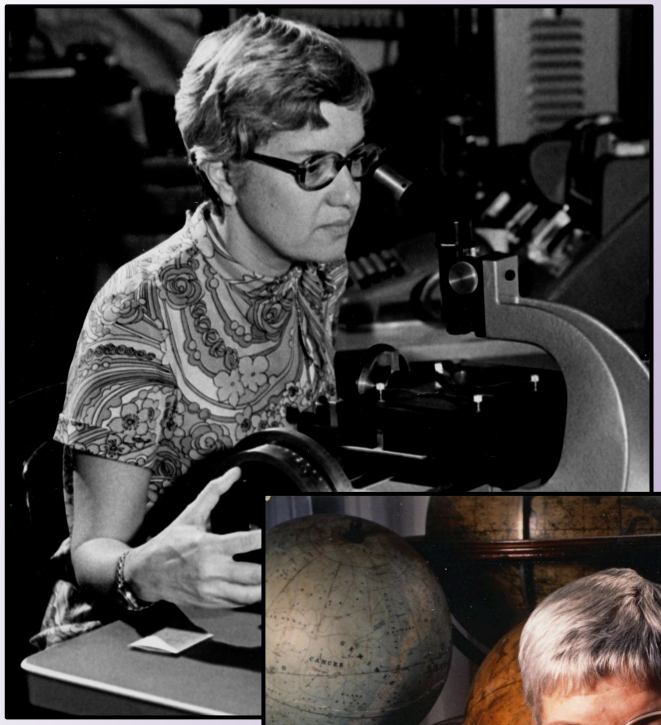
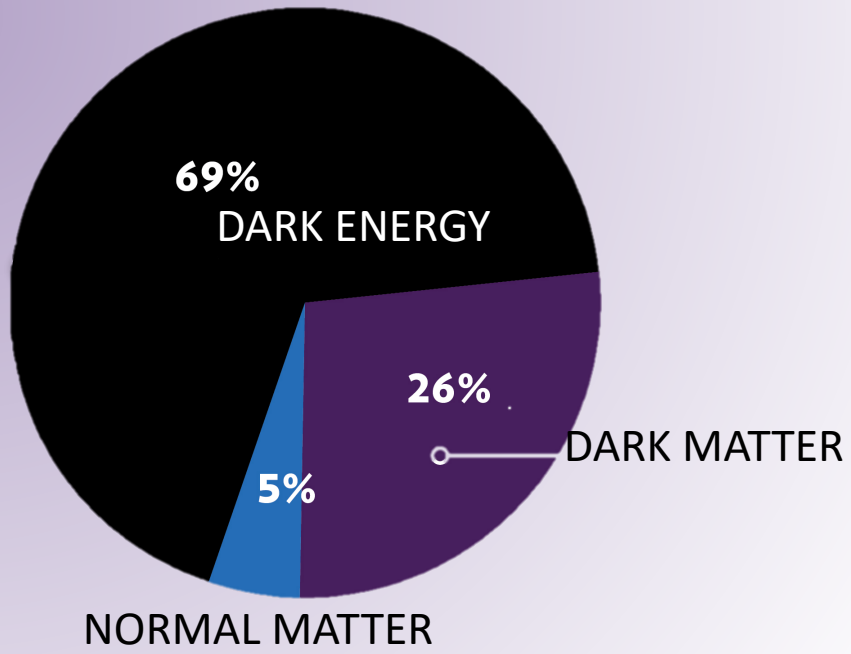
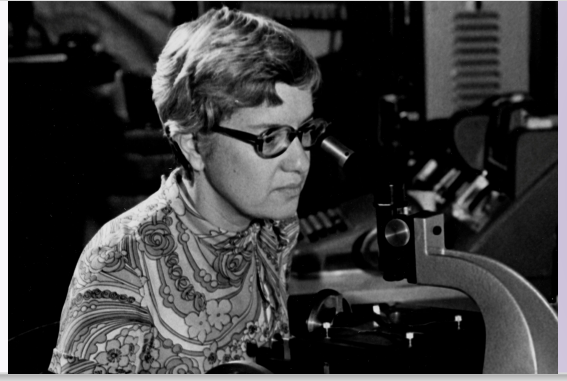




Vera Rubin was an astronomer who uncovered the **galaxy rotation problem**, the first evidence of the existence of **dark matter**.

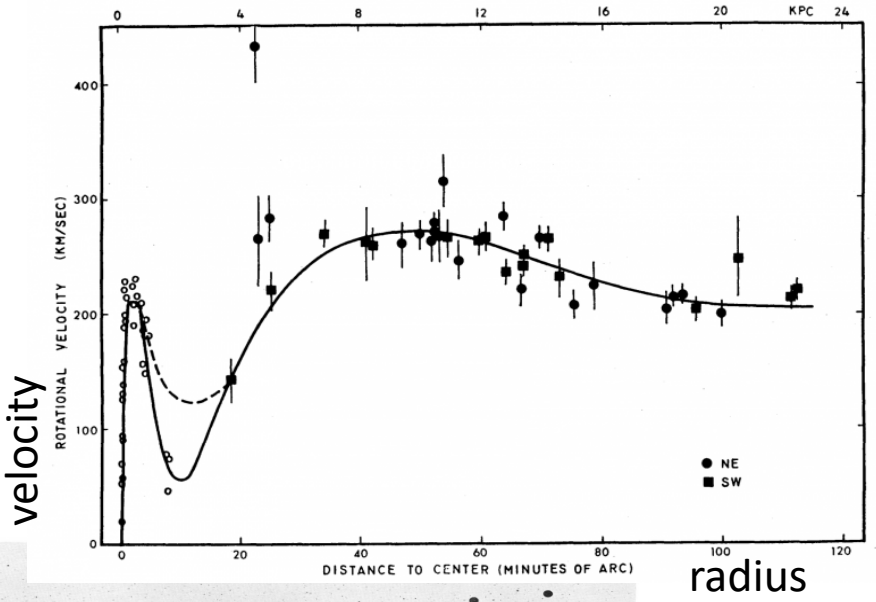




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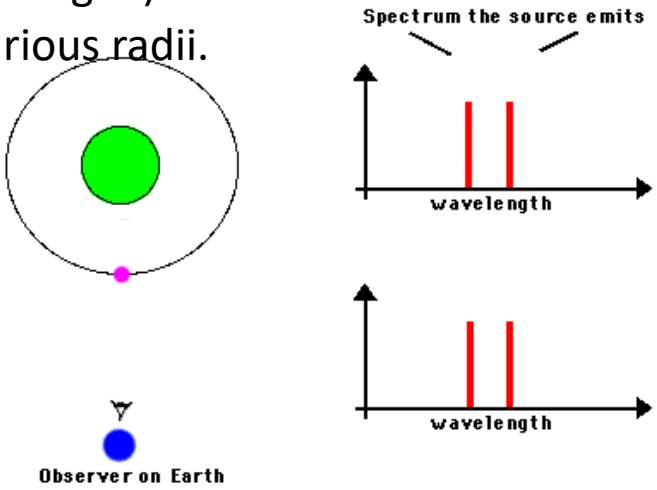
Rubin studied galaxy dynamics of spiral galaxies through **galaxy rotation curves**, the velocity of matter in a galaxy as a function of distance, to deduce mass distribution.

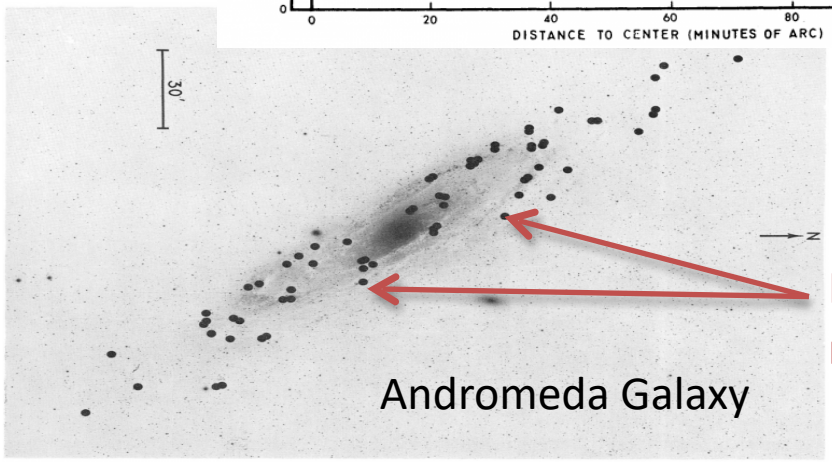
She measured the **Doppler shift of Hα emission lines from HII regions** (orbiting clouds of ionized hydrogen) to deduce the orbital velocity at various radii.



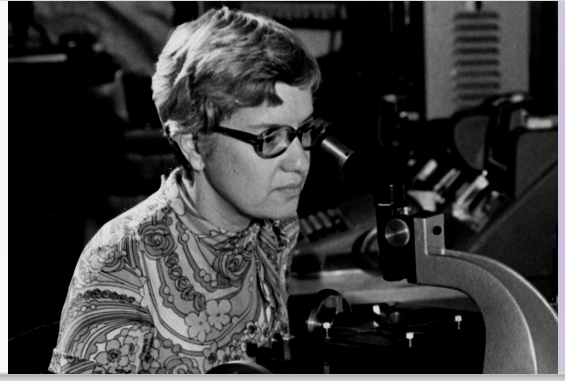
velocity

radius



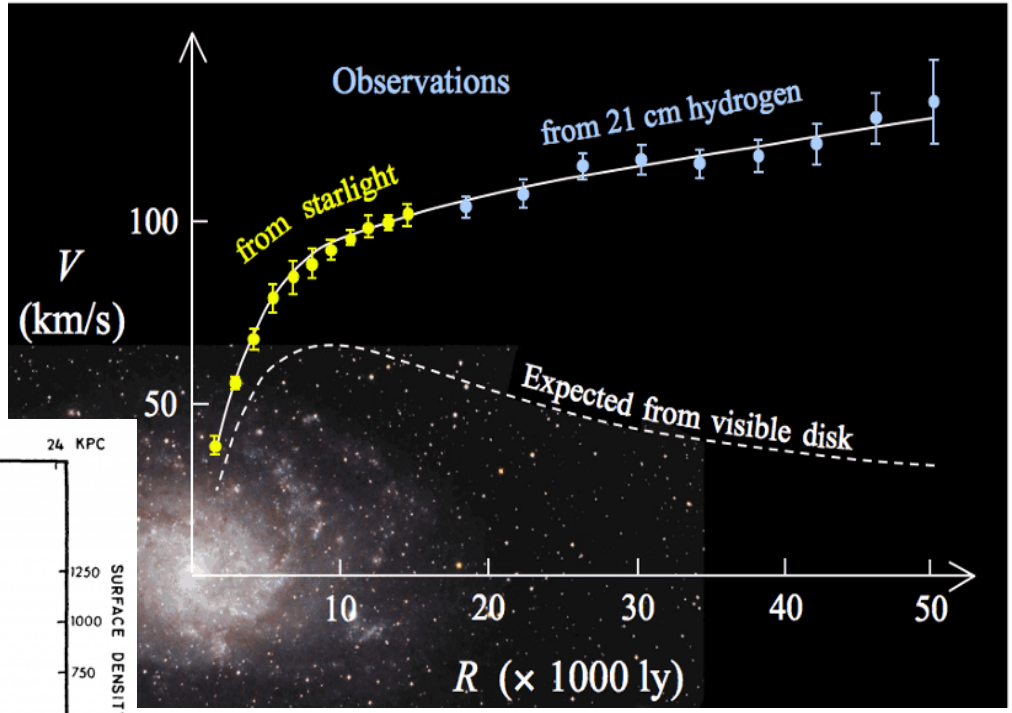


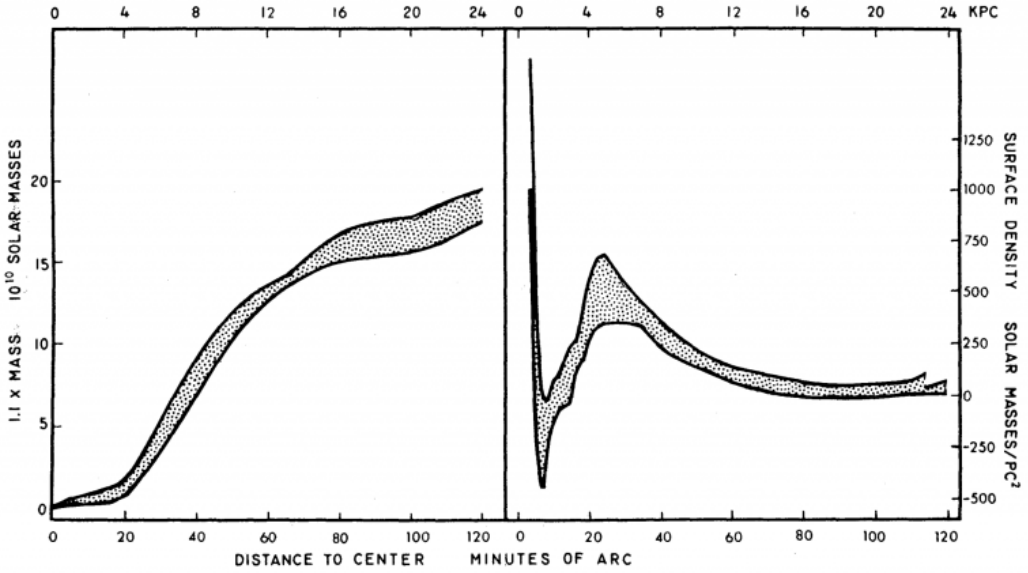
HII regions



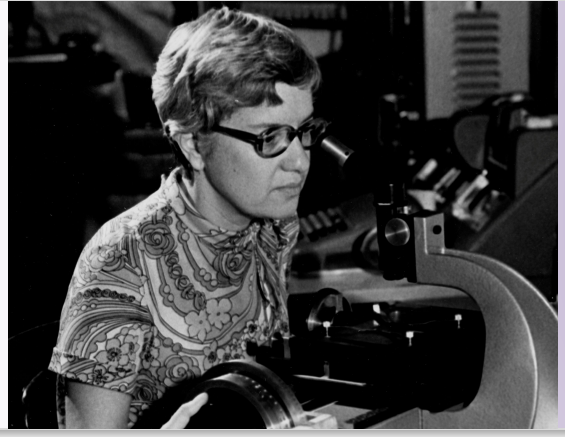
Vera Rubin was an astronomer who uncovered the **galaxy rotation problem**, the first evidence of the existence of **dark matter**.

Rotation speed did not drop at high radii as predicted by the visible distribution of stars, but remained high.
Her finding implied the existence of extra mass on the outer edge of these galaxies – the first evidence **of dark matter**.





Left: mass contained within a certain radius of the centre of Andromeda.
Right: corresponding density at the radius
Top: Rotation curve of spiral galaxy Messier 33



Vera Rubin was an astronomer who uncovered the **galaxy rotation problem**, the first evidence of the existence of **dark matter**.

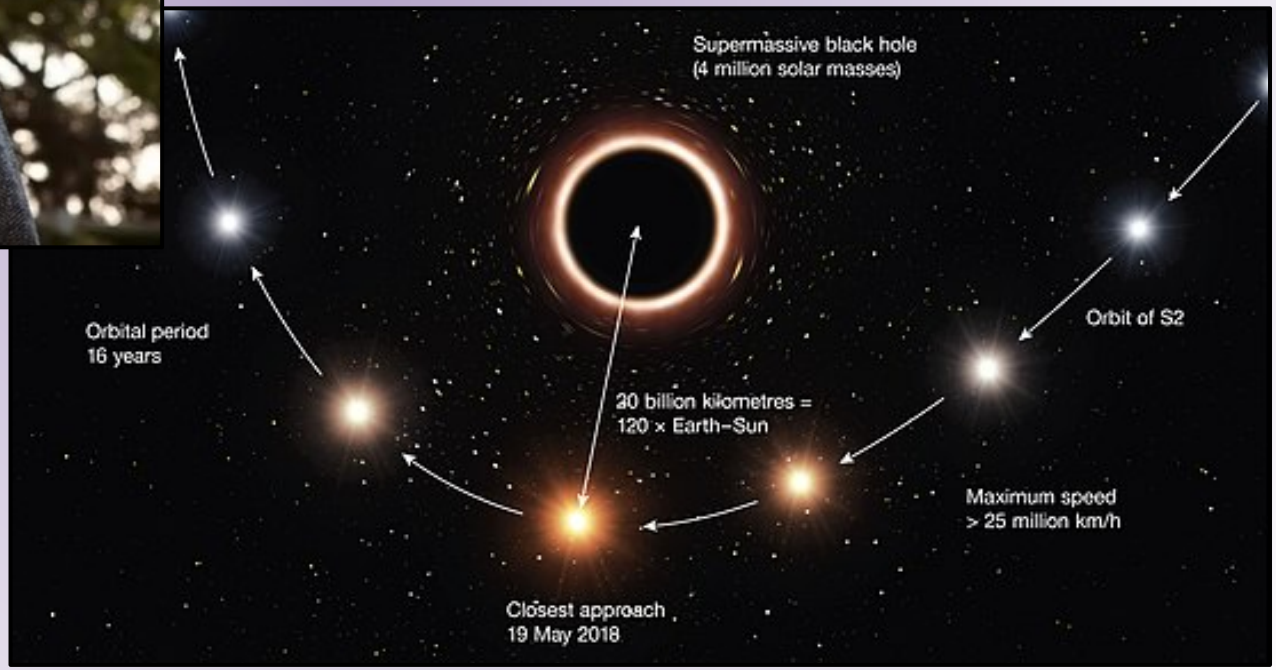
"*In a spiral galaxy, the ratio of dark-to-light matter is about a factor of ten. That's probably a good number for the ratio of out ignorance-to-knowledge. We're out of kindergarten, but only in about third grade*" – Vera Rubin



The National Science Foundation **Vera C. Rubin Observatory** in Chile



Andrea Ghez studies the center of our Milky Way Galaxy. She was awarded a Nobel Prize for imaging the orbit of stars in the **Galactic Center**, demonstrating the existence of the **supermassive black hole Sgr A***





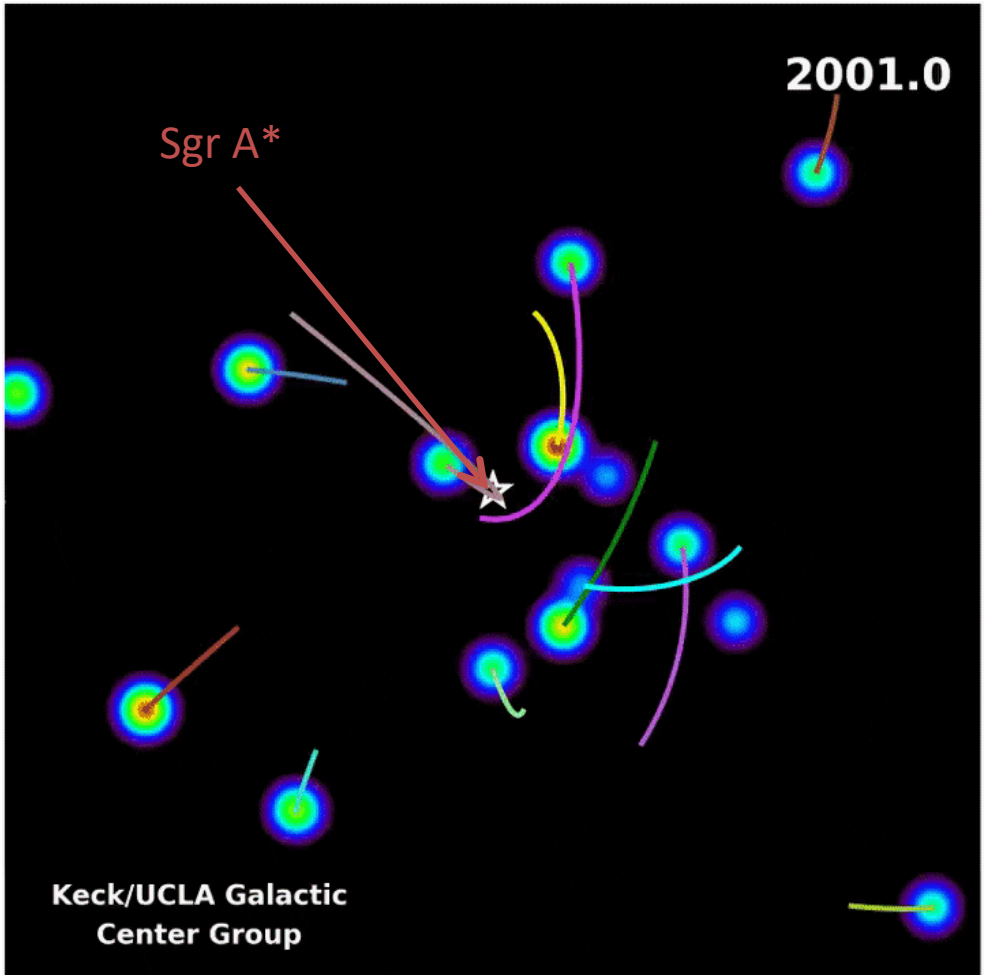
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Sgr A* is a supermassive black hole ≥ 10^6 $M_\odot$

Ghez used observations of the orbits of stars orbiting the Galactic Center, and **Kepler's third law**, to measure the mass of Sgr A* at $4.1 \pm 0.6 \times 10^6$ $M_\odot$

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

T = orbital period
r = semi-major axis
G = gravitational constant
M = mass





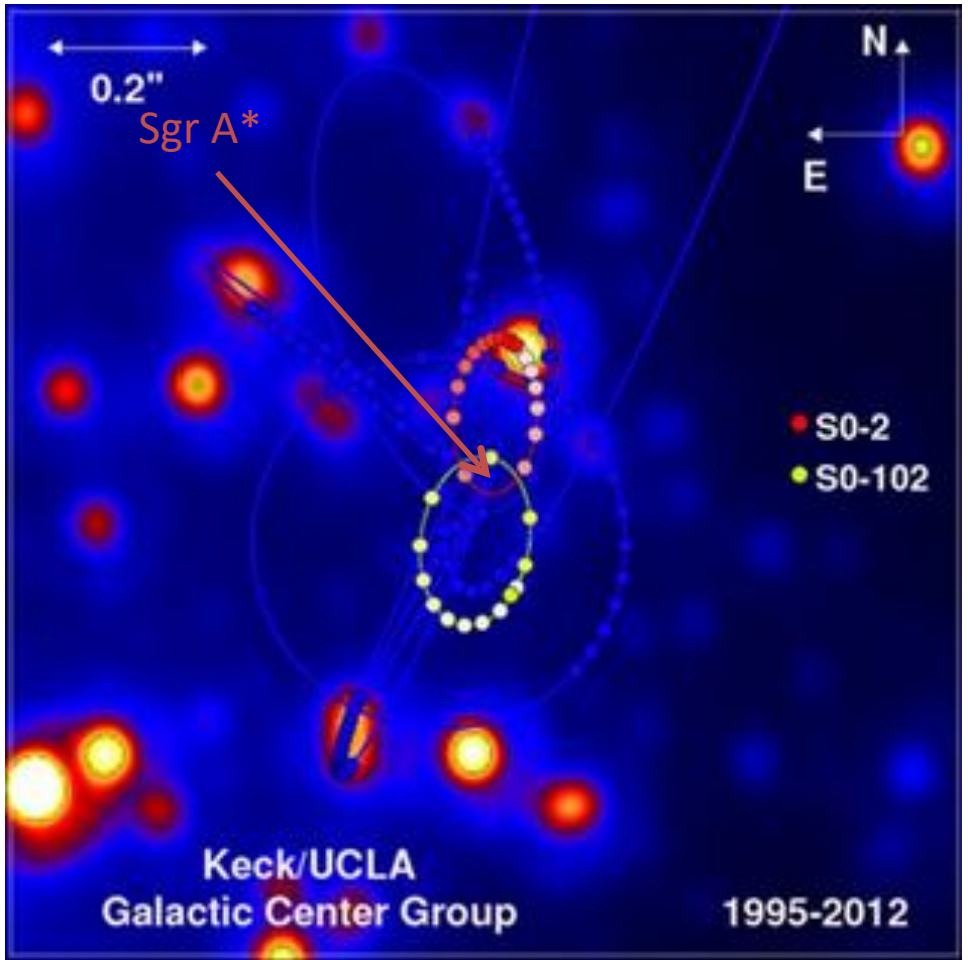
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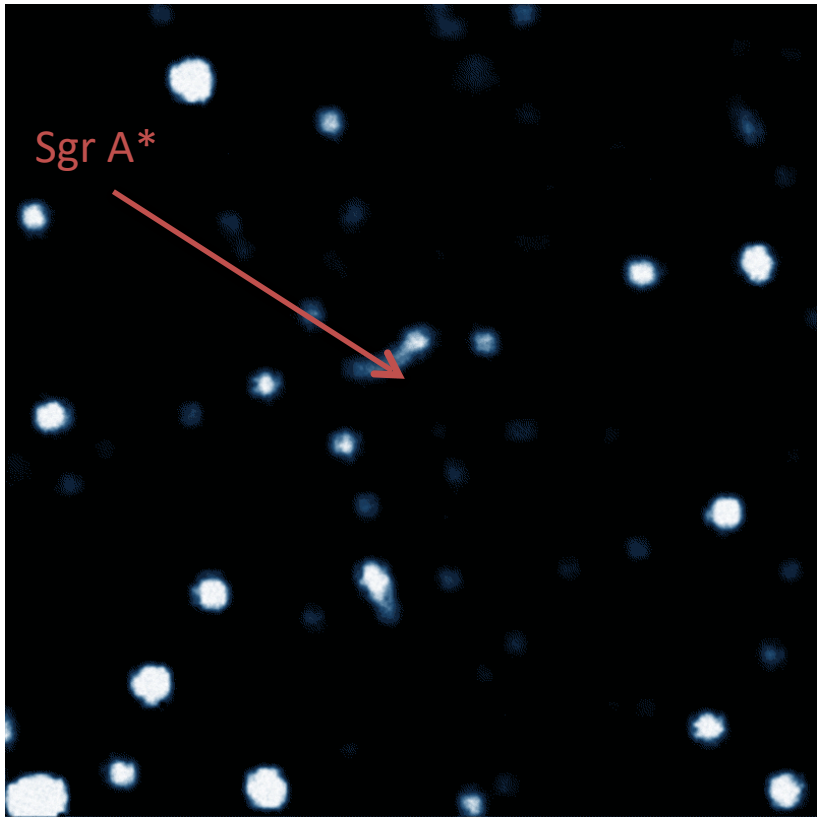
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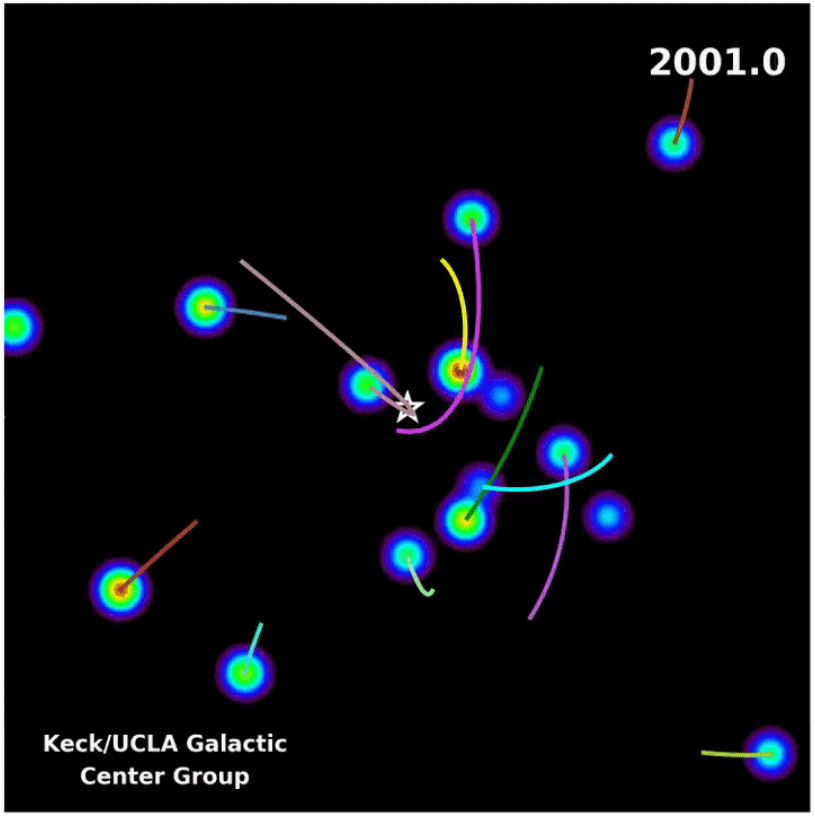


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Genzel's observations at European Southern Observatory's Very Large Telescope (VLT))



Ghez's observations at Keck Observatory



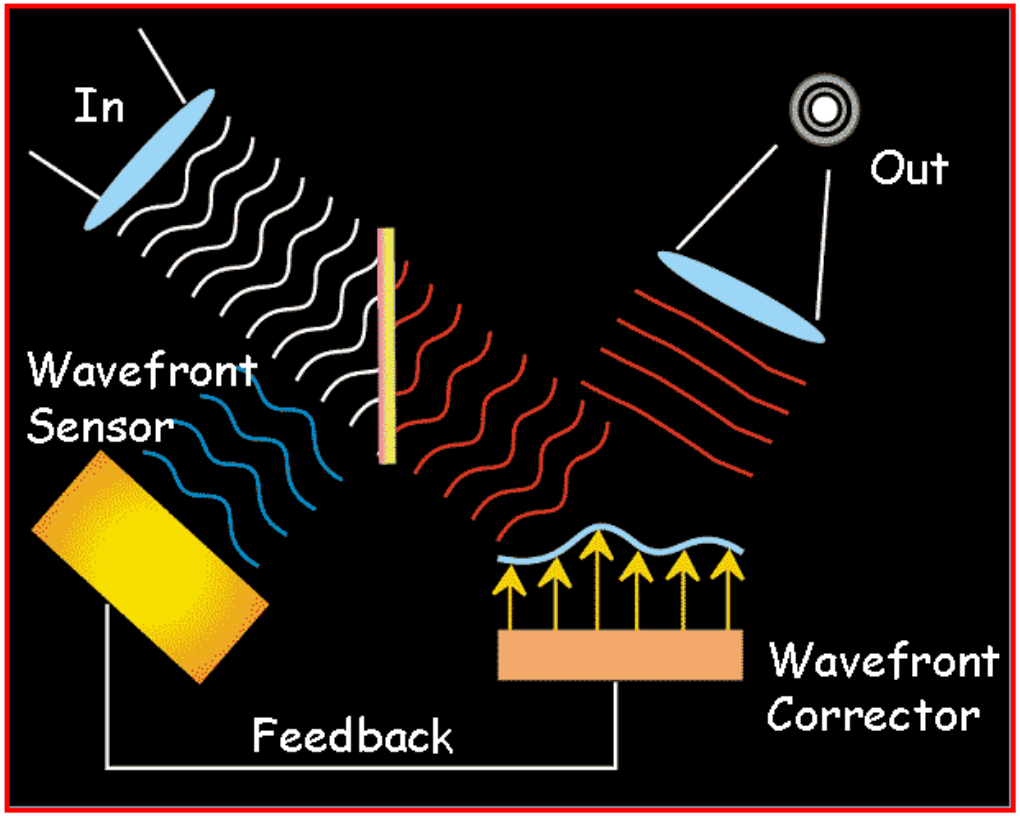


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Adaptive optics use deformable mirrors to adapt to atmospheric disturbances



Sgr A* was imaged using the Keck I and Keck II telescopes, which rely on adaptive optics. They use powerful lasers to create an artificial star in the sky that can be used to measure atmospheric turbulence.



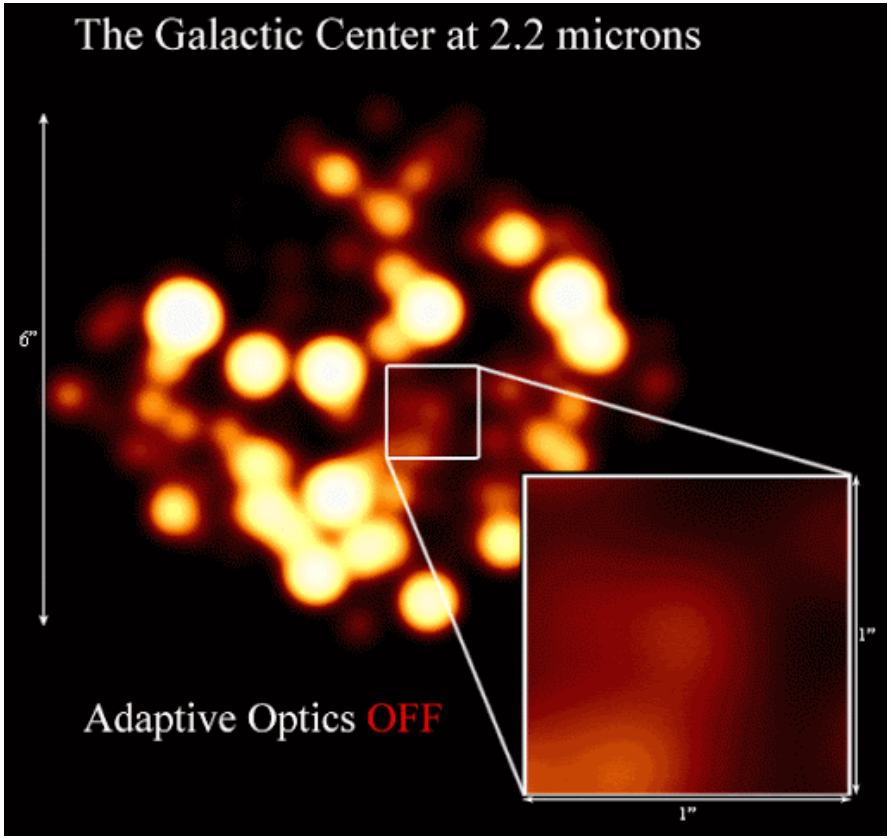


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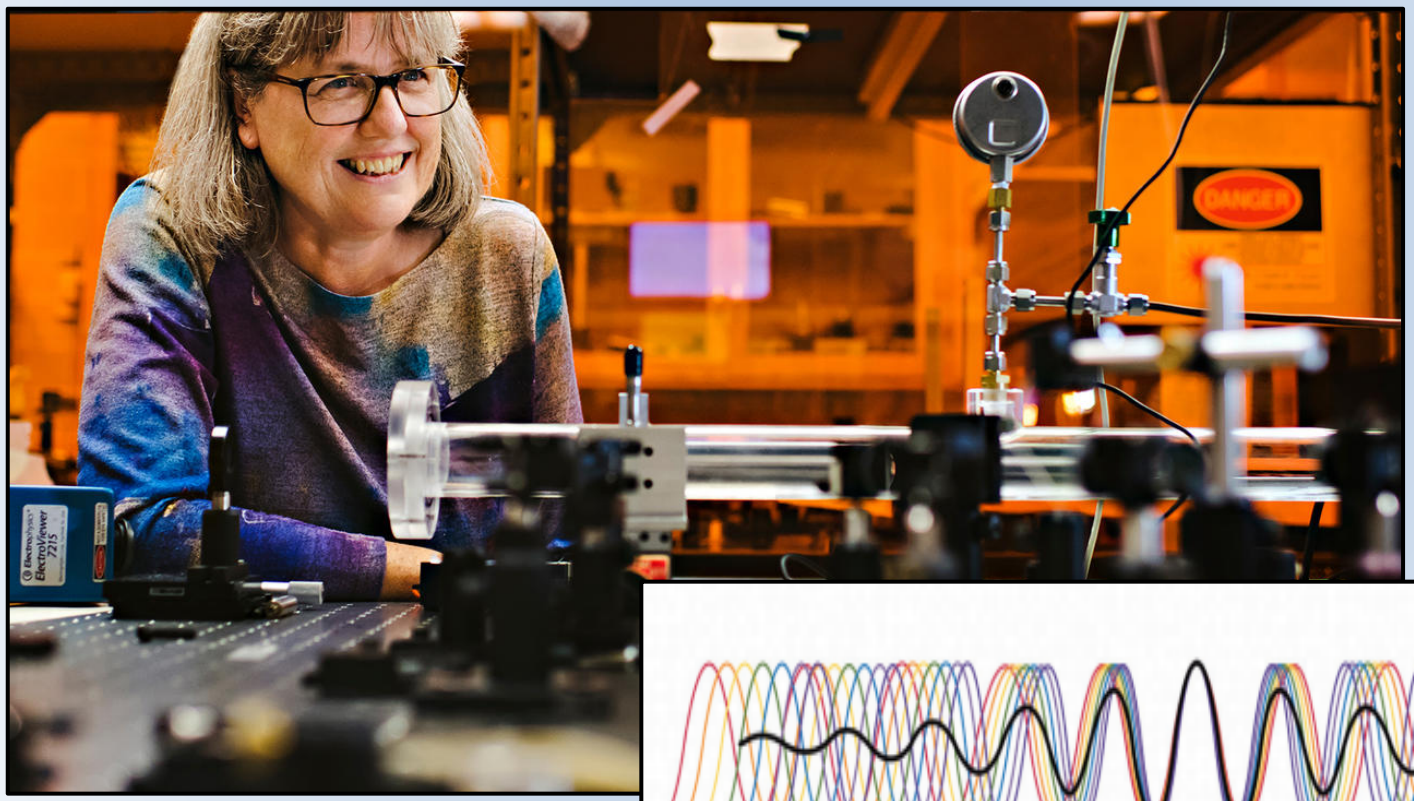
Adaptive optics use deformable mirrors to adapt to atmospheric disturbances

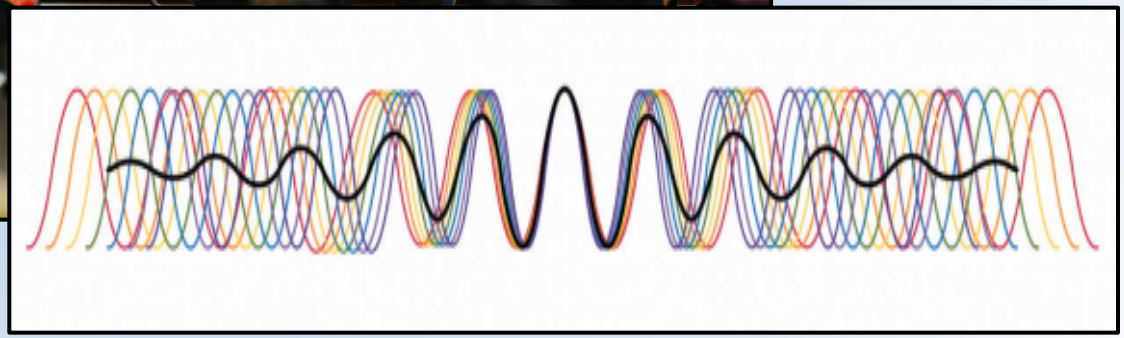


The Keck I and Keck II telescopes using their **laser guide star adaptive optics** to observe Sgr A*. The lasers excite sodium atoms in the Earth's mesosphere to create an artificial star that can be used to measure atmospheric turbulence.



Donna Strickland is an optical physicist and a pioneer in the field of lasers. She won the Nobel Prize for her invention: chirped pulse amplification (CPA).



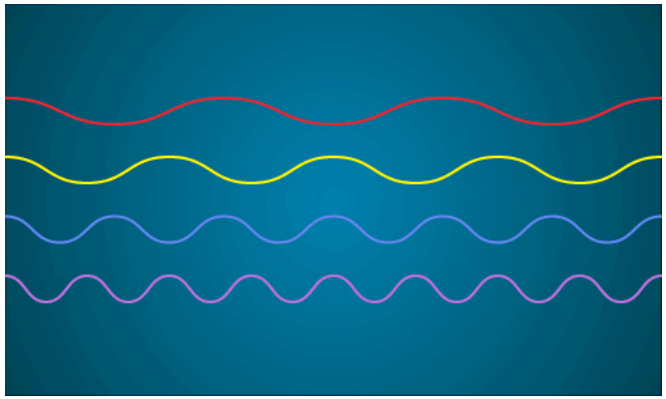




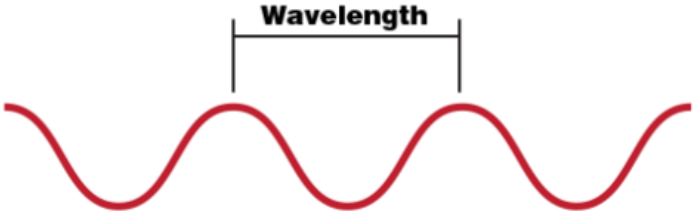
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Strickland studies **light and lasers.** What is a laser?

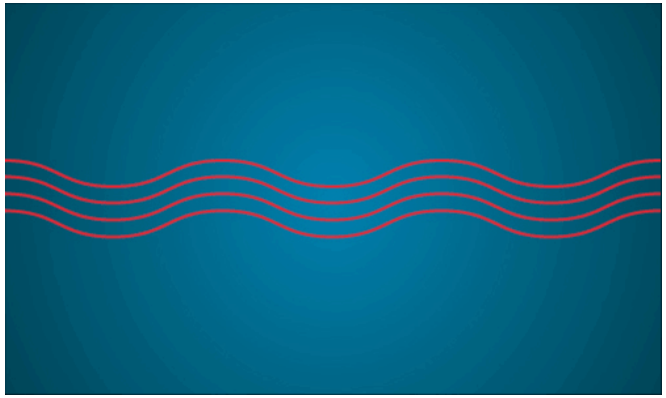
https://spaceplace.nasa.gov/laser/en/



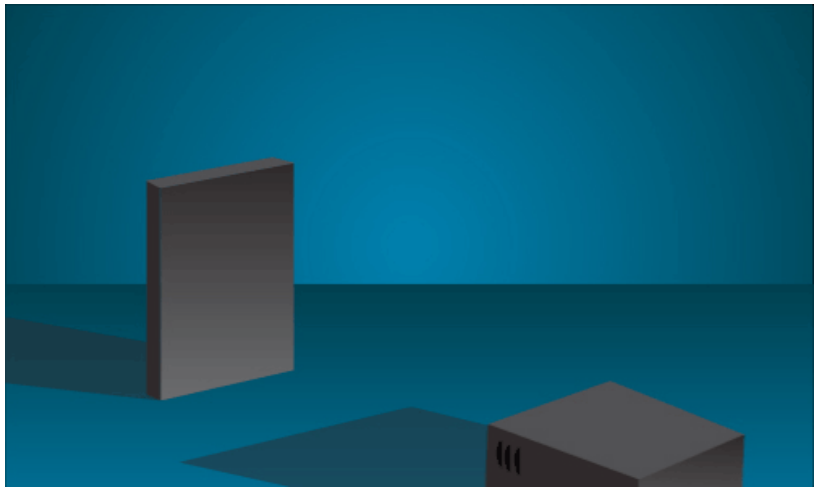
Incoherent



Light can act like a wave



Coherent





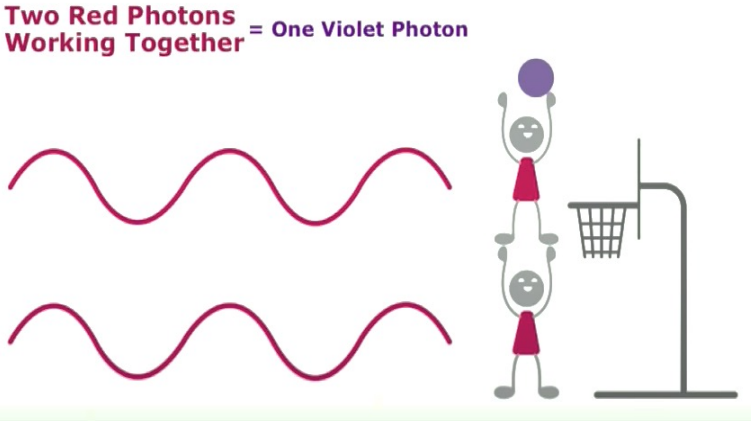
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Strickland studies **non-linear optics,** when multiple light particles (**photons**) interact with a single atom, through the use of **lasers.**

Photon energy ➔ Height of player

Height of basketball net ➔ Energy required to free an electron





If multiple photons pack themselves together, you can free electrons that are held more tightly!

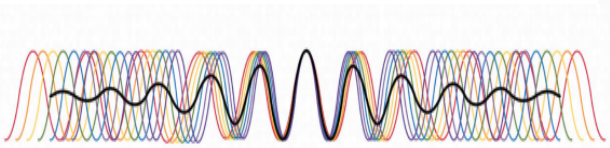
Source: D. Strickland Nobel Prize lecture



Donna Strickland is an optical physicist and a pioneer in the field of pulsed lasers. She won the Nobel Prize for her implementation of chirped pulse amplification (CPA).

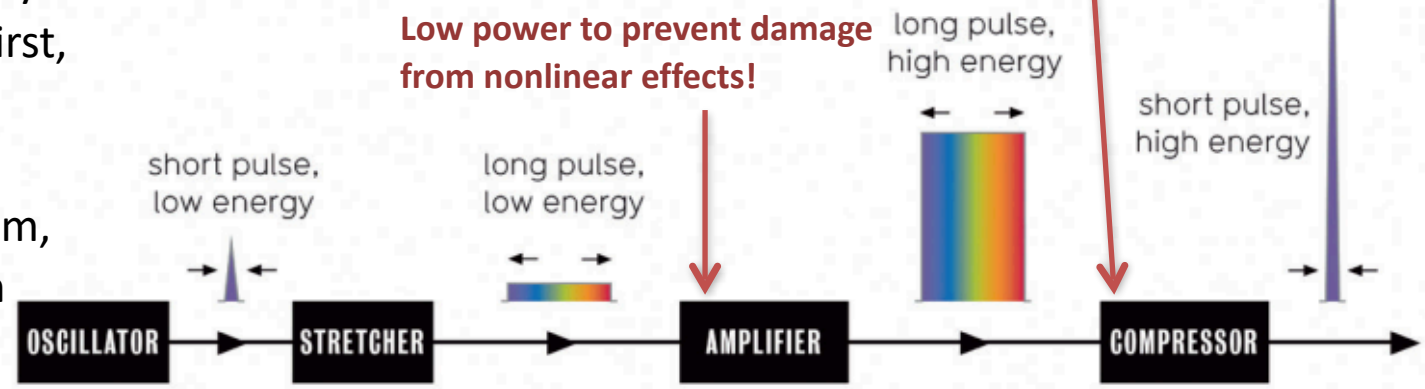
Strickland studies **non-linear optics,** which is the regime where multiple photons interact with a single atom, and very powerful lasers are required to do so. She developed CPA as a solution:

Adding different wavelengths in a controlled way can create a very short pulse.



Pulse is **stretched** over a distance and frequency spreads (red arrives first, violet last). "Chirp!"

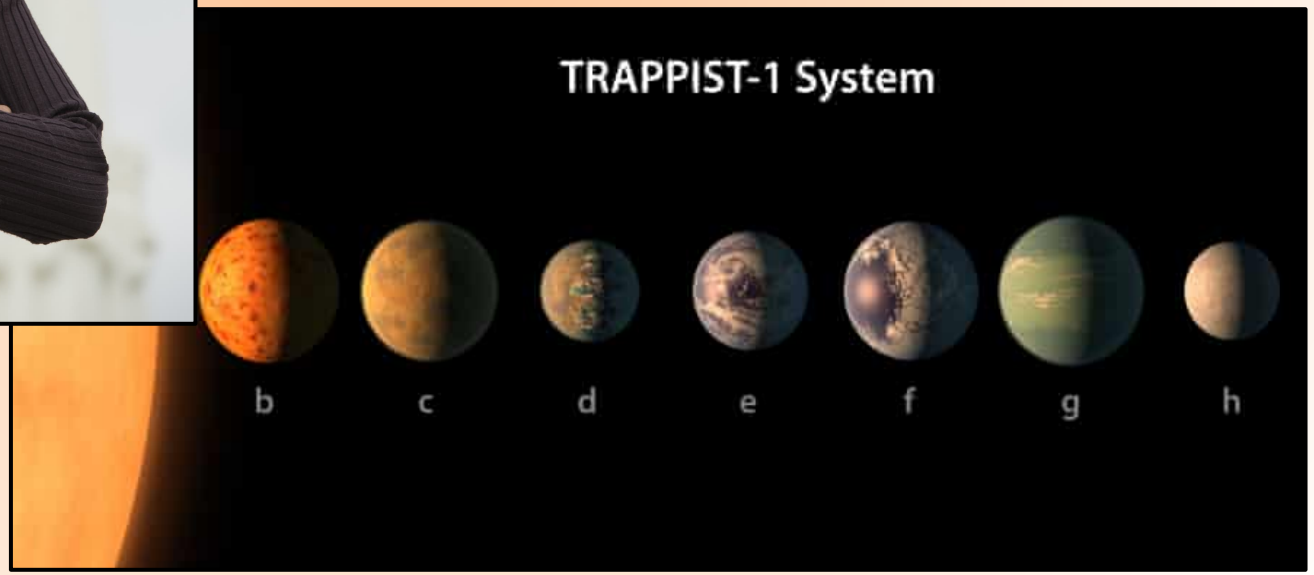
Pulse is **amplified** through a gain medium, and compressed **with parallel gratings.**



Source: D. Strickland Nobel Prize lecture



Aomawa Shields is an astronomer and astrobiologist, who studies the climate and habitability of small earth-sized planets orbiting low-mass stars by searching for liquid water.





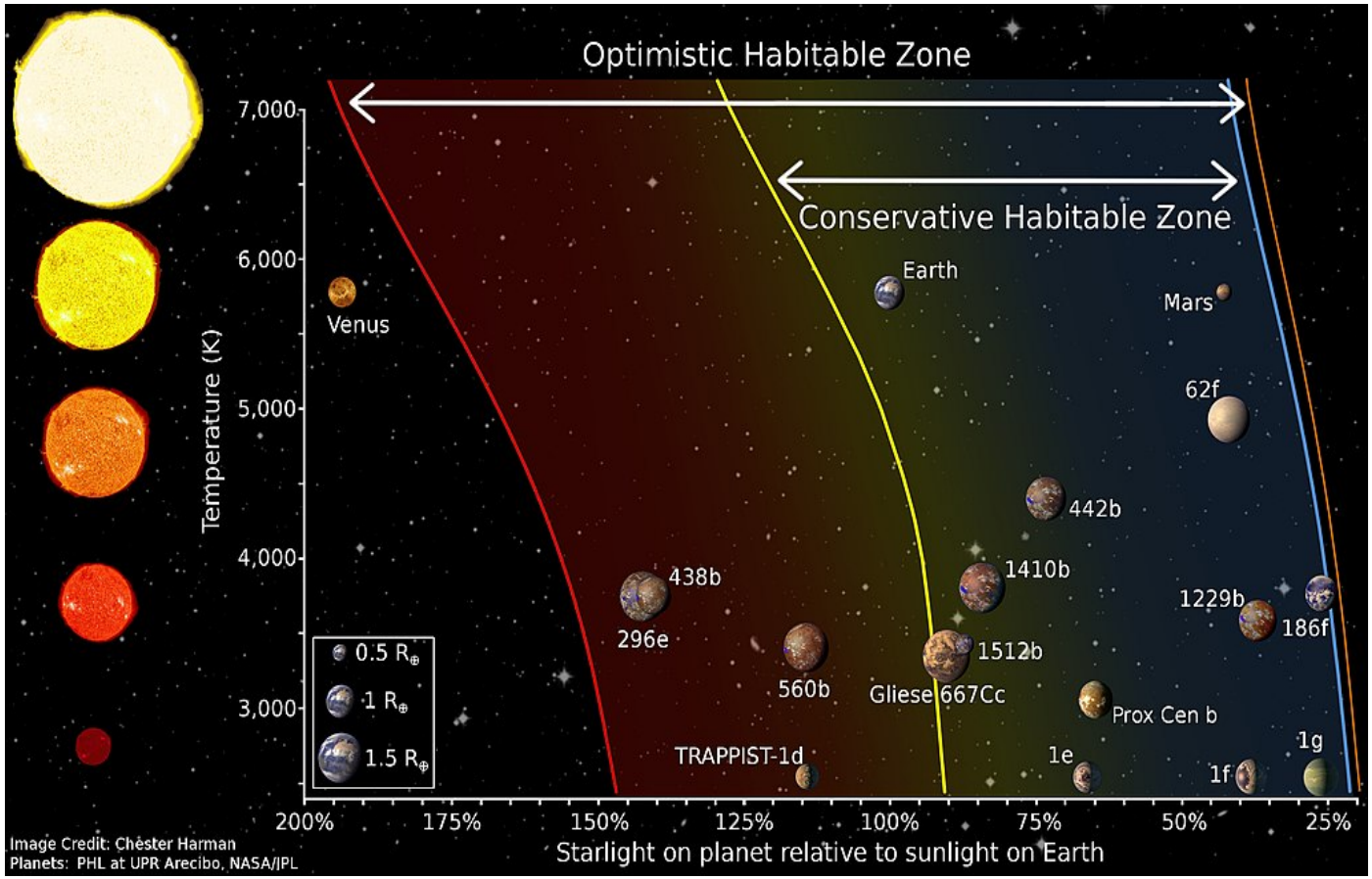
Aomawa Shields is an astronomer and astrobiologist, who studies the climate and habitability of small earth-sized planets orbiting low-mass stars by searching for liquid water.

HABITABLE ZONE : ORBITS WHICH SUSTAIN LIQUID WATER

Shields studies how different:

- **Stars types**
- **Planet surfaces**
- **Atmospheres**
- **Orbits**

affect the presence of liquid water on a planet.



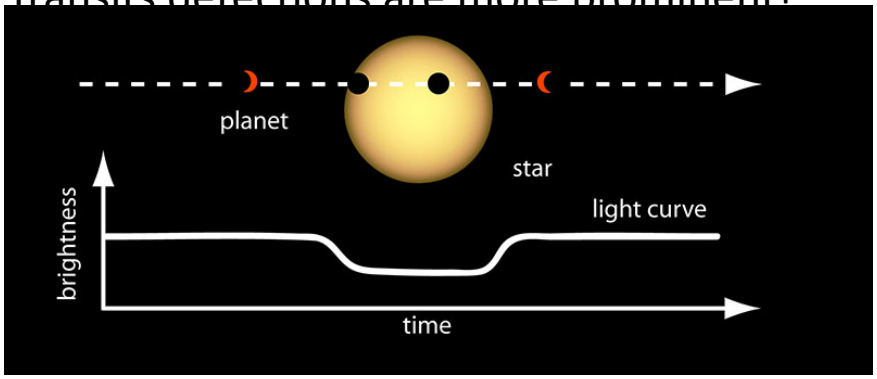


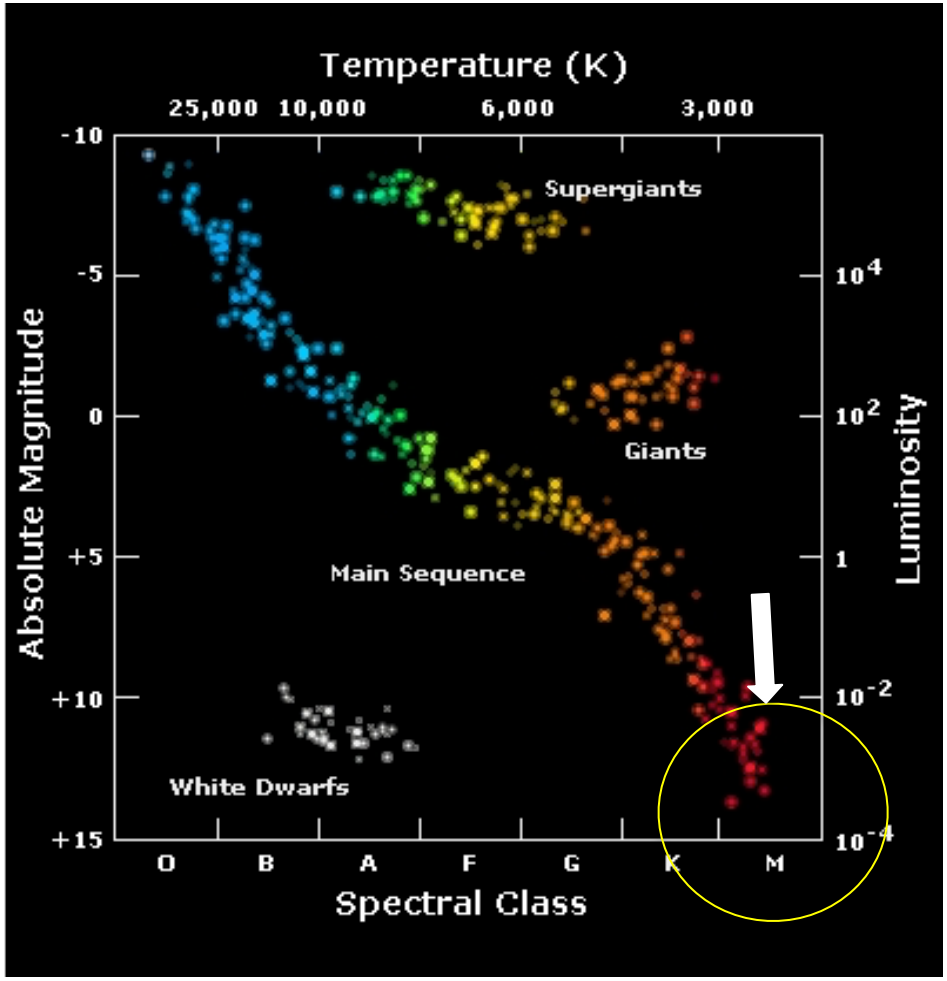
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Shields studies planets orbiting **M-dwarf** stars, the most common stars in our galaxy and therefore the most likely place for life due to sheer numbers

M-dwarfs compared to our sun are:
- Smaller
- Cooler
- Less bright

Transits detections are more prominent!







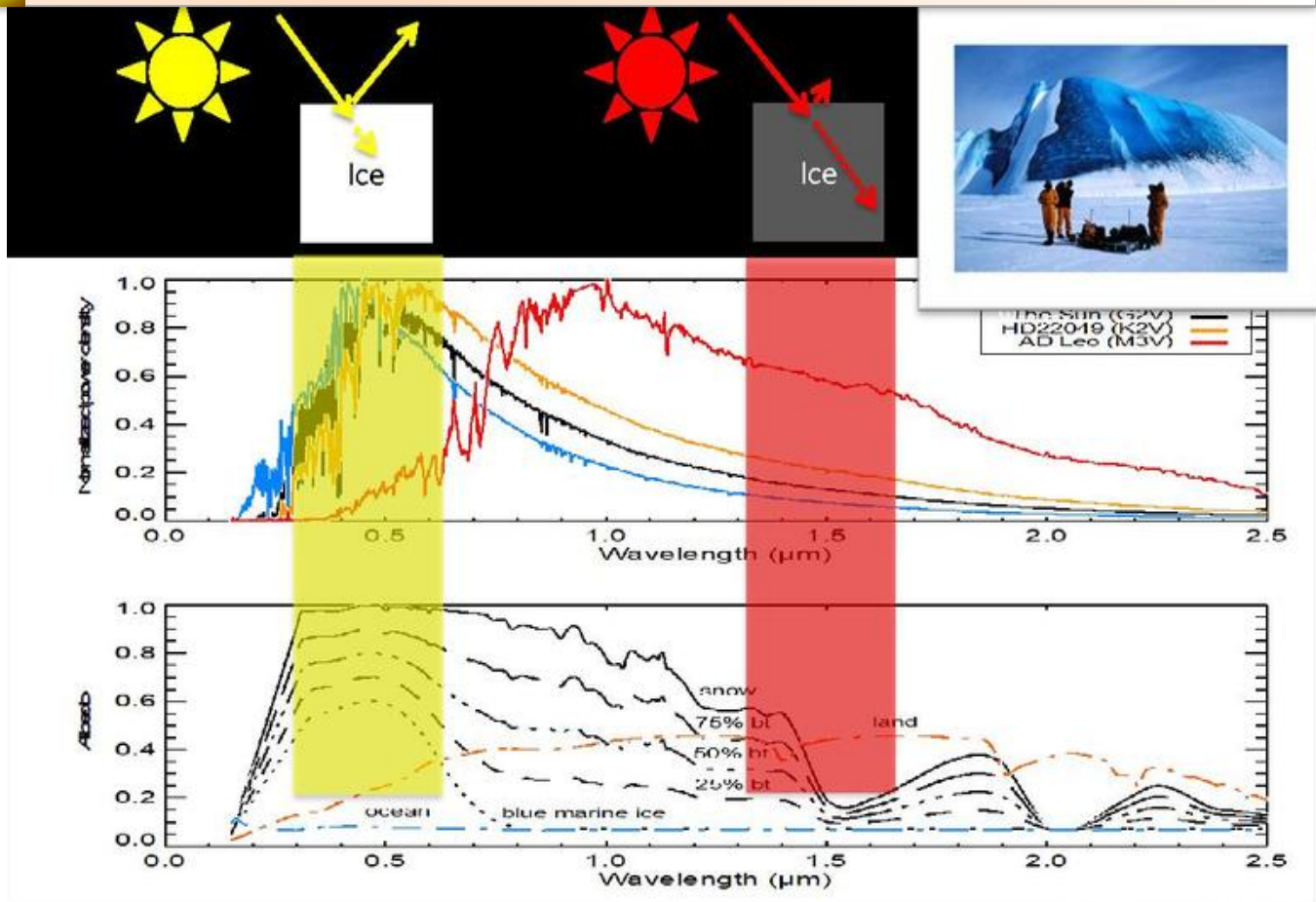
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Shields studies how the **spectral energy distribution** (SED) of stars affect the presence of liquid water on a planet.

M-dwarf planets are less susceptible to **"snowball earth"** as ice absorbs more in IR, where M-dwarfs emit strongly.

In earth-like atmosphere (CO2+water), more stable against convection.

Overall more stable climates for life!



Ice absorbs where M-dwarfs emit strongly

Shields et al. (2013)
Warren et al. (2002)
Grenfell et al. (1994)



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Shields et al. 2013



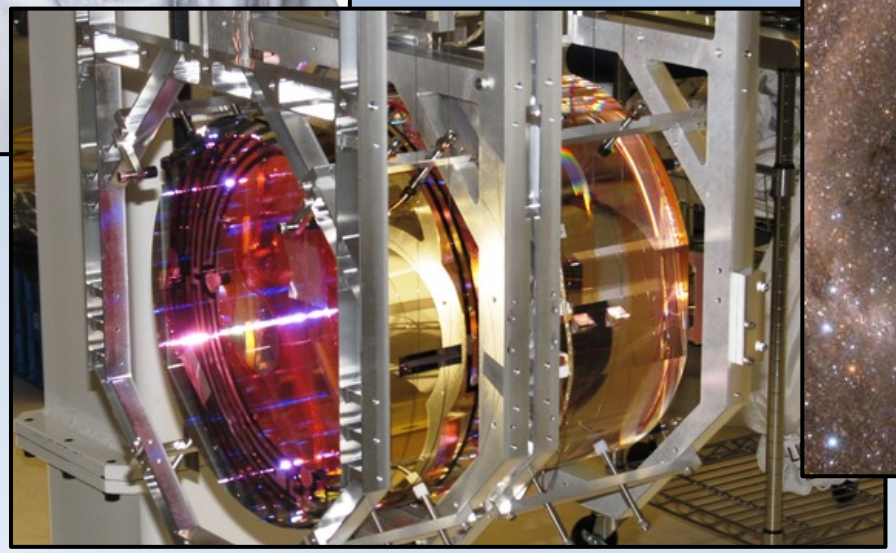
No ice!

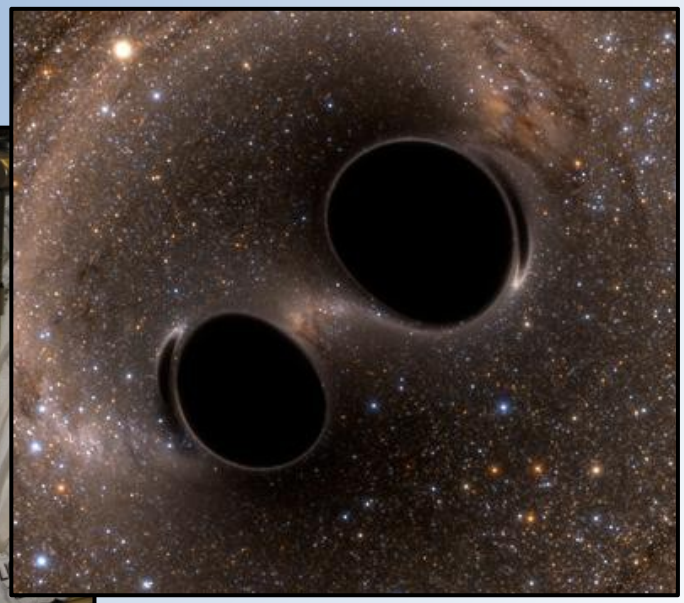


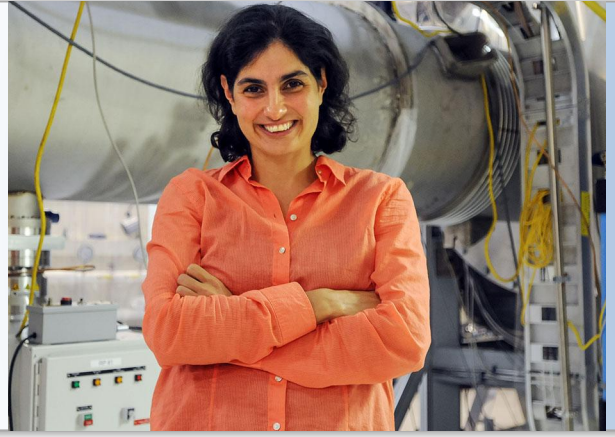
Snowball!



Nergis Mavalvala is a physicist who studies **gravitational wave astrophysics** and **quantum measurement science** at LIGO. She and her colleagues were the first to measure gravitational waves.







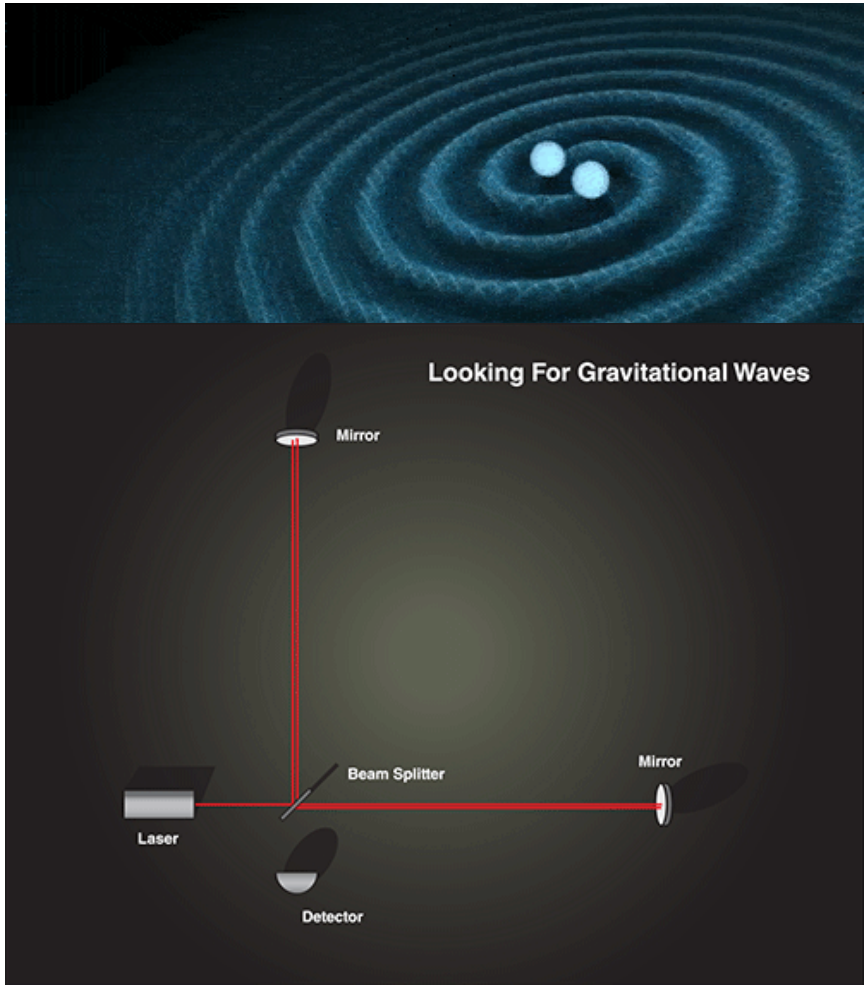
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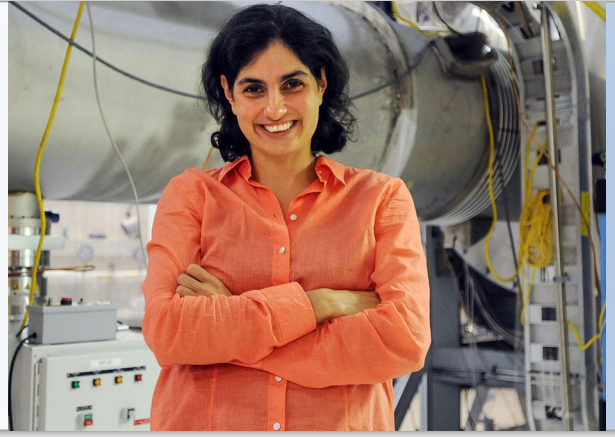
Mavalvala builds and uses extremely sensitive mirrors and lasers to detect gravitational waves produced by inspiralling **black holes and neutron stars.**

Gravitational waves are disturbances in the curvature of **spacetime**.

As predicted by Einstein, mass warps spacetime, and accelerating masses will produce waves through spacetime. These waves propagate at the speed of light.

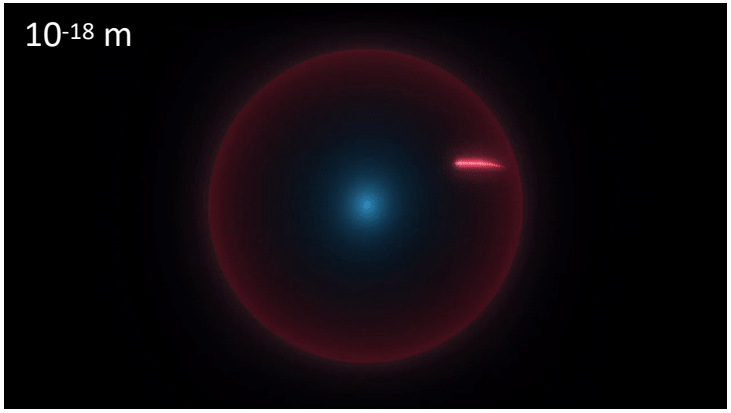
LIGO is an interferometer large enough to be sensitive to these disturbances.

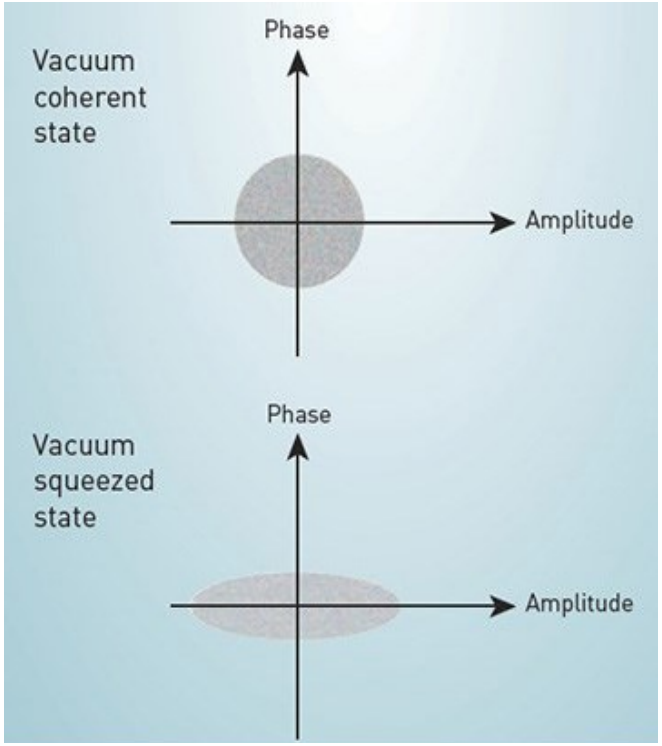




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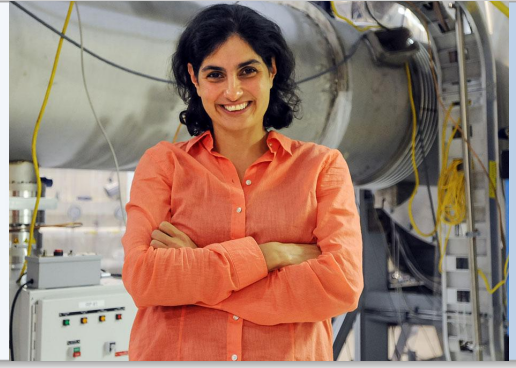
LIGO is an interferometer used to detect gravitational waves produced by inspiralling **black holes and neutron stars.** Mavalva works to push the sensitivity of the instrument.





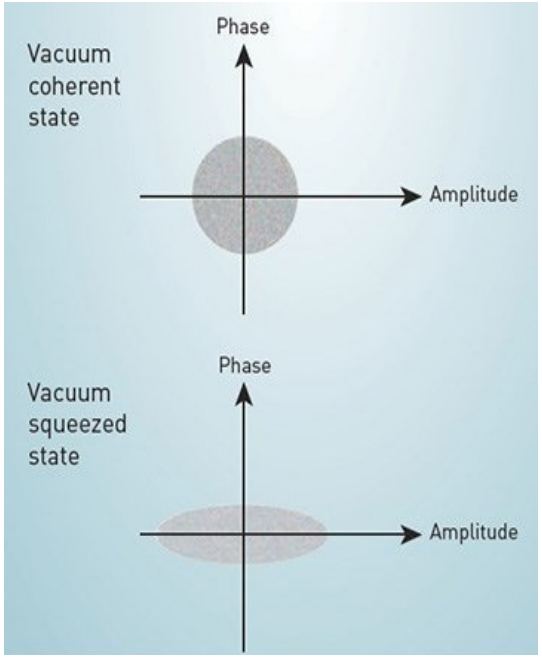
The perturbations are so tiny that **"squeezed light"** is used to push the sensitivity of LIGO, by reducing noise from quantum fluctuations.

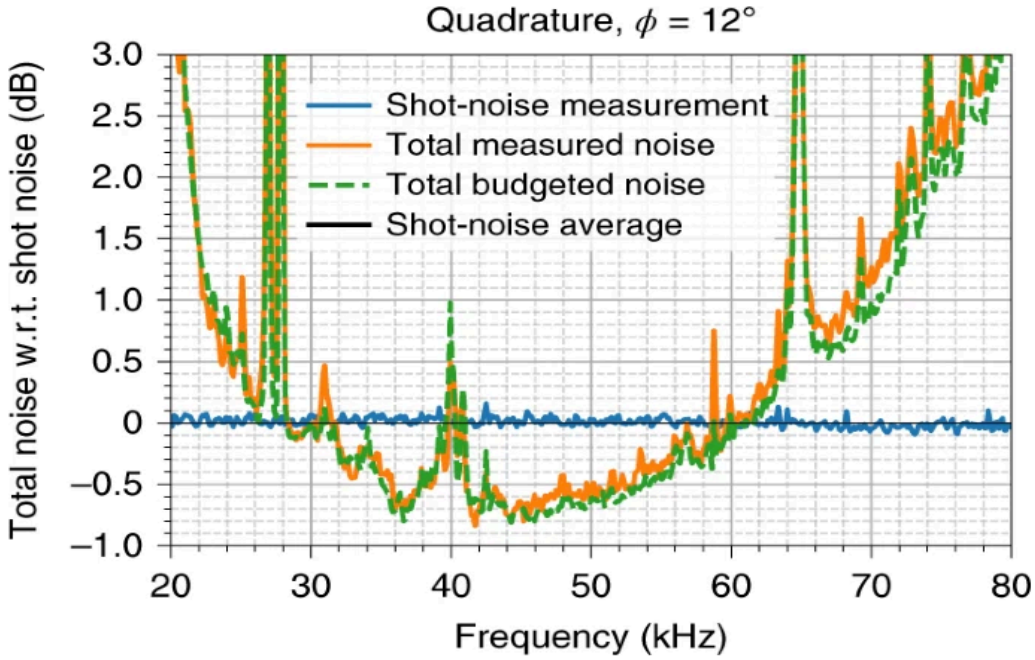
In a squeezed state of light, nonlinear optical techniques are used to **reduce the Heisenberg uncertainty** associated with one quadrature of the light field (eg. phase) by transferring some of it to the other quadrature (amplitude)



Nergis Mavalvala is a physicist who **studies gravitational wave astrophysics** and **quantum measurement** science at LIGO. She and her colleagues were the first to measure gravitational waves.

Mavalvala and her team created a **optomechanical squeezing instrument at room-temperature**. The "light squeezer" reduces quantum noise up to 15%.



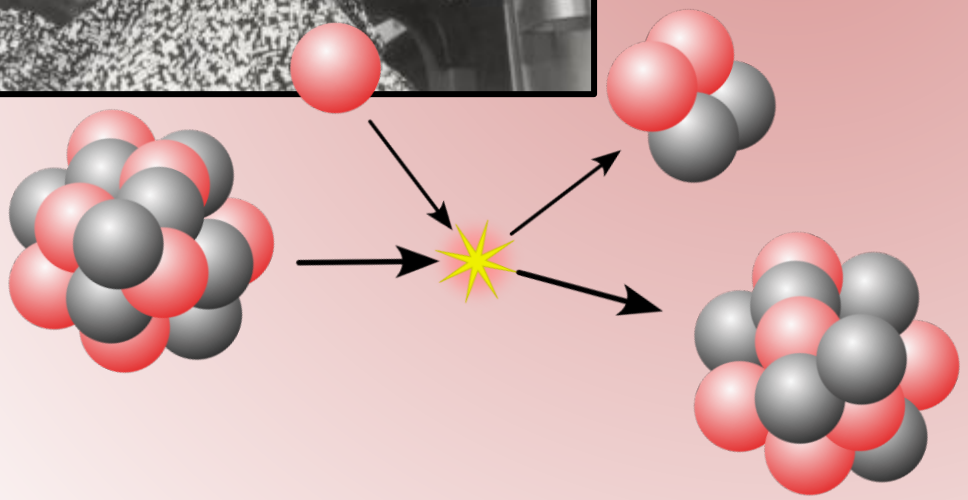


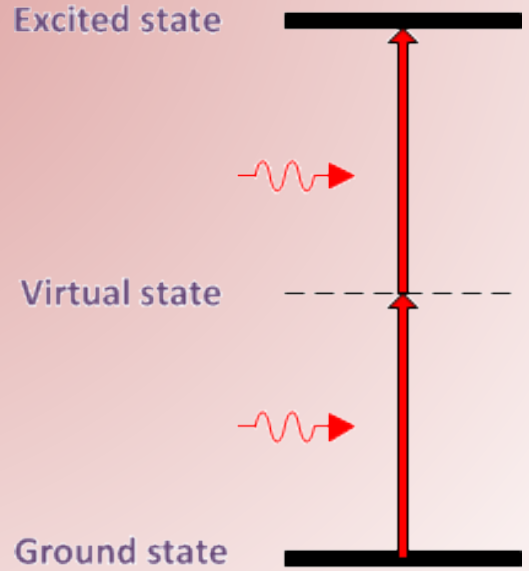
Squeezing methods employ light **with uncertainty below shot noise** in the signal quadrature, enhancing the precision of measurements that are limited by quantum noise.

This is done at room temperature by using materials which intrinsically absorb little thermal energy **to reduce thermal fluctuations** and the need for super-cooling.



Maria Goeppert Mayer was a theoretical physicist and Nobel Laureate who developed the mathematical model for the **structure of nuclear shells**, and first theorized **two-photon absorption** by atoms, as well as **double beta decay**.





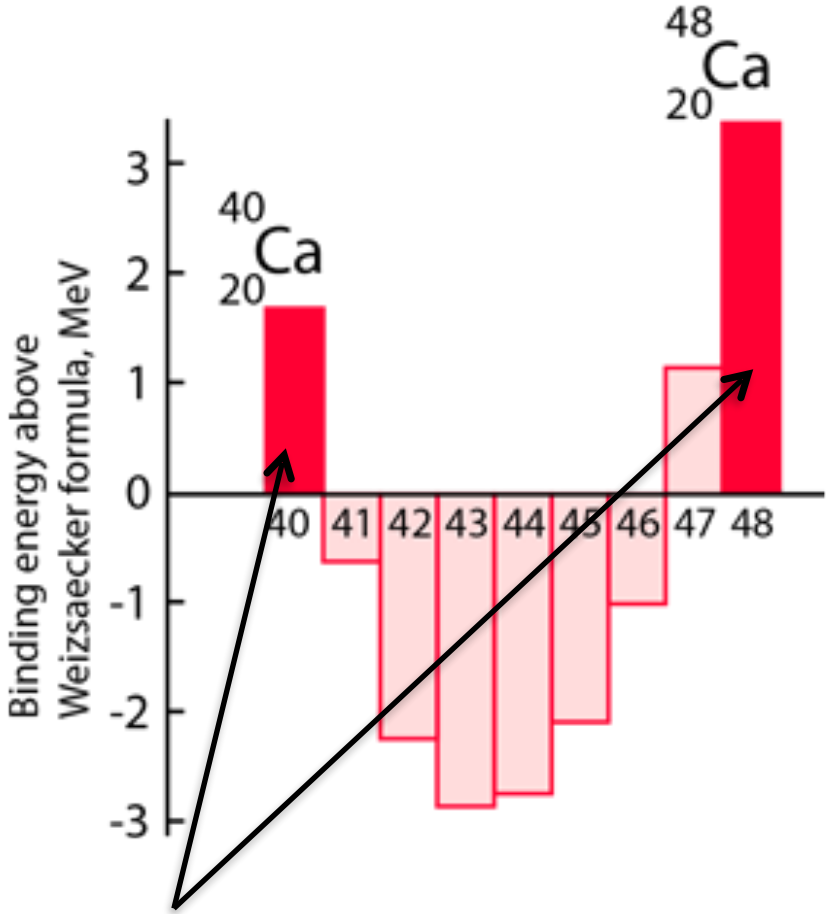


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While working on lists of isotope abundances, Goeppert Mayer noticed that **certain nuclei were especially stable,** namely those with **2, 8, 20, 28 or 50 protons or neutrons.**

These numbers were later termed **"magic numbers"** by Eugene Wigner.

To explain this, she suggested the **shell structure for nuclei, analogous to the electron shell structure in atoms.**



"Doubly magic" isotopes are particularly stable



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In the shell structure for nuclei, each nucleon moves in a central potential well created by other nucleons, and the orbits form a series of shells of increasing energy. Nuclei with completely filled outer shells are most stable. By also factoring in spin-orbit coupling, Goeppert was able to predict the 'magic numbers'.

"Woods-Saxon" *potential (strong interaction between nucleon and nucleus)*

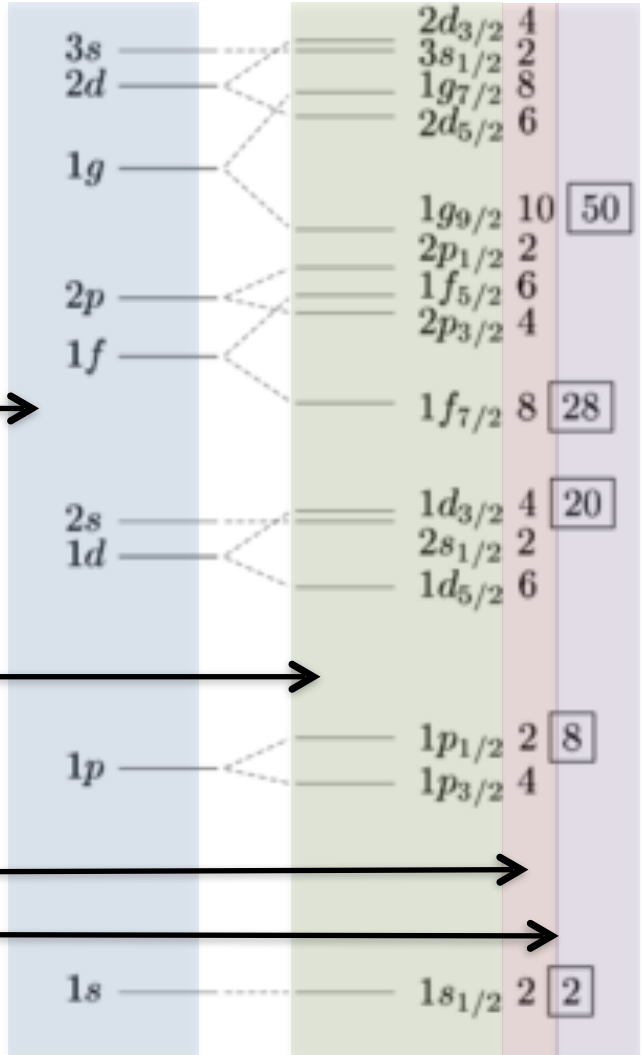
$$V(r) = -\frac{V_0}{1+\exp\left(((r-R)/\delta)\right)}$$

Spin-orbit coupling *included (interaction between orbital angular momentum and spin angular momentum)*

$$V(r) \rightarrow V(r) + W(r)\mathbf{L}\cdot\mathbf{S}.$$

Multiplicity of states

*"**Magic numbers**" = closed shells*





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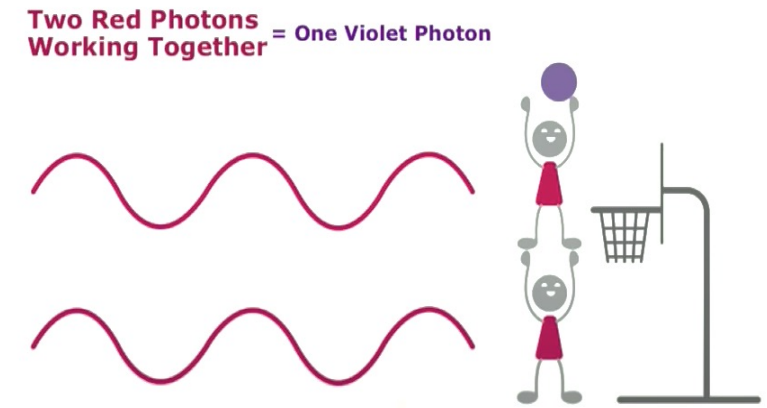
In her 1931 PhD thesis, **Goeppert Mayer predicted two-photon absorption.**
It took 30 years, with the invention of the laser, for this ever be observed!

Lasers are tightly packed enough that multiple light particles (**photons**) can interact with a single atom.

Photon energy ➔ **Height of player**

Height of basketball net ➔ **Energy required to free an electron**





If multiple photons work together, you can free electrons that are held more tightly!

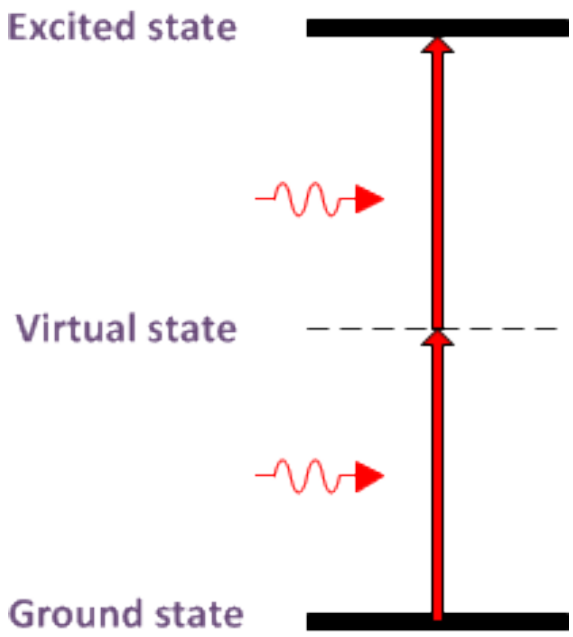
Source: D. Strickland Nobel Prize lecture



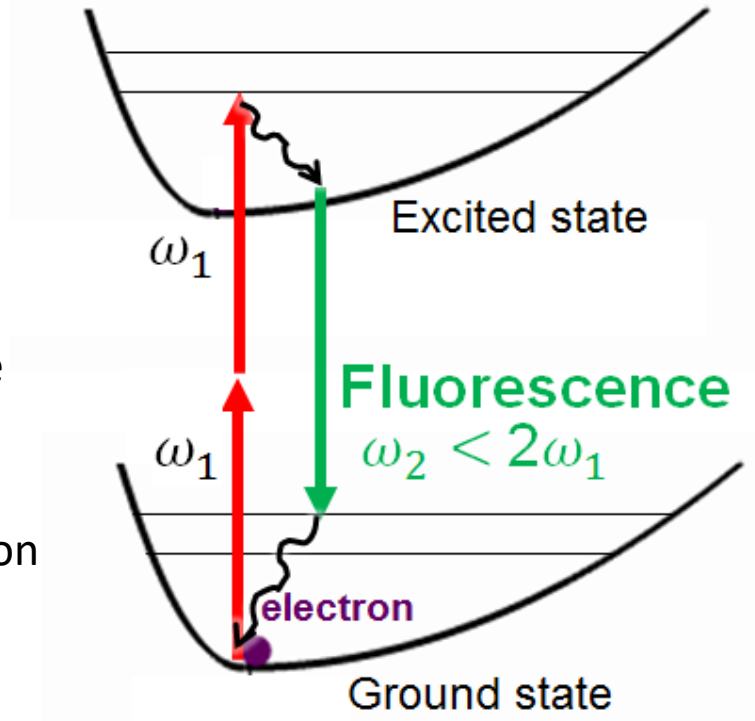
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In her 1931 PhD thesis, **Goeppert Mayer predicted two-photon absorption.**
It took 30 years, with the invention of the laser, for this phenomenon to be observed.

Two-photon absorption (TPA) = simultaneous absorption of two photons of identical of differing frequencies to excite a molecule from one energy state (ground) to a higher energy state.



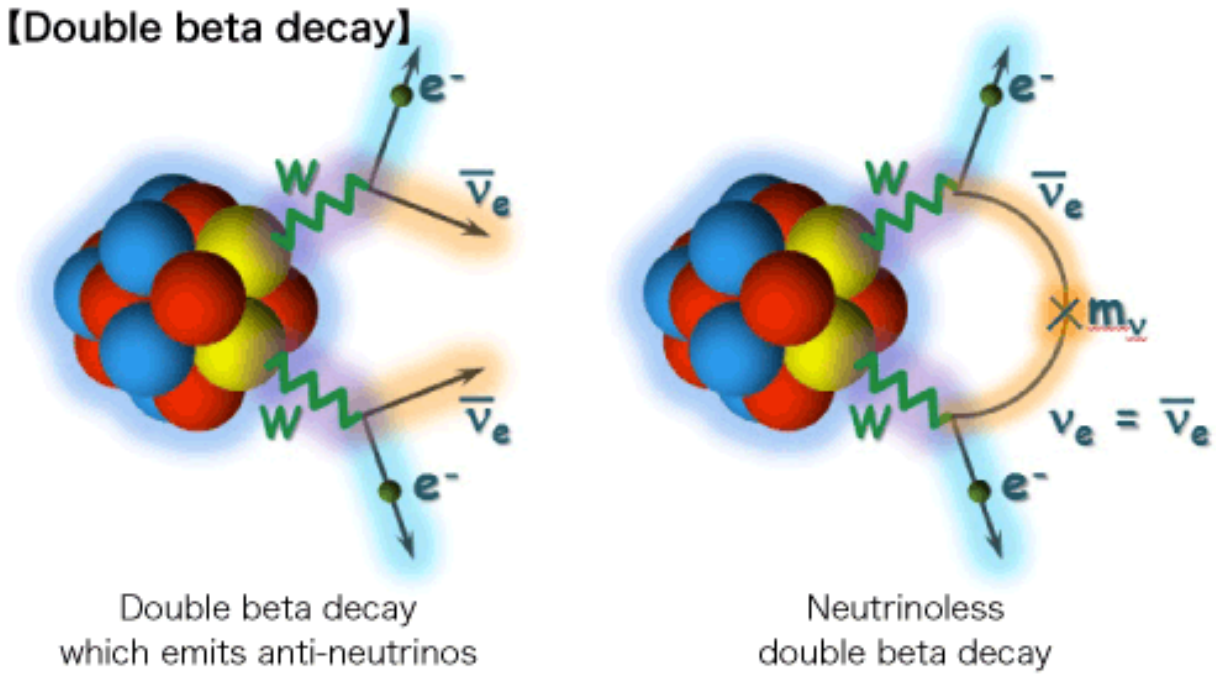
TPA of a fluorescent molecule leads to **two-photon excited fluorescence**, where the excited state decays by spontaneous emission of a photon





Maria Goeppert Mayer was a theoretical physicist and Nobel Laureate who developed the mathematical model for the **structure of nuclear shells**, and first theorized **two-photon absorption** by atoms, as well as **double beta decay**.

In 1935, **Goeppert Mayer predicted double beta decay.**
More than 50 years later, the first laboratory observation of double beta decay was made by Micheal Moe in 1987.



Double beta decay which emits anti-neutrinos

Neutrinoless double beta decay

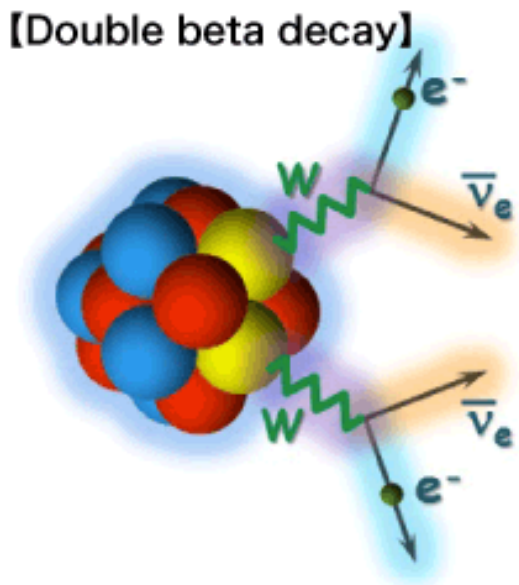
Double beta decay ($2\nu\beta\beta$) is a type of radioactive decay, where two neutrons transform into two protons inside an atomic nucleus and two beta particles (electrons or positrons) are produced.

Neutrinoless double beta decay ($0\nu\beta\beta$) is yet to be observed, but is theorized if the neutrino is it's own antiparticle (Majorana particle)



Maria Goeppert Mayer was a theoretical physicist and Nobel Laureate who developed the mathematical model for the **structure of nuclear shells**, and first theorized **two-photon absorption** by atoms, as well as **double beta decay**.

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Double beta decay
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Double beta decay ($2\nu\beta\beta$) is a type of radioactive decay, where two neutrons transform into two protons inside an atomic nucleus and two beta particles (electrons or positrons) are produced.

The process can be thought of as two β^- decays :

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p \rightarrow {}^{0}_{-1}\beta + \overline{\nu} $$

The final nucleus must have a larger binding energy than the original nucleus, and lepton number is conserved.



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SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

Double Beta-Disintegration

M. GOEPPERT-MAYER, *The Johns Hopkins University*

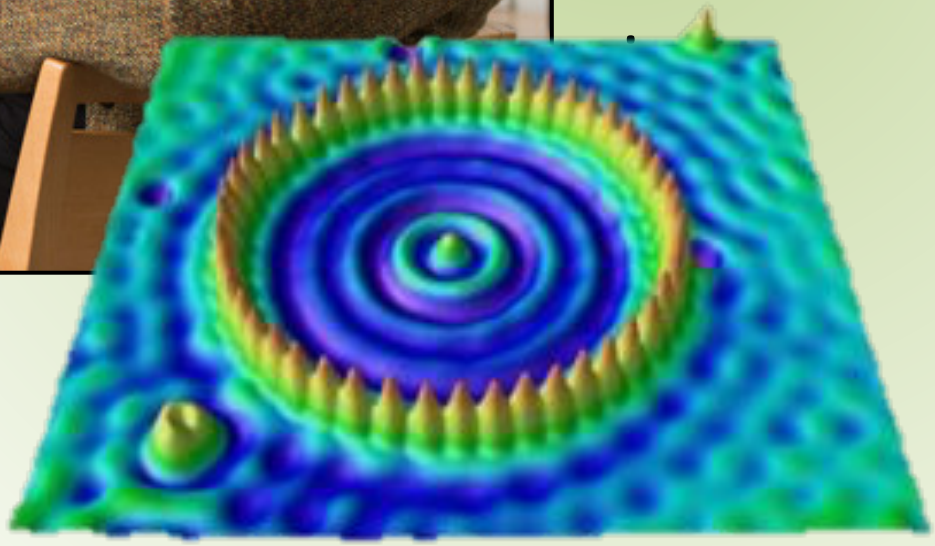
(Received May 20, 1935)

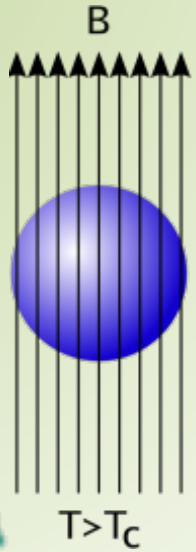
From the Fermi theory of β-disintegration the probability of simultaneous emission of two electrons (and two neutrinos) has been calculated. The result is that this process occurs sufficiently rarely to allow a half-life of over 10^{17} years for a nucleus, even if its isobar of atomic number different by 2 were more stable by 20 times the electron mass.

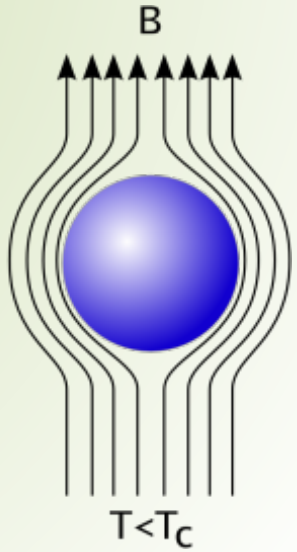
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Kathryn Moler is a physicist who develops instruments which allow us to **see down to the atomic and quantum scale**. She has also contributed to furthering our understanding of **unusual superconductors**.







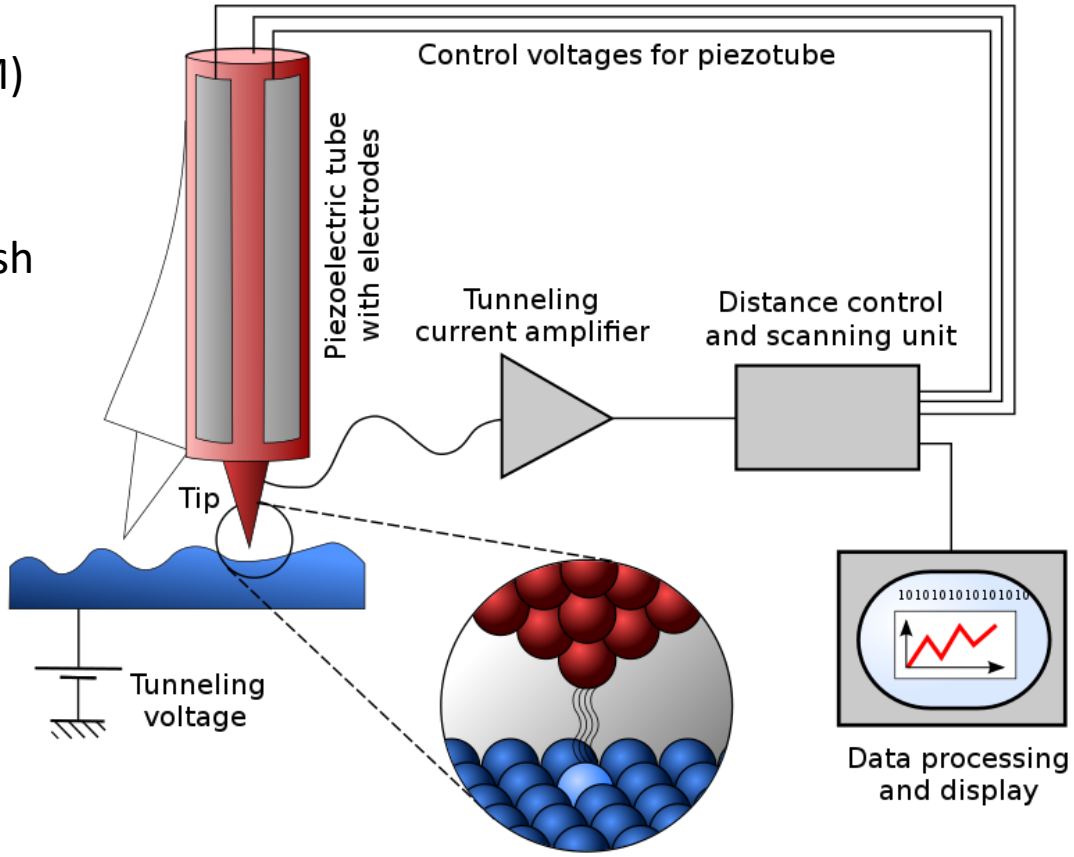


Kathryn Moler is a physicist who develops instruments which allow us to see down to the **quantum scale**, and has contributed to furthering our understanding of **unusual superconductors**.

How can we see down to the atomic level?

A **scanning tunneling microscope** (STM) is a type of microscope that can image surfaces at the atomic level by using a sharp conducting tip that can distinguish surface features of a material at a fraction of a nanometer.

STM uses **quantum tunneling**: a bias voltage applied between the tip and surface allows electrons to tunnel through the vacuum between them, creating a **tunneling current**. The current is a function of tip position, voltage, and the l**ocal density of states**.





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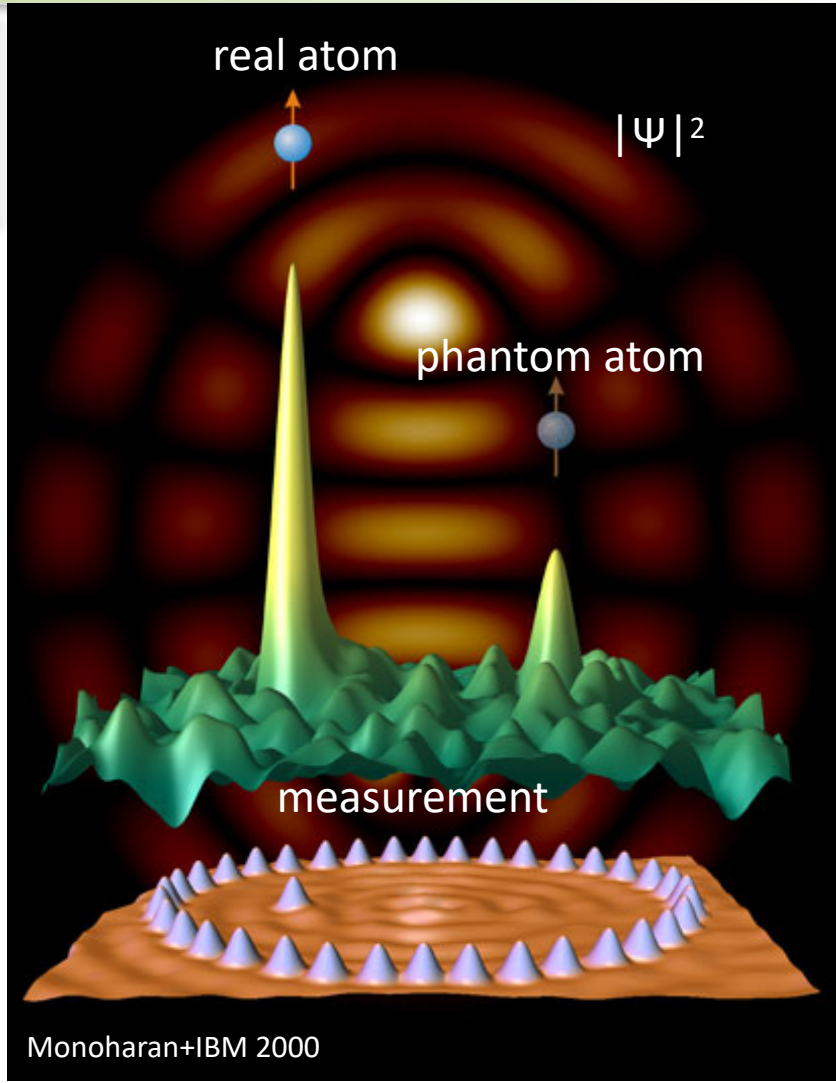
*Moler and colleagues at the **Centre for Probing the Nanoscale** develop techniques that **allow researchers to "see" wavefunctions**.*

Low temperature STM imaged a **"quantum mirage"**.

Cobalt atoms were individually arranged on a copper surface in an ellipse such that the wavefunction of the electrons formed **standing waves** in the ellipse with concentrated electron densities at each focus point.

When placing an atom of magnetic cobalt at one focus, **a mirage appeared at the other focus**, the same electronic states but at a third of the intensity.

This technique allows scientists to remotely probe atoms, and manipulate individual electrons or nuclear spins.



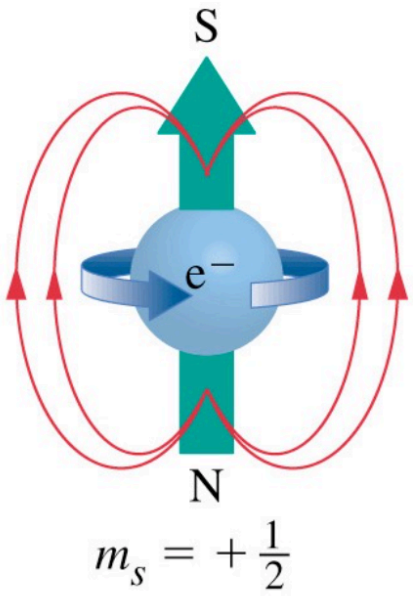


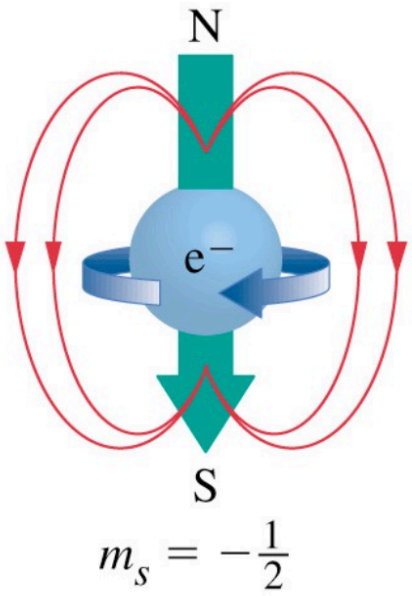
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How do magnetic fields help us understand quantum properties?

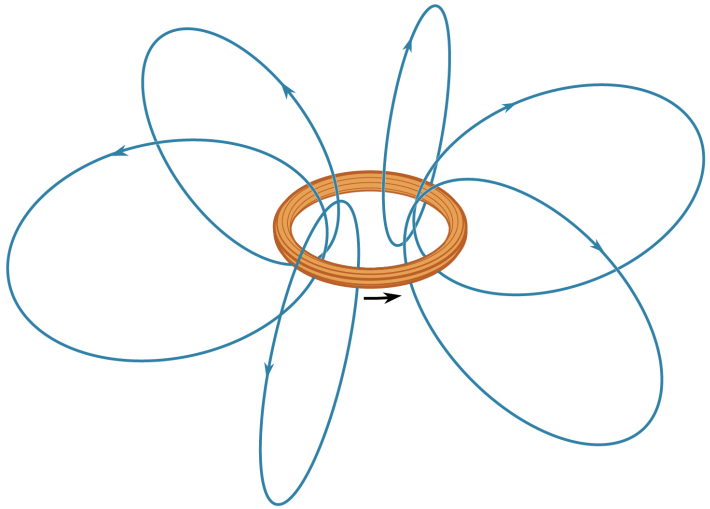
Electrons are charged particles in motion!

Moler's group uses magnetic fields to study quantum properties of materials.





Magnetic **dipole moment** created by the spin of an electron



Magnetic field created by the motion of a moving charge (electron)



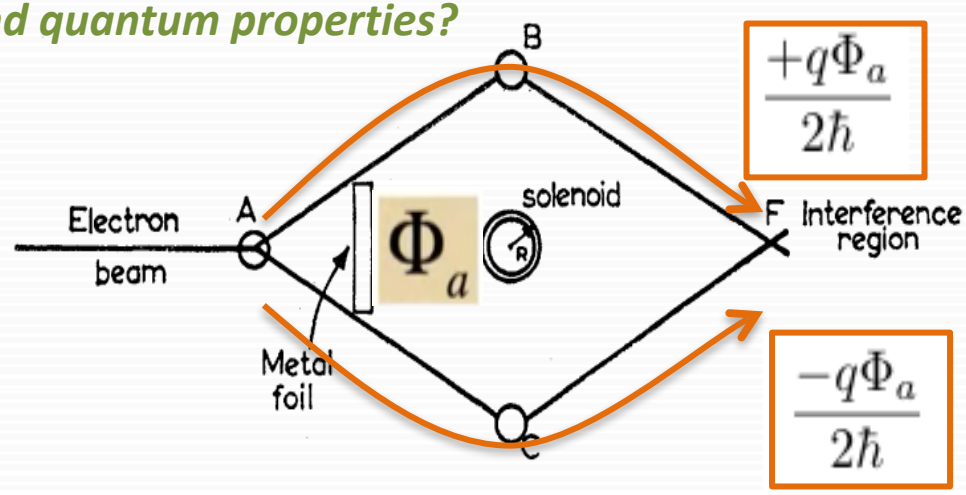
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How do magnetic fields help us understand quantum properties?

The wave nature of particles means constructive and destructive interference is possible.

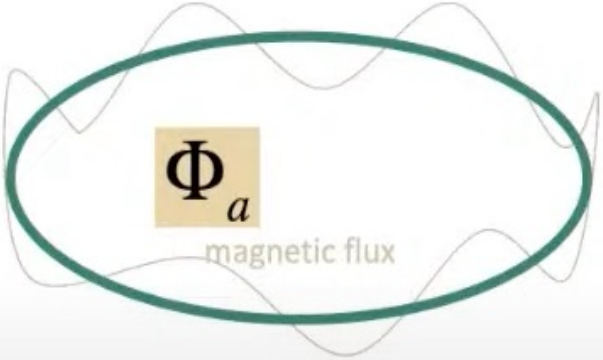
Experiment: A beam of electron is split, and a magnetic flux is passed through the loop.

Electrons are charged, so the Hamiltonian depends on magnetic vector potential and therefore can change the phase of the electron**. They pick up equal and opposite phases and interfere at the end of the loop.**



$$H_{\vec{A}} = \frac{1}{2m}\left(\frac{\hbar}{i}\vec{\nabla} - q\vec{A}\right)^2 + \ldots$$

q = particle charge



$$\Phi_0 = \frac{h}{e}, \frac{h}{2e}\cdots$$

In a superconducting ring, the phase must wind by an **integral number of 2π's.** The **flux quantum** depends on the **charge carriers**, and is therefore a way to probe phase-coherent charges states



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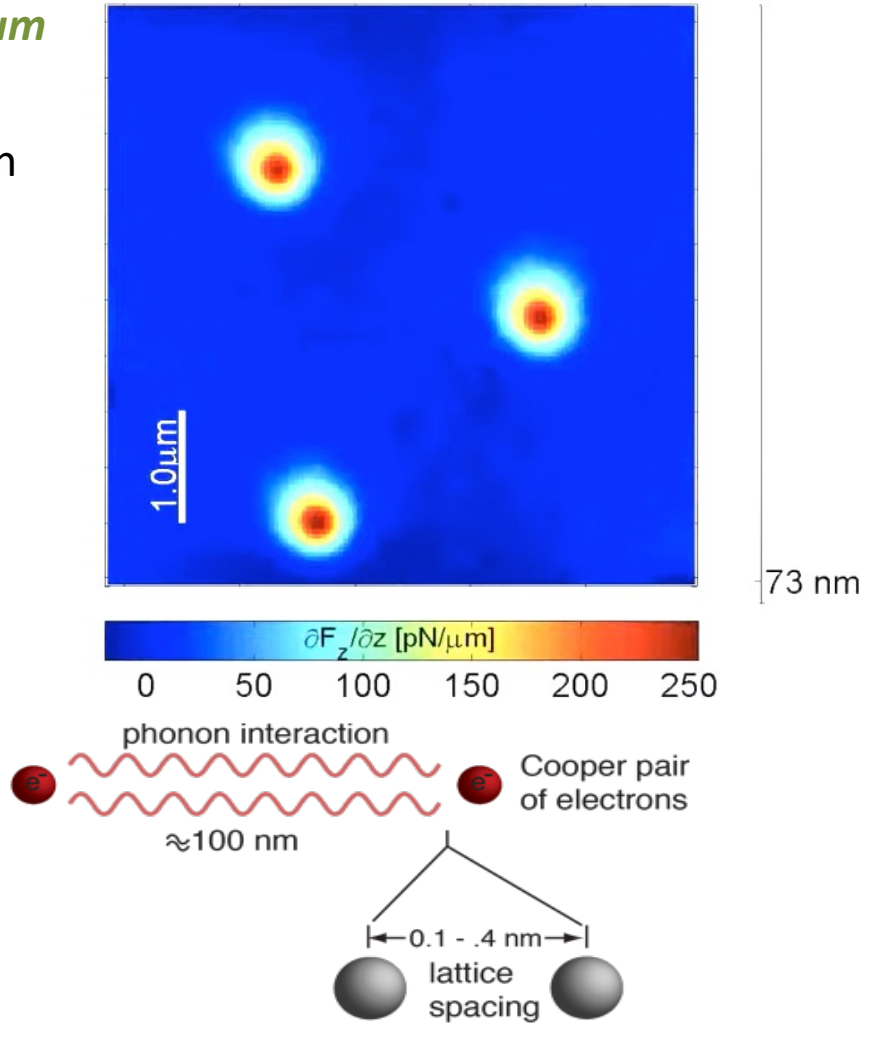
How do magnetic field help us understand quantum properties?

These are **vortices in a superconductor** trapped on defects at low temperature, from the Moler lab.
All vortices carry magnetic flux of exactly:

$$\Phi_B = \frac{hc}{\boxed{2e}}$$

This is proof of **cooper pairs!**

- Paired state of electrons with lower energy than the Fermi energy (**bound**)
- Arise due to **electron-phonon** interactions in superconductors
- Pairs have the same phase: "phase coherent"
- Total spin = 0 or 1
  - composite boson
  - cooper pairs can occupy the same state





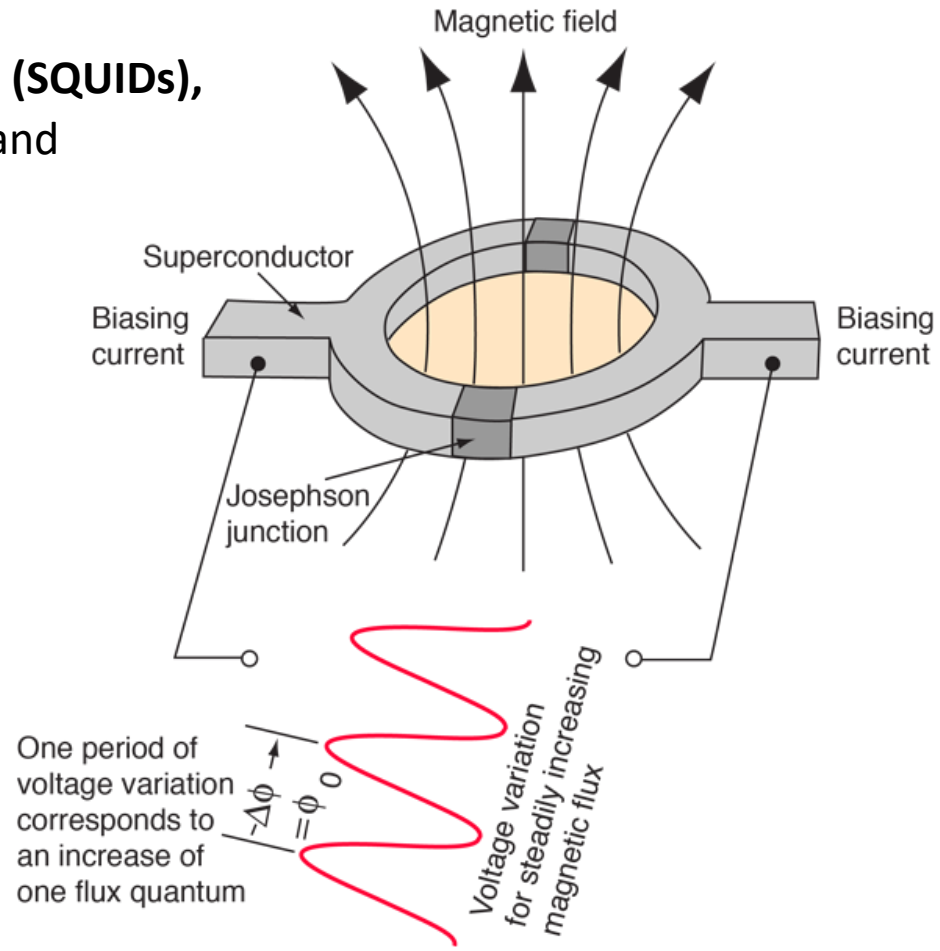
Kathryn Moler is a physicist who develops instruments which allow us to see down to the **quantum scale**, and has contributed to furthering our understanding of **unusual superconductors**.

Moler and her team develop and use **Scanning Superconducting Quantum Interference Devices (SQUIDs),** which allow you to image dynamics in magnetic and superconducting materials and devices.

SQUIDs are made from:

- a micron-scale pickup loop for detection of local magnetic flux
- a field coil to apply a local magnetic field to the sample
- a modulation coil to operate the SQUID sampler in a flux-locked loop to linearize the flux response



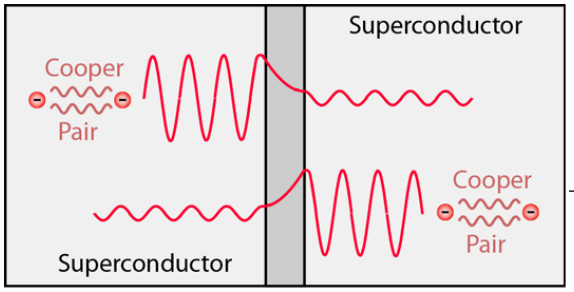


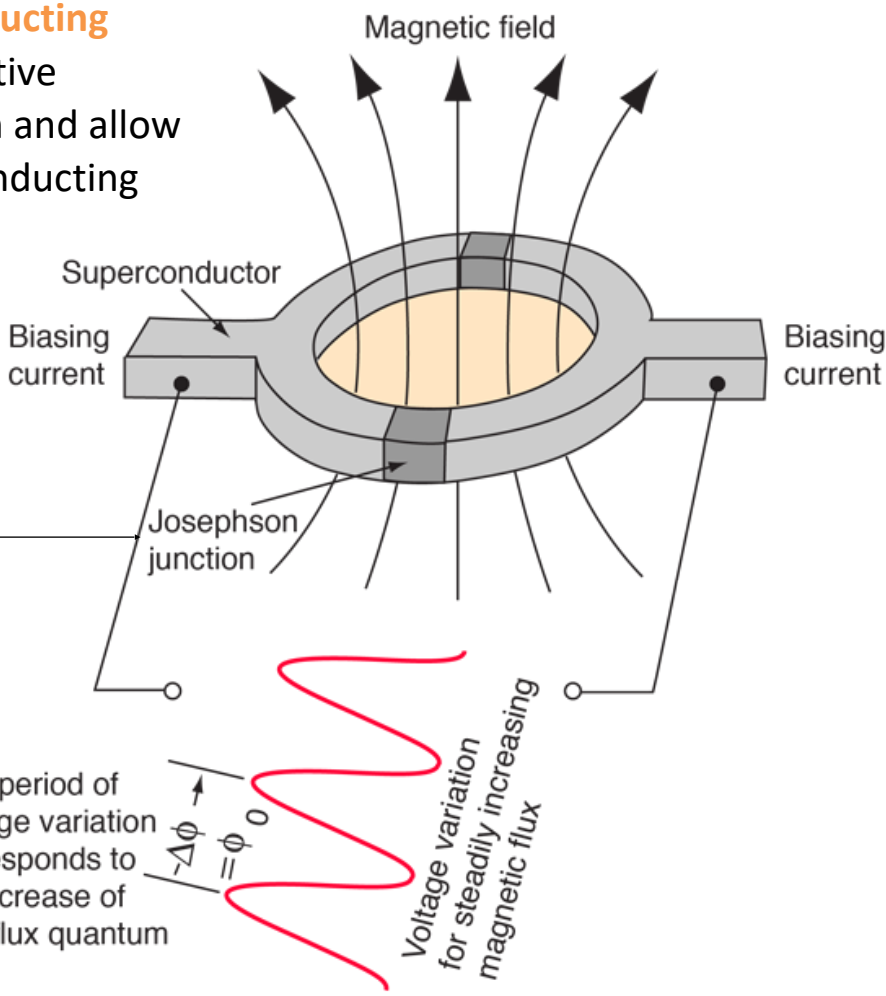


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Moler and her team develop and use **Scanning Superconducting Quantum Interference Devices (SQUIDs)**, extremely sensitive **magnetometers** which take advantage of flux quantization and allow you to precisely image dynamics in magnetic and superconducting materials and devices.

DC SQUIDs use two parallel **Josephson Junctions** in a loop.





With a constant bias current across the SQUID, the measured **voltage oscillate with the changes in phase** at the two junctions, which depends on the **change in magnetic flux**.

Counting oscillations allows you to evaluate the flux change.



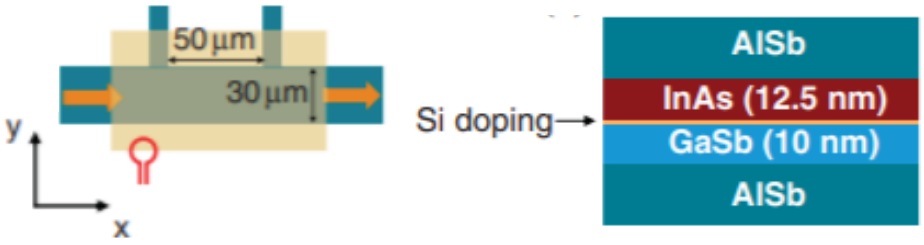
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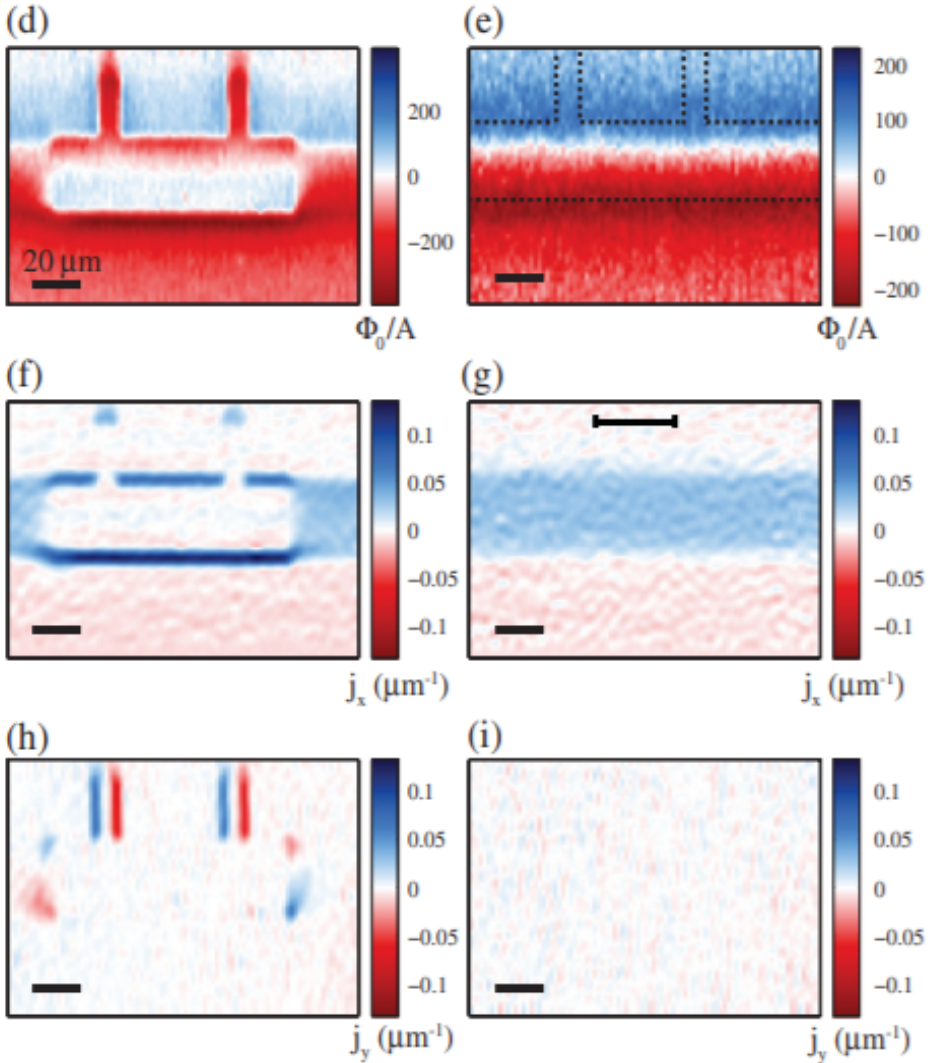
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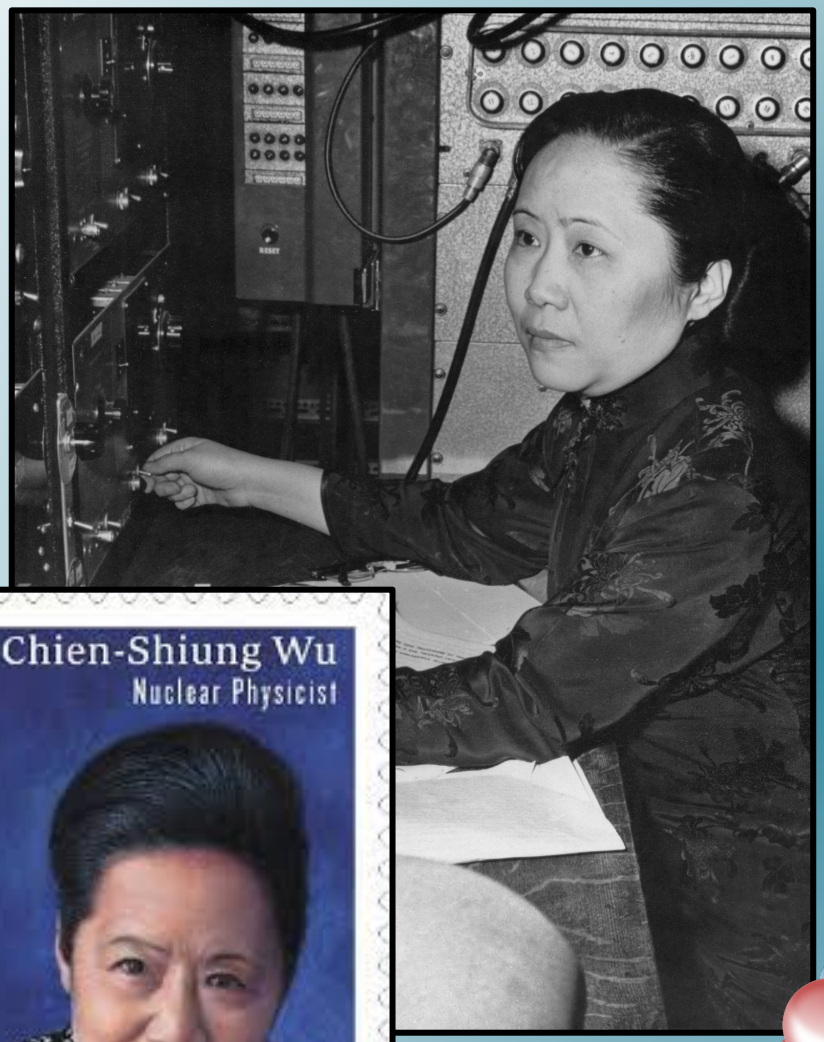
The SQUID can detect **tiny currents via the magnetic flux they create** in their vicinity.

Moler's group made these measurements of a quantum spin Hall insulator (QSHI) with counterpropagating spin-polarized edge states.

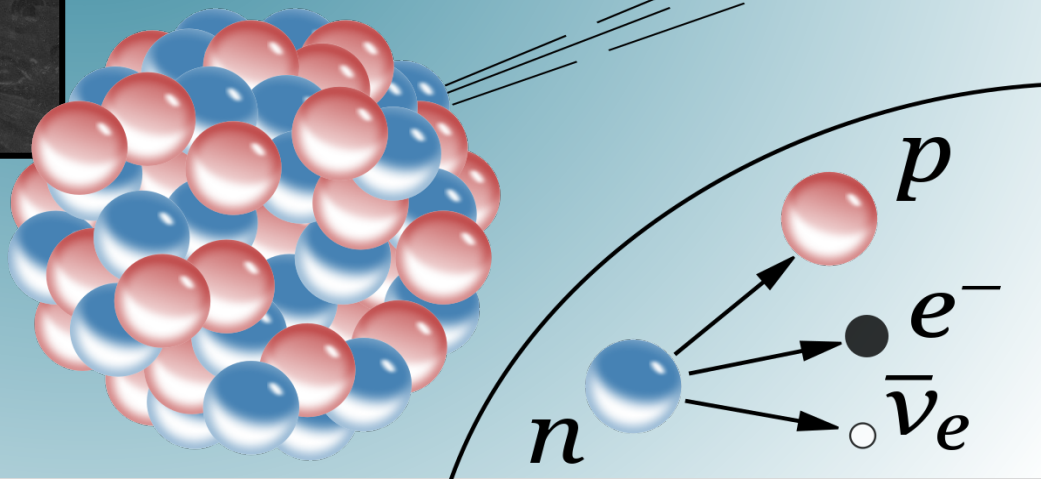
The flux is seen wrapping around the 1d edge currents, and reversal of the magnetic flux density vector indicates the directional change of the current density (red and blue).







Chien-Shiung Wu was a physicist who pioneered experimental research in **nuclear weak interaction**, showing **parity is not always conserved** through demonstration of **beta decay asymmetry**.





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Wu established the theory of **beta decay**, first theorized by Enrico Fermi.

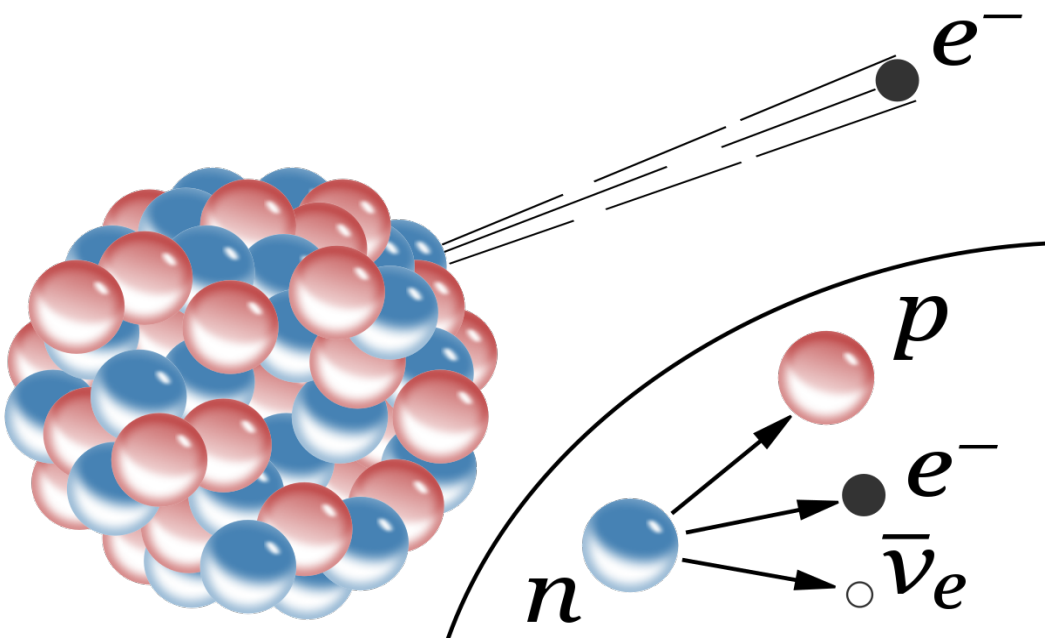
Beta decay: radioactive decay where a **beta particle** (energetic electron or positron) is emitted from an atomic nucleus. This process transforms the original nuclide into an **isobar** of that nuclide (same number of nucleons, same mass, **different atomic number**).

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p \rightarrow {}^{0}_{-1}\beta + \bar{\nu} $$

$$ {}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni}^{+} + e^{-} + \bar{\nu}_e $$

Beta decay of a neutron (β^-) transforms it into a proton, and creates an electron and antineutrino.

Beta decay of a proton (β^+) transforms it into a neutron, and creates a positron and electron neutrino





Chien-Shiung Wu was a physicist who pioneered experimental research in **nuclear weak interaction**, showing **parity is not always conserved** through demonstration of **beta decay asymmetry**.

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Beta decay is due to the **weak force**.

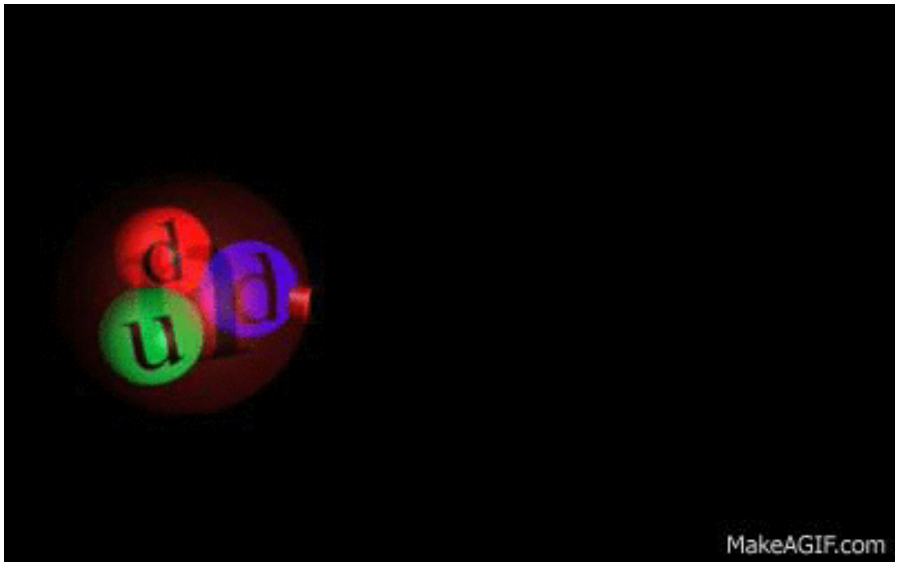
Neutron ➔ two down quarks, one up quark
Proton ➔ two up quarks, one down quark

Weak force allows a **quark** to change its flavour by emission of a **W boson** (intermediate vector boson) which leads to the creation of a beta particle and the corresponding neutrino/antineutrino.

Beta decay of a neutron (β^-) transforms it into a proton, emits an electron and antineutrino.

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p \rightarrow {}^{0}_{-1}\beta + \bar{\nu} $$

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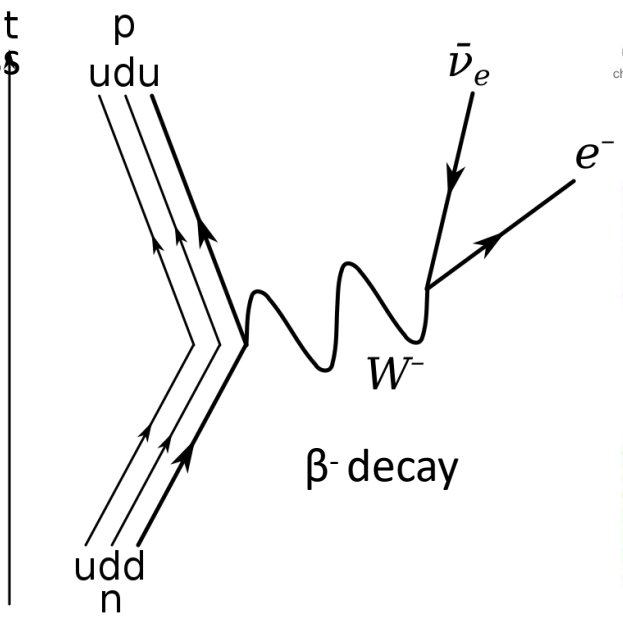


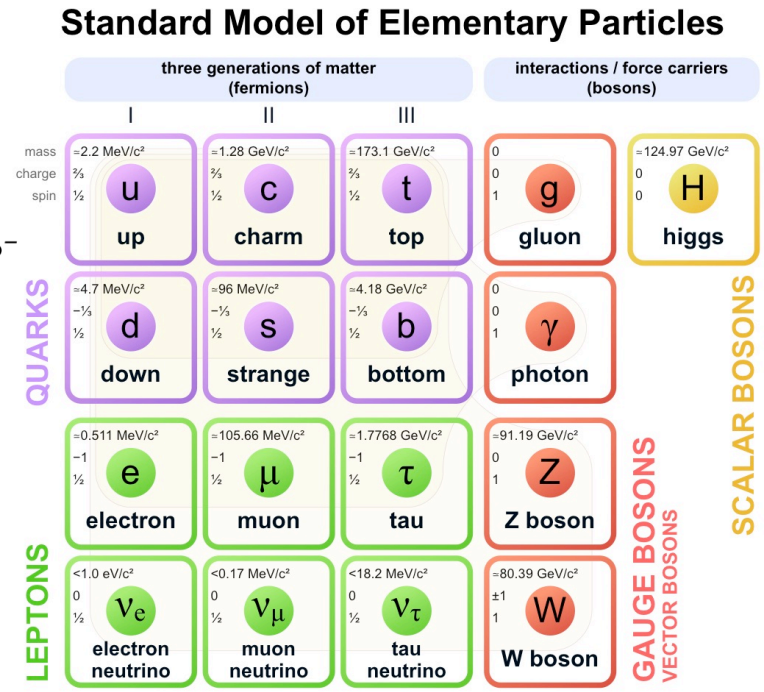
Chien-Shiung Wu was a physicist who pioneered experimental research in **nuclear weak interaction**, showing **parity is not always conserved** through demonstration of **beta decay asymmetry**.

The **weak force** is the mechanism of interaction between subatomic particles that is responsible for the **radioactive decay of atoms**. It's effective range is **less than the diameter of a proton**, and is felt by all fermions.

The weak force is characterized by long lifetimes, and small cross sections.

It's mediated by two massive gauge bosons: the charged ***W*± boson** and the neutral ***Z*⁰ boson**.







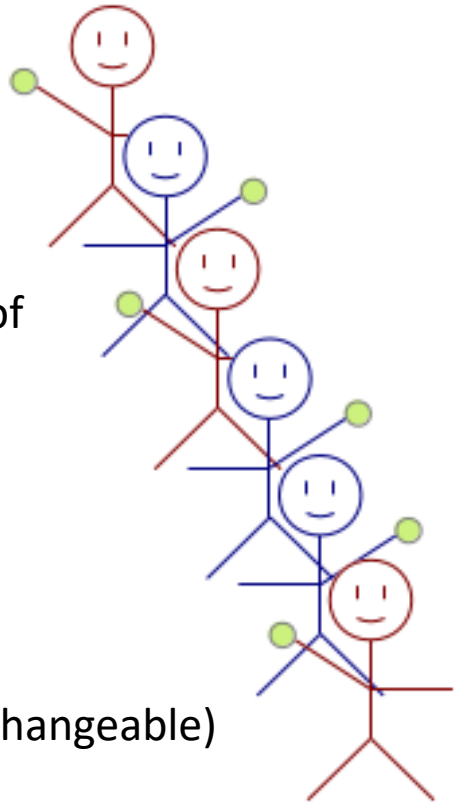
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PARITY CONSERVATION

Parity conservation is a rule that dictates that in a **mirror-image world**, objects should behave in mirror-image ways. In other words, "left" and "right" have no physical definition.

$$\mathbf{P}: \begin{pmatrix} x \\ y \\ z \end{pmatrix} \mapsto \begin{pmatrix} -x \\ -y \\ -z \end{pmatrix}$$

Imagine a lineup of people ready to throw tennis balls, equally made up of left and right-handed throwers.



*In a **parity-conserved** world :*

- Balls would end up the same average distance to the left and right of the throwers.
- This means left-handed and right-handed people throw the same way, but inverted.

*In in **parity-violating** world:*

- Balls on the right might be found to have travelled further
- Right handed people are not a true inversion of the left! (Not interchangeable)

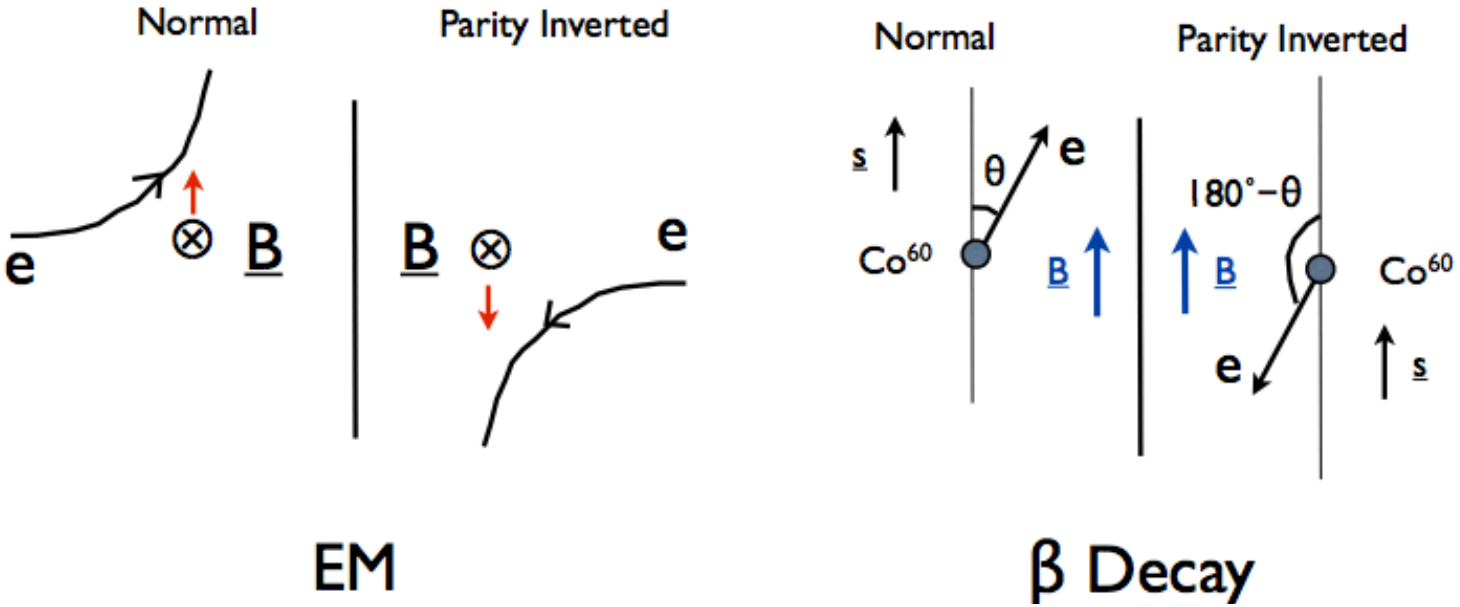


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PARITY CONSERVATION

Parity conservation is a rule that dictates that in a **mirror-image world**, objects should behave in mirror-image ways. In other words, "left" and "right" have no physical definition, and do not affect the laws of physics.

$$\mathbf{P}: \begin{pmatrix} x \\ y \\ z \end{pmatrix} \mapsto \begin{pmatrix} -x \\ -y \\ -z \end{pmatrix}$$



EM β Decay

Axial vectors do not change sign under parity transformation, whereas polar vectors do.

$\vec{L}$ **is an axial vector**
$\vec{p}$ **is a polar vector**

Parity is conserved in electromagnetism. What about beta decay?



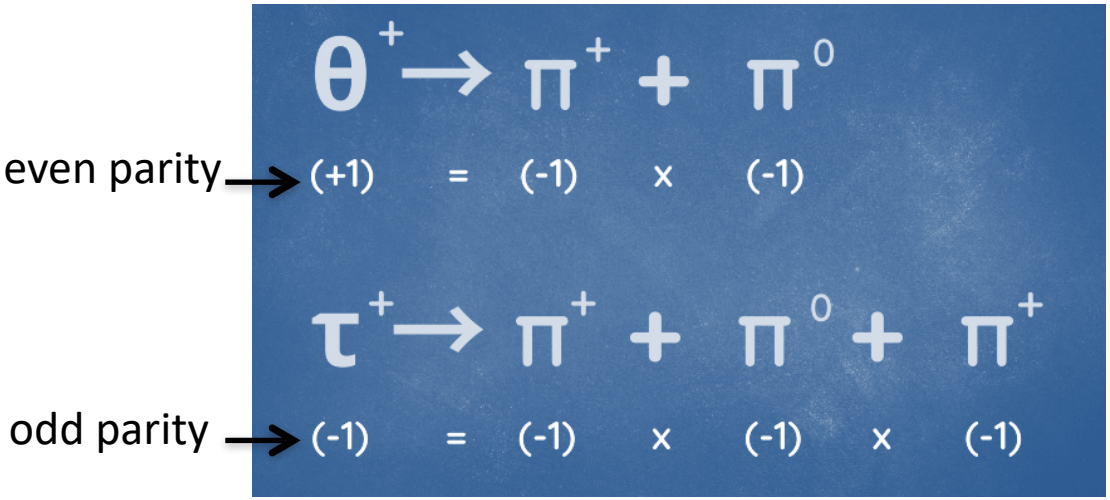
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➢ The electromagnetic force and strong nuclear force had both been deemed to conserve parity. The weak force, however, had no such proof!

In the 1950's, the **decay of ϑ and τ kaons** could not be explained by existing theories in which parity conservation was true. Although identical in every respect (mass, spin, charge, etc.), the mesons decayed into different parity states.

After observing this, C.D. Yang and T.D. Lee in 1956 theorized that **parity was not conserved in the weak interaction** and these particles were indeed the same.

Chien-Shiung Wu devised the elegant experiment to test the possibility of parity violation in beta-decay.





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Wu set up the following system to test parity violation in beta decay:

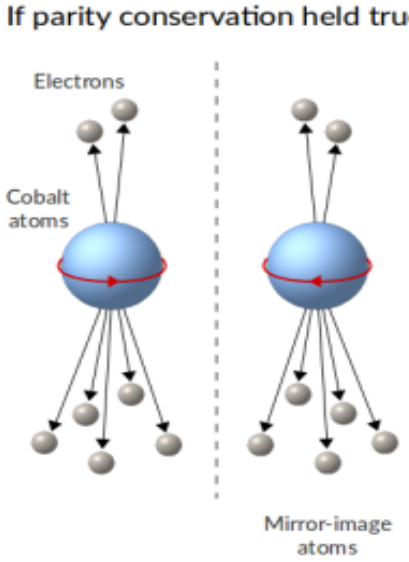
$$^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + e^- + \bar{\nu}_e + 2\gamma$$

- Aligned all Co^{60} spin vectors with a magnetic field, cooled to near absolute zero, and let them decay.
- Detected **electron and gamma-ray emission** (EM emission conserves parity, acts as a control measure of anisotropy of alignment).

The spin vector remains in same direction in parity-transformed world , but electron emission vector is inverted.

Parity symmetric ➔ observe no preference in emission direction of electrons, and isotropic emission in both real and mirror world.

Parity breaking ➔ observe emission aligned in a preferential direction, making mirror image asymmetric.



Angular momentum = axial vector
Momentum = polar vector



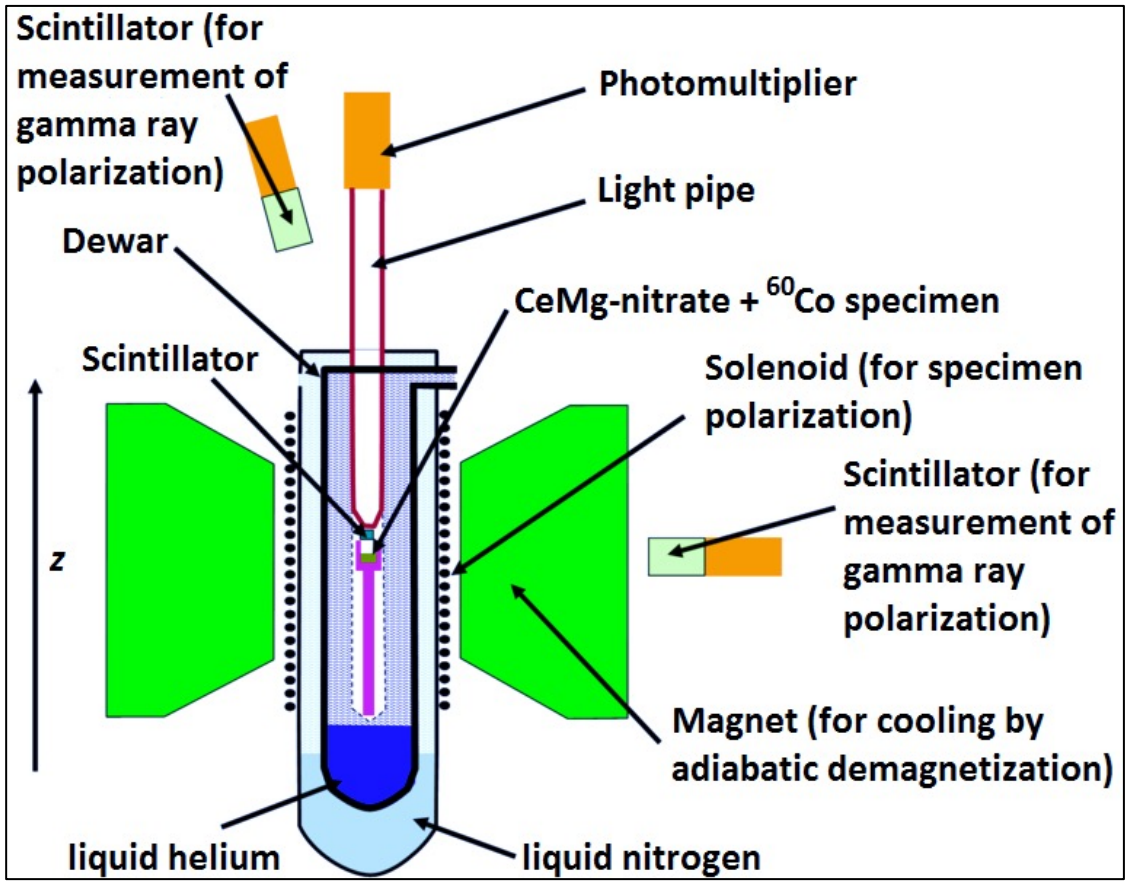
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The small magnetic moments of Co^{60} required **strong magnetic fields at extremely low temperatures** to polarize the sample as much as possible, through **adiabatic demagnetization.**

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<u>Experiment:</u>

a. Reverse the direction of the magnetic field and measure asymmetry in the beta decay rates to test parity conservation.
b. Measure the gamma-ray anisotropy to confirm the polarization.

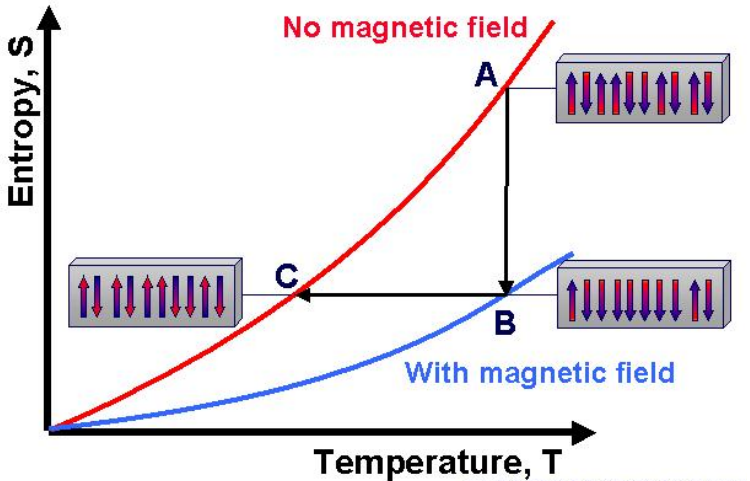




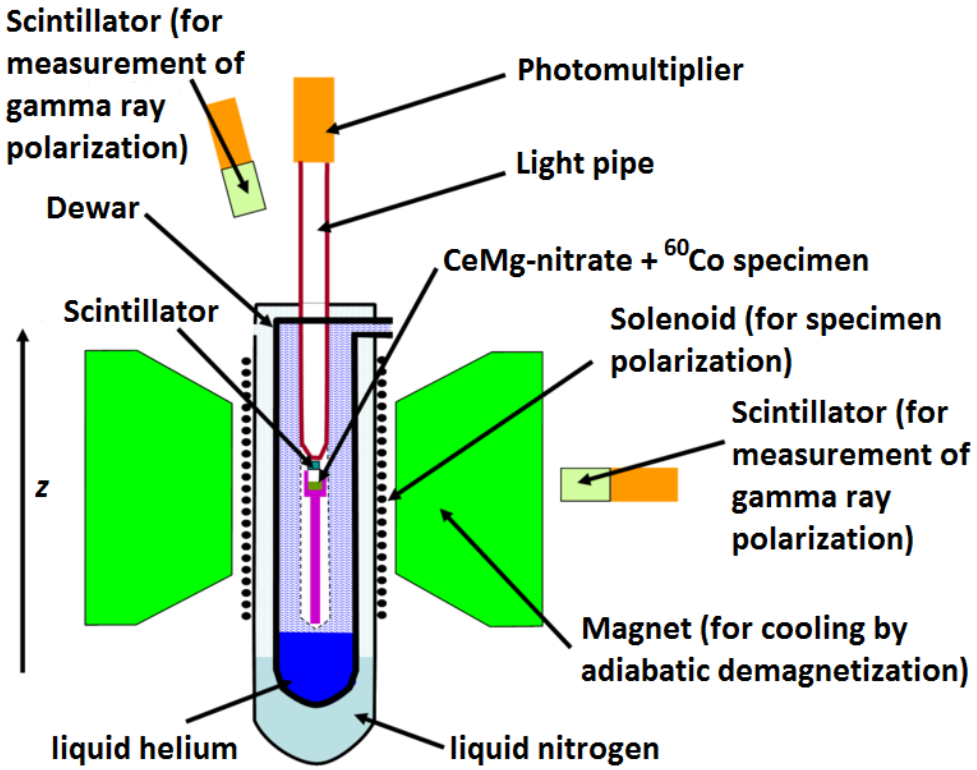
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The small magnetic moments of Co^{60} required **strong magnetic fields at extremely low temperatures** to polarize the sample as much as possible, through **adiabatic demagnetization.**

- Cobalt was deposited on a paramagnetic salt magnetized along the axis of high g-factor.
- Cooled to 1.2K via low pressure helium.
- Magnetic field replaced by solenoid along low g-factor axis, reducing temperature to 0.003K



$$^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + e^{-} + \bar{\nu}_e + 2\gamma$$





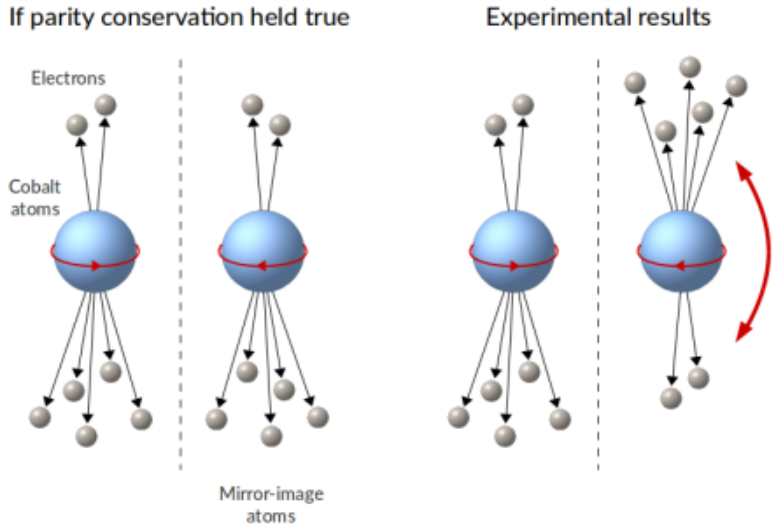
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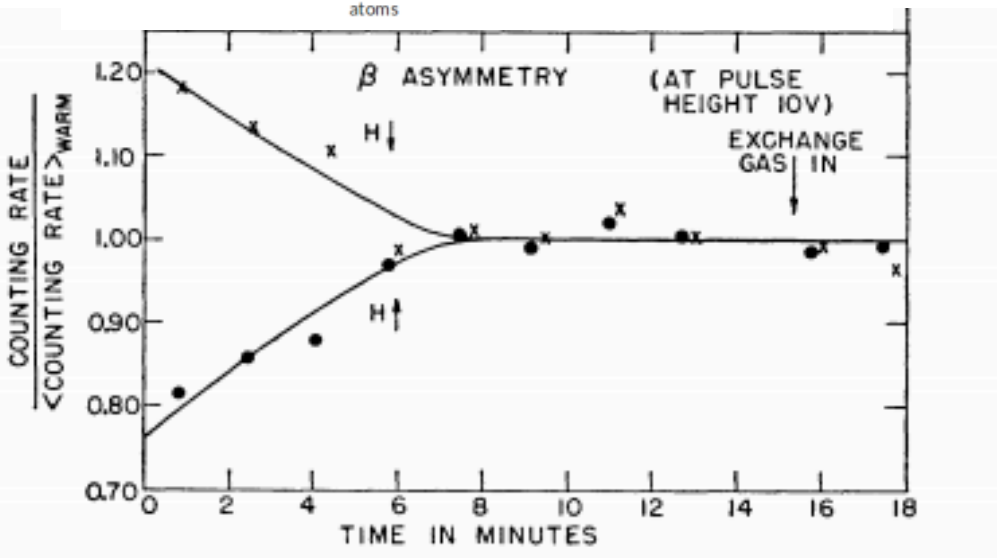
Observations from Wu's experiment:

- 60% of gamma rays emitted in one direction, 40% in the other
- Electron asymmetry much greater than gamma-ray anisotropy
- Electrons emitted in a direction **preferentially opposite to nuclear spin** direction
- Electron asymmetry did not change sign when magnetic field was reversed (*not due to remnant magnetization!*)

Conclusion:

- **Parity violation was maximal!**



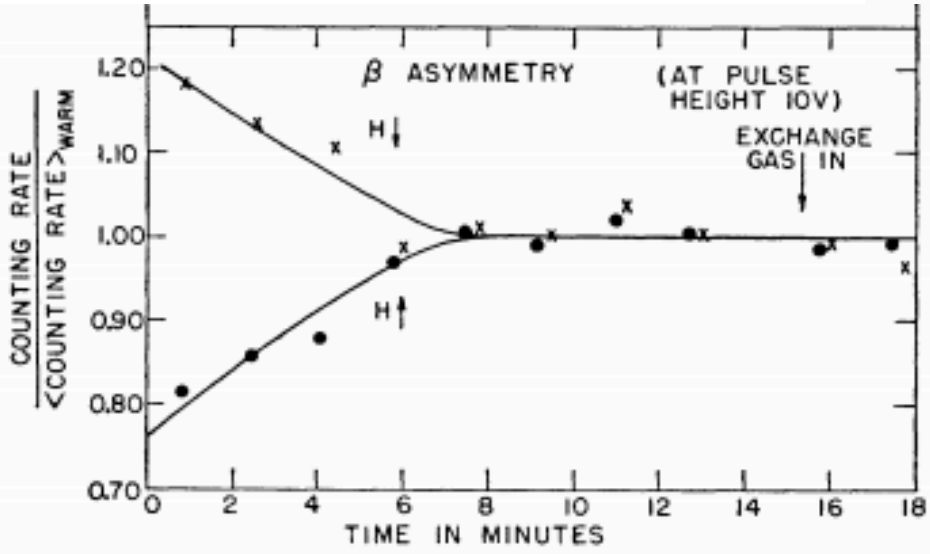


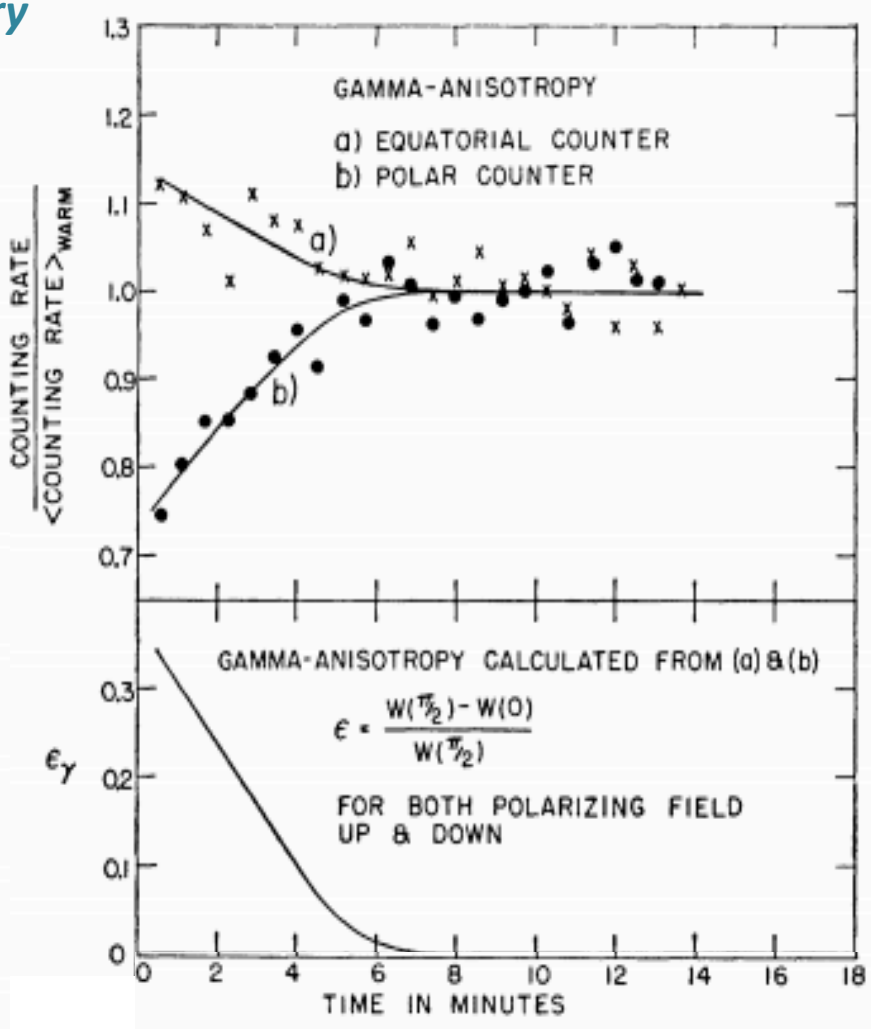


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Figure: Gamma anisotropy and beta asymmetry for polarizing field pointing up and pointing down.

- After about 6 minutes the sample warms up and polarization is lost (same time for both beta and gamma anisotropy)
- Clear beta asymmetry
- Sign of beta asymmetry is negative, beta emission opposite direction to spin







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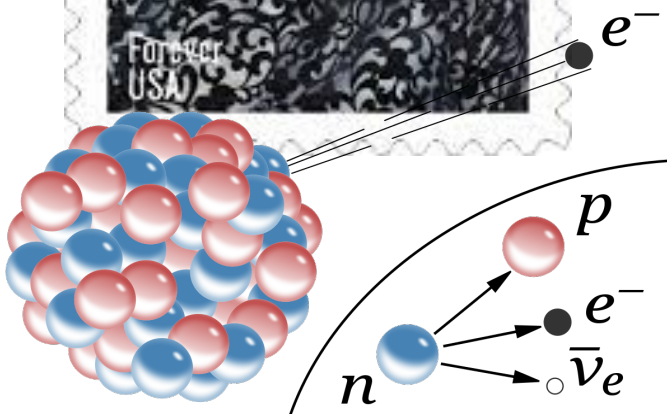
Chien-Shiung Wu's legacy

C.D. Yang and T.D. Lee were awarded the Nobel Prize for their theory of parity violation in the weak interaction, and Wu was mentioned in the award speech.

Many believe she was greatly overlooked for the Nobel Prize as she conducted the experimental work that brought their theory to fruition.

Wu has since received recognition, including but not limited to the Wolf Prize, National Medal of Science in Physics, and election as president of the American Physical Society in 1975.







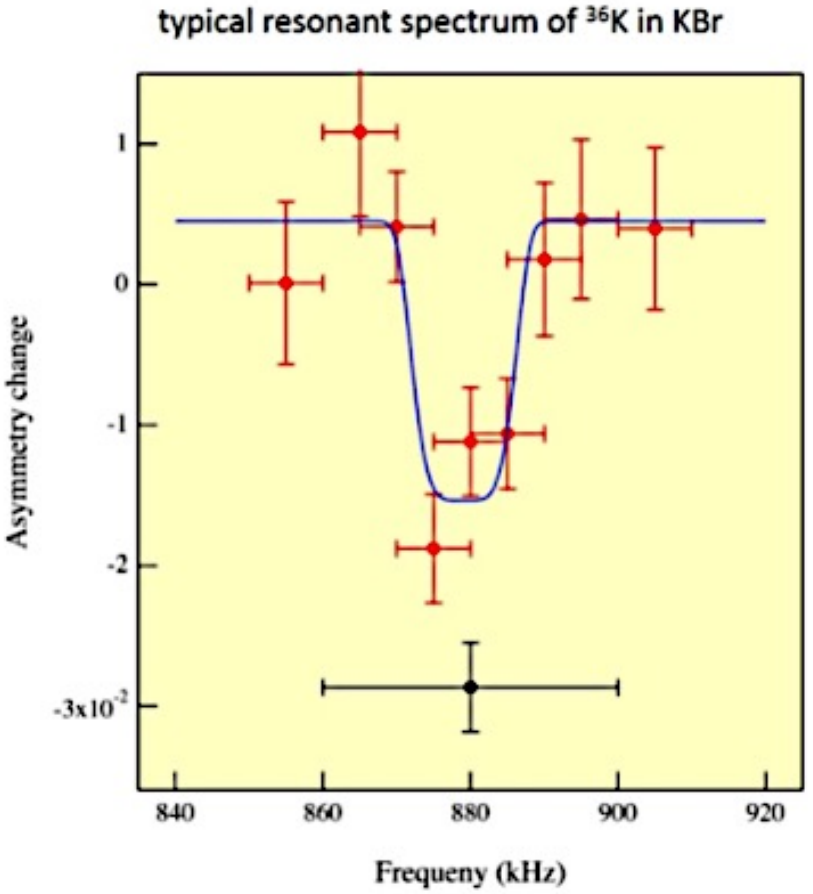
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Chien-Shiung Wu's legacy: Beta-NMR

The discovery of anisotropic emission of beta particles from polarized nuclei, allowed for the development of **Beta-detected Nuclear Magnetic Resonance** (Beta-NMR). Beta-NMR is one of the **most sensitive methods for determining electric quadrupole and magnetic dipole moments**.

Radio frequencies are used to induce **transitions between Zeeman levels** at the **Larmor Frequency** of spin-aligned beta-decaying radioactive nuclei, destroying the asymmetric beta-ray distribution in such a way that this resonant frequency can be retrieved. The magnetic dipole moment can be deduced from the Larmor frequency if the nuclear spin is known.

Beta-NMR has wide applications, including material characterization, and detecting metal-ion interactions with biomolecules.



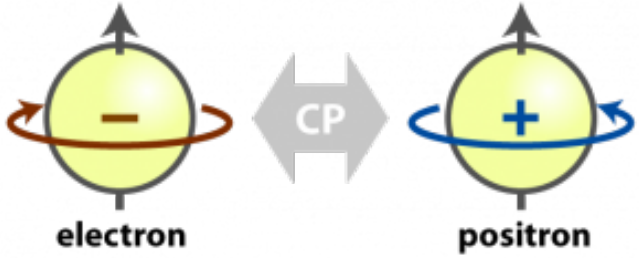


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Chien-Shiung Wu's legacy: Cosmology

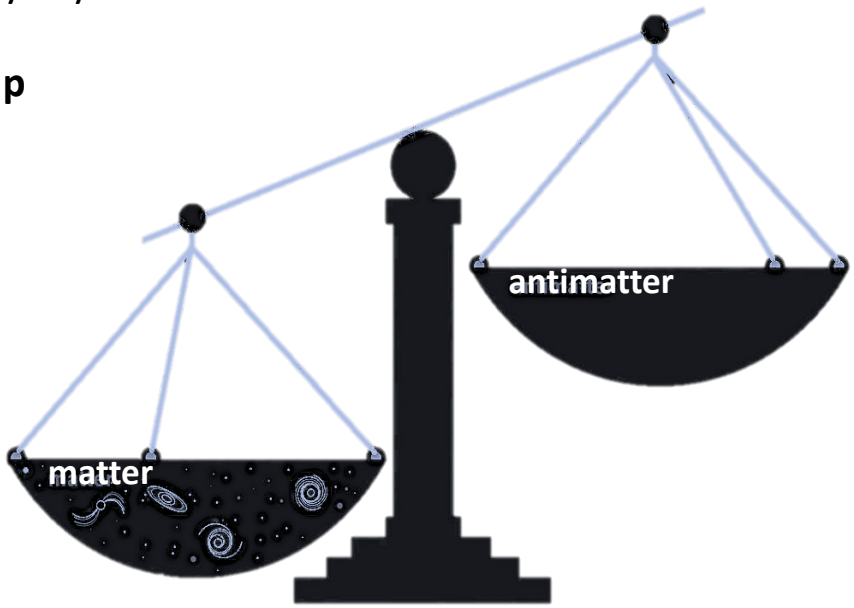
Following Wu's discover of parity-violation**, charge conjugation parity symmetry (CP symmetry)** was proposed to restore order, a rule which dictated that laws of physics remained the same when:

- all particles are exchanged with their antiparticles
- spatial coordinates are mirrored.



CP violation was directly observed in strange B-meson decays by LHCb in 2013.

The non-dark-matter part of our Universe is **mostly made up of matter**, as opposed to 50-50 matter and antimatter. This imbalance has been theorized by cosmologists as a direct result of CP violation occurring in the first seconds after the big-bang (**Sakharov Conditions**).



Physical laws **must have acted differently for matter and anti-matter (CP violation)** to produce a matter-dominated universe instead of a radiation dominated universe caused by matter-antimatter annihilation.



Rachel McKendry is a chemist and digital public health pioneer





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Slide on NV diamonds



Rachel McKendry is a chemist and digital public health pioneer

Slide on nanosensing in vitro



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General slide on the goals of her team?