

Observation of Ramsey fringes toward development of high-sensitivity magnetometer using alkali atoms in an optical lattice



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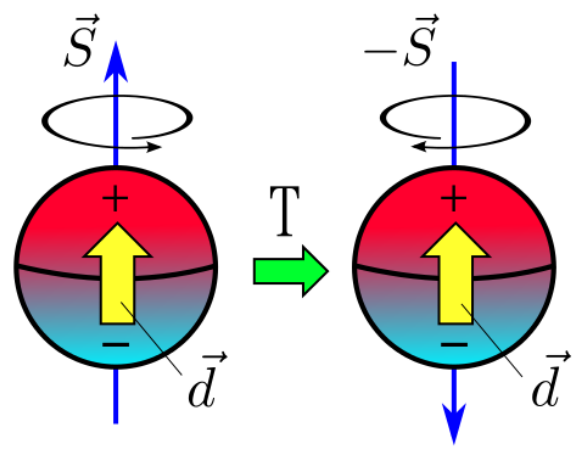
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We have a plan to search an electron EDM by measuring spin precession of laser cooled Fr atom. The development of a high-sensitivity magnetometer is also required for this search. The Rb co-magnetometer using Ramsey's method is one of the most useful techniques for the fluctuation of magnetic field. At first, we have developed an experimental setup using Rb cell coated with paraffin and observed the Ramsey fringes.

1. Background of research

Search for electron EDM



Time reversal

\vec{d} : Permanent Electric Dipole Moment (EDN)

T violation \leftrightarrow CP violation

Currently experimental upper limit :

$$|\vec{d}_e| < 8.7 \times 10^{-29} \text{ e cm}$$

The ACME Collaboration *et al.* Science 343, 269 (2014)

• Francium has an enhancement factor $R \sim 895$ of \vec{d}_e .

• The limitation of \vec{d}_e :

$$\delta d_e \sim \frac{\hbar F}{2E\tau} \frac{1}{\sqrt{Nm}}$$

F : Total angular momentum

E : Electric field

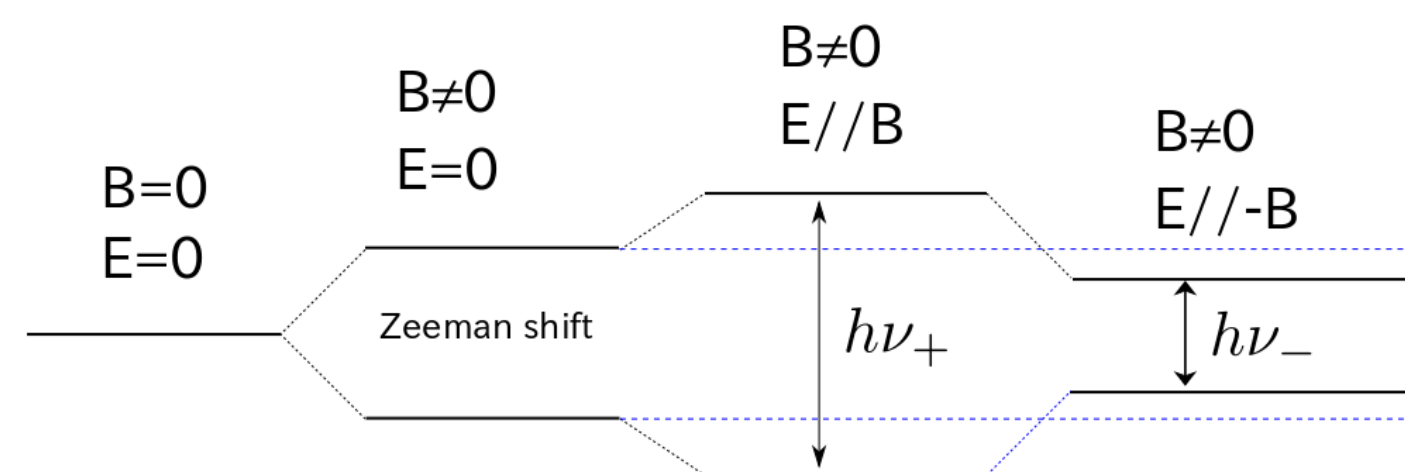
τ : Interaction time

N : The number of atom

m : The number of measurement

→ We use laser-cooled Fr atoms!

2. Method of eEDM search



$$\hbar\nu_+ = -\mu \cdot B - d \cdot E$$

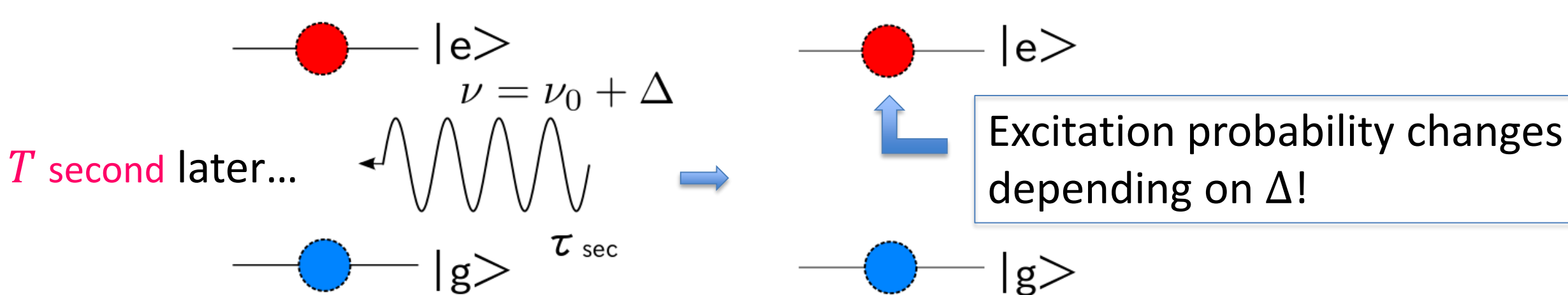
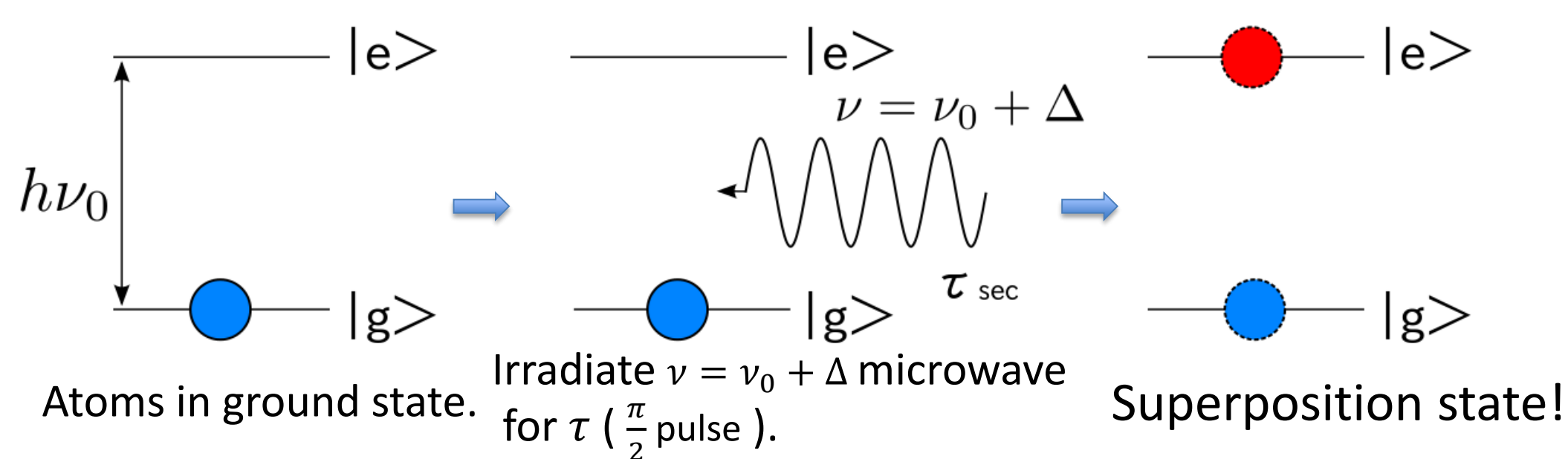
$$\hbar\nu_- = -\mu \cdot B + d \cdot E$$

$$\therefore d = -\frac{\hbar(\nu_+ - \nu_-)}{2E}$$

\vec{B} fluctuates → Mimic EDM signal! : $\delta d > \frac{\mu\delta B}{\sqrt{2}E}$ When $|\vec{d}_e| < 10^{-29} \text{ [e cm]}$: $\delta B < 10 \text{ [fT]}$ with 100 [kV/cm]

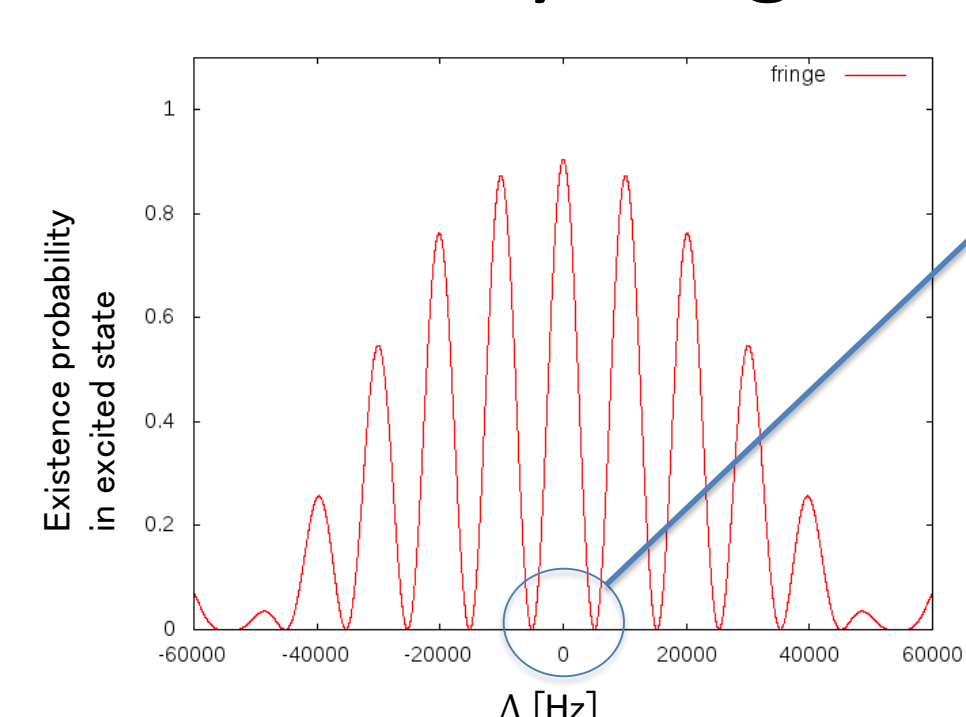
→ Rb co-magnetometer based on Ramsey's method is significant.

3. Ramsey's method



Irradiate the same microwave again.

Ramsey fringes



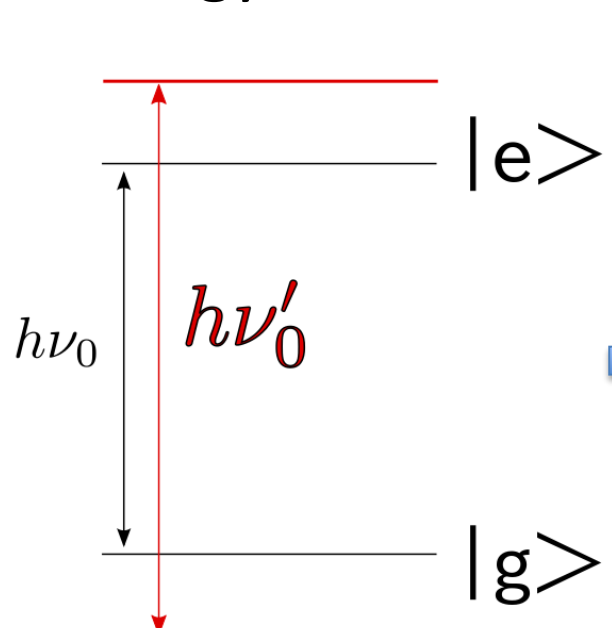
Width of one fringe: $\frac{1}{T} \text{ [Hz]}$

Large T → Sharp fringes

High resolution spectroscopy!

4. Magnetometer based on Ramsey's method

Energy level shifts...



Fringes shift!

Apply to Zeeman sublevel...

$$\Delta B = \frac{\Delta E}{m_F g_F \mu_B}$$

ΔE : Energy shift
 m_F : Magnetic quantum number
 g_F : g factor
 μ_B : Bohr magneton
 ΔB : \vec{B} fluctuation

Monitor \vec{B} fluctuation!

5. Process of research

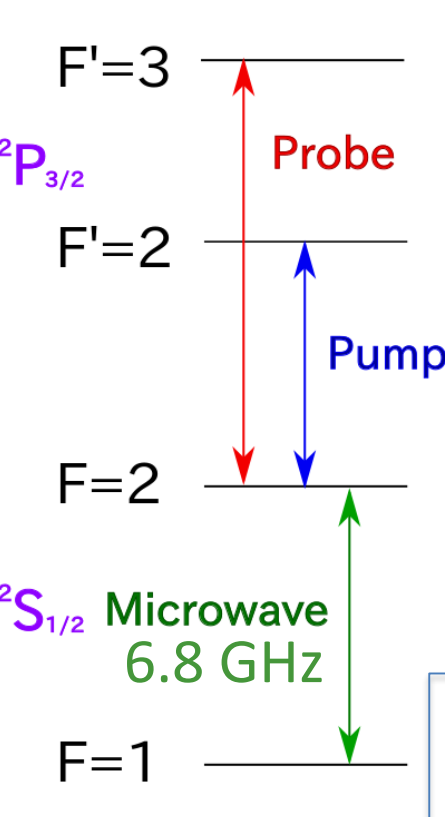
• Rb co-magnetometer using Ramsey's method in an optical lattice.

• Observe Ramsey fringes by laser cooled Rb.

★ • Observe Ramsey fringes using coated Rb cell and establish a method to estimate \vec{B} fluctuation from the fringes.

6. Experimental setup

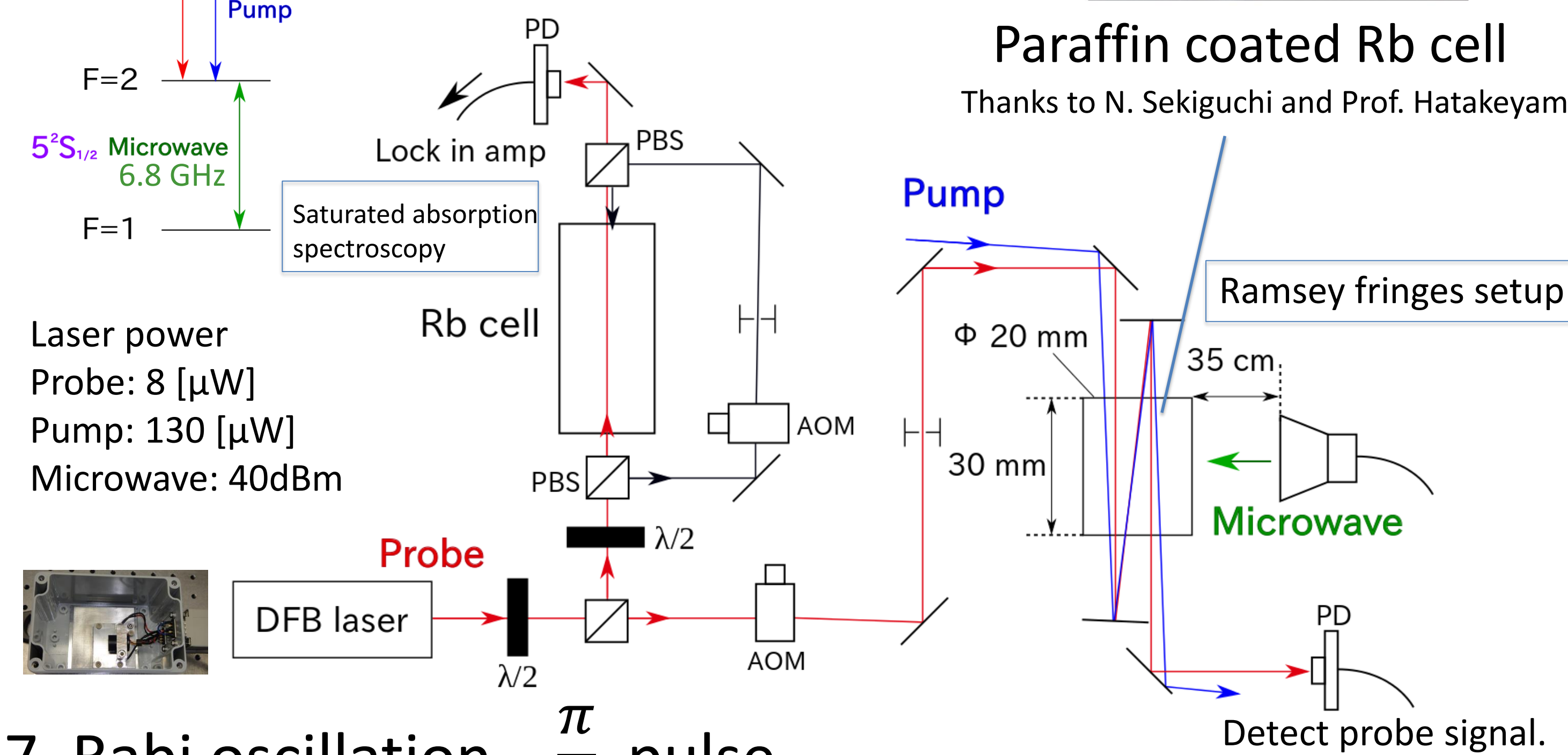
⁸⁷Rb D2 line 780 nm



Probe: Probing the number of ⁸⁷Rb in F=2

Pump: Pumping ⁸⁷Rb from F=2 to F=1

Microwave: For Ramsey fringes

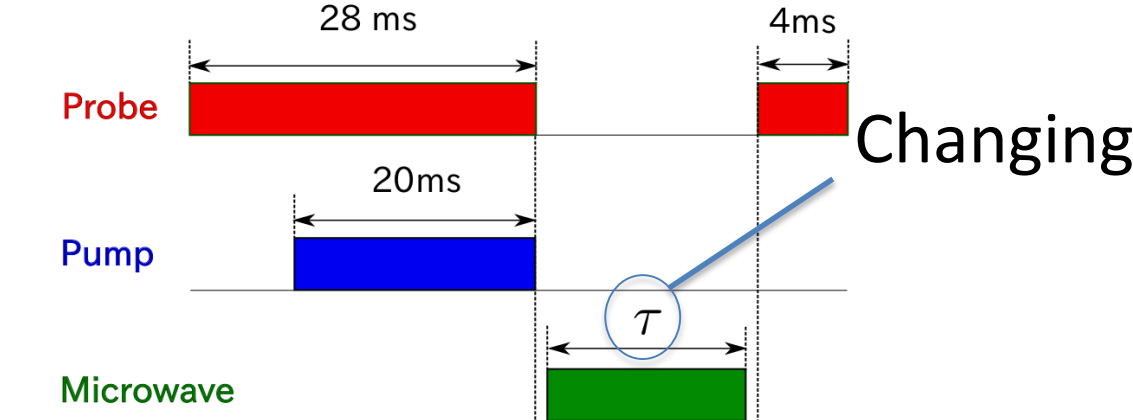


Paraffin coated Rb cell

Thanks to N. Sekiguchi and Prof. Hatakeyama.

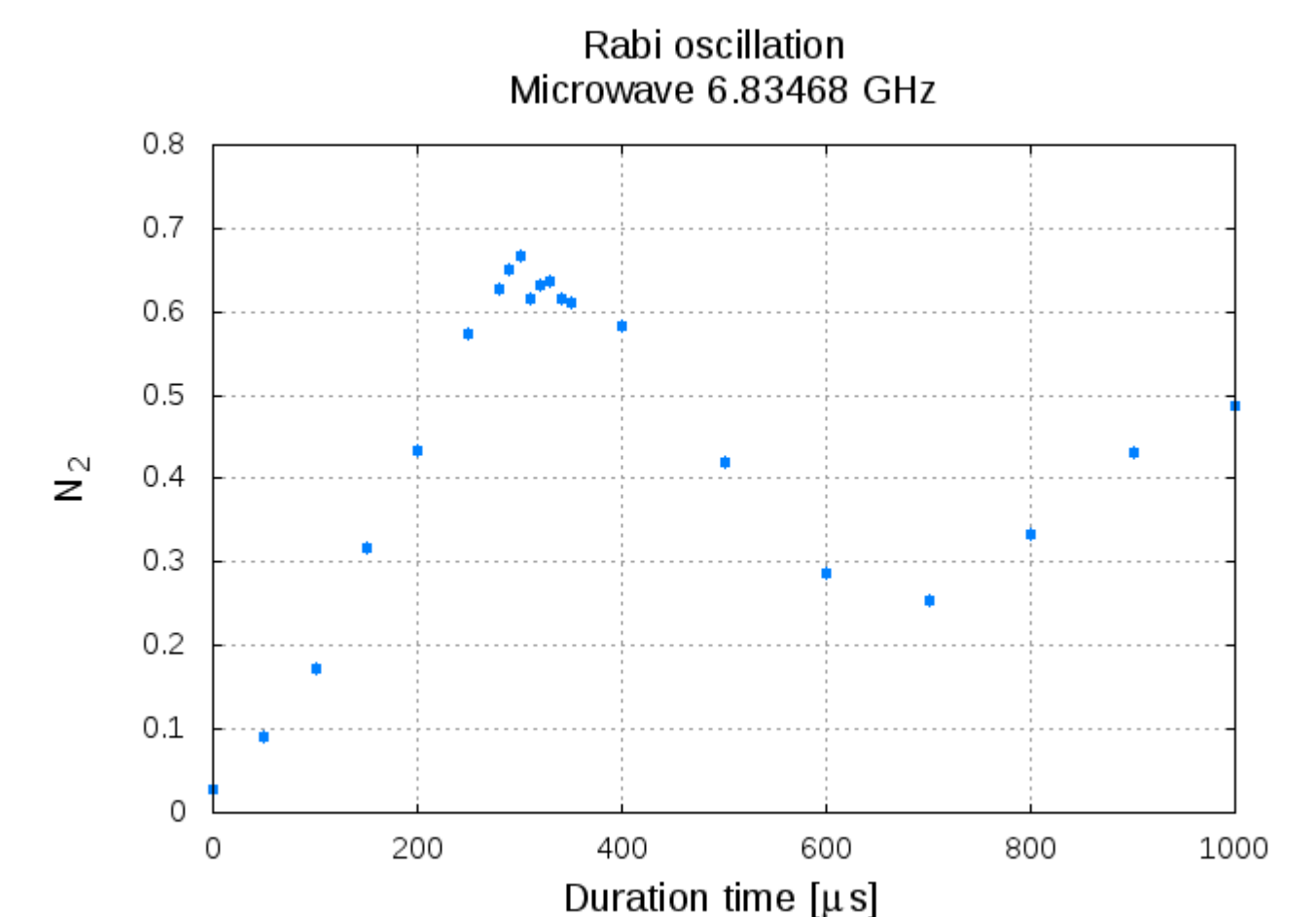
7. Rabi oscillation – $\frac{\pi}{2}$ pulse

Time sequence for Rabi oscillation



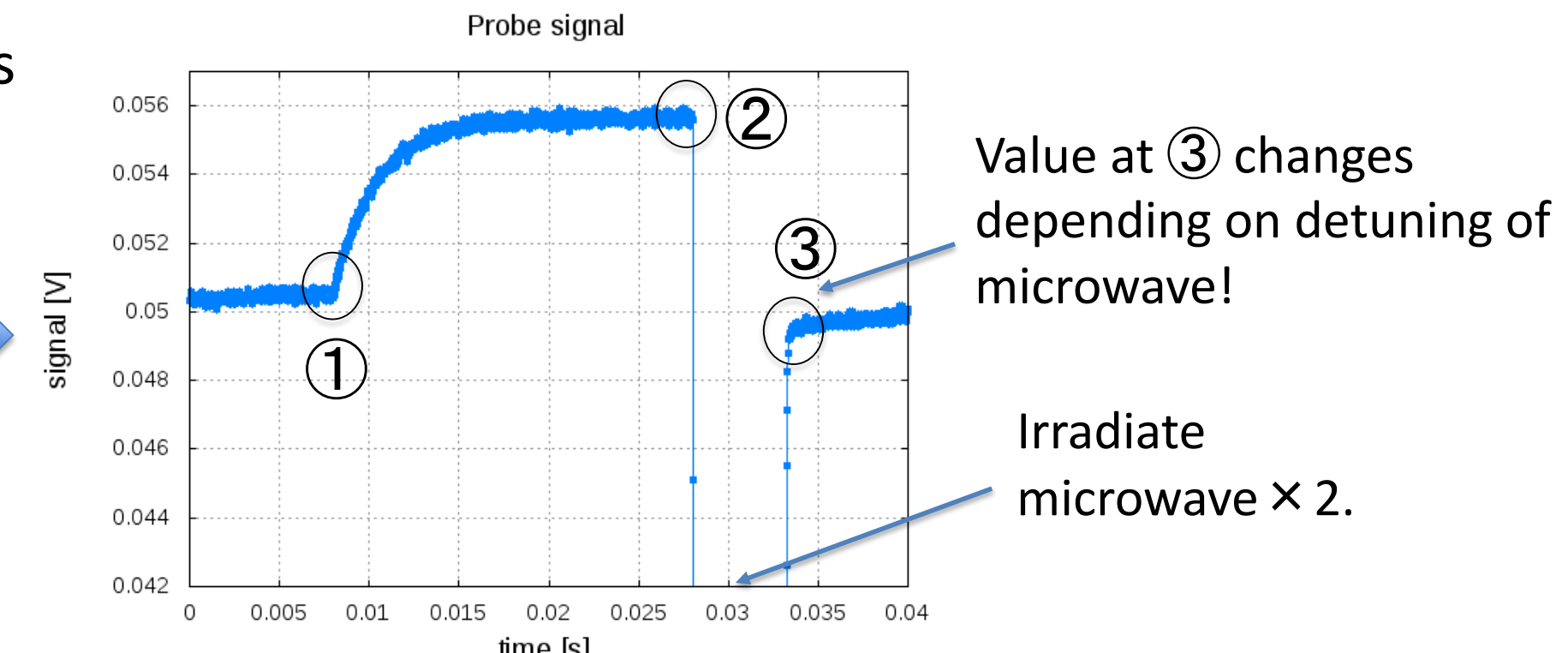
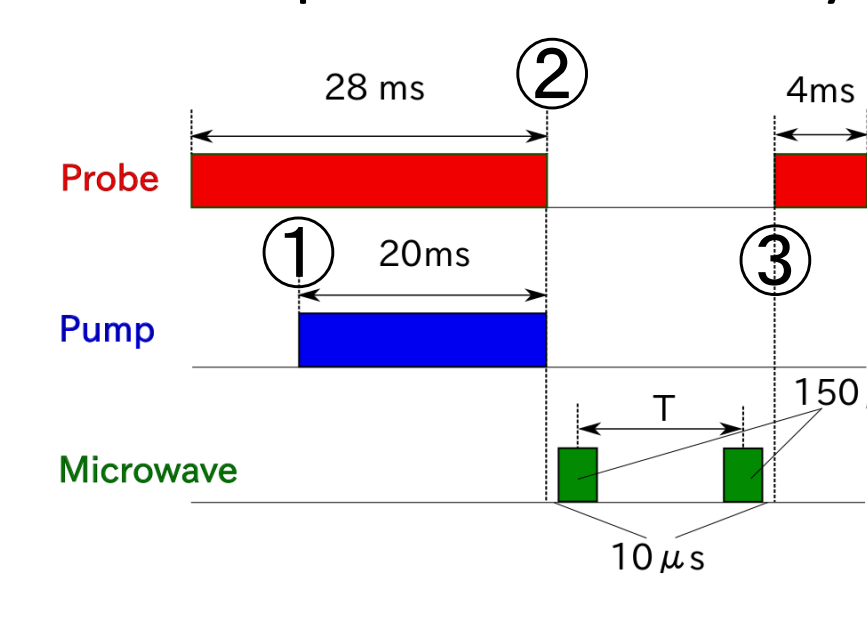
N_2 (population in F=2) Max : 300 [μ s]

→ $\frac{\pi}{2}$ pulse: 150 [μ s]



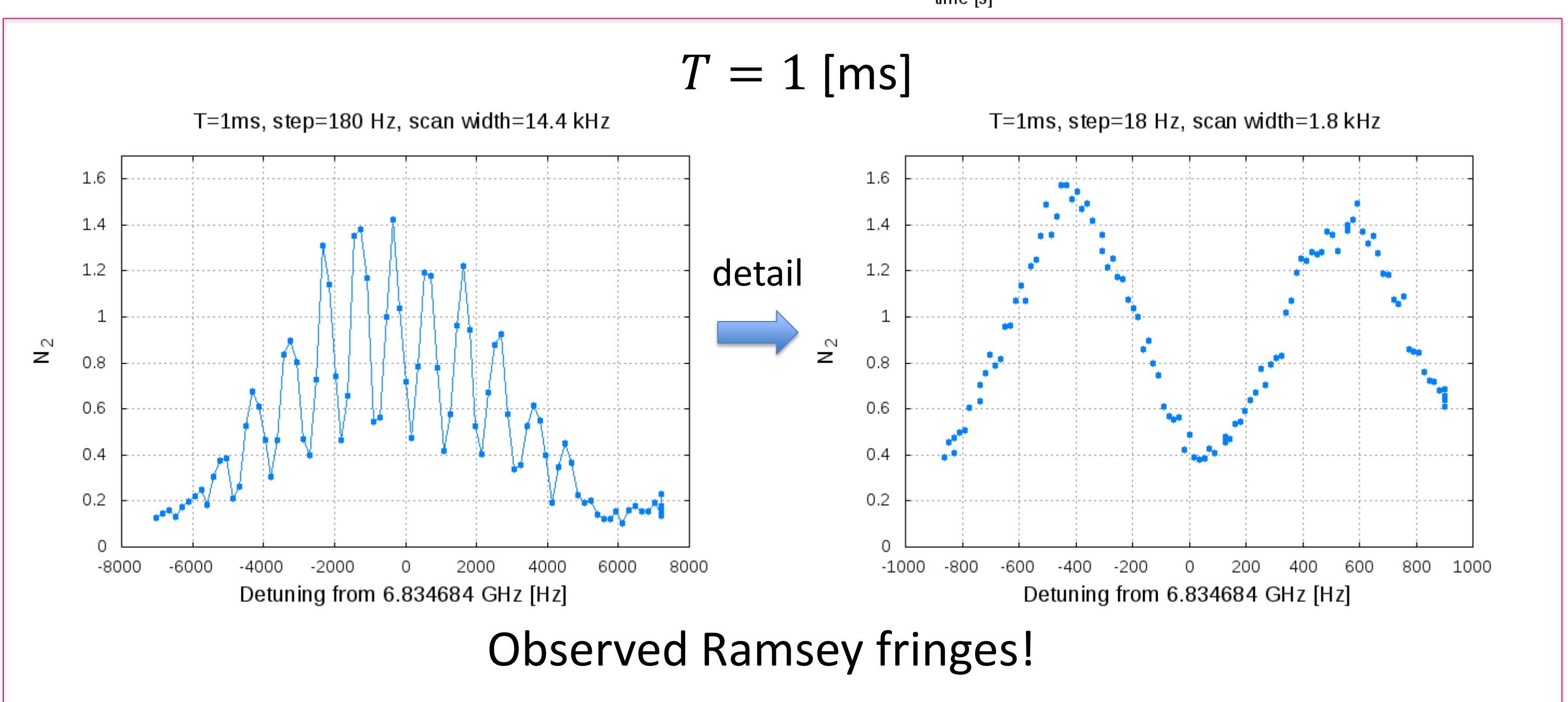
8. Observation of Ramsey fringes

Time sequence for Ramsey fringes

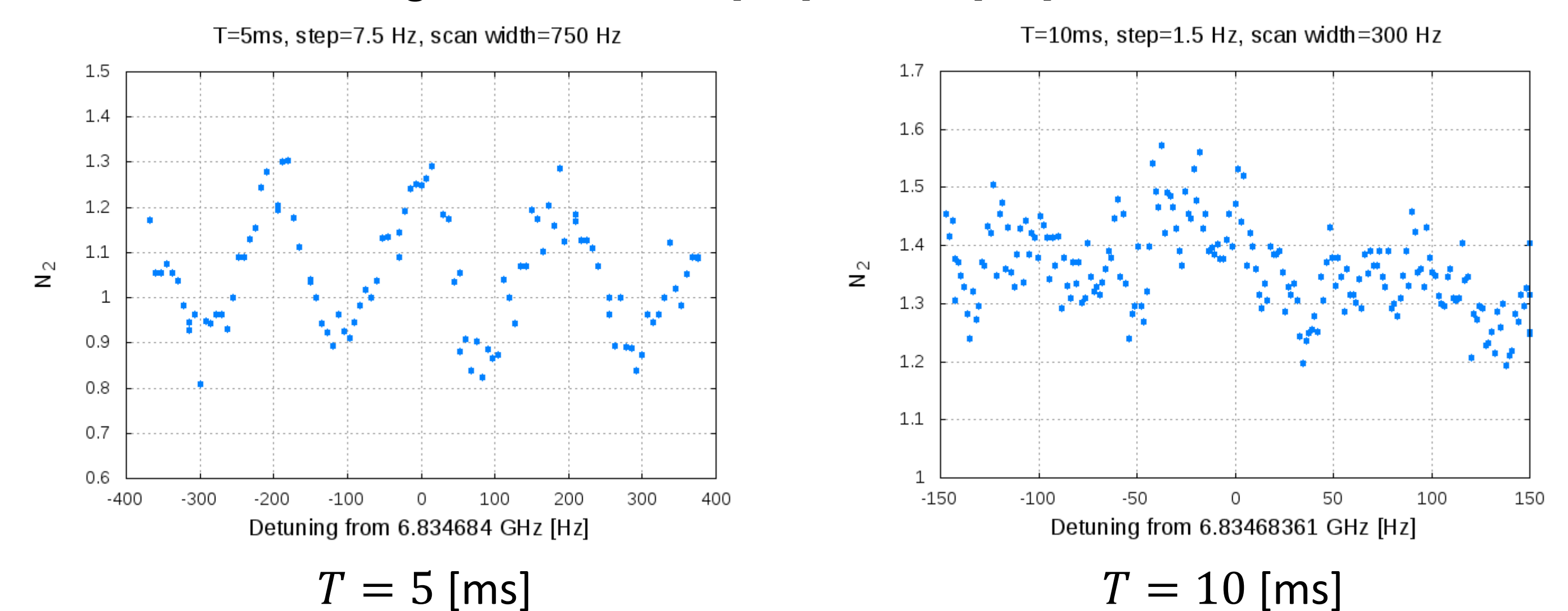


Value at ③ changes depending on detuning of microwave!

Irradiate microwave $\times 2$.



Observed the fringes when $T = 5 \text{ [ms]}$ and 10 [ms] .



The shape of fringes is unclear when $T = 10 \text{ [ms]}$.

→ Relaxation! • atomic collision
• collision to cell wall...

9. Summary and future plan

- Succeeded in observation of Ramsey fringes using coated Rb cell.
- Observed the fringes up to 5 [ms].
- Establish a method to estimate magnetic sensitivity from the fringes.