

量子センサー勉強会

Study group for Quantum sensors

諸言

Some introductory remarks

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Motivation

- SM seems to have been established and explain almost all the phenomena observed so far, but...
- Still some open puzzles
 - mass hierarchy, matter-antimatter asymmetry in the Universe, mysteries of dark matter, dark energy, ...
- There must (may) be new particles waiting to be discovered, and there a lot of efforts to find physics beyond the SM;
 - Direct searches at high energy colliders; (HL-)LHC, future colliders
 - Indirect searches at low-energy precision measurements
 - And, many searches for DM

But, no clear evidence yet!

Quantum sensor (sensing) technology has potential to improve greatly the sensitivity

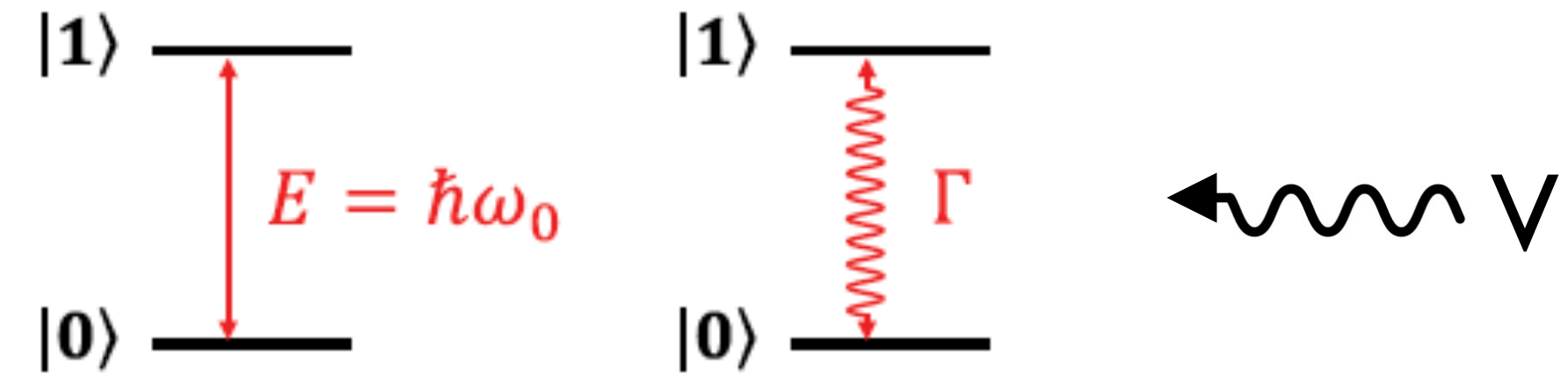
Quantum sensors

- **Definition** (Rev. Mod. Phys. 89 (2017)035002)

Quantum sensing is typically used to describe one of the following:

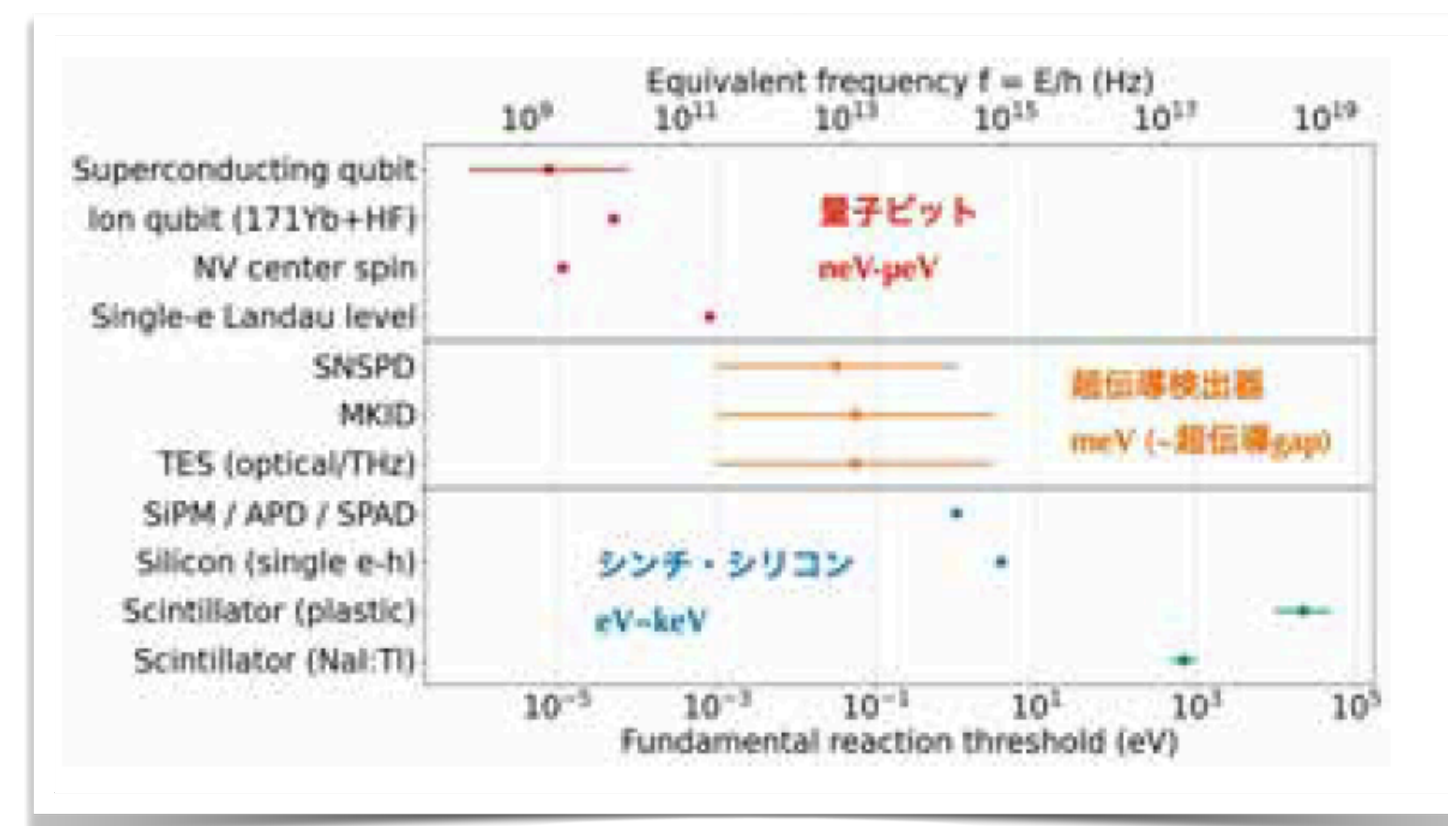
- (I) Use of a quantum object to measure a physical quantity (classical or quantum). The quantum object is characterized by quantized energy levels. Specific examples include electronic, magnetic or vibrational states of superconducting or spin qubits, neutral atoms, or trapped ions.
- (II) Use of quantum coherence (i.e., wavelike spatial or temporal superposition states) to measure a physical quantity.
- (III) Use of quantum entanglement to improve the sensitivity or precision of a measurement, beyond what is possible classically.

Belle (II) is a large quantum sensor!
Produce quantum-entangled BB and measure CPV phase via quantum interference



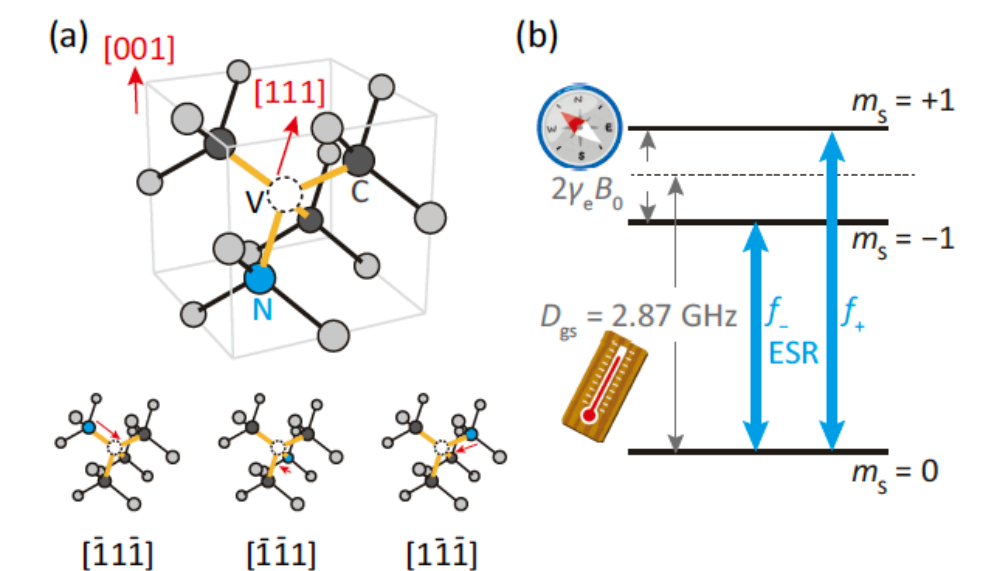
Quantum sensing explores the change in the transition frequency (ω_0) or the transition rate (Γ) in response to an external signal (V)

- with a controlled sequence (initialization and readout with low enough noise)



陳, 新田, High Energy News Vol.44, No.3, 2025

ダイヤモンド中窒素-空孔中心



佐々木健人、第66回物性若手夏の学校 (2021)

Motivation

今やっってることに胡座をかくな。

- We are trying to critically test SM and find NP with ATLAS, Belle II and Muon g-2/EDM currently. We should go on.
- There are also future projects; ILC?, FCC?, muon colliders?
- But, these projects are very very long-term efforts and we'd better develop alternative ideas!
- QM sensors may open new window → (at least) worth for studying and we may have some efforts for development.
 - It is fun!
 - Some of them may fit to university-based researches
 - QM sensors may change the conventional baseline detector technique in HEP experiments (like ML/AI is changing the analyses, triggering scheme, ...)

- Application of quantum dots in calorimeters already being considered.
- Maybe direct sensing of particle spin, photon polarization.?
- Quantum computing must come in future.

Motivation

- QM sensing technologies are rapidly developing in many areas
 - QM computing/cryptography
 - Magnetometry
 - Biomedical applications
- Educational aspects
 - You'd better know about the technology (as physics majors) independent of your future directions.
- Our good connection and relation to the society
 - Dual use (we must be always careful)

世の中進んでいる。

HEPが最先端の時代ではない。

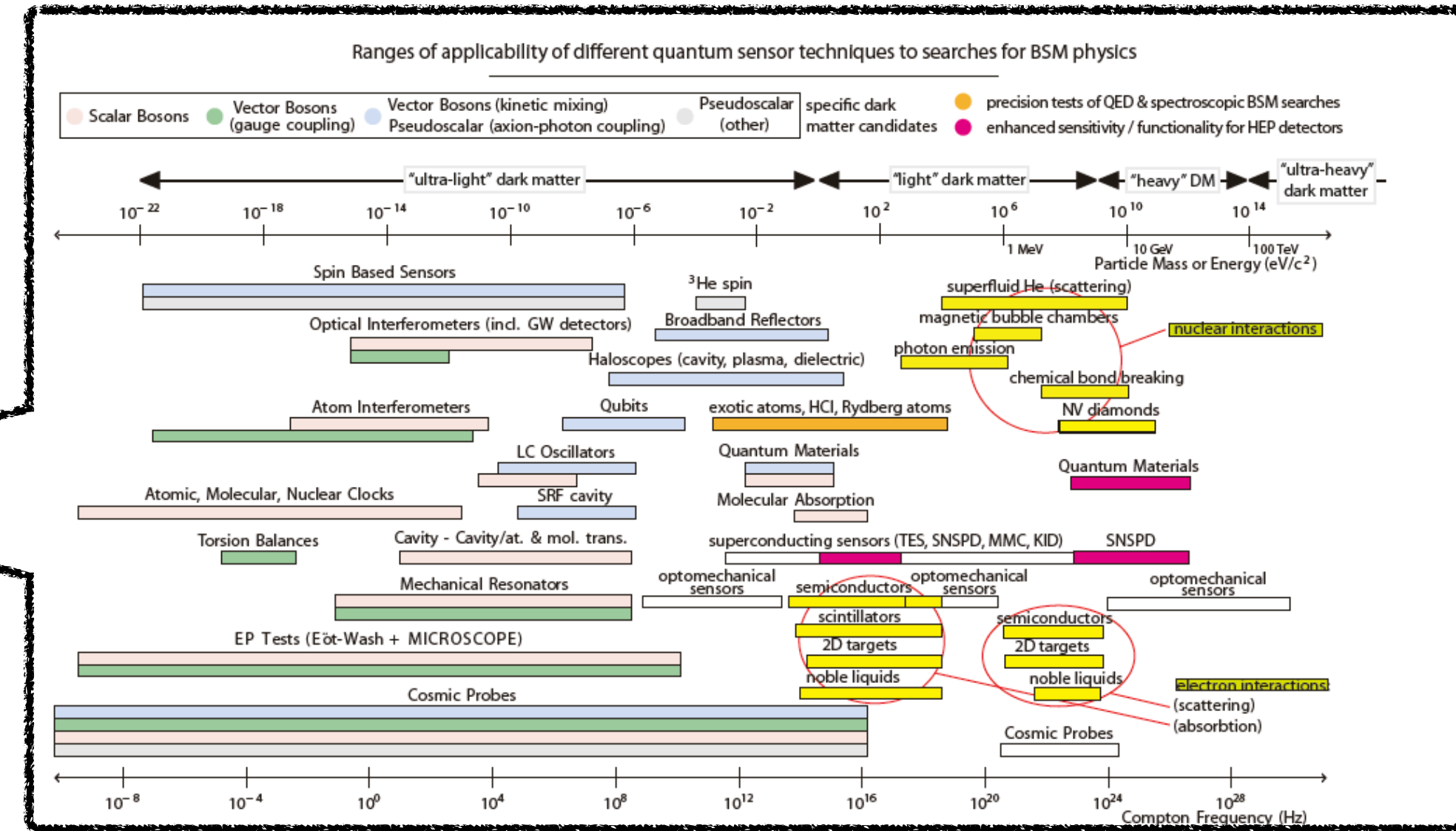
My personal issue;

My walking disability got much worse after the falling accident, but there was no change in my spinal cord in the conventional MRI images.

The doctor said "there must be invisible changes somewhere"

Materials, Organization

- Your suggestions are very welcome!
- Some frequently cited review papers
 - “Quantum sensing for particle physics” by S. Bass and M. Doser (arXiv:2305.11518v2)
 - Report for Snowmass 2021
 - Good to know the landscape (but no details)
 - “Quantum sensing” by C. L. Degen, F. Reinhard, P. Cappellaro (Rev. Mod. Phys. 89 (2017)035002)
 - Explain details; examples, sensing protocol, noise, sensitivity etc.
- Some articles written in Japanese
 - “Qubitによるダークマター探索 (中山和則)” (高エネルギーニューズ、第44巻2号、2025)
 - “ダイヤモンド中窒素-空孔中心のセンサー応用と物性計測” (佐々木健人、第66回物性若手夏の学校 (2021))
- Some proposals for DM/axion searches with QM sensors...
- We may invite some lecturers



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子どものように考え、大人として行動せよ

(think like a child, and act as an adult)

発想

純粹さ (pure mind)

好奇心 (curiosity)

自由な発想 (idea)

夢 (dream)

夢中 (concentration)

行動

目的の具体化 (clarify the target)

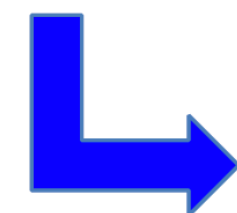
計画性 (planning)

組織力 (organization)

競争力 (competition)

協調性、表現力 (communication)

国際性 (internationality)



真の独創性 (real originality)

