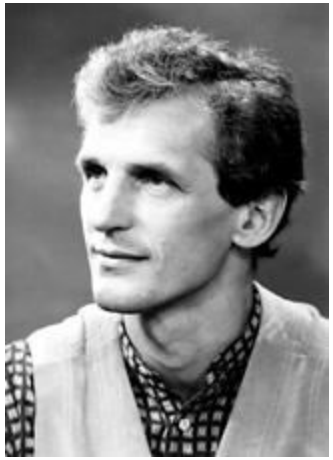


Phase space density ~ 1

Precisely : n λ^3 = 2.612

BEC: Nobel prize 2001

Eric A. Cornell

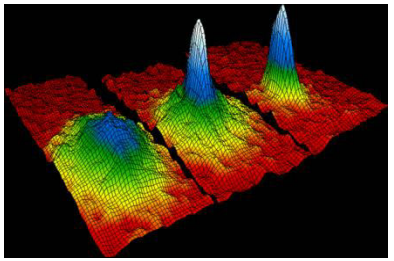


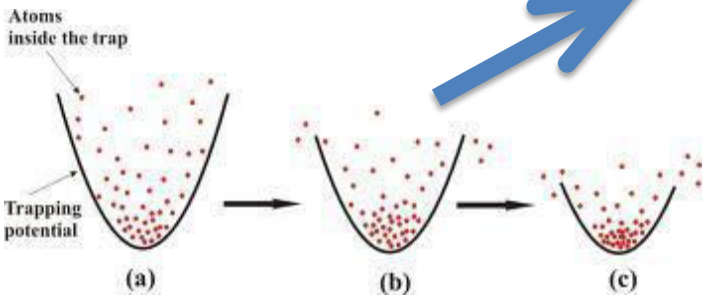
Wolfgang Ketterle

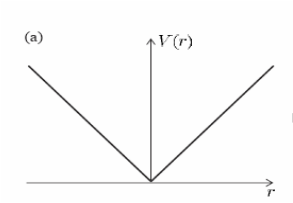
Carl E. Wieman

The Nobel Prize in Physics 2001: "for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates".

Path towards BEC







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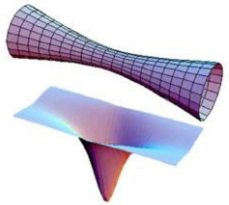

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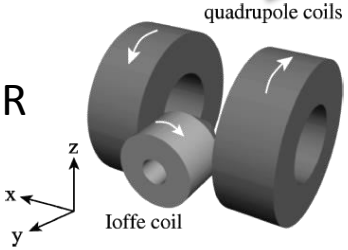

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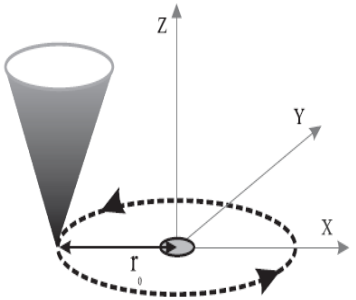
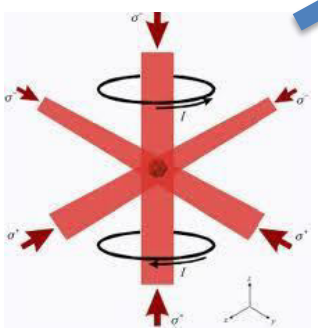
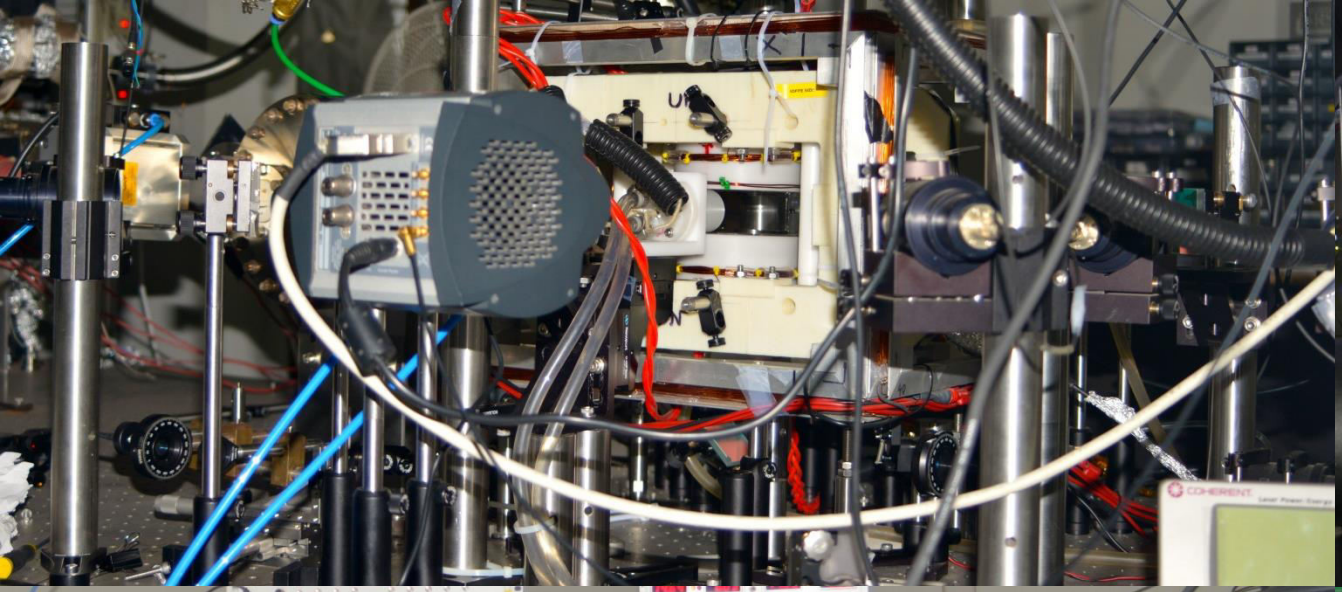
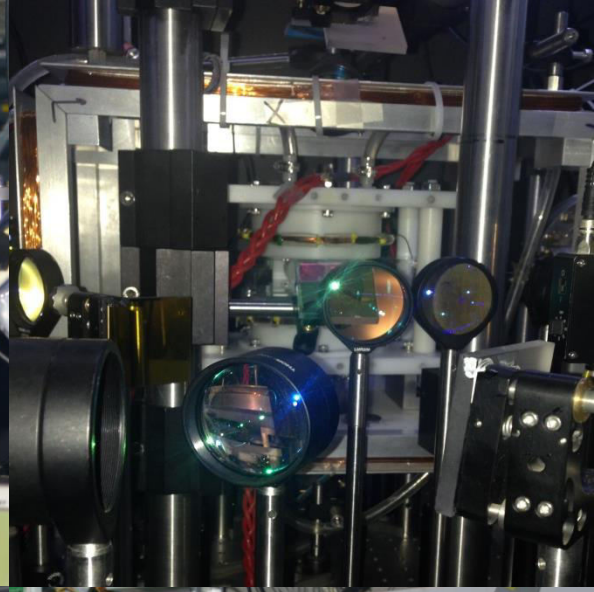
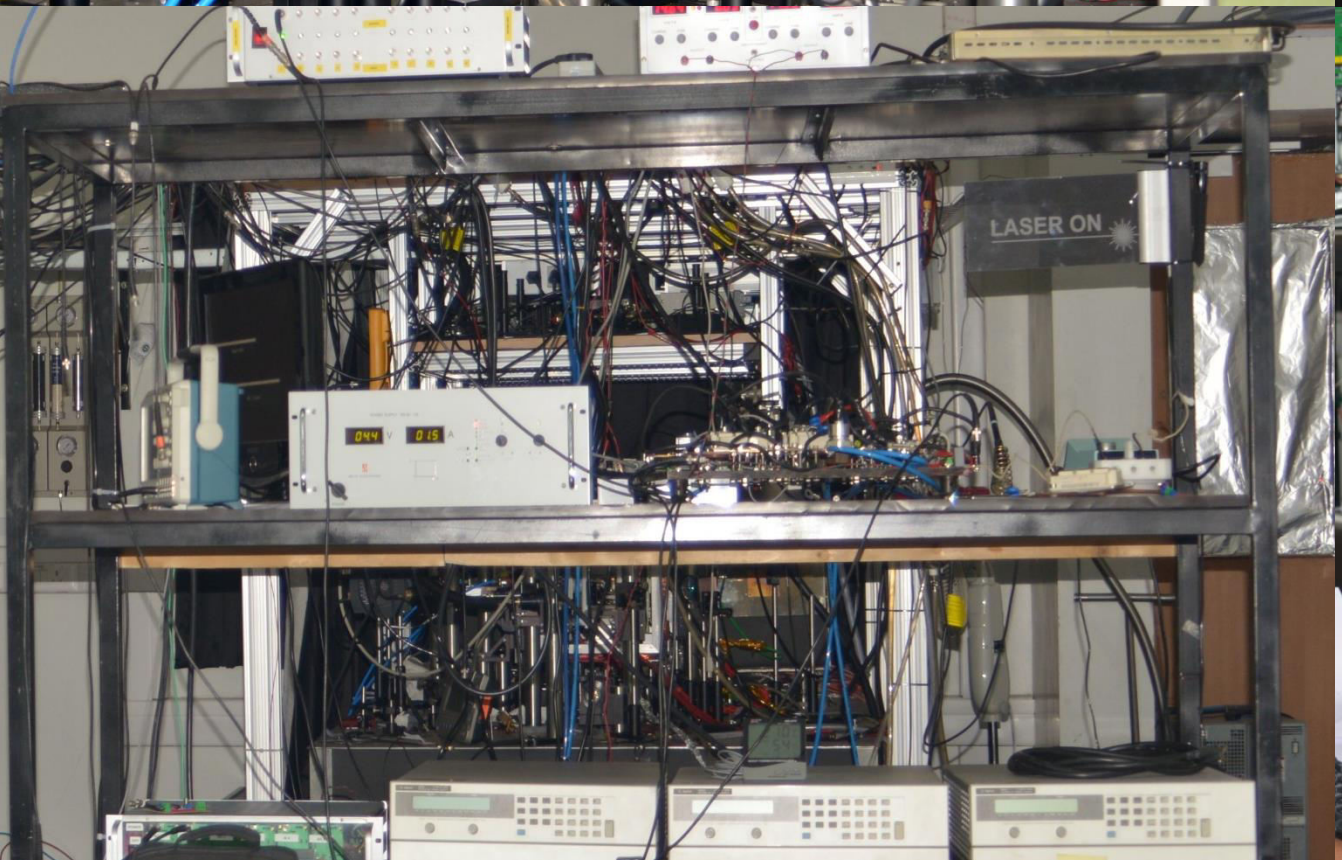


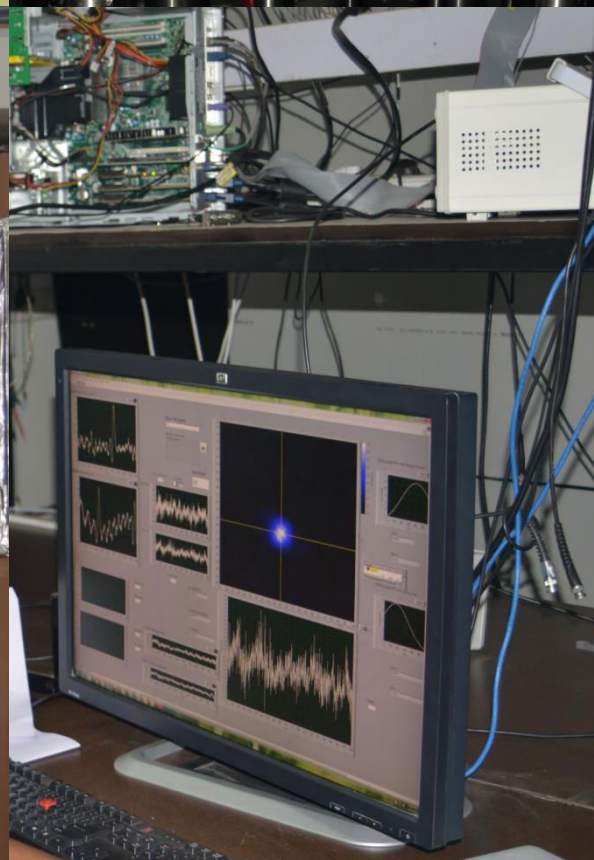


+ Molasses






LASER ON



BEC in a magnetic Trap @IISER-P

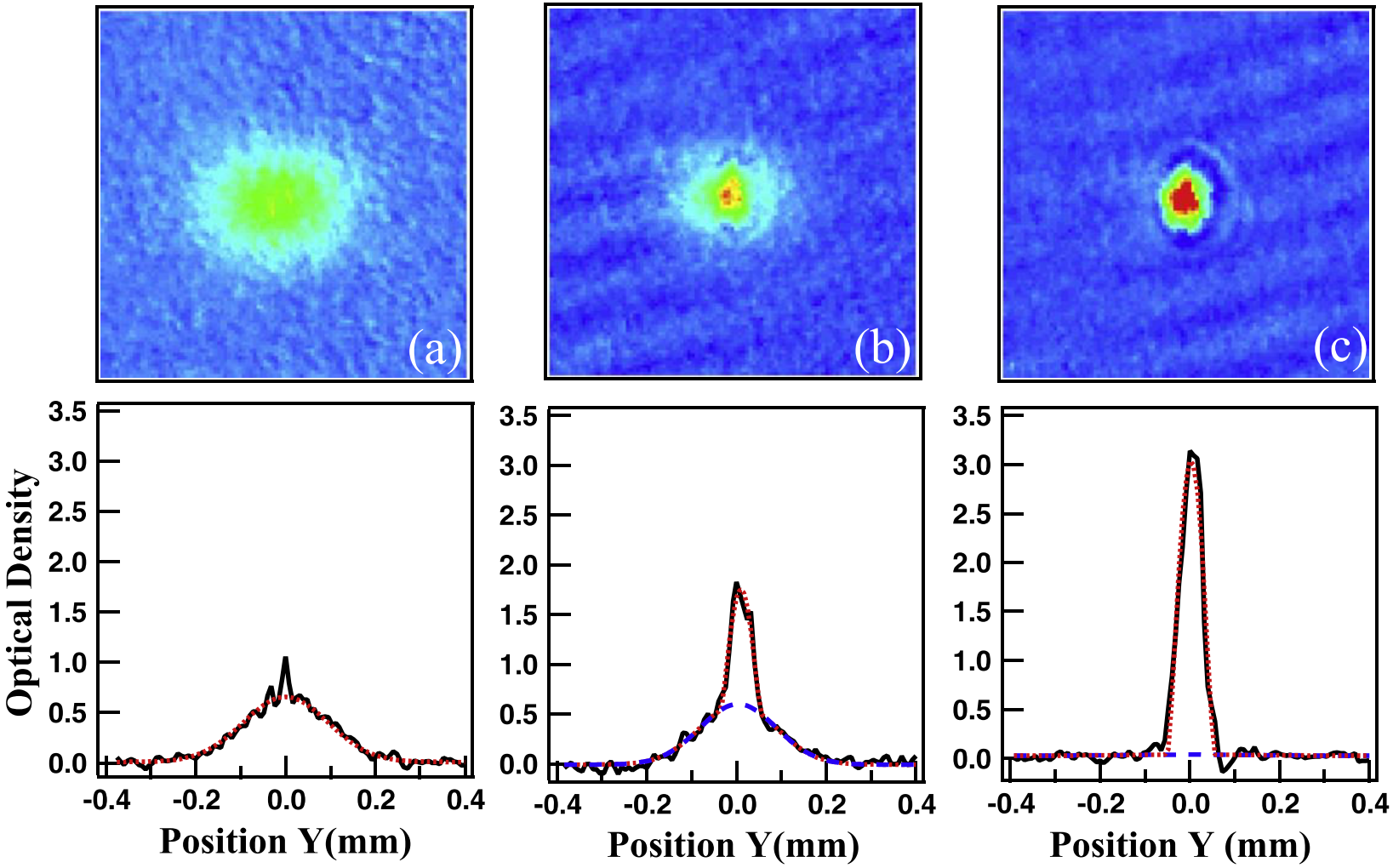
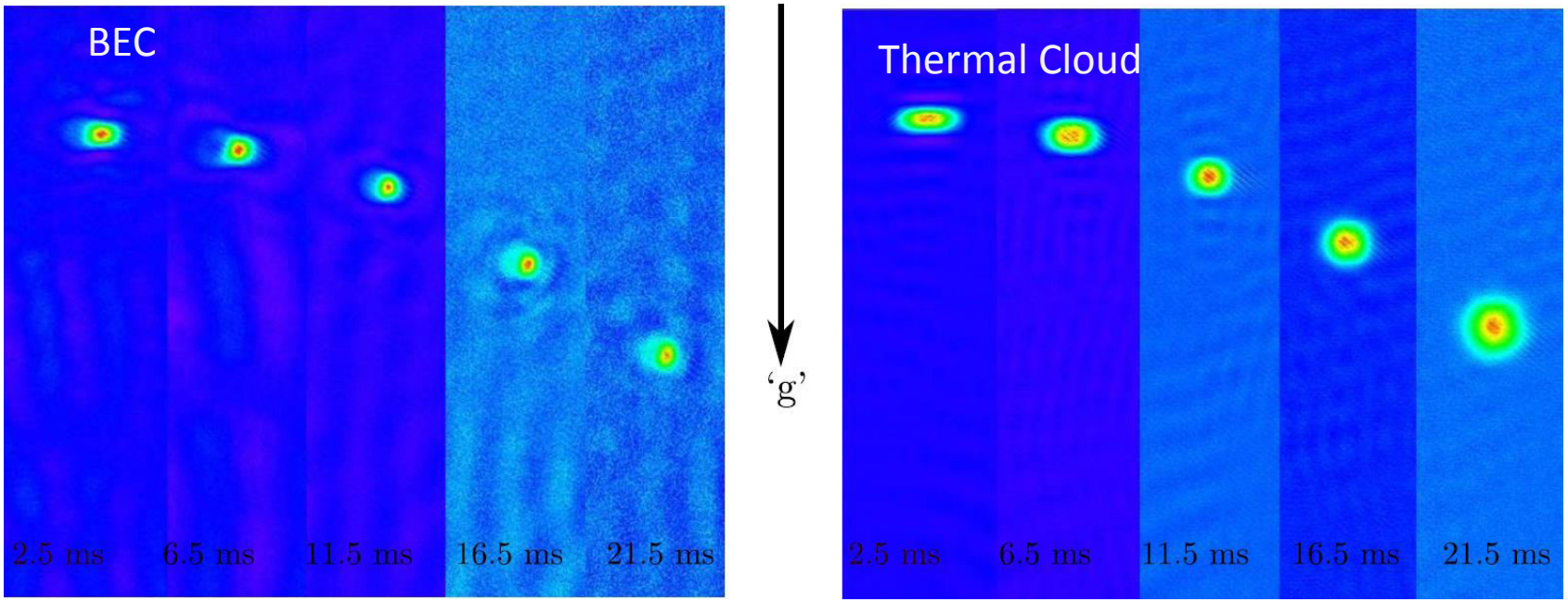
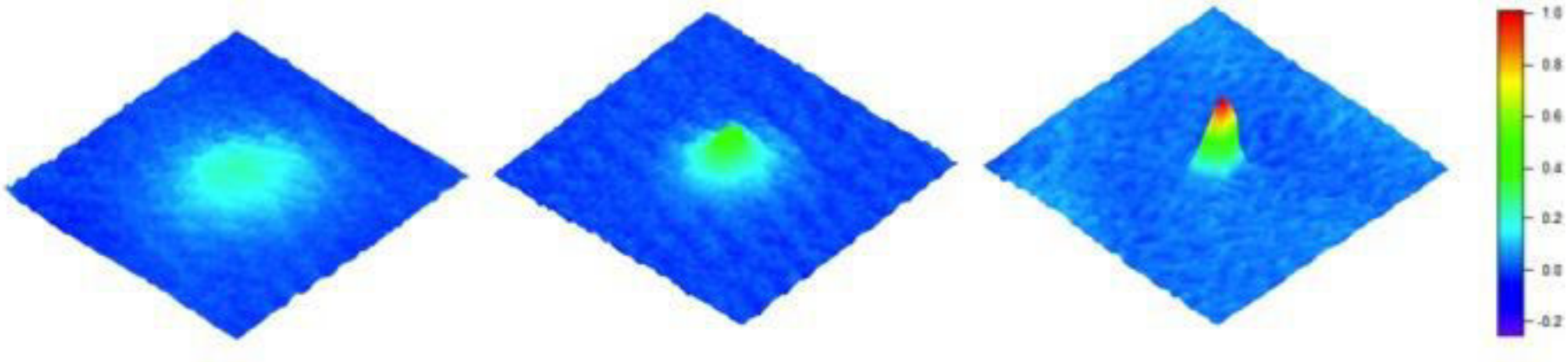


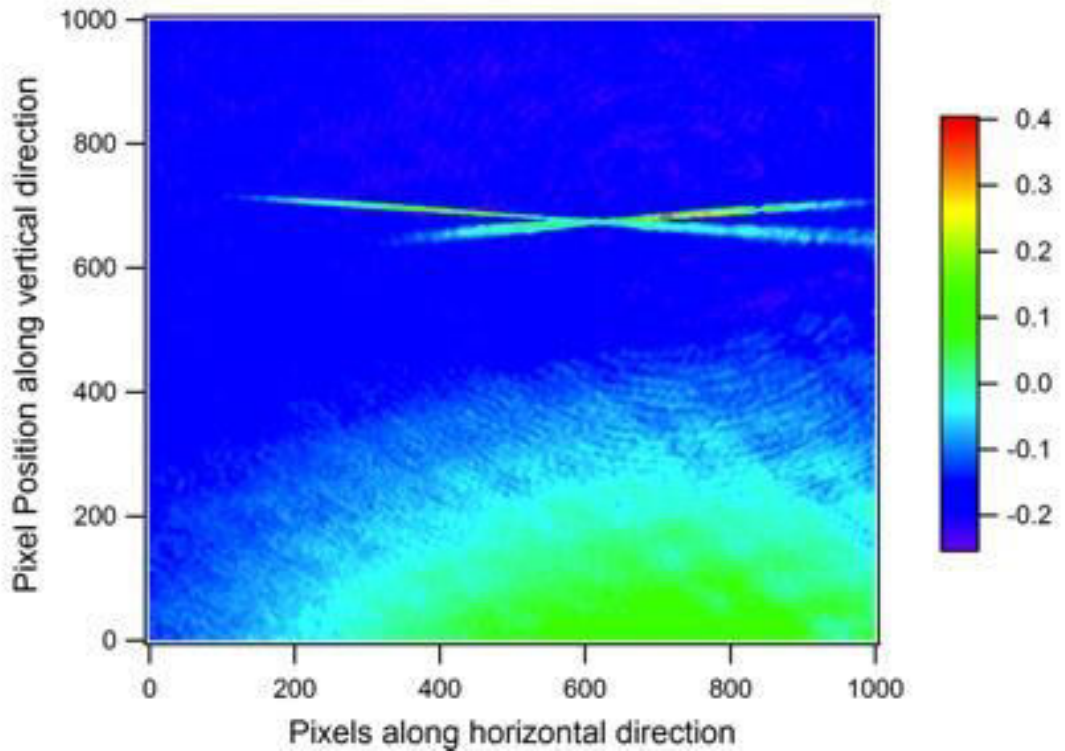
Figure 5. Typical images of the ultracold cloud of atoms taken after 21 ms of expansion under gravity. (a) Thermal cloud at a temperature about of 211 nK (final rf frequency 1.94 MHz), (b) bimodal density distribution at temperature 171 nK (final rf frequency 1.93 MHz) showing the emergence of a sharp peak at the center with a condensate fraction of 23 %. (c) Almost pure condensate at final rf frequency 1.919 MHz; the condensate fraction is 97 %. The lower set of curves is the horizontal cross-section plots of the images above. The field of view of the images is 0.8 mm × 0.8 mm.

TOF Images: Thermal cloud vs BEC

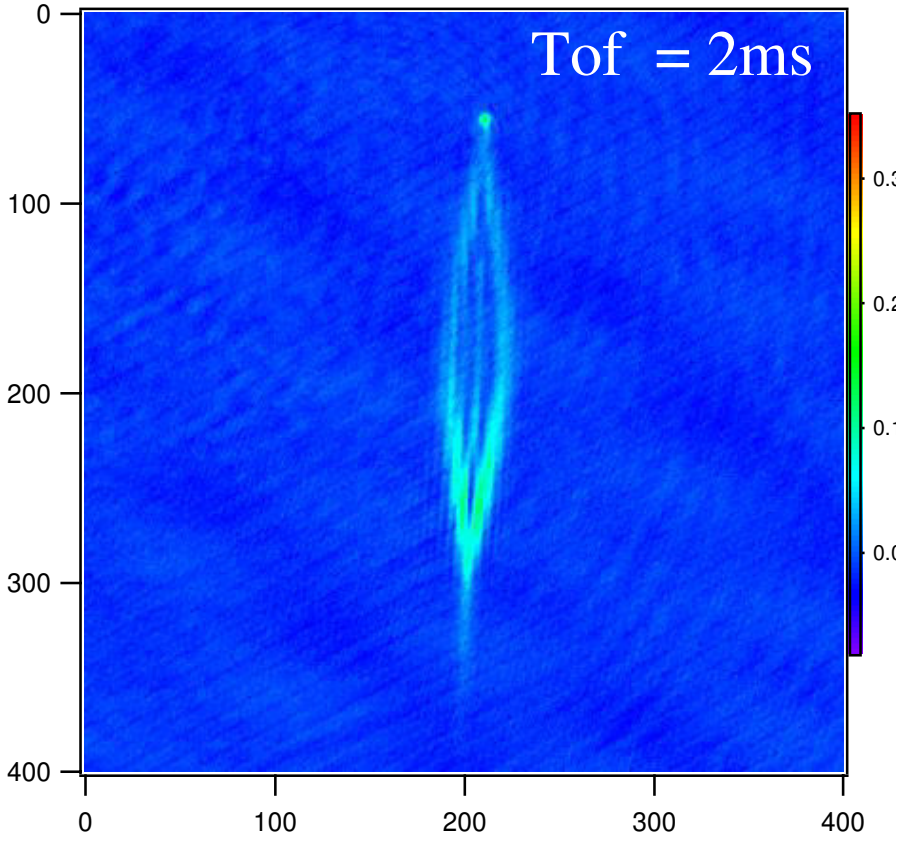


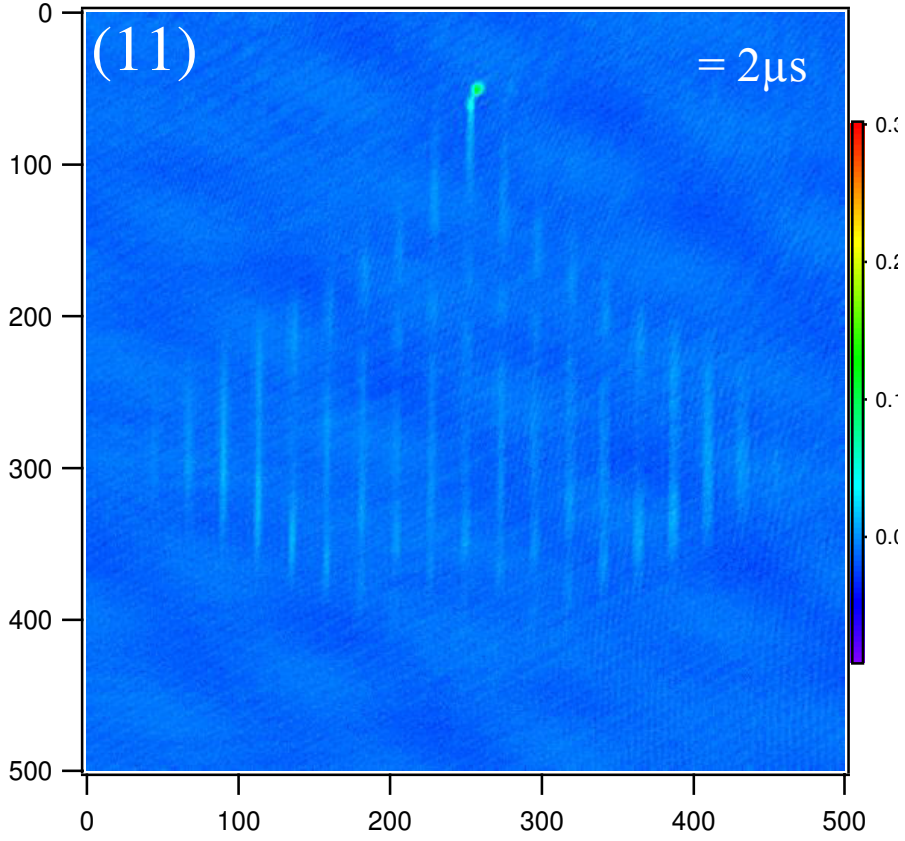
Atom-Laser: BEC from a dipole trap



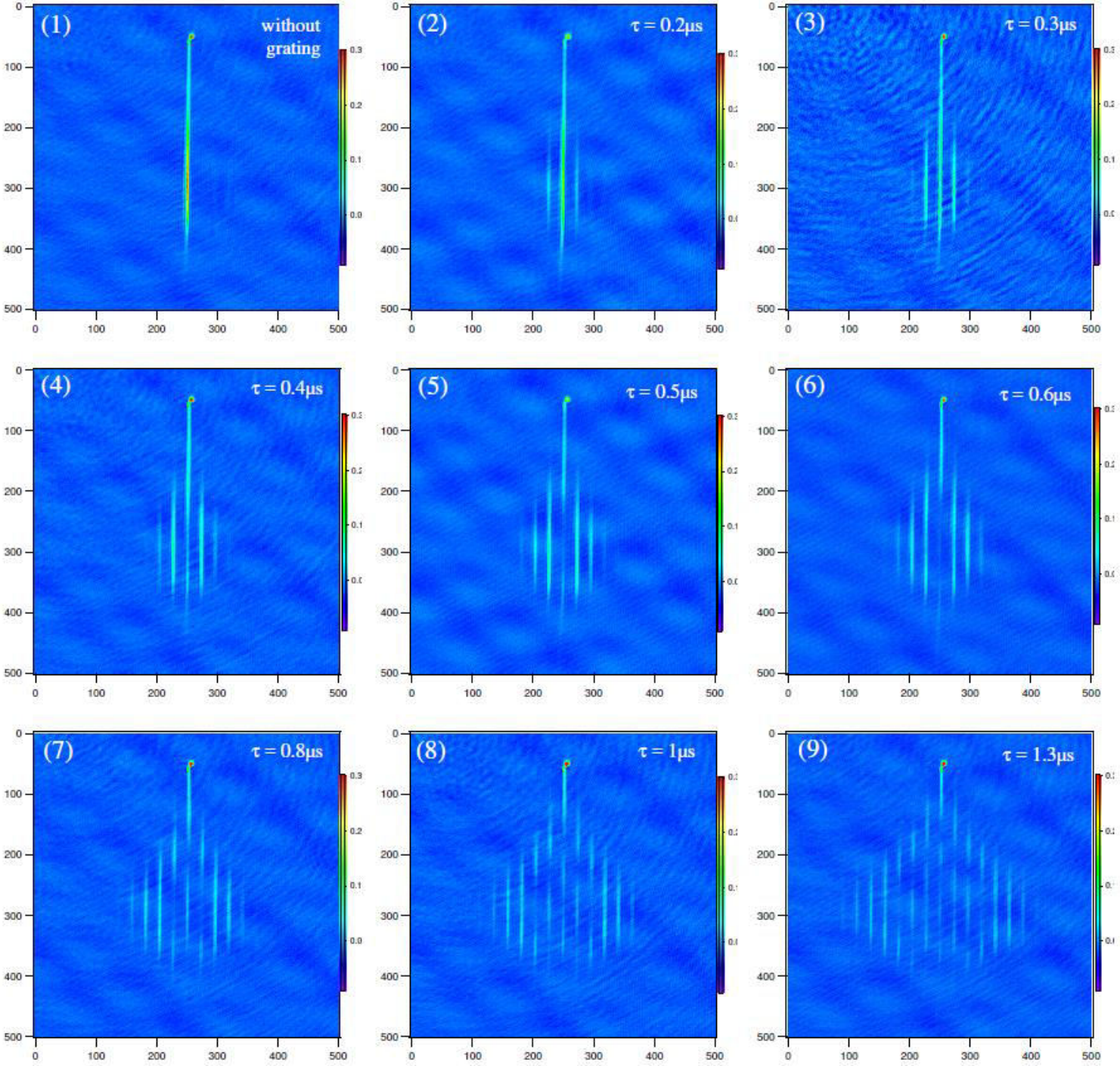


Diffraction of Atom-Laser

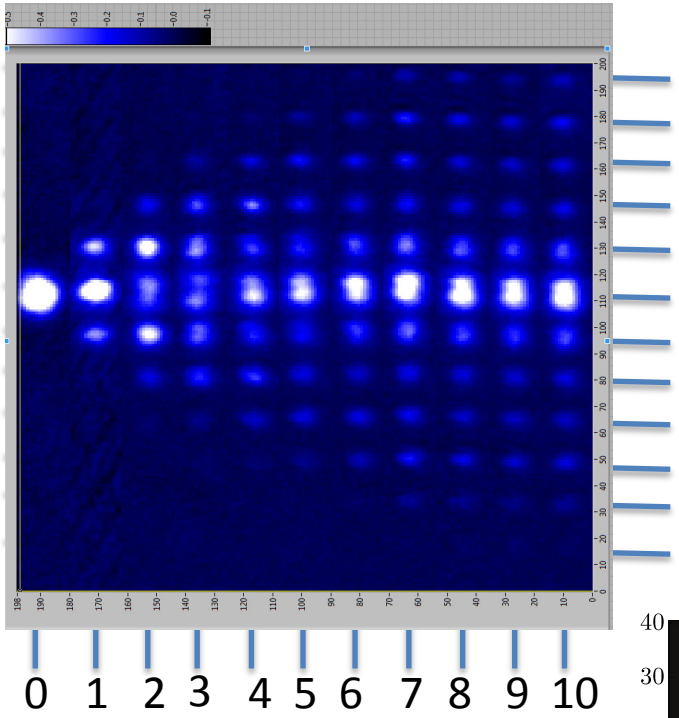




Near field and far-field interference of matter waves diffracted of Light Grating


(1)
without grating
(2)
τ = 0.2μs
(3)
τ = 0.3μs
(4)
τ = 0.4μs
(5)
τ = 0.5μs
(6)
τ = 0.6μs
(7)
τ = 0.8μs
(8)
τ = 1μs
(9)
τ = 1.3μs

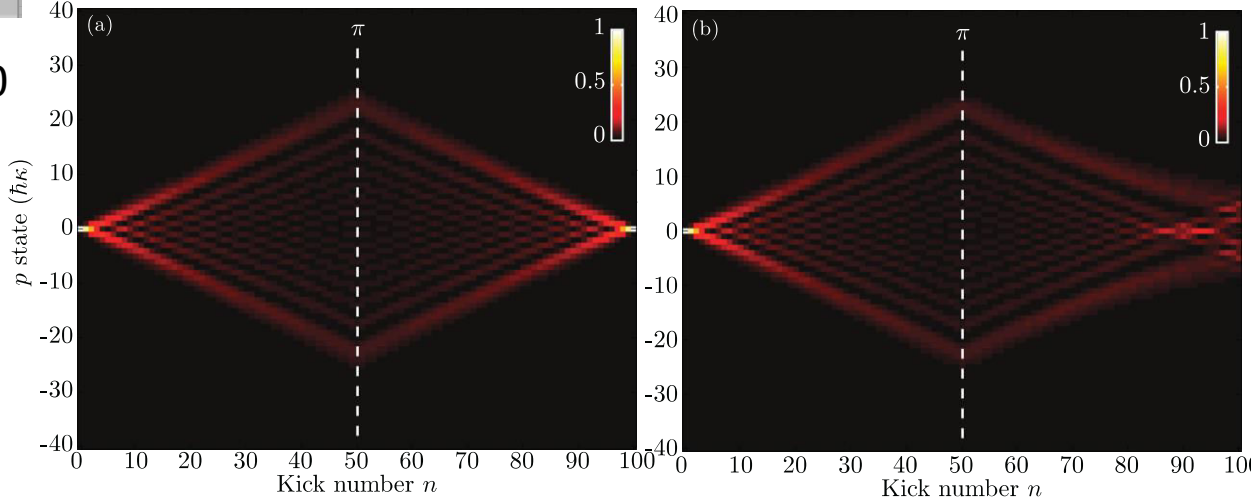
Atom interferometer with BEC



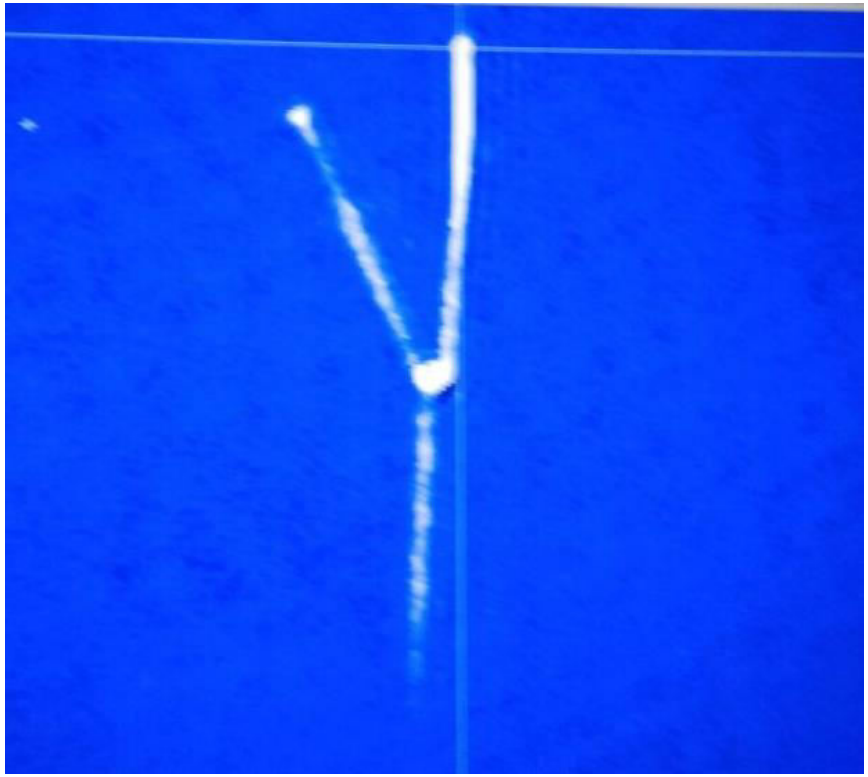
Talbot resonances:

BEC splits into higher order momentum states

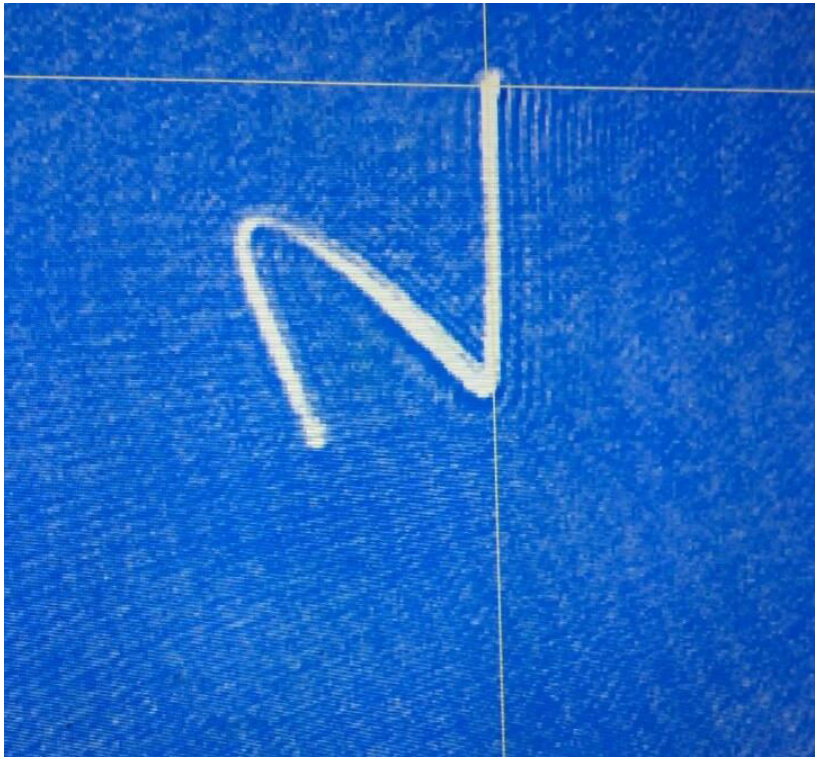
Phys. Rev. A, 86, 043604 (2012)



Mirrors and Beam splitters for Atom Laser

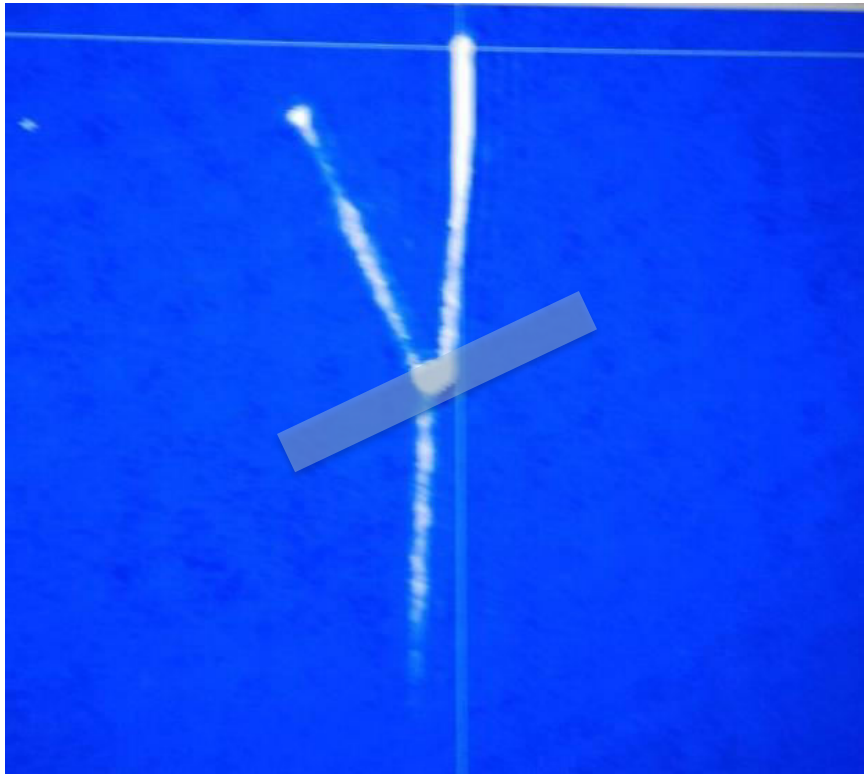


Beam Splitter

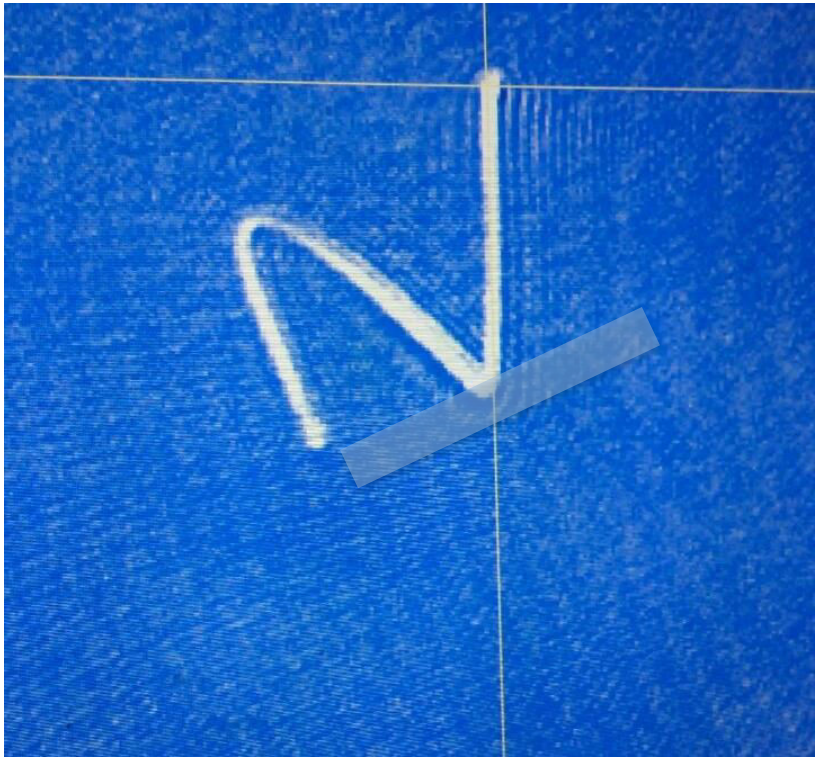


Mirror

Mirrors and Beam splitters for Atom Laser



Beam Splitter



Mirror

Thank you