Entangling atomic spins with a Rydberg-dressed spin-flip blockade

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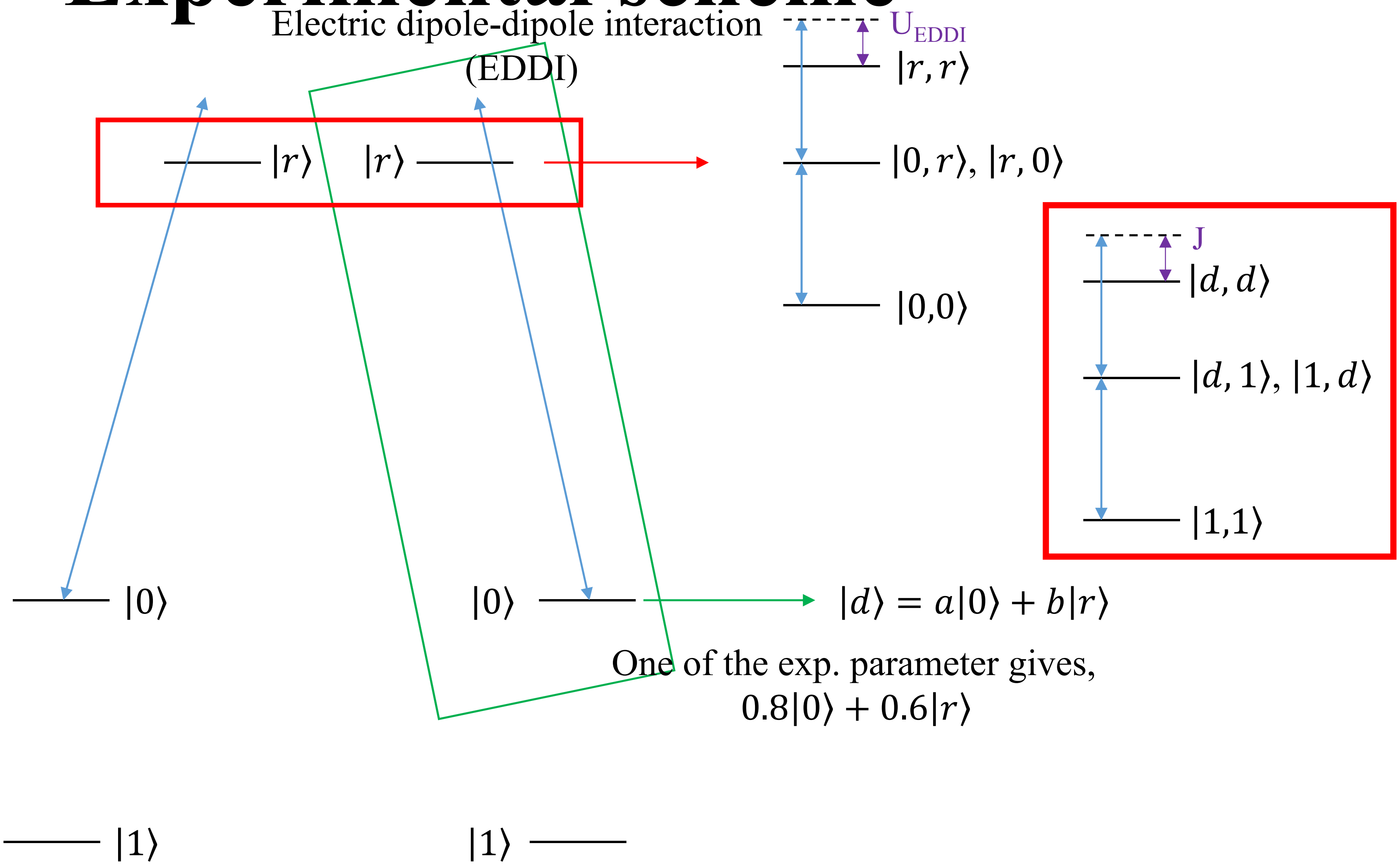
G. W. Biedermann

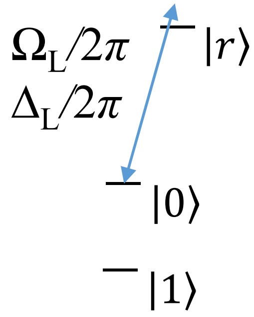
- Sandia National Lab.
- 2007 Ph.D. @ Kasevich Group, Stanford
- Now Research Associate Professor @ CQuIC

Experimental scheme

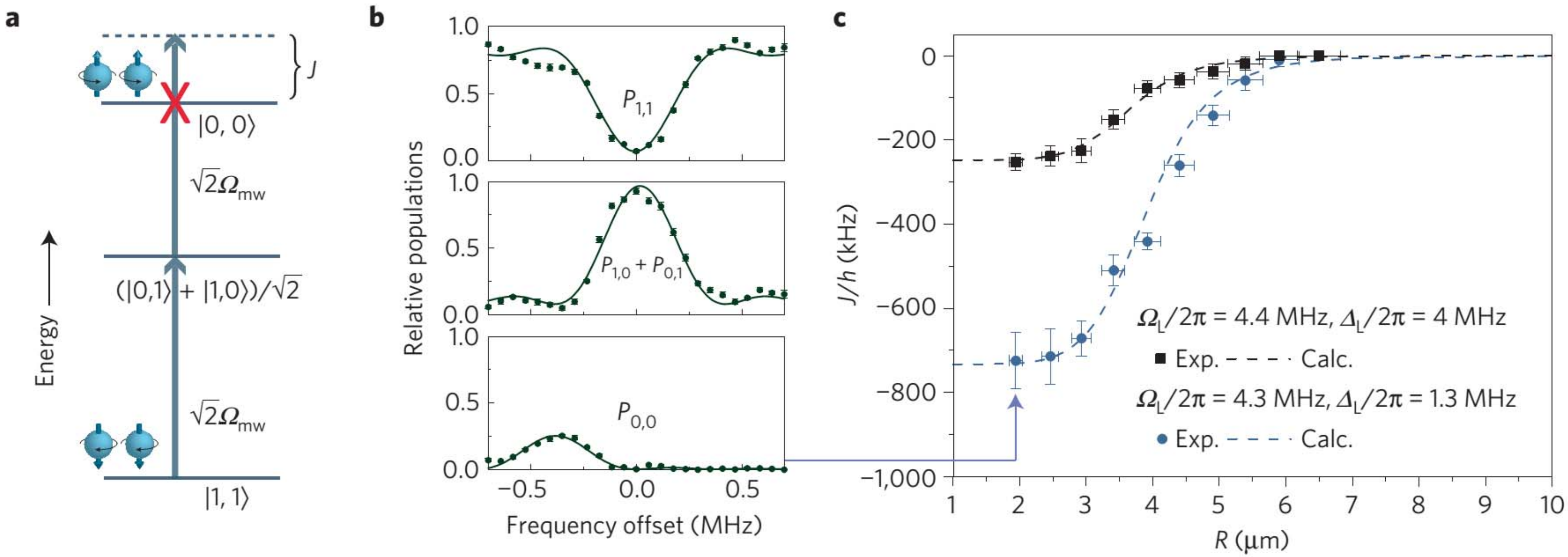


Backgrounds

Level splitting

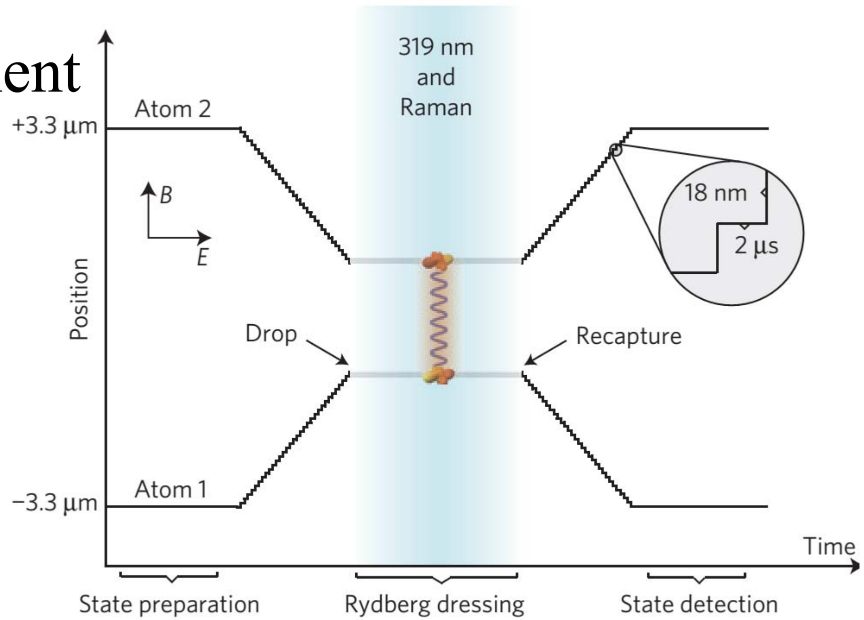


- Two conditions
  1. $\Omega_L/2\pi = 4.4$ MHz, $\Delta_L/2\pi = 4$ MHz => small shift $(0.91|0\rangle + 0.41|r\rangle)$
  2. $\Omega_L/2\pi$ =4.3 MHz, $\Delta_L/2\pi = 1.3$ MHz => large shift $(0.8|0\rangle + 0.6|r\rangle)$



Experimental Procedure

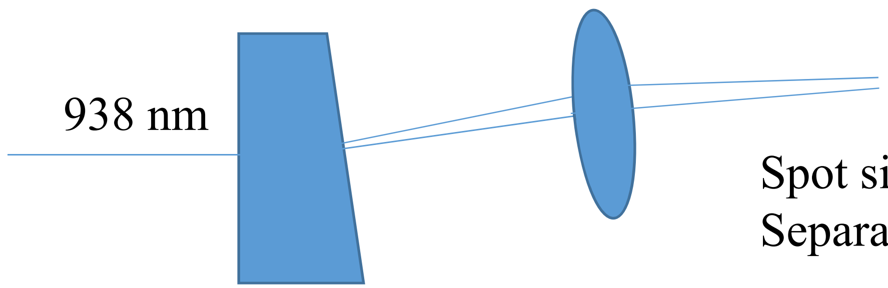
- Extract 2 atoms from MOT
- State preparation
  - Polarization gradient cooling to 20 uK
  - Optical pumping
- Translate the atoms
- Rydberg dressing and entanglement
- Translate the atoms again
- State detection



Experimental method

Translation of atoms

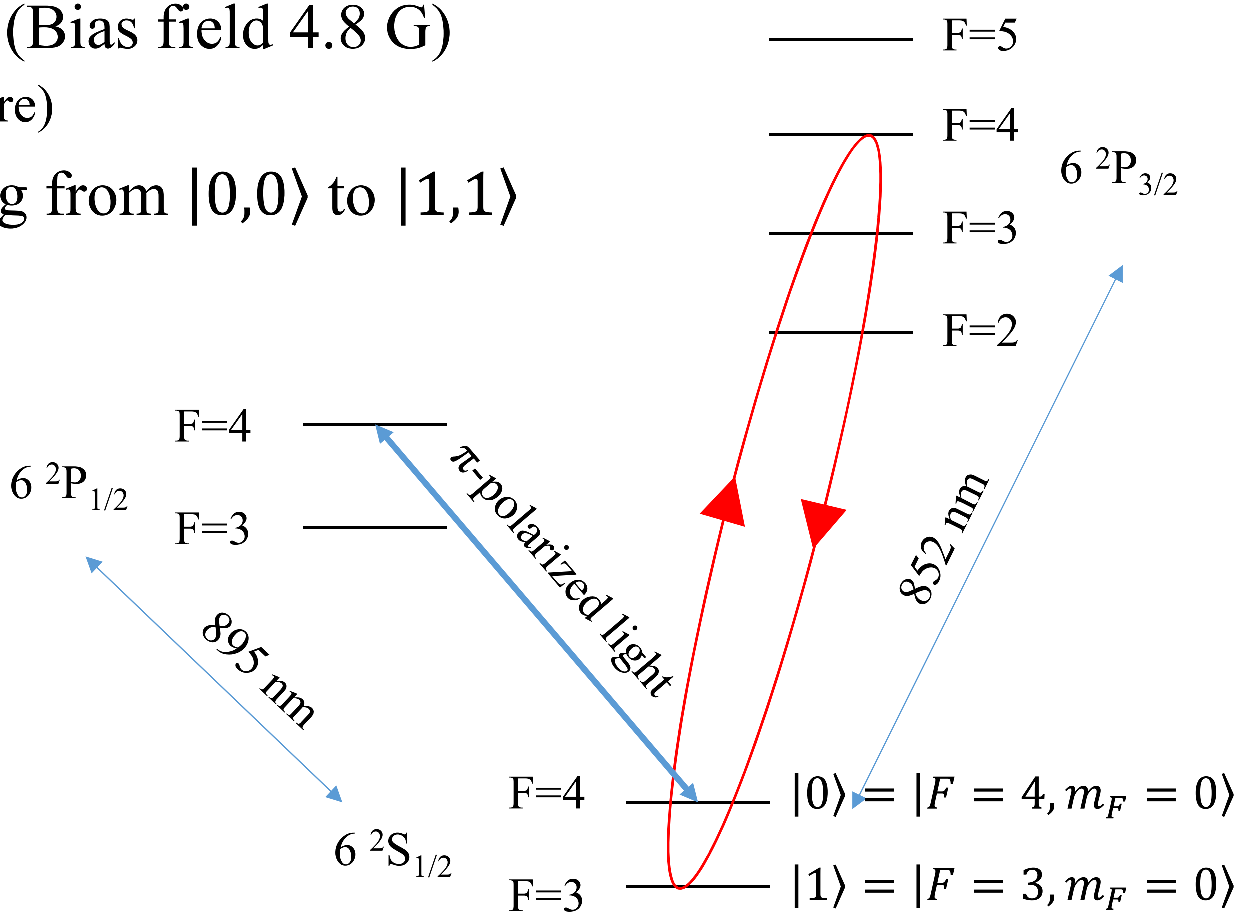
- Optical tweezer(Dipole trap)
  - Driving AOM with two different frequency, two angular-separated beams can be made.
  - Step: 18 nm per 2 us



Experimental method

State preparation

- Polarization gradient cooling to 20 uK
- Optical pumping (Bias field 4.8 G)
  Two lasers(as figure)
- Global π pumping from $|0,0\rangle$ to $|1,1\rangle$



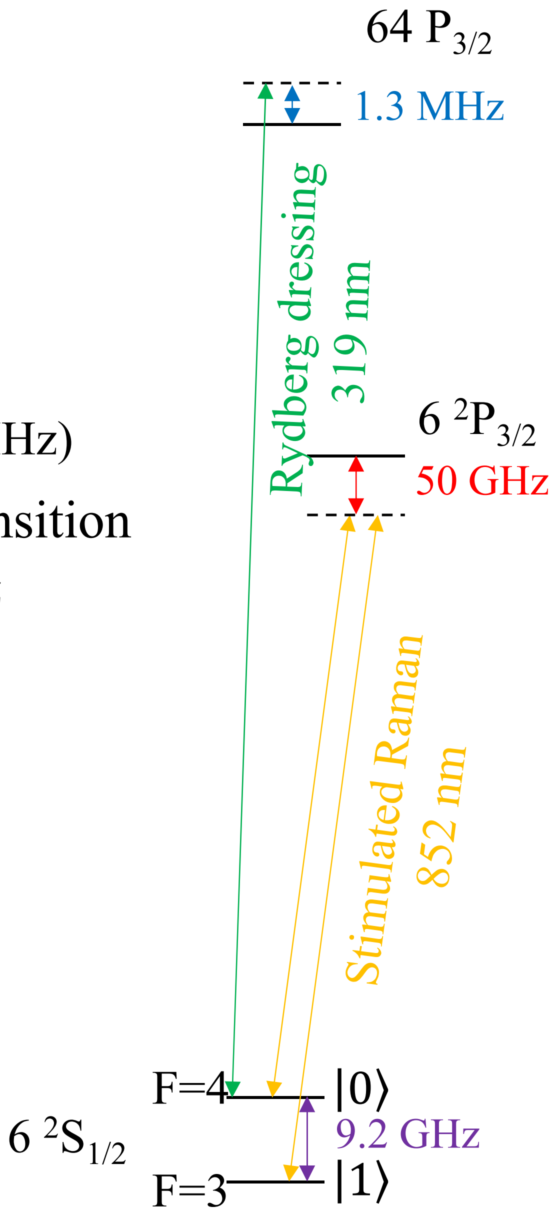
Preparation efficiency: 95%

$$|0\rangle = |F=4, m_F=0\rangle \to \left|F'=5, m_J=3/2\right\rangle$$

Experimental method

Rydberg dressing

- Turn off the trap beam during dressing
- Dressing beam: $6S_{1/2}$ <-> $64P_{3/2}$
  319 nm – blue detuned
  Detuning is small compared to hyperfine splitting(~MHz)
- Sweeping beam($|0\rangle \to |1\rangle$): Stimulated Raman transition
  $6S_{1/2}$ <-> $6P_{3/2}$: 852 nm Δ_{mw}= -50 GHz, Ω_{mw}~160kHz
- Turn on the trap beam after sweeping the states

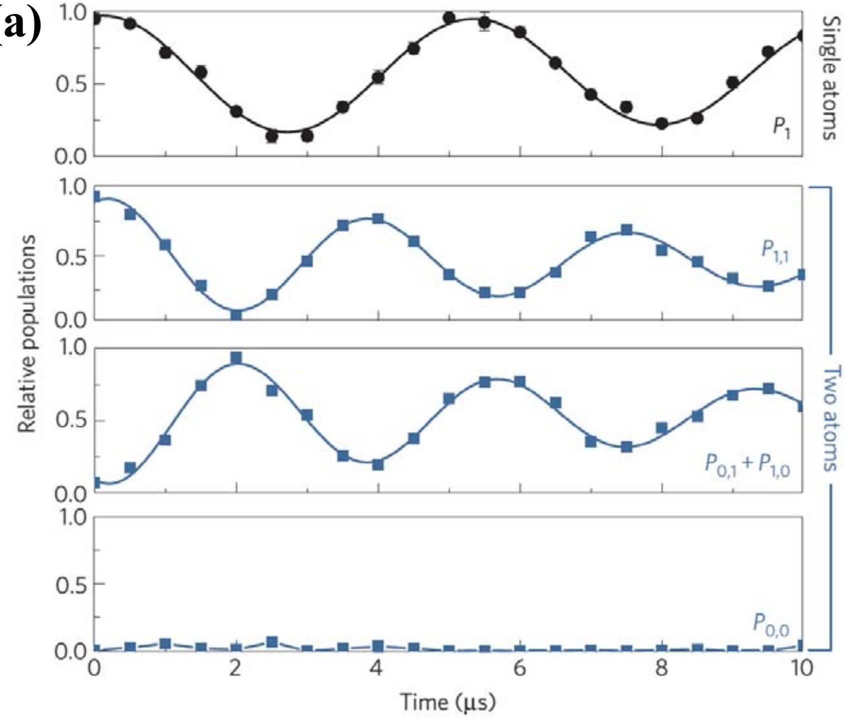


Experimental method

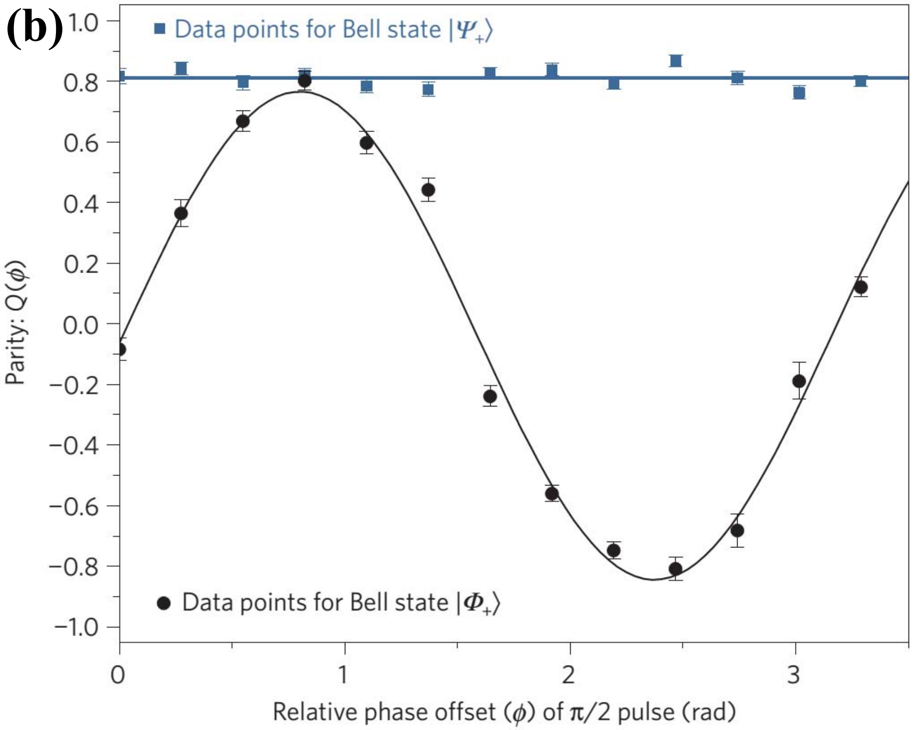
Bell state preparation

- $|\Psi_+\rangle = |0{,}1\rangle + |1{,}0\rangle$ state is generated by applying resonant light.
- $|\Phi_+\rangle = |1{,}1\rangle + |0{,}0\rangle$ state is generated by applying global $\frac{\pi}{2}$ pulse on the state $|\Psi_+\rangle$.
- Fidelity: 81(2)%, survival probability of atoms: 74%

(a)



(b)

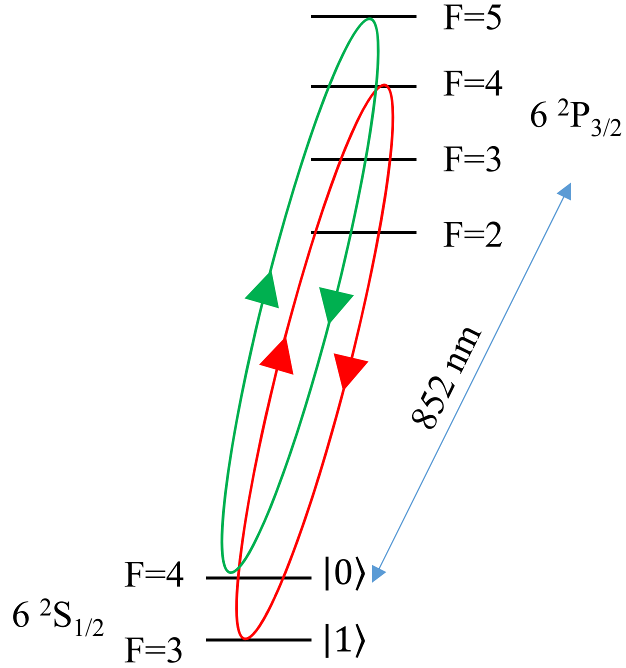


Experimental method

State detection

- Using cycling transition to detect $|0\rangle = |F = 4, m_F = 0\rangle$

  $|6S_{1/2}, F = 4\rangle \to |6P_{3/2}, F' = 5\rangle$
- If dark, then turn on the repump laser and cycling transition again in order to verify atom's presence.



[redacted]

π-polarized light

- F-F'=0, m_F=0 is forbidden

proof) Like getting CG coef., we start from $|F+1,F+1\rangle = |F,F\rangle|1,1\rangle$.

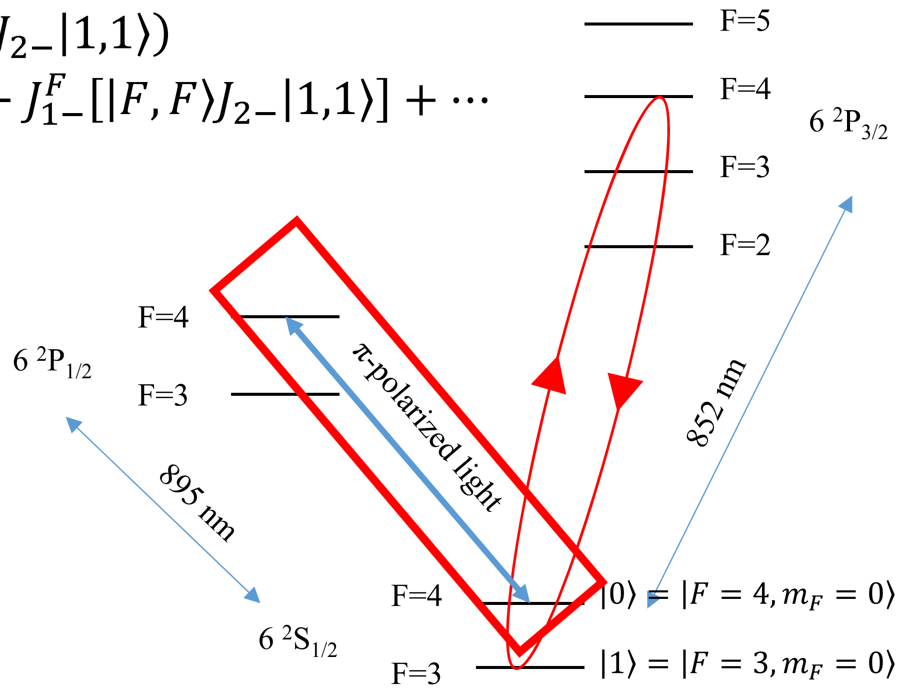
$$|F+1,F\rangle = J_{-}|F,F\rangle|1,1\rangle = J_{1-}|F,F\rangle|1,1\rangle + |F,F\rangle J_{2-}|1,1\rangle$$

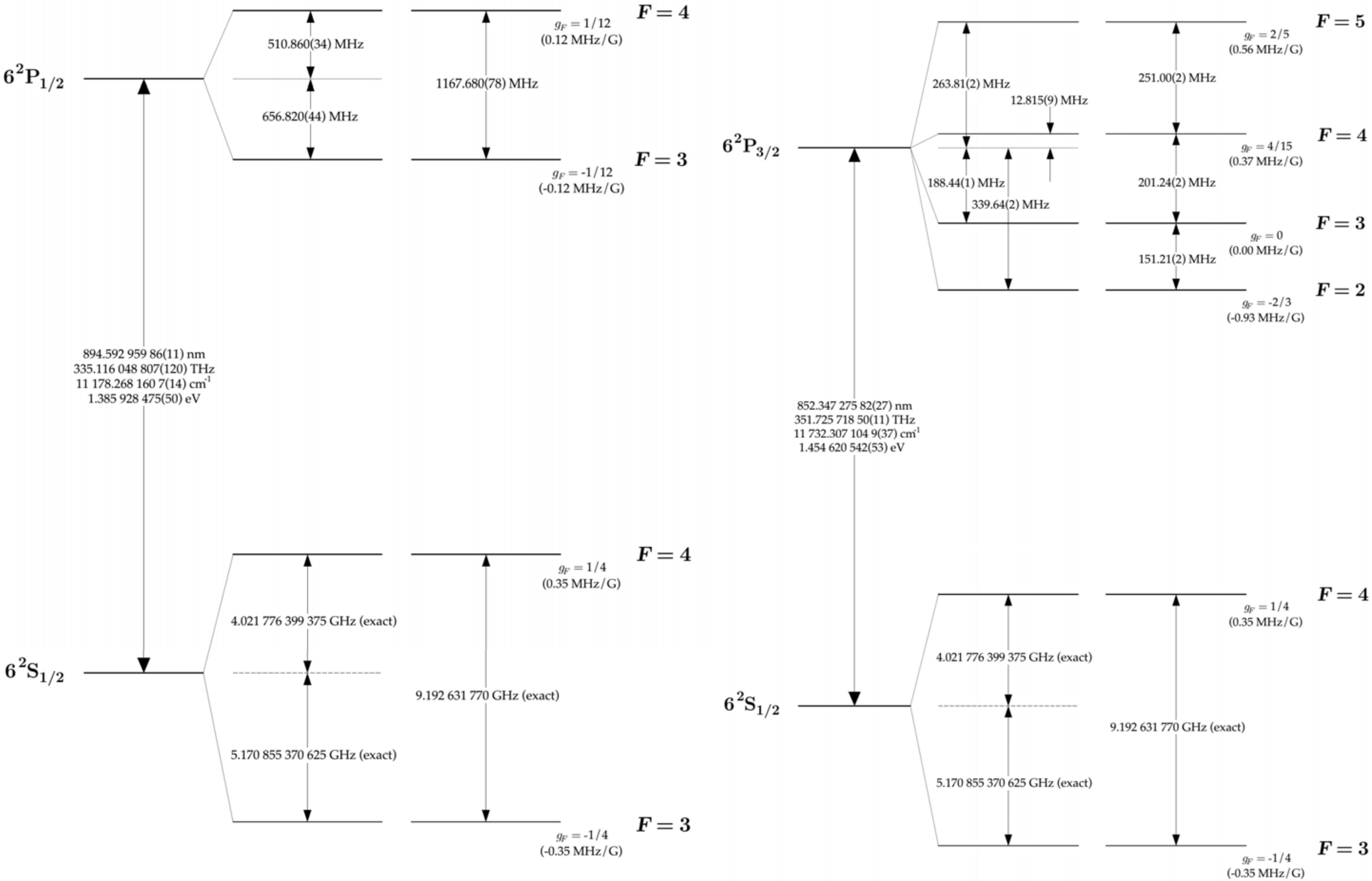
$$|F,F\rangle = J_{1-}|F,F\rangle|1,1\rangle - |F,F\rangle J_{2-}|1,1\rangle$$

$$\Rightarrow |F,0\rangle = J_{-}^{F}(J_{1-}|F,F\rangle|1,1\rangle - |F,F\rangle J_{2-}|1,1\rangle)$$

$$= \cdots + J_{1-}^{F-1}J_{2-}[J_{1-}|F,F\rangle|1,1\rangle] - J_{1-}^{F}[|F,F\rangle J_{2-}|1,1\rangle] + \cdots$$

$$= \cdots + 0[|F,0\rangle|1,0\rangle] + \cdots$$





$6^2P_{1/2}$
$F = 4$
510.860(34) MHz
$g_F = 1/12$
(0.12 MHz/G)
1167.680(78) MHz
656.820(44) MHz
$F = 3$
$g_F = -1/12$
(-0.12 MHz/G)
894.592 959 86(11) nm
335.116 048 807(120) THz
11 178.268 160 7(14) cm^{-1}
1.385 928 475(50) eV
$F = 4$
$g_F = 1/4$
(0.35 MHz/G)
4.021 776 399 375 GHz (exact)
$6^2S_{1/2}$
9.192 631 770 GHz (exact)
5.170 855 370 625 GHz (exact)
$F = 3$
$g_F = -1/4$
(-0.35 MHz/G)
$F = 5$
$g_F = 2/5$
(0.56 MHz/G)
263.81(2) MHz
251.00(2) MHz
12.815(9) MHz
$6^2P_{3/2}$
$F = 4$
$g_F = 4/15$
(0.37 MHz/G)
188.44(1) MHz
201.24(2) MHz
339.64(2) MHz
$F = 3$
$g_F = 0$
(0.00 MHz/G)
151.21(2) MHz
$F = 2$
$g_F = -2/3$
(-0.93 MHz/G)
852.347 275 82(27) nm
351.725 718 50(11) THz
11 732.307 104 9(37) cm^{-1}
1.454 620 542(53) eV
$F = 4$
$g_F = 1/4$
(0.35 MHz/G)
4.021 776 399 375 GHz (exact)
$6^2S_{1/2}$
9.192 631 770 GHz (exact)
5.170 855 370 625 GHz (exact)
$F = 3$
$g_F = -1/4$
(-0.35 MHz/G)