Quantum Superposition and Interference

September 30, 2022

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UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing | NIST | TQT Transformative Quantum Technologies

Outline

1. Background and Intro
2. Case 1: Characterizing the structures in the macula
3. Case 2: Ghost Imaging
4. Case 3: Precise measurement of Big G
5. Case 4: Structured probes of topological materials

Background and Intro

Probes

Particle Beams

$$\lambda = \frac{h}{m\,v}$$

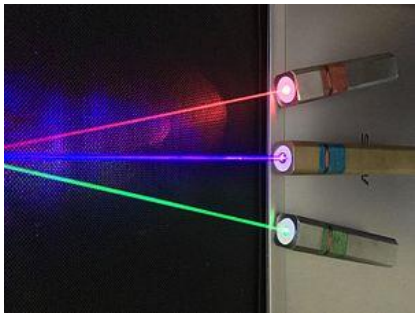
The "Rule of 2's"

2 Å

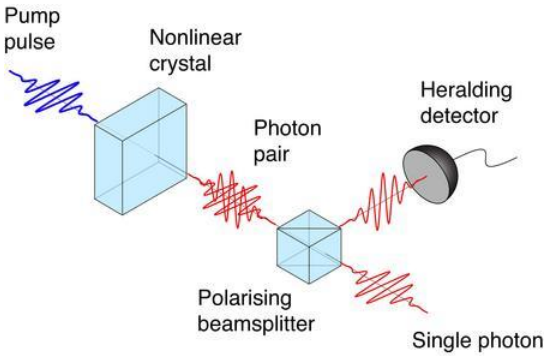
20 meV

2000 m/s

Lasers



Single Photons



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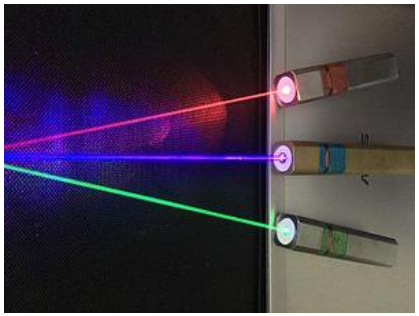

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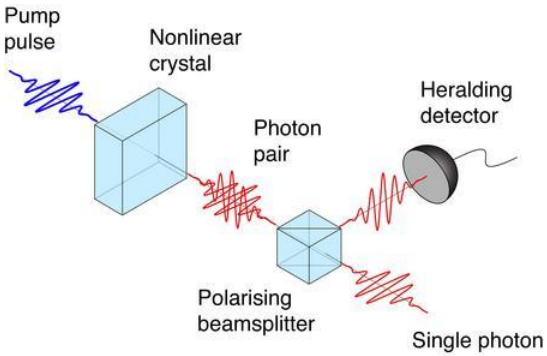
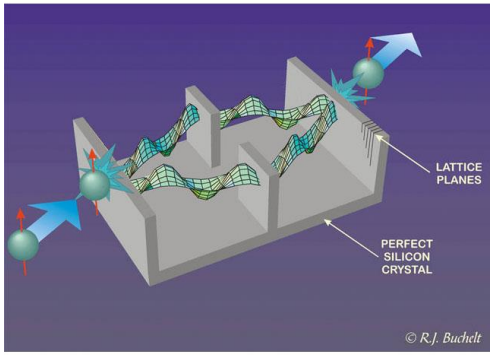


Similarities in Behaviour

Waves



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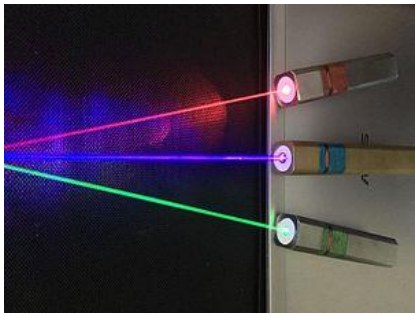

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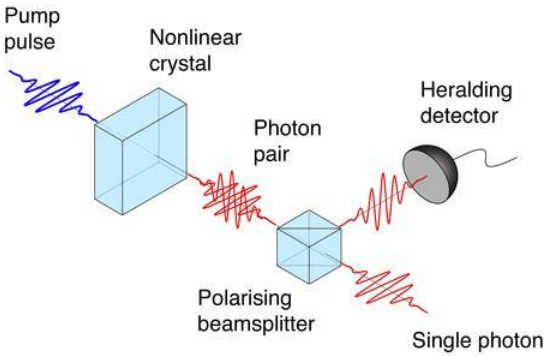

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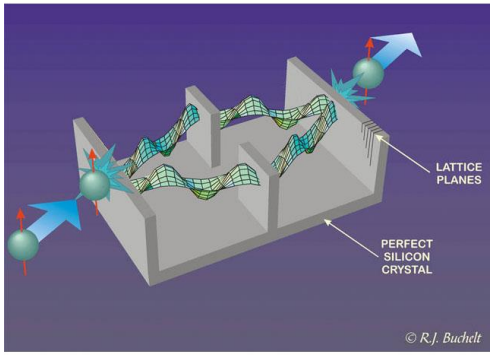
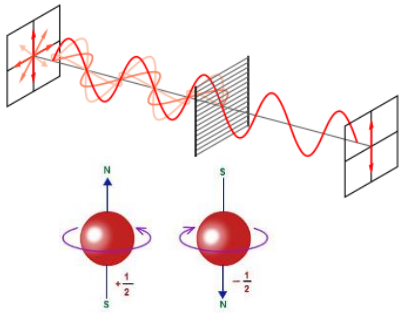
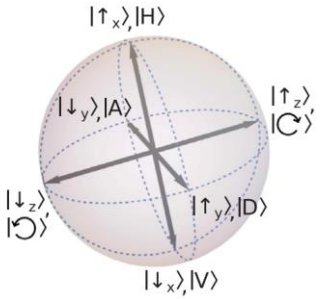


Polarization and spin



Poincaré and Bloch sphere isomorphism



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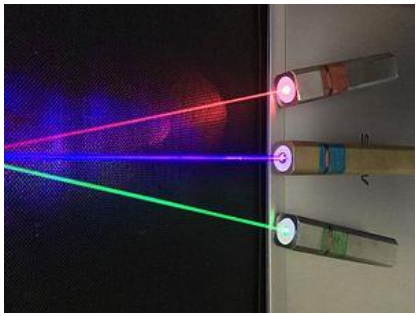

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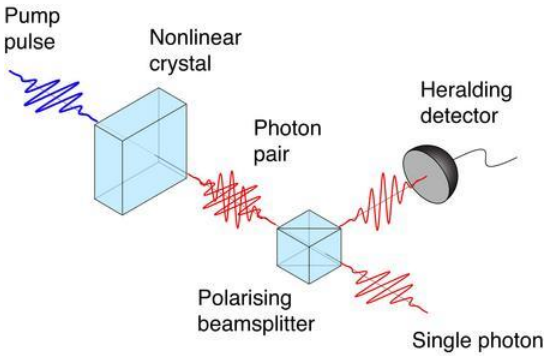

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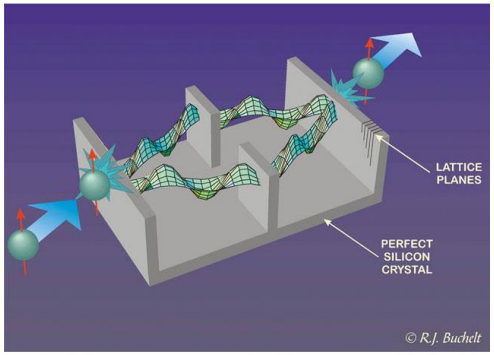

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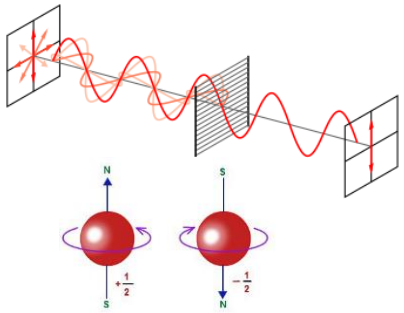

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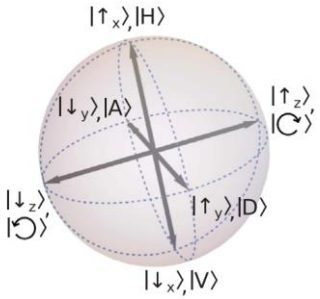
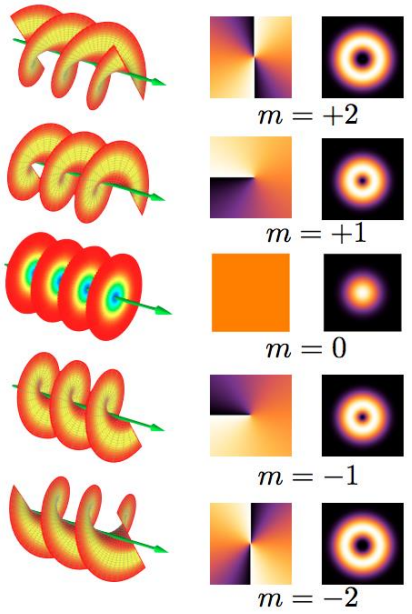
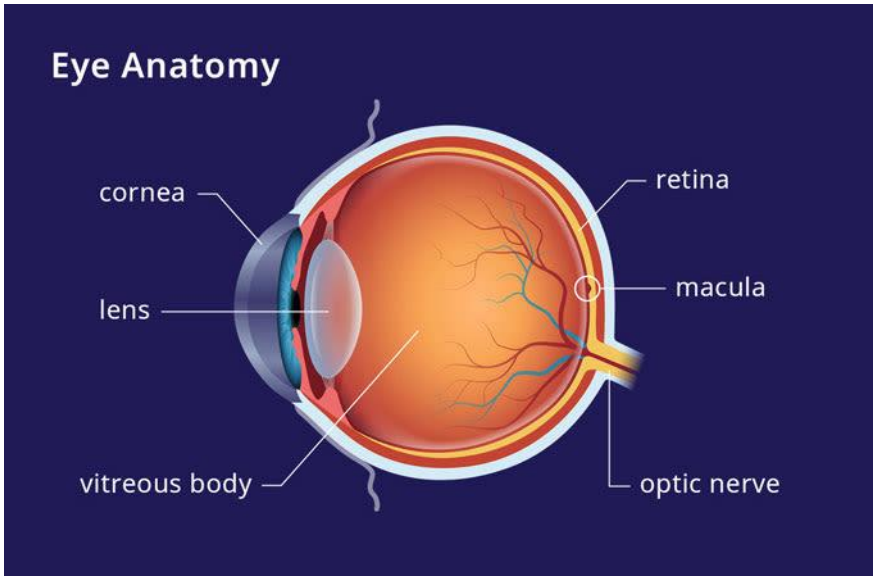


Quantized spatial modes

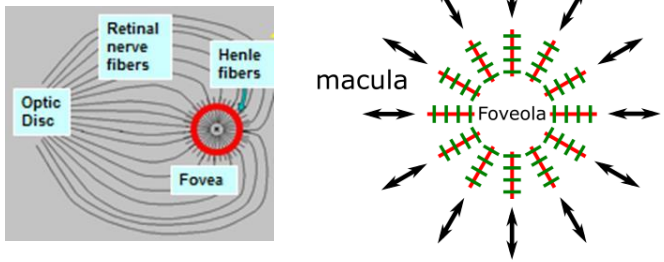


Case 1: Characterizing the structures in the macula

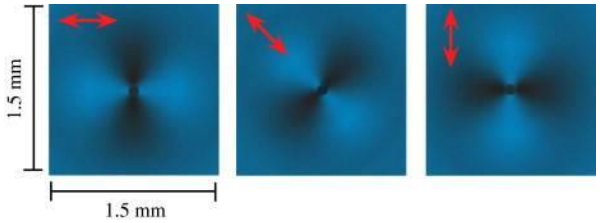


Background: Human Perception of Polarization

The human eye effectively acts as a radial polarizer for blue light

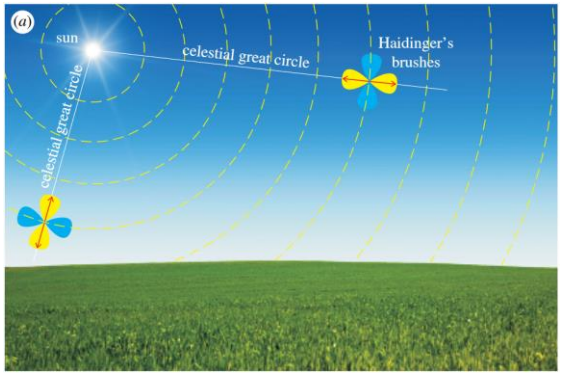


Haidinger's brush is an entoptic phenomena



Le Floch et al. 2010. The polarization sense in human vision. *Vision research*, *50*(20), pp.2048-2054.

With some practice, one can perceive the Haidinger's brush in the sky when viewing a region of high linear polarization (scattering 90° from the sun)



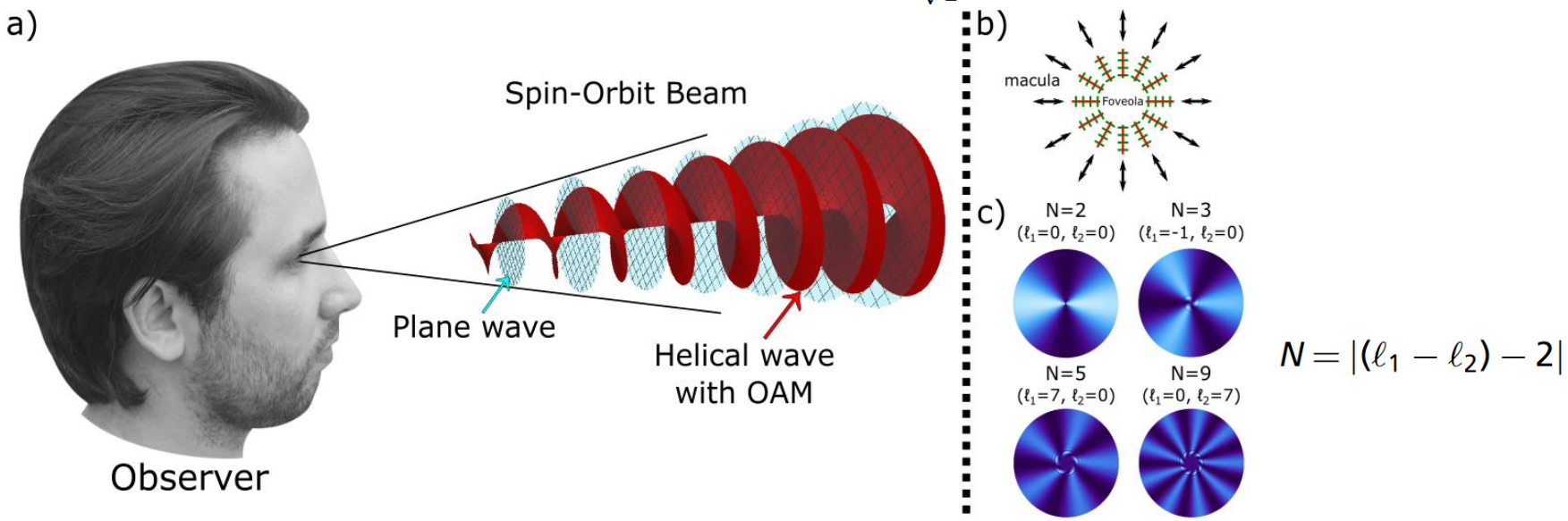
Horváth et al. Royal Society open science. 2017 Feb 1;4(2):160688.

However, the entoptic profiles are perceivable only by a healthy macula. AMD has been correlated with the loss of perception of these profiles

Human Perception of Structured beams

Direct perception and discrimination of the particular states of light with polarization coupled spatial modes is possible through the observation of distinct entoptic profiles.

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[C_1(\ell_1, r, z)e^{i\ell_1\phi}|R\rangle + C_2(\ell_2, r, z)e^{i\ell_2\phi}|L\rangle\right]$$



$$N = |(\ell_1 - \ell_2) - 2|$$

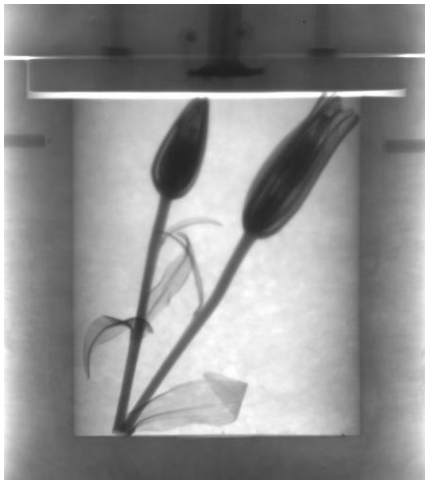
The number of azimuthal fringes that a human sees when viewing the spin-orbit beams is equal to the number of radial lines (N) in the corresponding polarization profile of the beam.

Proceedings of the National Academy of Sciences 117 (26), 14682-14687

Case: Ghost Imaging

Different probes see different features

Ordinary photography



Neutron radiography

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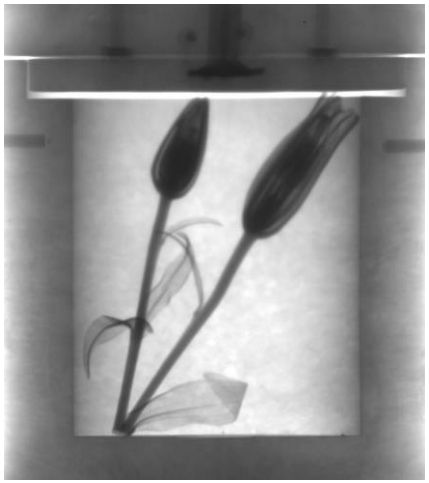
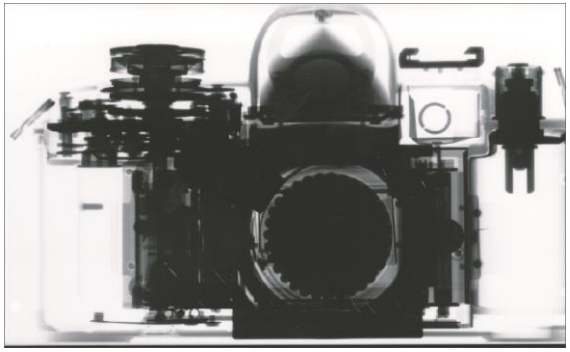


Neutron radiography

X-ray image

- Metal parts: opaque
- Plastic parts: transparent



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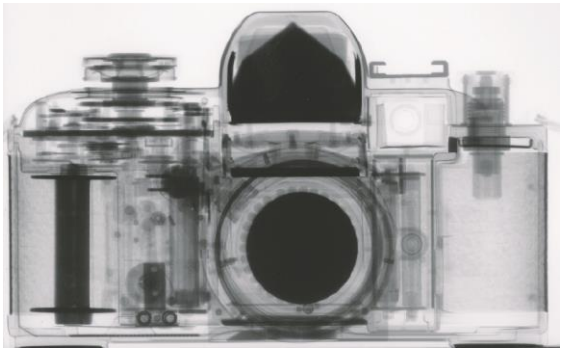

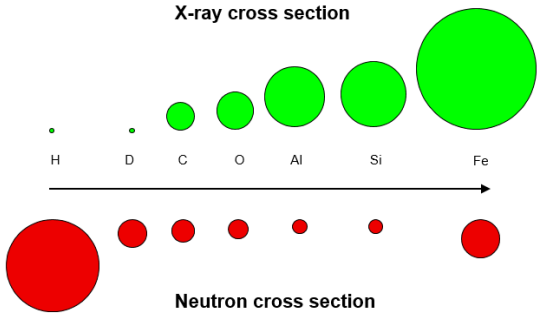

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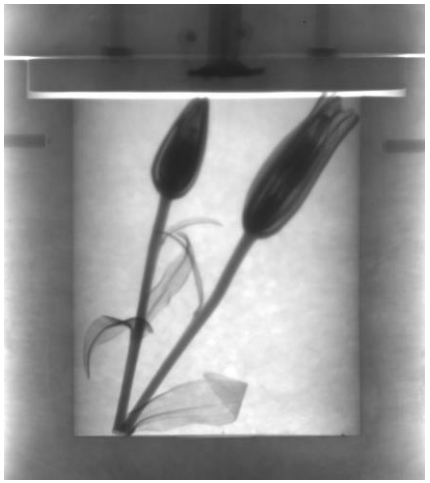

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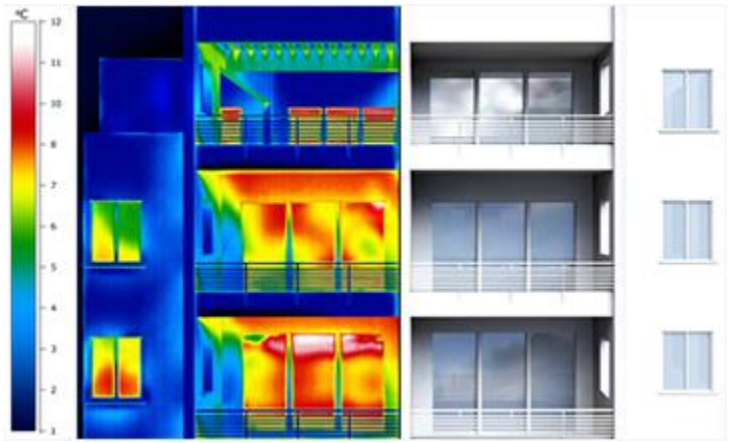
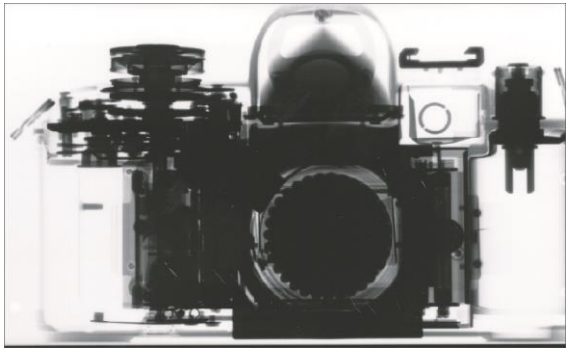


Infrared thermography

X-ray image

- Metal parts: opaque
- Plastic parts: transparent



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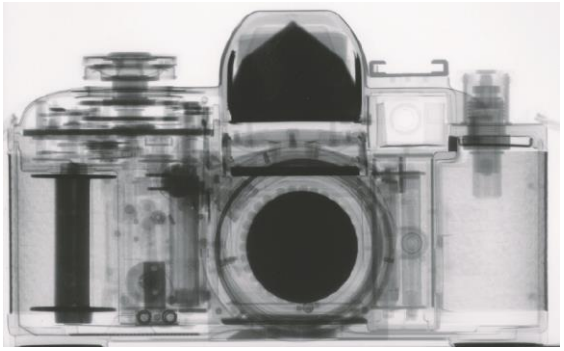

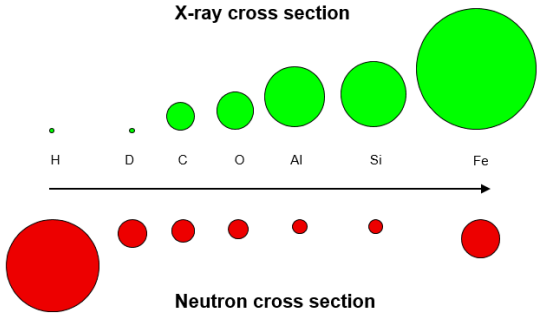

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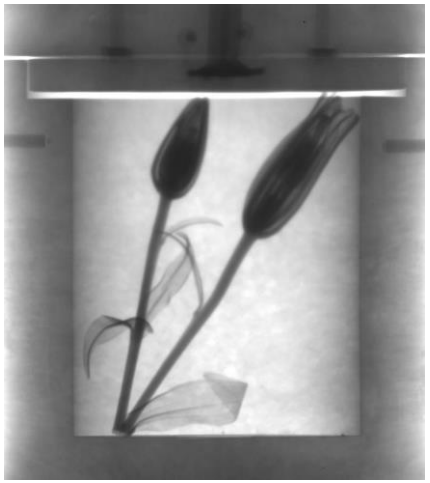

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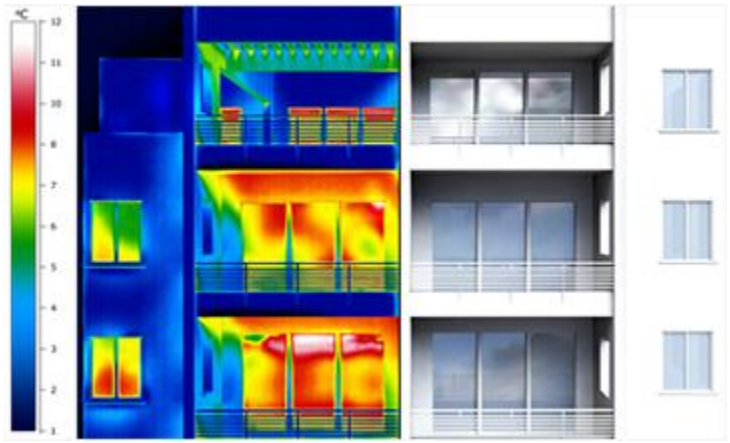
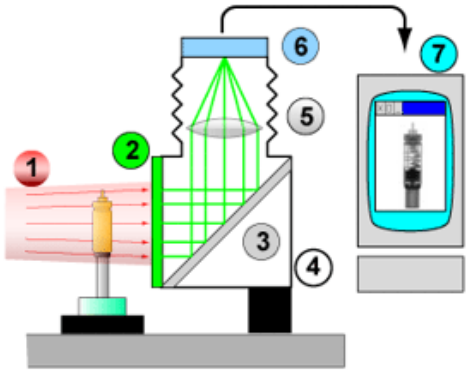


Infrared thermography

Detecting different probes

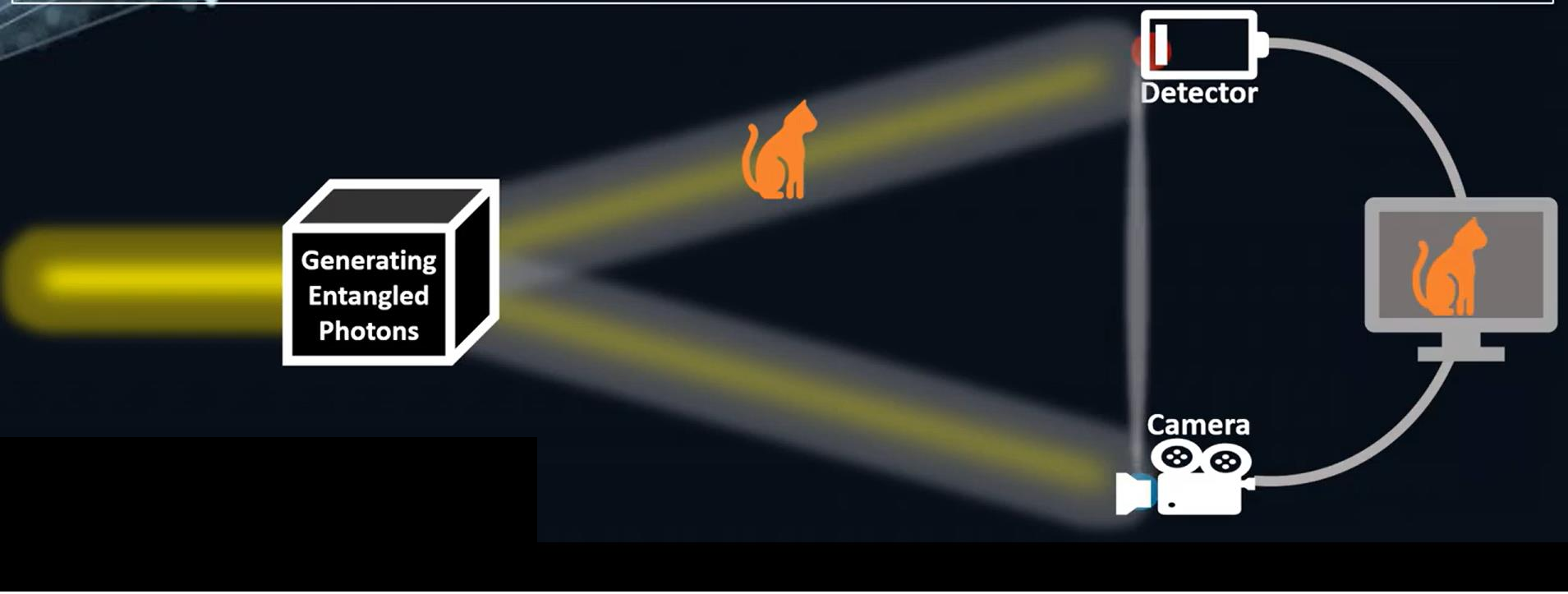
Normal Camera



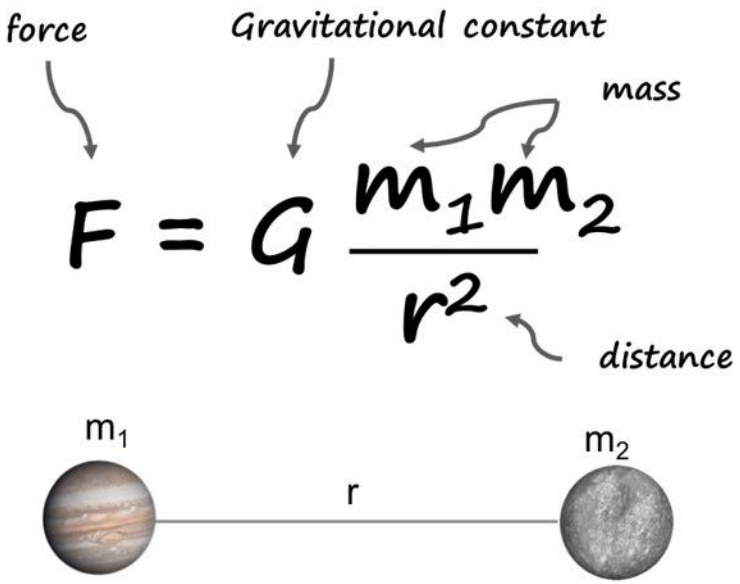
Neutron Camera

Quantum Ghost Imaging

Quantum ghost imaging is a technique to illuminate an object using invisible infrared photons entangled with visible light photons. The image is formed from the visible light photons and is recorded by the camera.



Case: Measurement of Big G

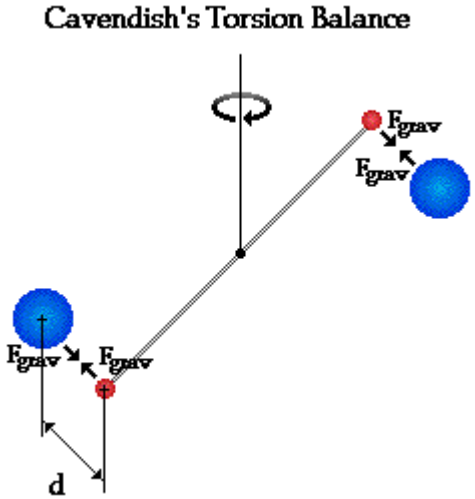


The Least Well-Known Fundamental Constant: G

Henry Cavendish

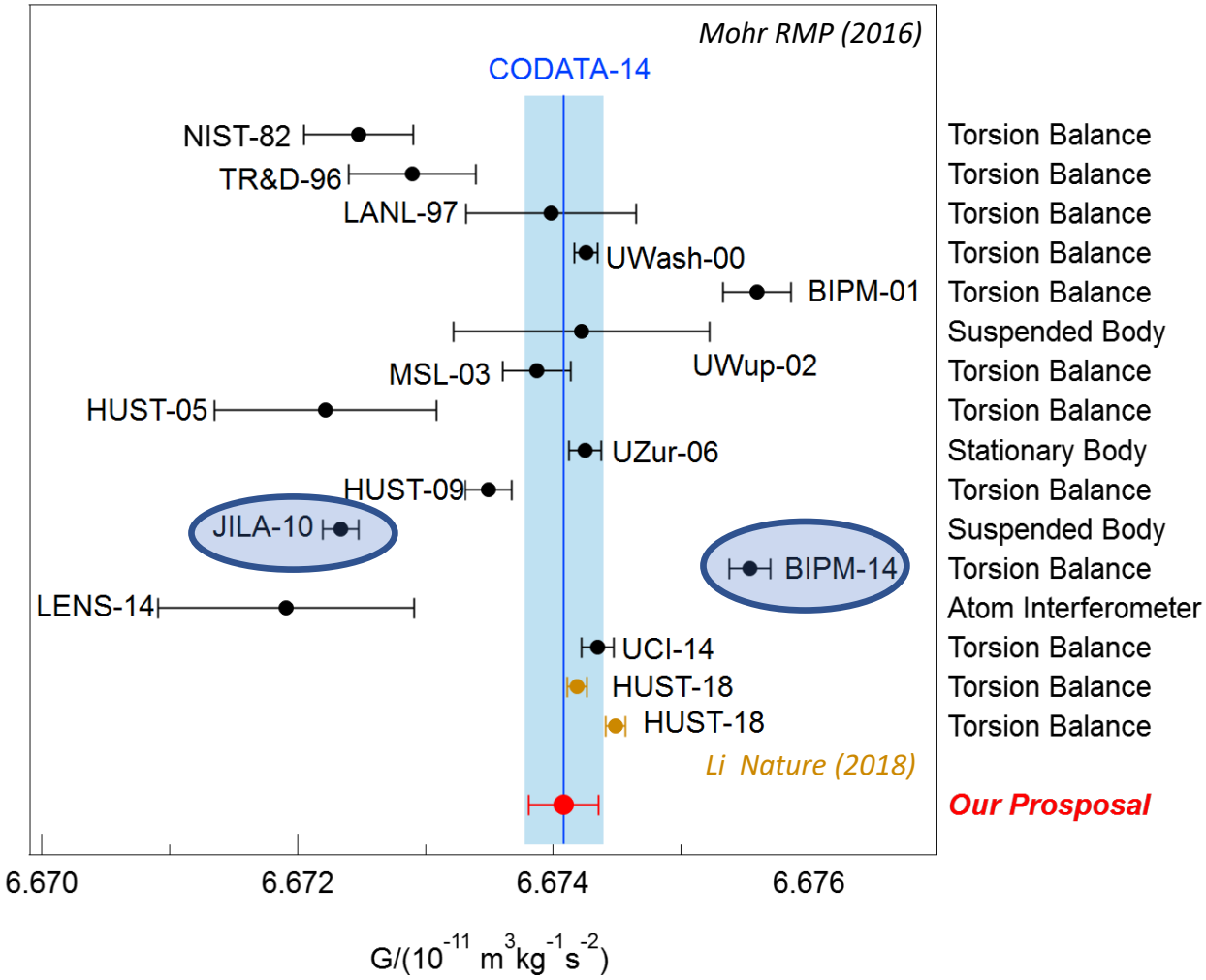
1798: 6.754×10^{-11}N-m^2/kg^2

Today: 6.75430×10^{-11}N-m^2/kg^2



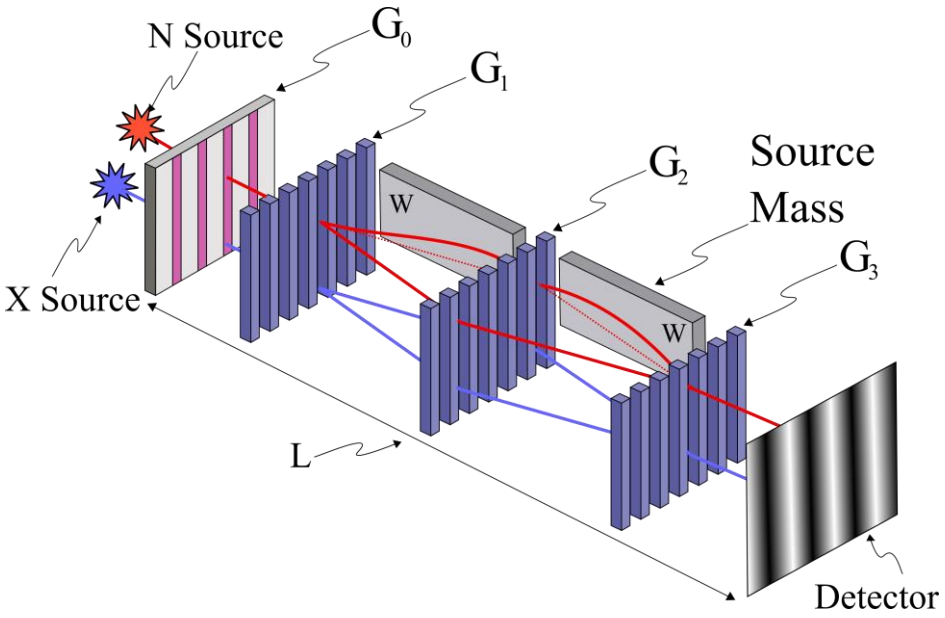
The Least Well-Known Fundamental Constant: G

10 σ !!!



"As shown above, we do not understand either the physics behind gravitation, or the physics used in the instruments used to perform these measurements, or both. ***New Ideas*** for new measurements can illuminate both of these aspects, which are very important for science and technology." - **NSF Ideas Laboratory at NIST (2016)**

Measurement of Big-"G"



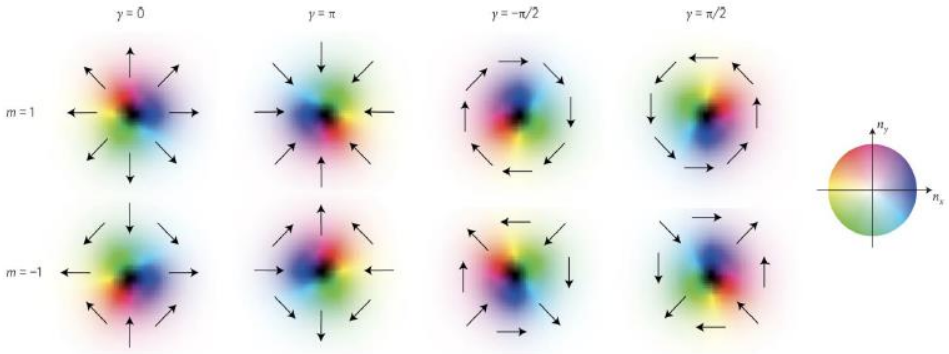
<u>Advantages of our Approach For Measuring Big-G:</u>

- Novel measurement approach
- Permits a source mass on the length scale of meters
- Probes gravity perpendicular to local gravity
- Insensitive to stray electric fields
- Neutron and Source Mass location using 2D detector and probe beam
- Massless photons (X-rays or infrared) can be used in situ to monitor interferometer stability

Case: Structured probes of topological materials

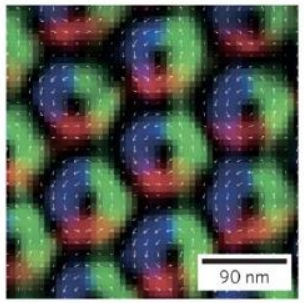
Magnetic Topological Materials

- Various topological spin configurations may be realized through unique combinations of vorticity and helicity, determined by the chiral interaction of the DM type.

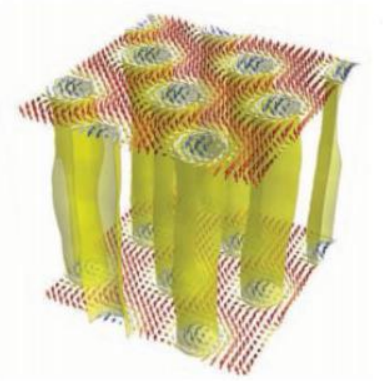


Nagaosa, N. & Tokura, Y. Nature Nanotech. **8**, 899–911 (2013).

2D

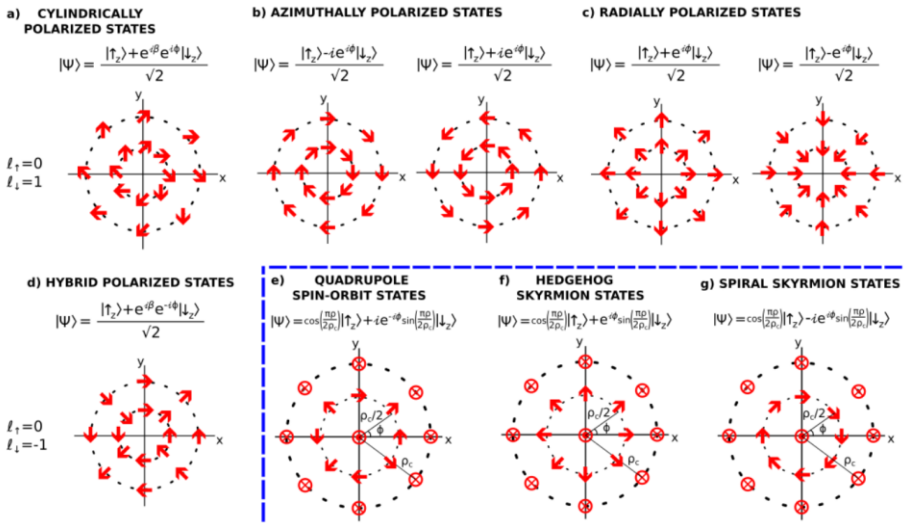


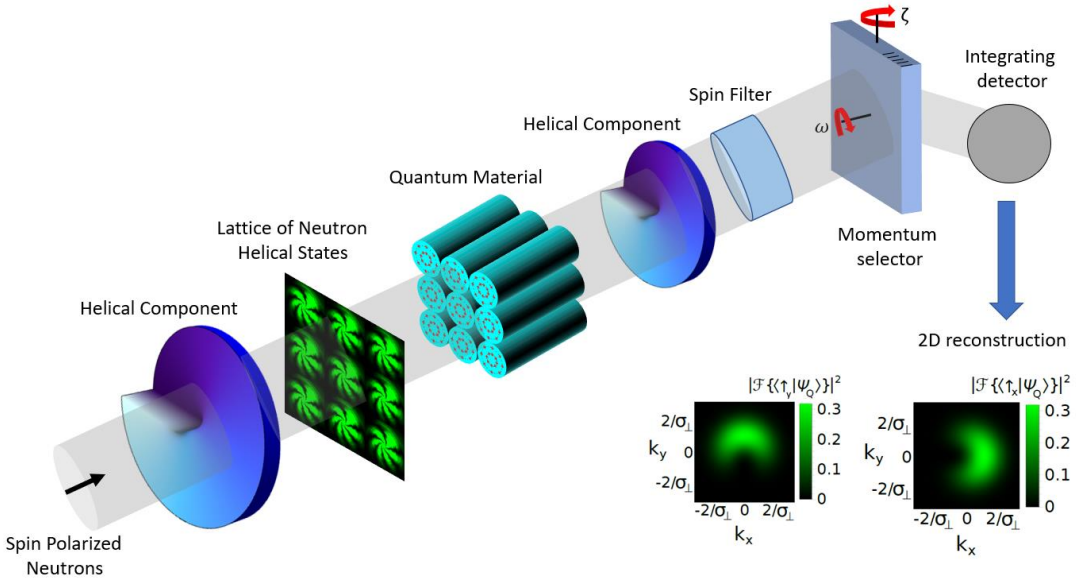
3D



Milde, P. et al., Science. **340**, 1076 (2013).

Tailoring probes for specific features





Questions?