Prospects for Two-Photon Optical Magnetometry

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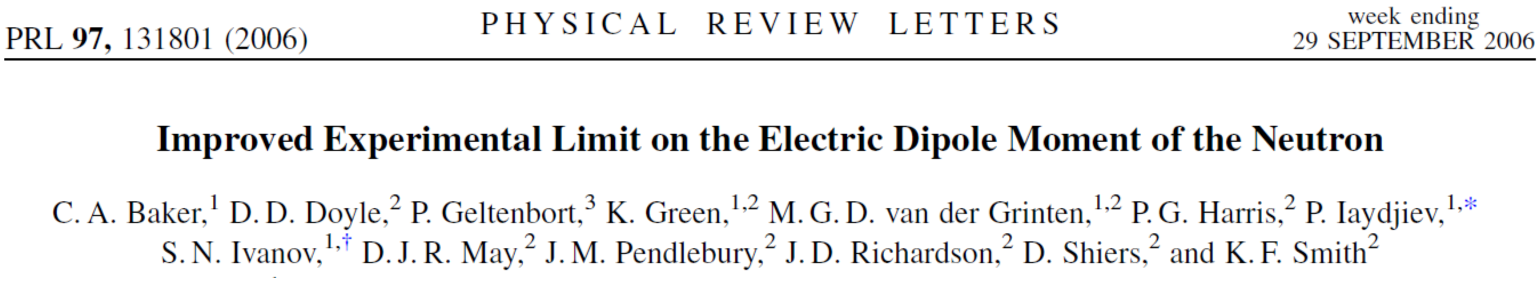
Current State of the Art
Atomic Co-magnetometer



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Improved Experimental Limit on the Electric Dipole Moment of the Neutron

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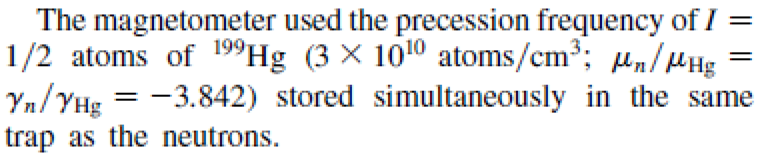


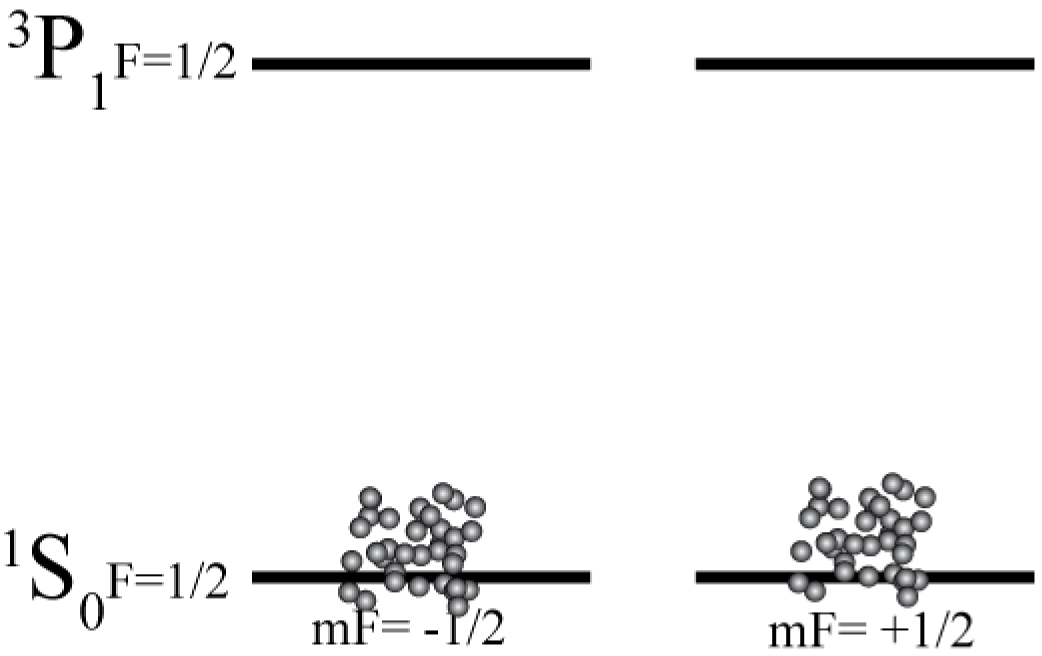
The magnetometer used the precession frequency of $I = 1/2$ atoms of ^{199}Hg (3×10^{10} atoms/cm^3; $\mu_n/\mu_{\rm Hg} = \gamma_n/\gamma_{\rm Hg} = -3.842$) stored simultaneously in the same trap as the neutrons.

70 $^1S_0$	80 $^1S_0$	54 $^1S_0$
Yb	**Hg**	**Xe**
Ytterbium	Mercury	Xenon
173.04	200.59	131.293
[Xe]$4f^{14}6s^2$	[Xe]$4f^{14}5d^{10}6s^2$	[Kr]$4d^{10}5s^25p^6$
6.2542	10.4375	12.1298

Magnetometry with Nuclear Spin

70 $^1S_0$
Yb
Ytterbium
173.04
$[Xe]4f^{14}6s^2$

Unpolarized



$^3P_1$ F=1/2

$^1S_0$ F=1/2

mF= -1/2

mF= +1/2

Magnetometry with Nuclear Spin

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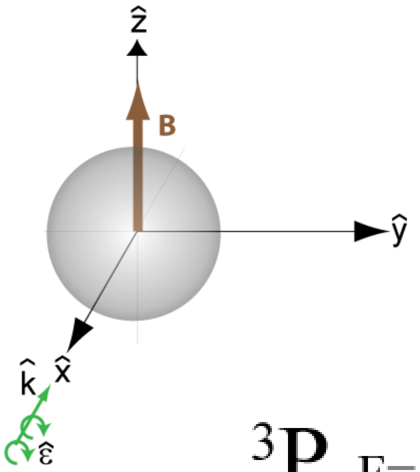
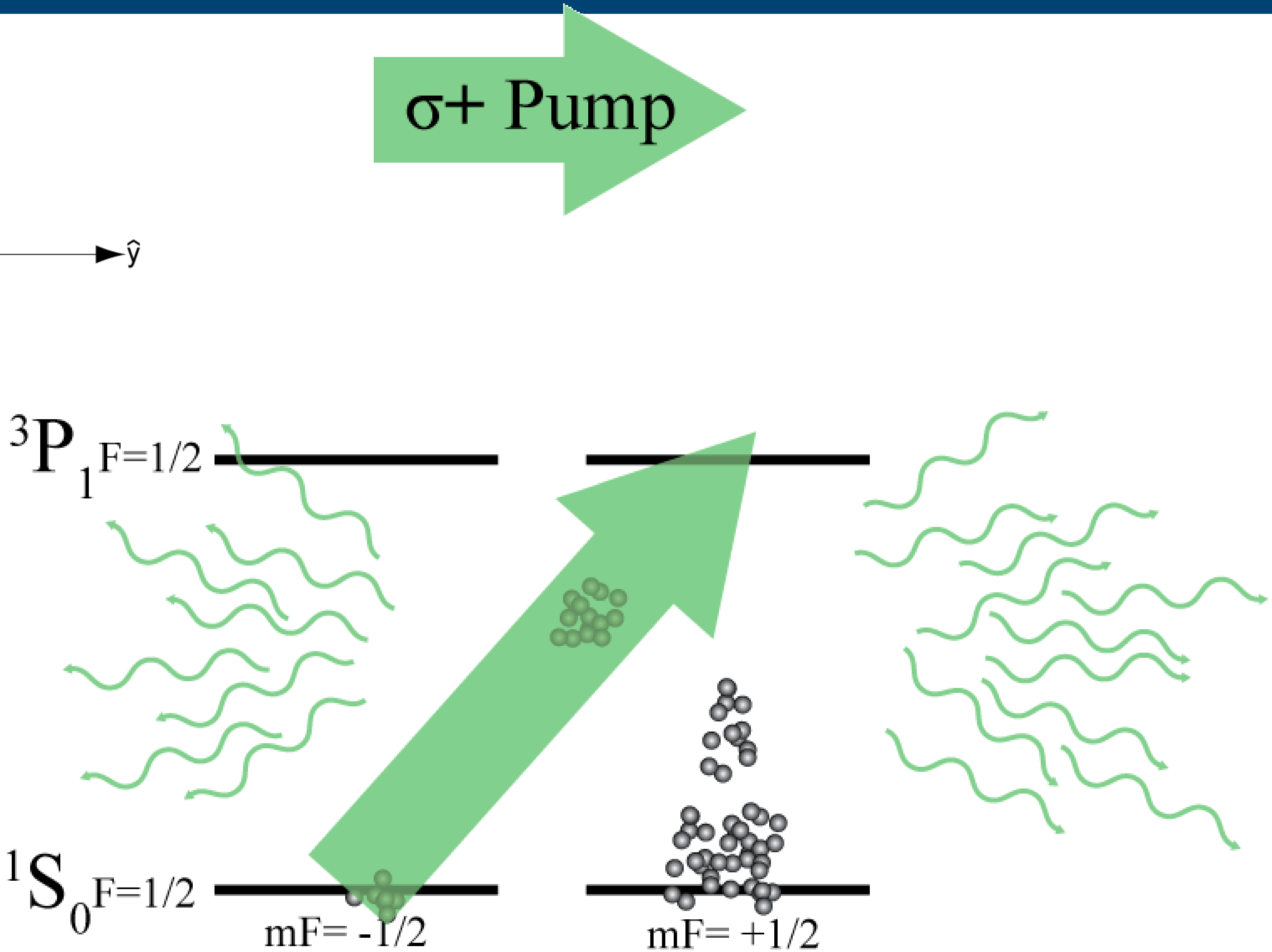
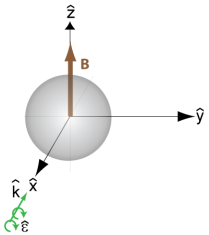
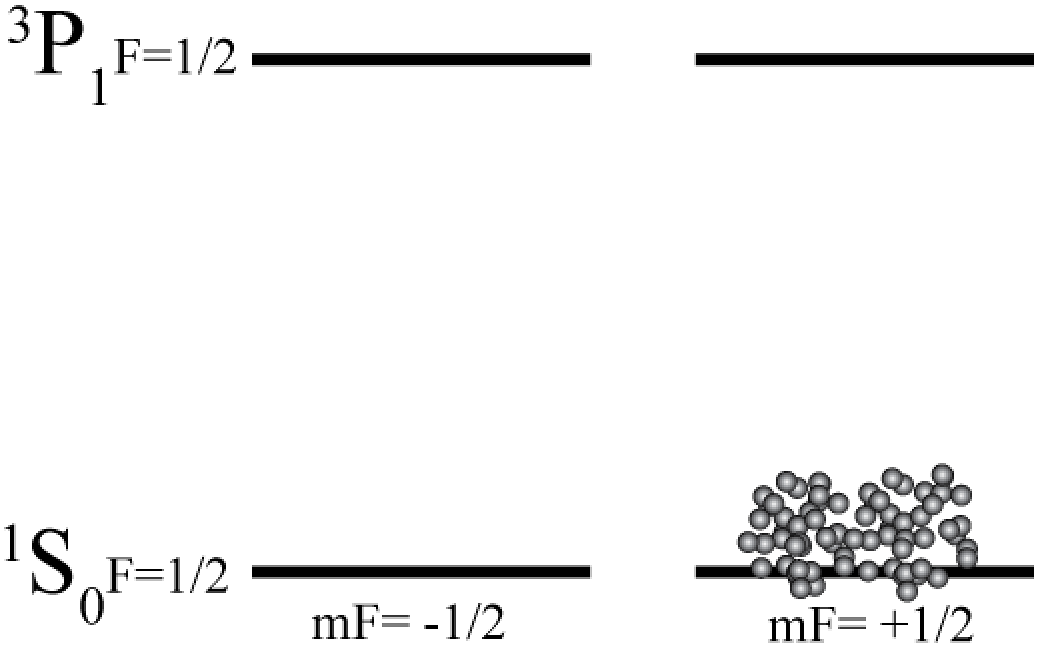




Magnetometry with Nuclear Spin



Polarized



$^3P_1$ F=1/2

$^1S_0$ F=1/2

mF= -1/2

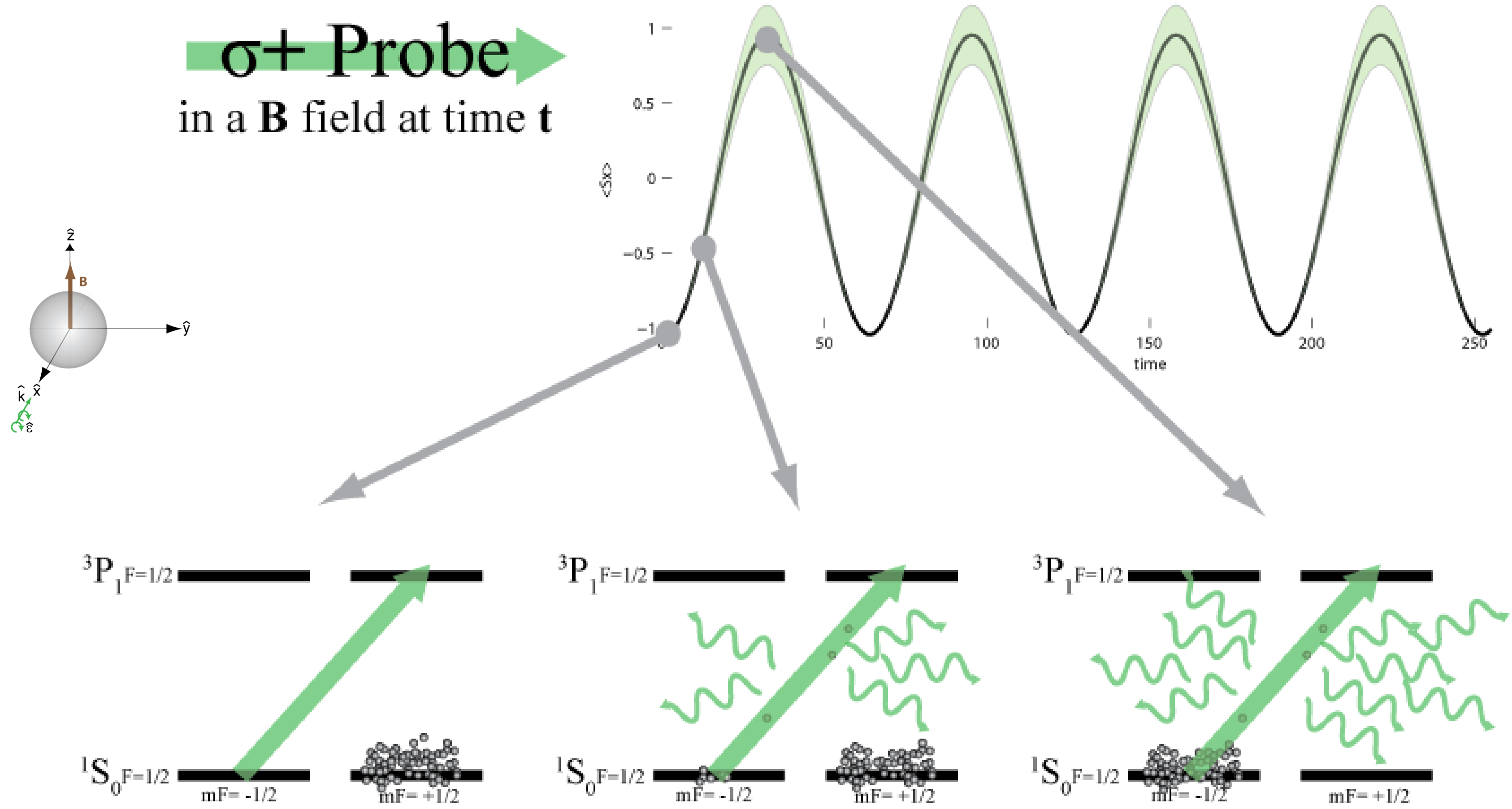
mF= +1/2

Magnetometry with Nuclear Spin

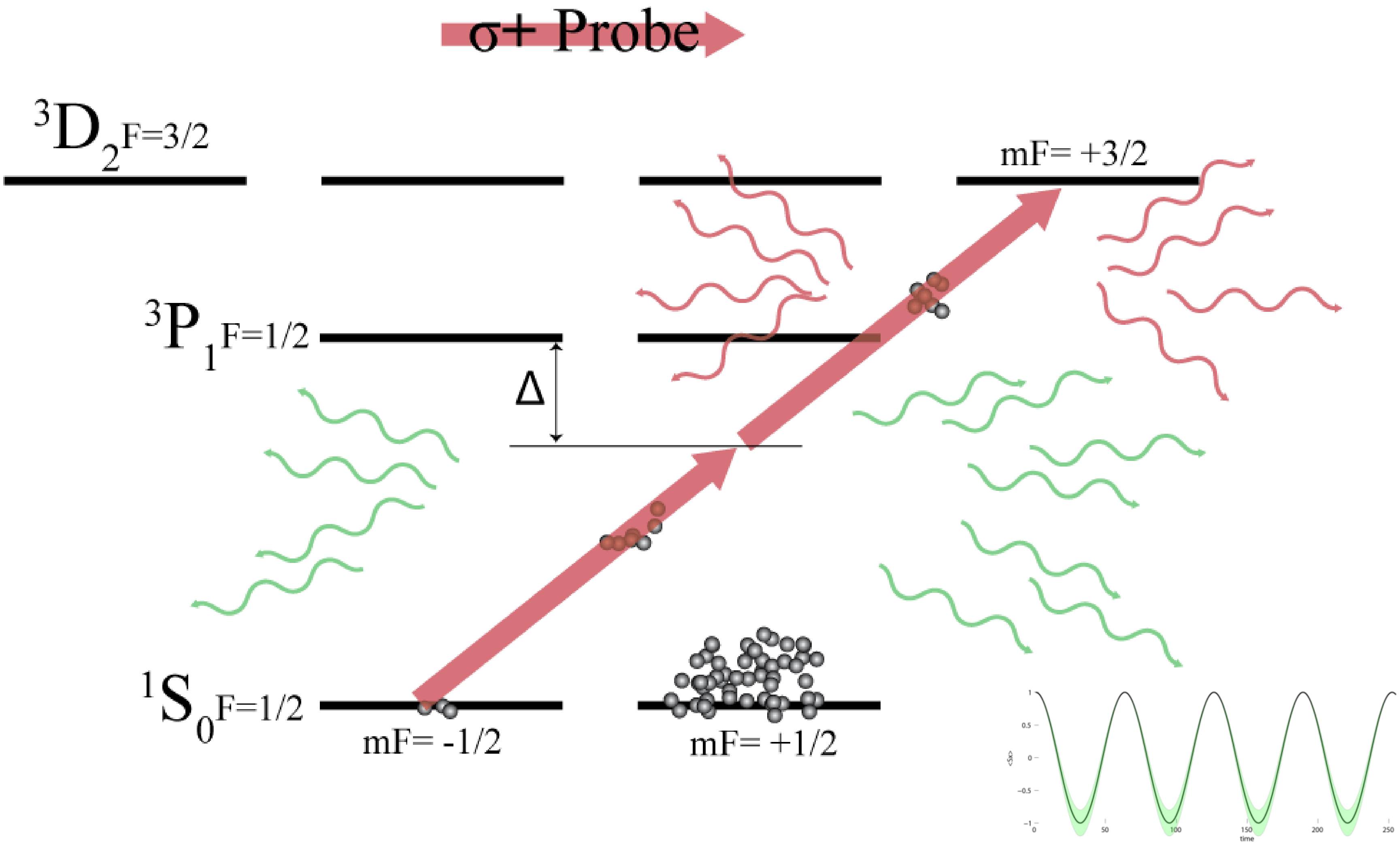
70 $^1S_0$
Yb
Ytterbium
173.04
$[Xe]4f^{14}6s^2$

σ+ Probe

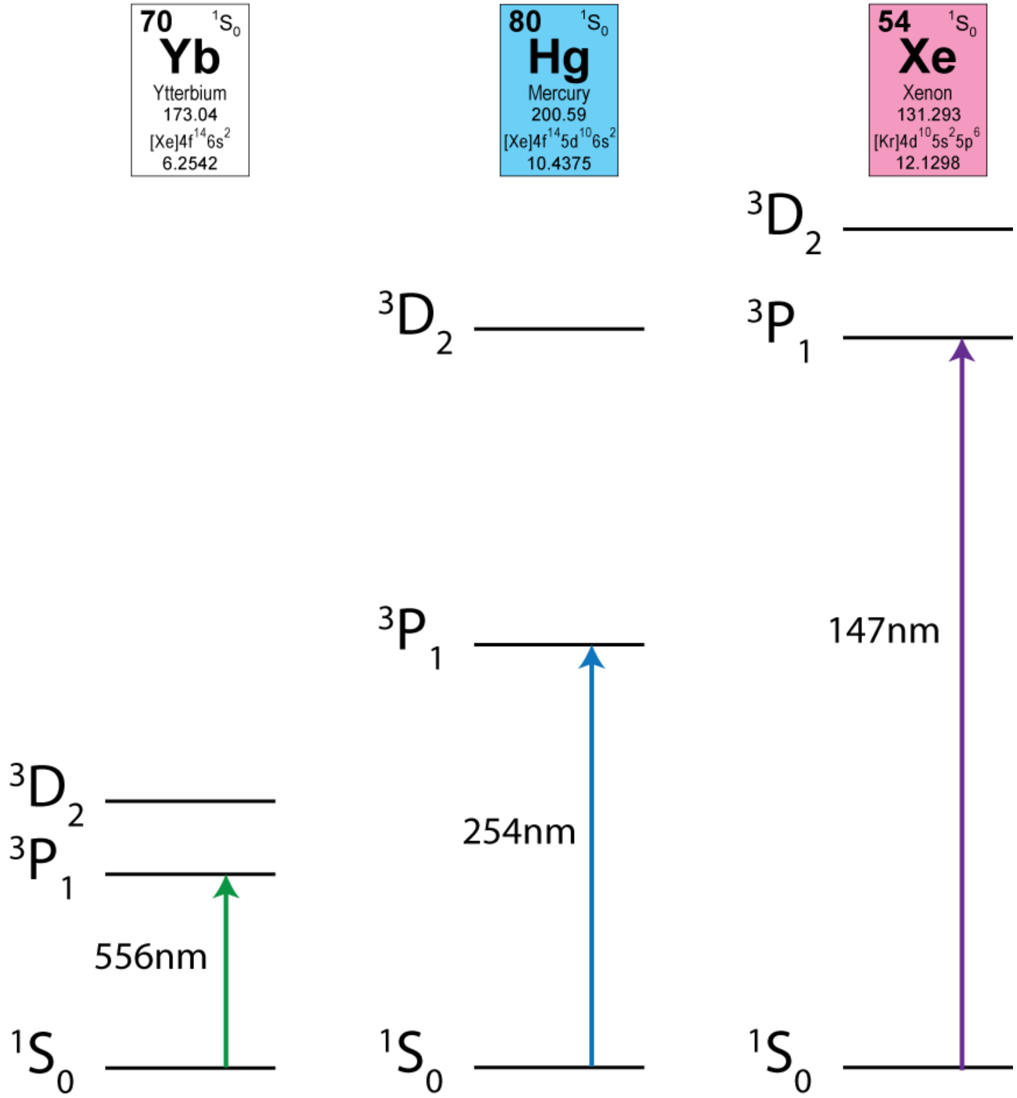
in a **B** field at time **t**



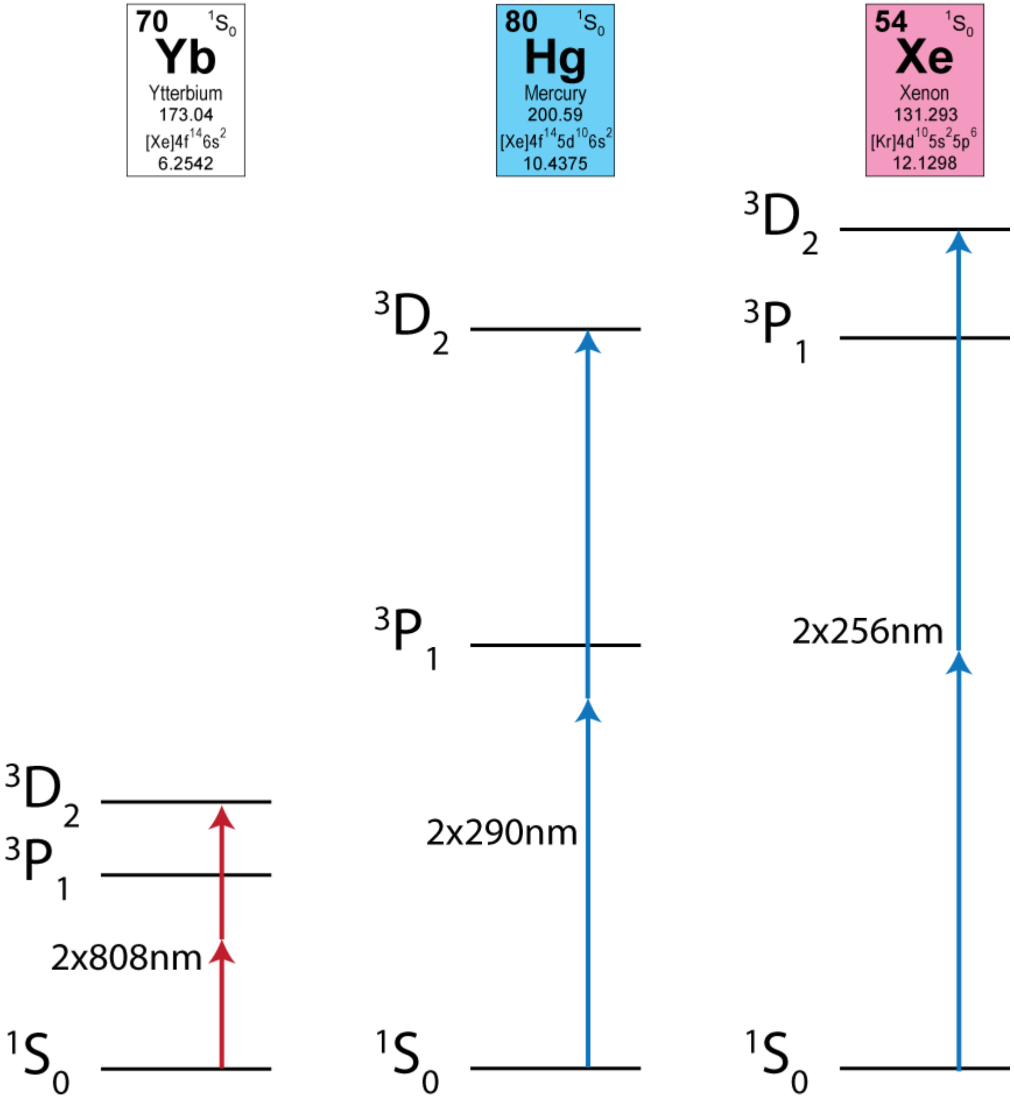
Magnetometry in Three Level Systems



Energy Spacings $^1S_0 \rightarrow {}^3P_1$



Energy Spacings $^1S_0 \rightarrow {}^3D_2$



Fundamental Precision of Magnetometers

$$\delta B \propto \frac{1}{\gamma\sqrt{NT\tau}}$$

	Gyromagnetic Ratio	Density of Atoms	Coherence Time
70 $^1S_0$ **Yb** Ytterbium 173.04 [Xe]$4f^{14}6s^2$ 6.2542	$\lvert\gamma\rvert$=0.75 kHz/G NIST Standard Reference Database 108	$\rho = 5\cdot10^{12}$ cm^{-3} DOI: 10.1103/PhysRevA.60.1103	τ>5ms DOI: 10.1007/s00340-006-2136-y
80 $^1S_0$ **Hg** Mercury 200.59 [Xe]$4f^{14}5d^{10}6s^2$ 10.4375	$\lvert\gamma\rvert$=0.77 kHz/G NIST Standard Reference Database 108	$\rho = 4\cdot10^{13}$ cm^{-3} DOI: 10.1103/PhysRevLett.102.101601	τ >200s DOI: 10.1103/PhysRevLett.102.101601
54 $^1S_0$ **Xe** Xenon 131.293 [Kr]$4d^{10}5s^25p^6$ 12.1298	$\lvert\gamma\rvert$=1.18 kHz/G NIST Standard Reference Database 108	$\rho = 10^{22}$ cm^{-3} DOI: 10.1103/PhysRevLett.87.067601	τ_N=880s τ >1300s DOI: 10.1103/PhysRevLett.87.067601

Characteristic Rates

$$\mathcal{R} \approx \rho V \frac{|\mu_{01}|^2|\mu_{12}|^2}{\hbar^4\Delta^2\Gamma}\left(\frac{I}{\epsilon_0 c}\right)^2$$

	$^1S_0 \rightarrow {}^3D_2$ **#photons/atom** **@ 1W/cm^2**	Density of Atoms
70 $^1S_0$ **Yb** Ytterbium 173.04 [Xe]$4f^{14}6s^2$ 6.2542	**31 mHz**	$\rho = 5\cdot10^{12}$ cm^{-3}
54 $^1S_0$ **Xe** Xenon 131.293 [Kr]$4d^{10}5s^2 5p^6$ 12.1298	**56 μHz**	$\rho = 10^{17}$-10^{22} cm^{-3}

Our Yb Experiment

70 $^1S_0$
Yb
Ytterbium
173.04
$[Xe]4f^{14}6s^2$

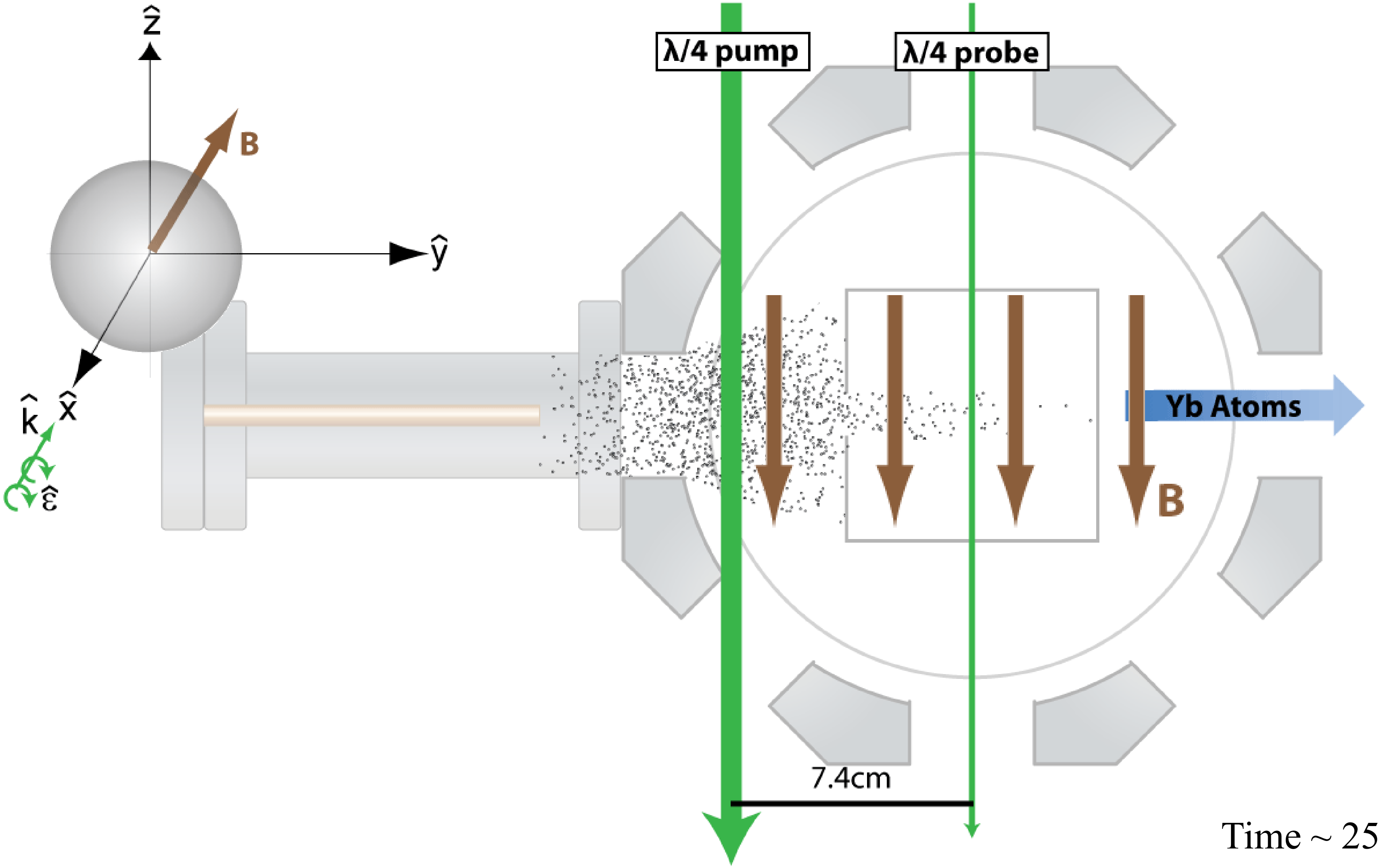
Thermal Yb Beam

Stage 1: Polarize & Probe $^1S_0 \rightarrow {}^3P_1$

Stage 2: Drive & Detect $^1S_0 \rightarrow {}^3D_2$

Stage 3: Polarize & Probe $^1S_0 \rightarrow {}^3D_2$

Current Experimental System

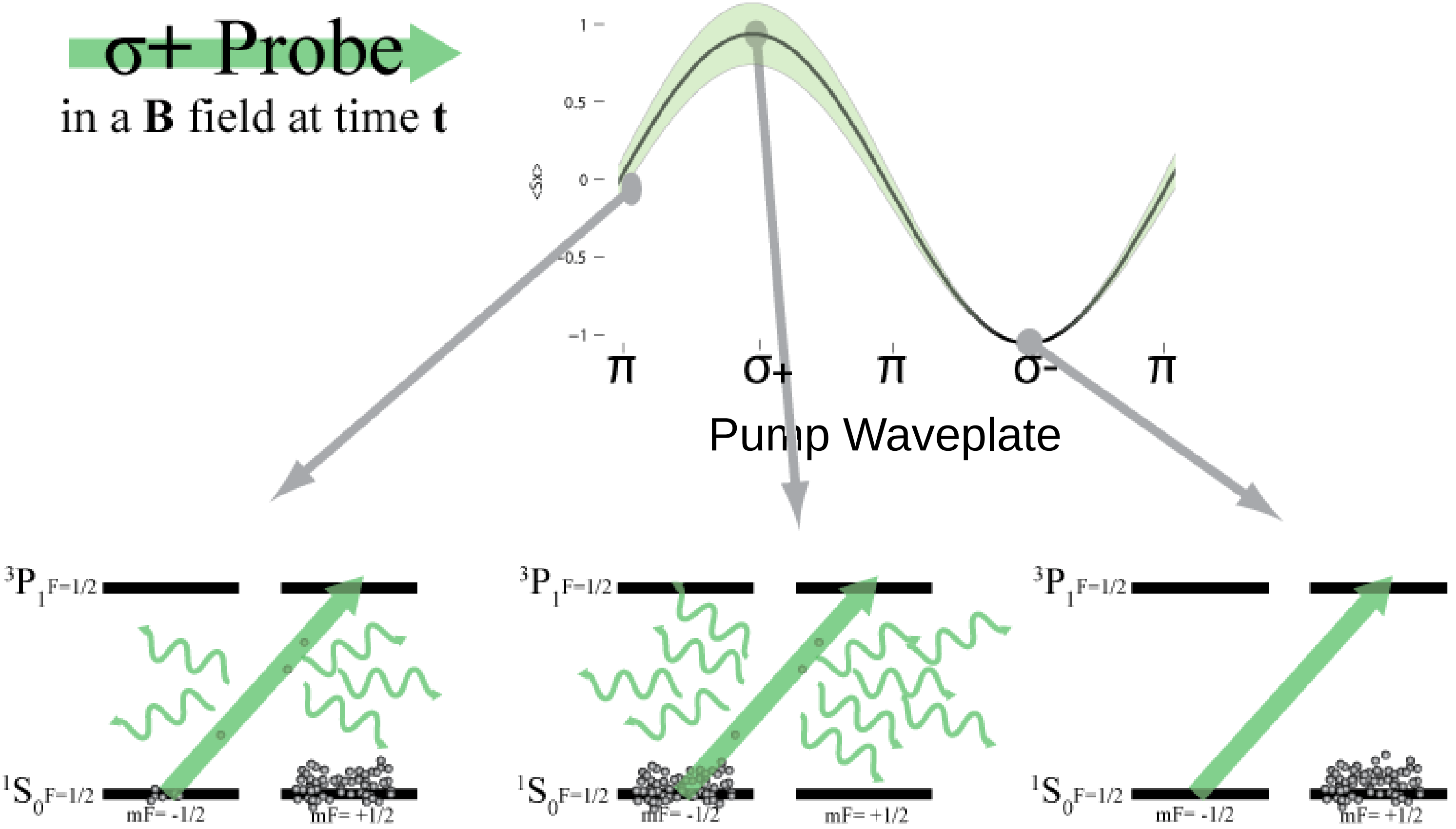


Time ~ 250μs

Stage 1: Experiment

σ+ Probe

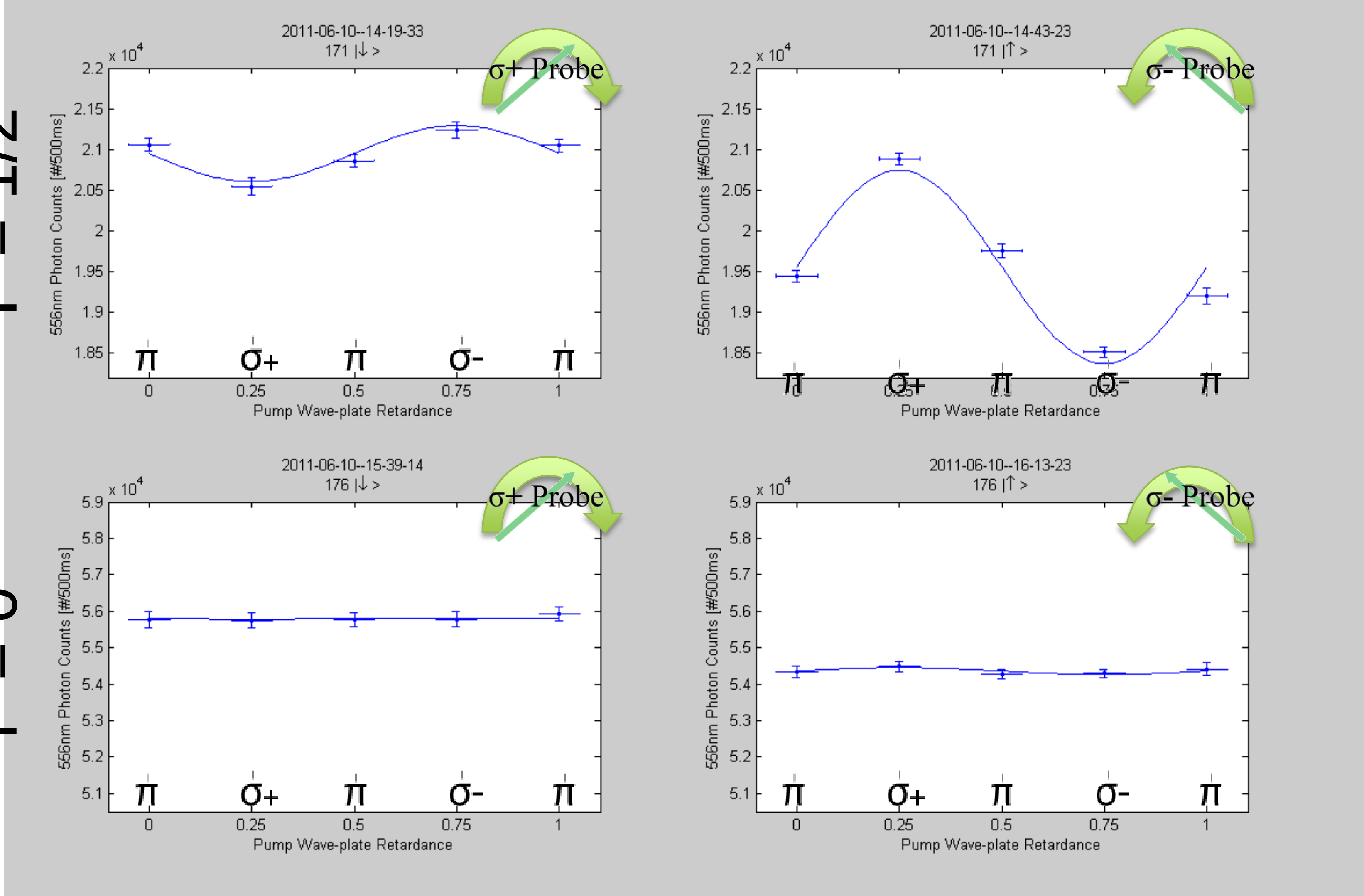
in a **B** field at time **t**



Stage 1: Polarization Data

F = 1/2

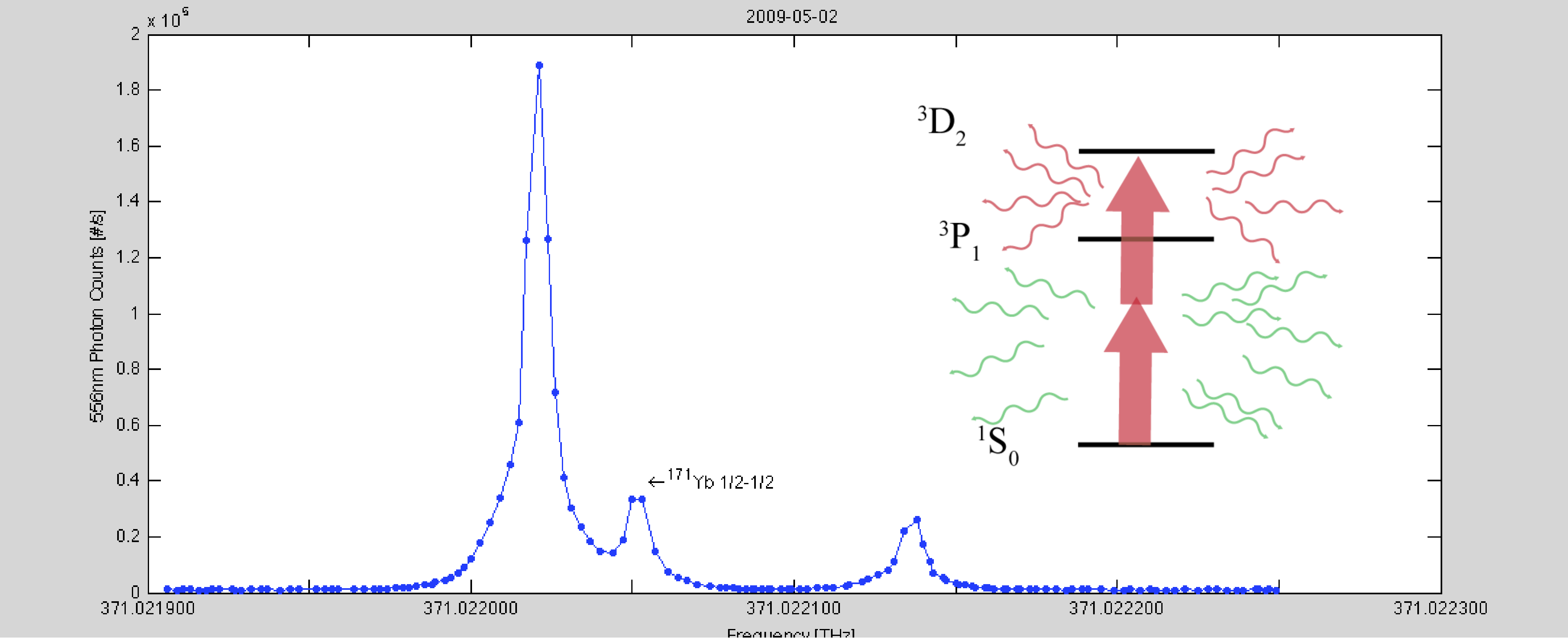
F = 0



Stage 2: $^1S_0 \rightarrow {}^3D_2$

70 $^1S_0$
Yb
Ytterbium
173.04
$[Xe]4f^{14}6s^2$

Completed



$^1S_0 \rightarrow {}^3D_2$ in Xe

70 $^1S_0$
Yb
Ytterbium
173.04
$[Xe]4f^{14}6s^2$

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Two-photon laser spectroscopy of xenon collision pairs

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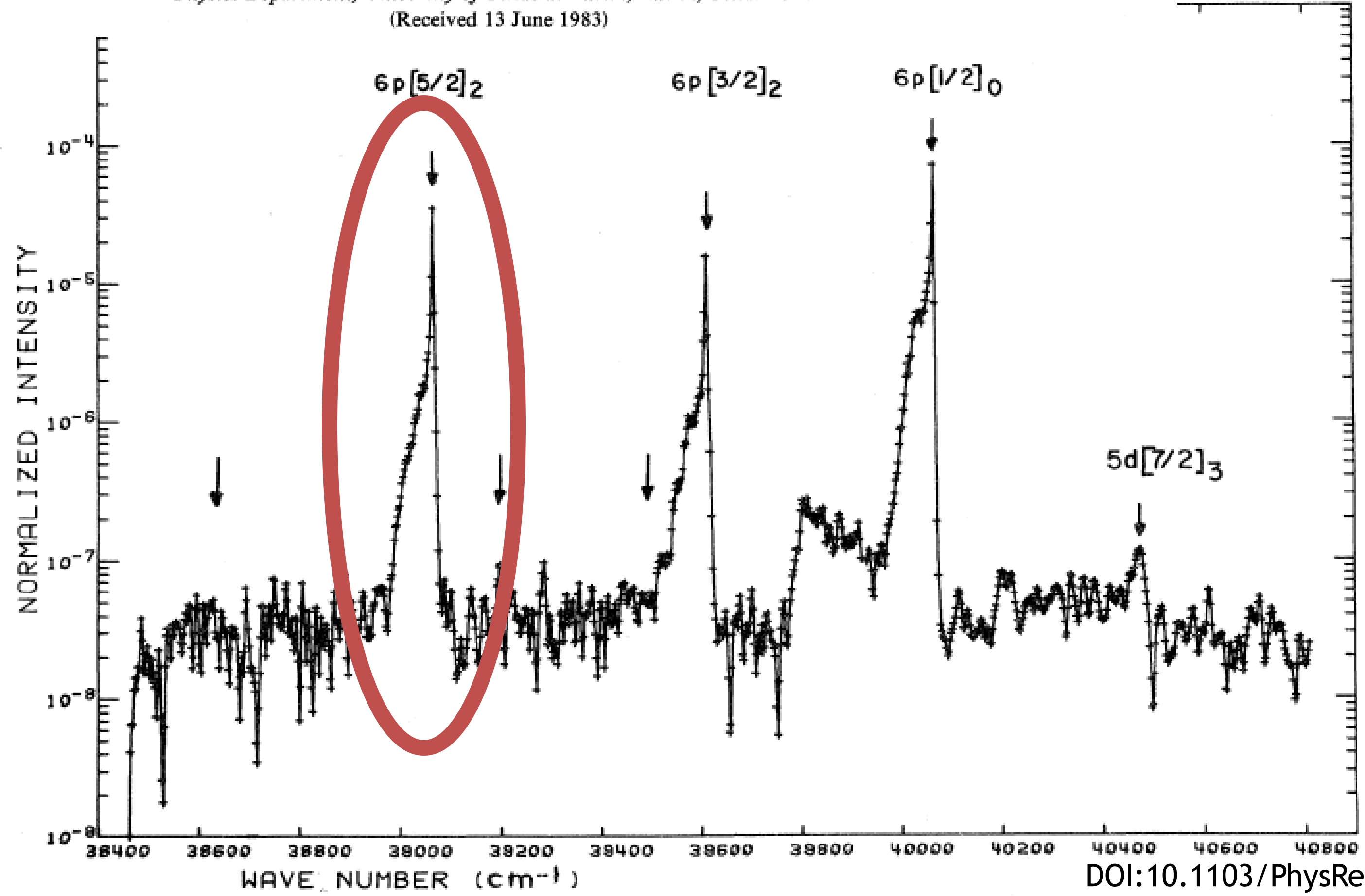
(Received 13 June 1983)



DOI:10.1103/PhysRevA.29.721

Conclusions

Diamagnetic atoms optimal for magnetometry are made accessible with a two-photon excitation scheme.

- Applications to ^{129}Xe and the nEDM measurement

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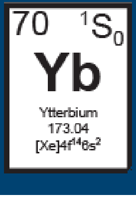
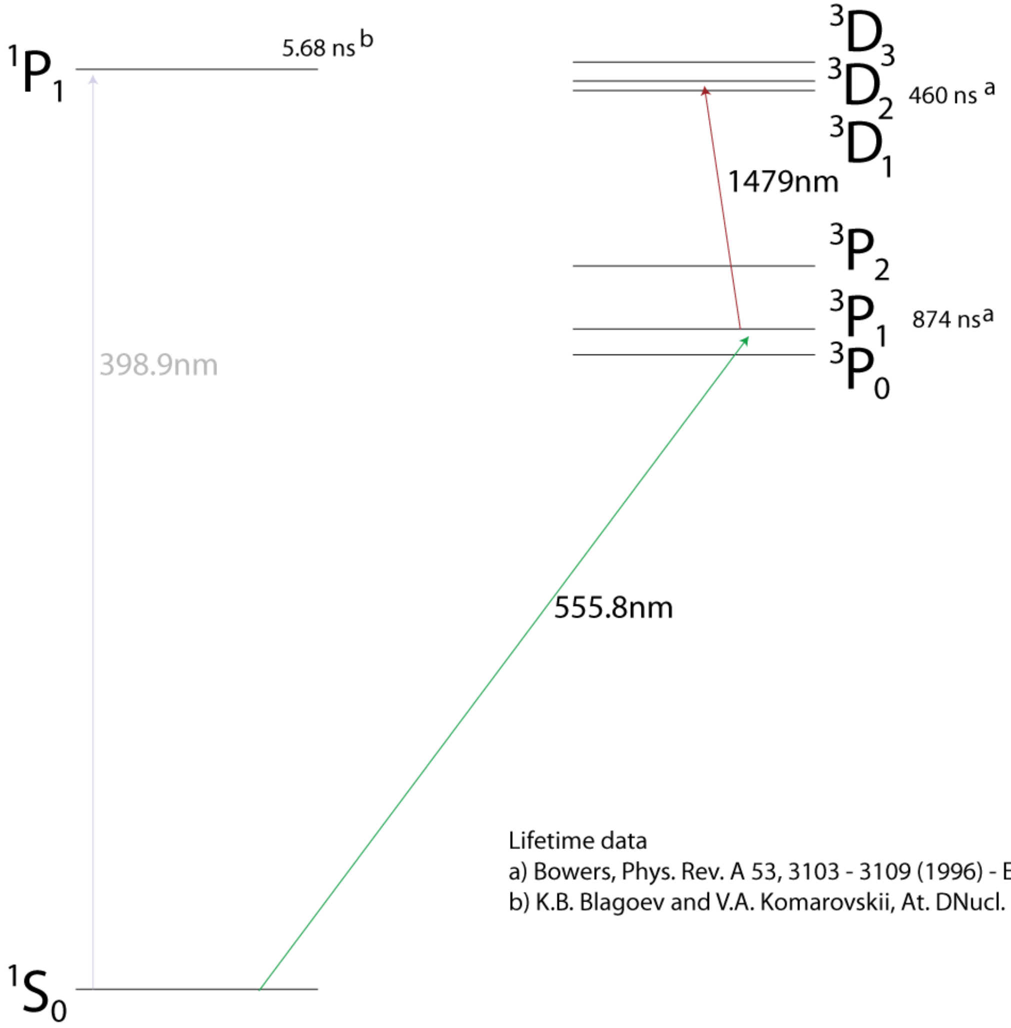
Yb Level Structure





Lifetime data
a) Bowers, Phys. Rev. A 53, 3103 - 3109 (1996) - EXP
b) K.B. Blagoev and V.A. Komarovskii, At. DNucl. D Tables 56, 1 (1994) - EXP

Caveats

- dEDM Hg & Xe

$$\frac{\mu_n}{\mu_{\mathrm{Hg}}} = -3.842,$$

$$\frac{\mu_n}{\mu_{\mathrm{Xe}}} = +1.529.$$

$$\omega_n = \frac{\mu_n}{\mu_{\mathrm{Hg}}}\omega_{\mathrm{Hg}} + (\gamma_n - \frac{\mu_n}{\mu_{\mathrm{Hg}}}\gamma_{\mathrm{Hg}}) + (d_n - \frac{\mu_n}{\mu_{\mathrm{Hg}}}d_{\mathrm{Hg}}),$$

^{199}Hg has $\sigma_0 = 2150\ \frac{v_0}{v}$ barns,

^{129}Xe is $\sigma_0 = 21\frac{v_0}{v}$ barns,

System	Primary Sensitivity	d (e-cm)	Reference
^{129}Xe	$\theta_{QCD}, g_{\pi NN}, C_T$	$(0.7 \pm 3.3) \times 10^{-27}$	[1]
^{199}Hg	$\theta_{QCD}, g_{\pi NN}, C_T$	$(0.49 \pm 1.50) \times 10^{-29}$	[14]