Massachusetts Institute of Technology

C²QA

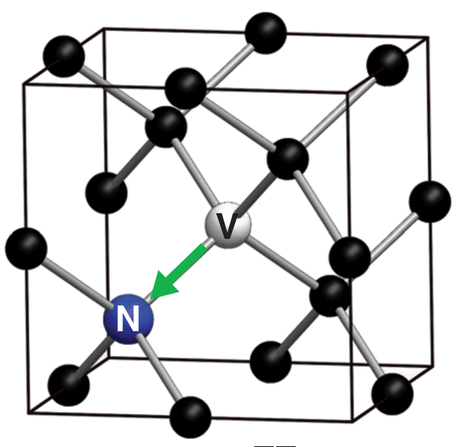
International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles
WPI research center at KEK

Nuclear spin metrology with NV sensors for axion dark matter detection

So Chigusa

NV centers in diamond as quantum sensors

(a)



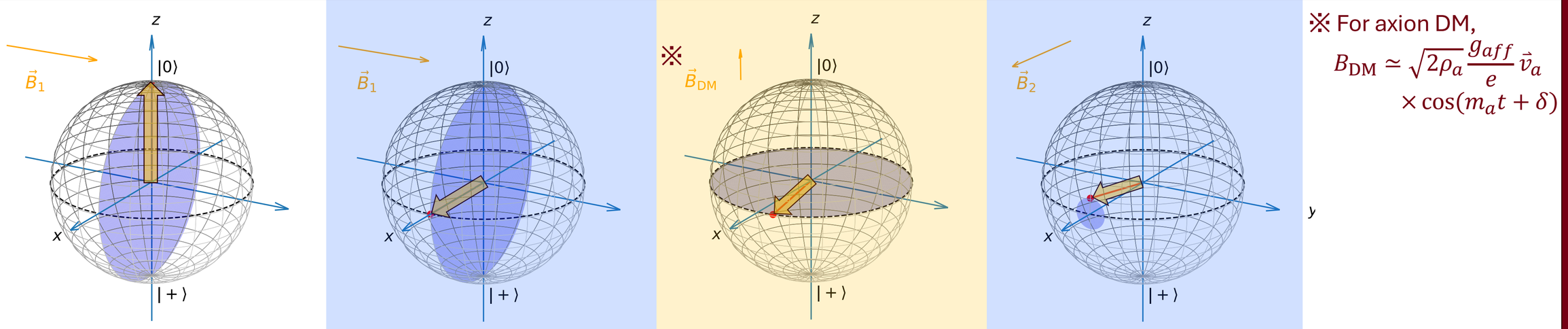
NV ∥ $[1\bar{1}\bar{1}]$ L. M. Pham '13

A lattice defect of **N**itrogen-**V**acancy in diamond ↔ 2-qutrit system of electron/nuclear spins

Benefits as a quantum sensor

1. **Manipulate quantum states** microwaves/radio waves
2. **Readout quantum states** fluorescence
3. **Isolated from environment** long coherence time
4. **Large number** $\propto N_{\mathrm{Avogadro}}$

NV center "magnetometry"



Ground state → State preparation (1. Manipulation) → Spin precession (Sensing phase) → State operation (1. Manipulation) → Measurement (2. Readout)

※ For axion DM,

$$B_{\mathrm{DM}} \simeq \sqrt{2\rho_a}\frac{g_{aff}}{e}\vec{v}_a \times \cos(m_a t + \delta)$$

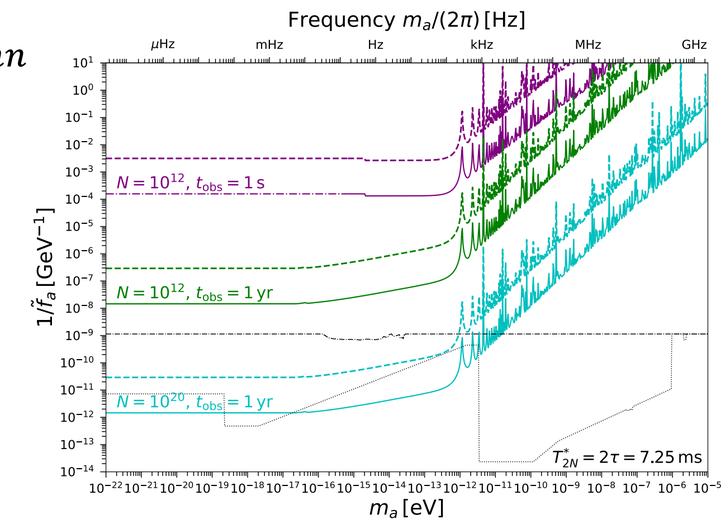
Sensitivities to axion dark matter

Sensitive to all $g_{aee}, g_{app}, g_{ann}$

SC, et al. '23

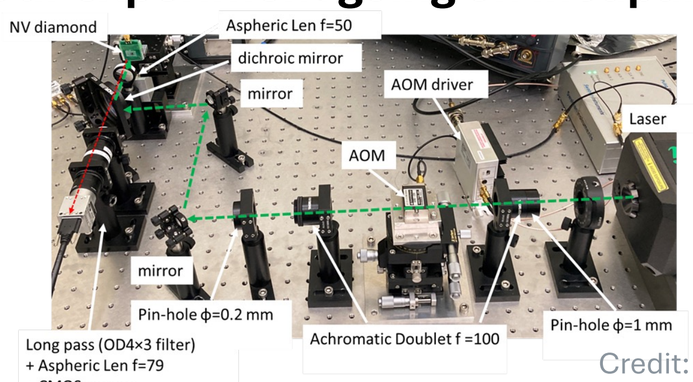
Nuclear spins interesting

1. Lower magnetic noise
2. Unexplored in context of magnetometry
3. Comagnetometry

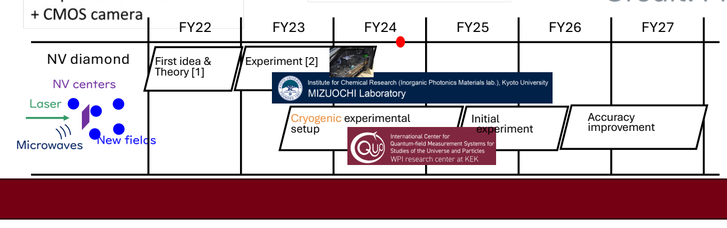


SC, Hazumi, Herbschleb, Matsuzaki, Mizuochi, Nakayama '24

Our experiment going on in Japan!!



Credit: Prof. Iizuka



Improve measurement protocols!! ~ comagnetometry & mixed dynamic decoupling

Dynamic decoupling

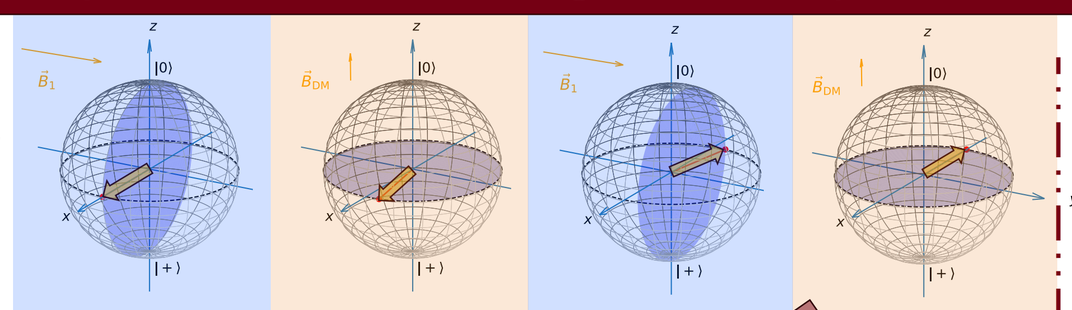
..... flips spin $2n$ times during protocol

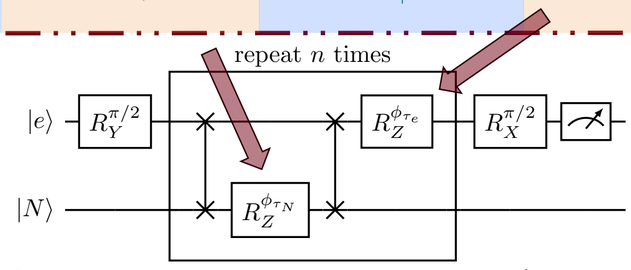
Pros:

- Cancel dc noise effects coherence time $T_2 \gg T_2^*$

Cons:

- Narrow-band sensitivities cancels dc signal effects





Tuned setup: $\gamma_N \tau_N + \gamma_e \tau_e = 0$ $(\gamma_N \gamma_e < 0)$

Mixed dynamic decoupling

..... use both $e^-/^{14}N$ spins to cancel noise

Pros:

- Cancel dc noise effects coherence time $T_2 \gg T_2^*$
  $T_2 \to O(T_1)$ @ cryogenic, $n \to \infty$
- Comagnetometry approach
- Broad-band search for axion!

SC, et al. (work in progress)