Xe/Hg dual-comagnetometer for the TRIUMF neutron EDM experiment

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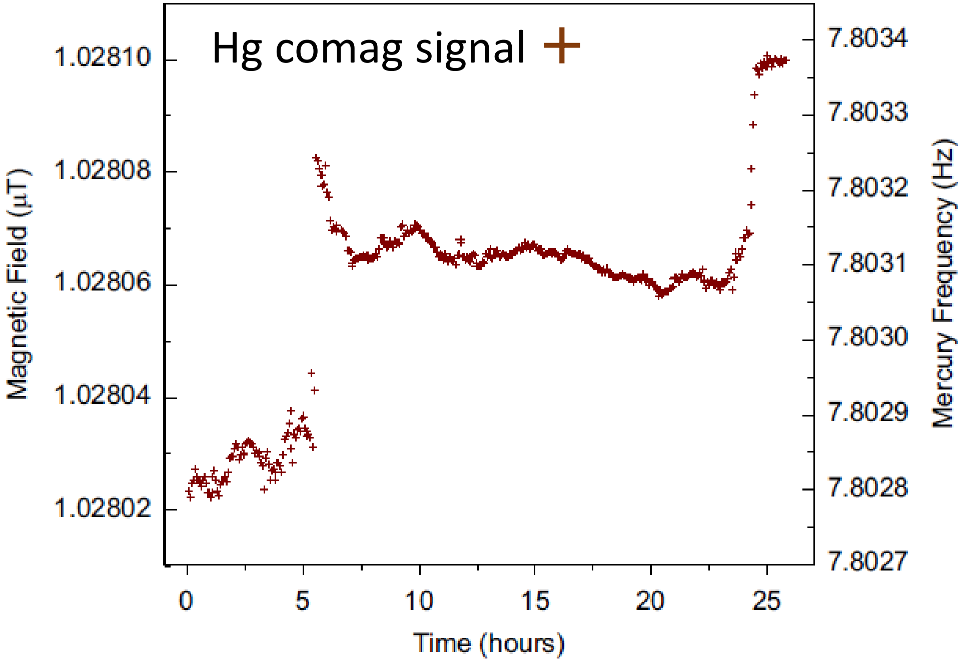
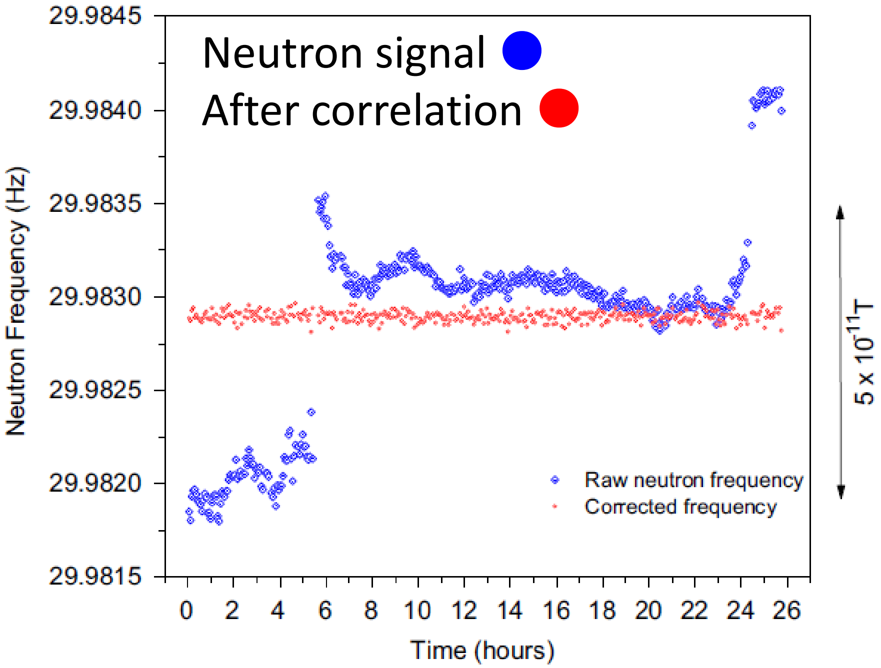
Comagnetometer for nEDM measurement

Comagnetometer for neutron EDM measurement

- TRIUMF proposed $|d_n| < 10^{-27}$ e cm EDM measurement
- nEDM detection: static magnetic field (B_0) = 1 μT→ B field drift ~ 0.05 nT
- **In-situ magnetic field sensor** for canceling frequency shifts

Example: Field drift at ILL experiment monitored by ^{199}Hg comagnetometer





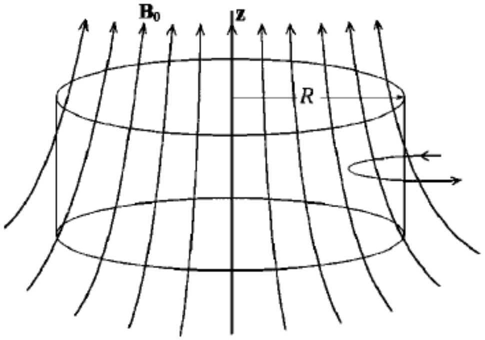
Baker et al., NIM-A 736 (2014)

Geometric Phase Effect

Geometric Phase Effect

- Particle motion (velocity v_n) in static electric field ***E*** and inhomogeneous magnetic field causes a false EDM signal → Systematic errors

Pendlebury et al., Phys. Rev. A70 (2004)



Motional magnetic field $$\mathbf{B}_v = \frac{\mathbf{E}\times\mathbf{v}}{c^2},$$

False EDM signal $$d_{nf} = -\frac{\hbar}{4}\frac{\langle v_n^2\rangle}{c^2}\boxed{\frac{1}{B_{0z}^2}}\boxed{\frac{\partial B_{0z}}{\partial z}},$$

z component of B_0 field

Gradient of B_0 field

It is better to monitor ***B_{0z}*** and **∂B_{0z} /dz** both.

Dual-Comagnetometer: principle

Dual-comagnetometer plan of ^{129}Xe and ^{199}Hg

- Idea to resolve two unknowns (B0z and ∂B0z/dz) by two equation
- Spin polarized ^{129}Xe and ^{199}Hg atoms (spin 1/2) enclosed with UCN into a EDM measurement cell.

Spin precession frequency of comagnetometer atoms (Hg and Xe)

$$\omega_{Hg\uparrow\uparrow} = -\gamma_{Hg}\boxed{B_{0z}} - \frac{\gamma_{Hg}^2 R^2}{2c^2}\boxed{\frac{\partial B_{0z}}{\partial z}} E + \frac{\gamma_{Hg}^3 R^2}{2c^4}\boxed{B_{0z}} E^2 + \text{(higher order)}$$

$$\omega_{Xe\uparrow\uparrow} = -\gamma_{Xe}\boxed{B_{0z}} - \frac{\gamma_{Xe}^2 R^2}{2c^2}\boxed{\frac{\partial B_{0z}}{\partial z}} E + \frac{\gamma_{Xe}^3 R^2}{2c^4}\boxed{B_{0z}} E^2 + \text{(higher order)}$$

z component of B_0 field

Gradient of B_0 field

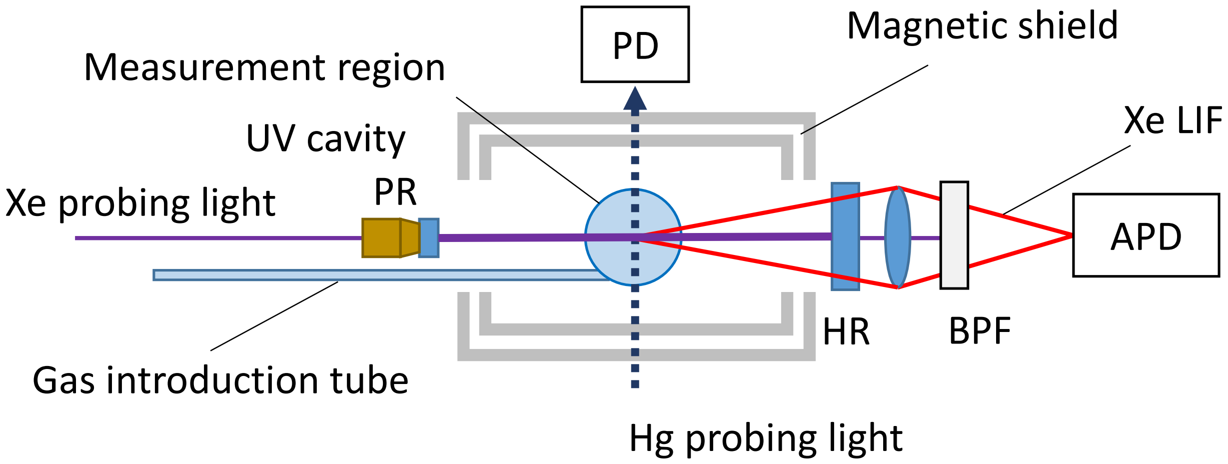
Dual-Comagnetometer: elements

	^{129}Xe	^{199}Hg	n
Spin	1/2	1/2	1/2
Gyromagnetic ratio γ (μHz/T)	-11.77	7.65	-29.16
UCN capture cross section (barn)	21	2150	
Transition (nm)	252.5 nm	253.7 nm	
Transition process	Two-photon	One-photon	
Detection	Light-induced fluorescence (LIF)	Absorption or Faraday rotation	
Polarization build	Spin Exchange Optical Pumping (SEOP)	Optical pumping	
EDM (95% C. L.)	$< 6.6 \times 10^{-27}$ ecm [1]	$< 7.4 \times 10^{-30}$ ecm [2]	$< 3.6 \times 10^{-26}$ ecm [3]

[1] Rosenberry and Chupp, Phys. Rev. Lett. 86 (2001)
[2] Graner et al., Phys. Rev. Lett. 116 (2016)
[3] Pendlebury et al., Phys. Rev. D 92 (2001)

Towards dual-magnetometer work

Dual-comagnetometer image

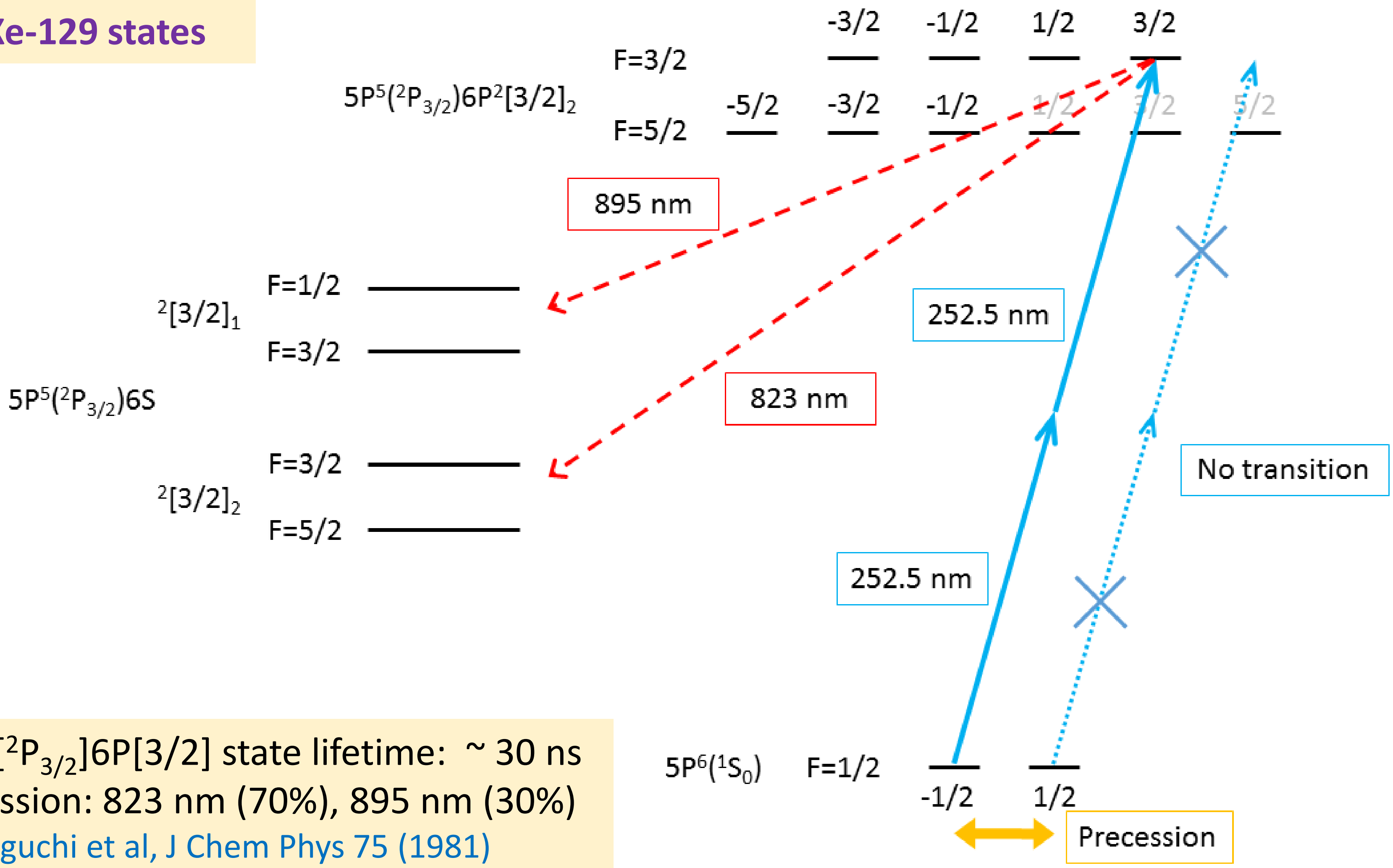


To Do list before combining Xe-Hg system

1. Preparing UV light sources (Xe 252 nm, Hg 254 nm).
2. Observe/Identify a transition for monitoring the spin precession (especially **Xe**).
3. Obtain highly spin-polarized atoms.
4. Observe spin-precession and estimate field sensitivity.

Xe comagnetometer (Transition)

Xe-129 states



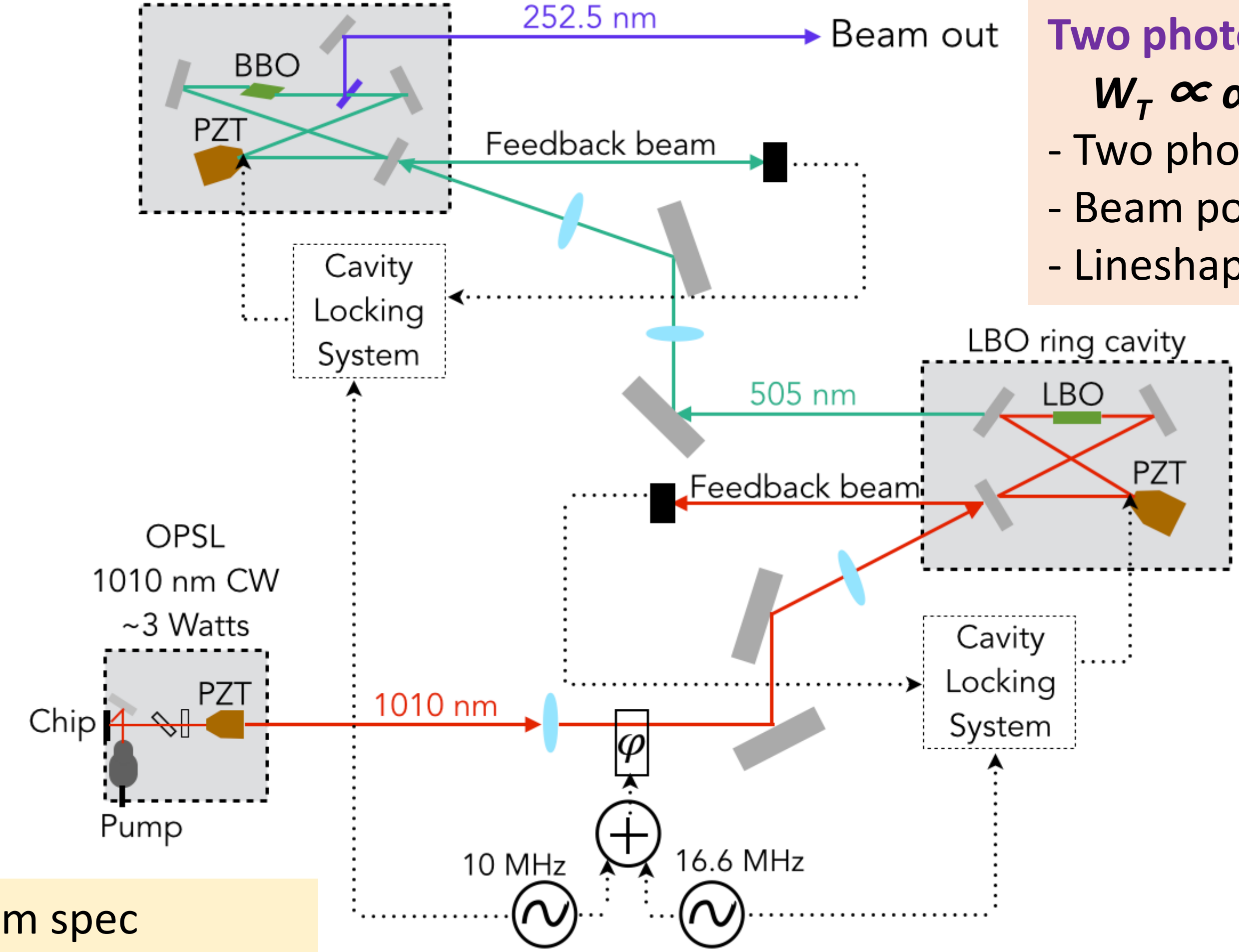
$5P^5[^2P_{3/2}]6P[3/2]$ state lifetime: ~ 30 ns

Emission: 823 nm (70%), 895 nm (30%)

Horiguchi et al, J Chem Phys 75 (1981)

Bruce et al, J Chem Phys 92 (1990)

Xe comagnetometer (laser light source)



Two photon transition rate

$$W_T \propto \alpha I^2 g(\omega)$$

- Two photon coefficient α
- Beam power I
- Lineshape function $g(\omega)$

252.5 nm spec
Max. power: 300 mW

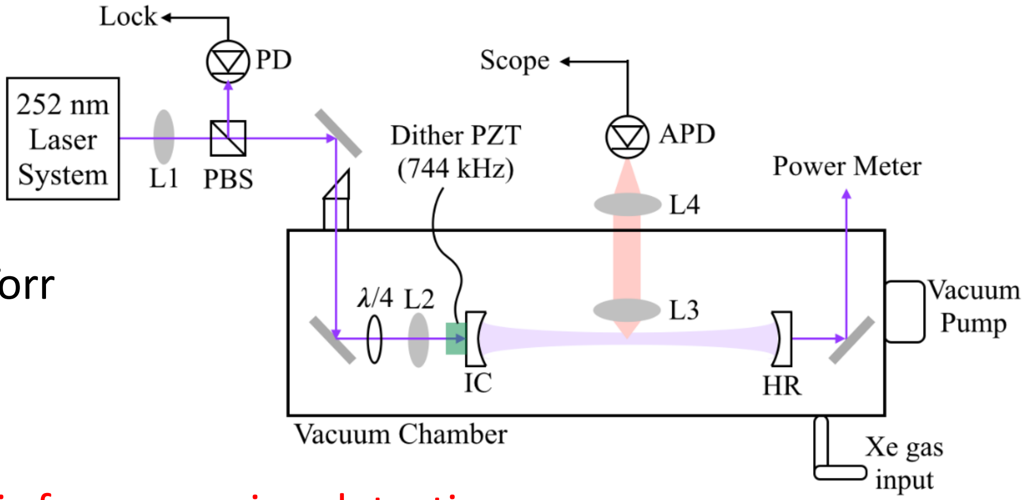
UBC comag team, Submitted to Phys. Rev. D

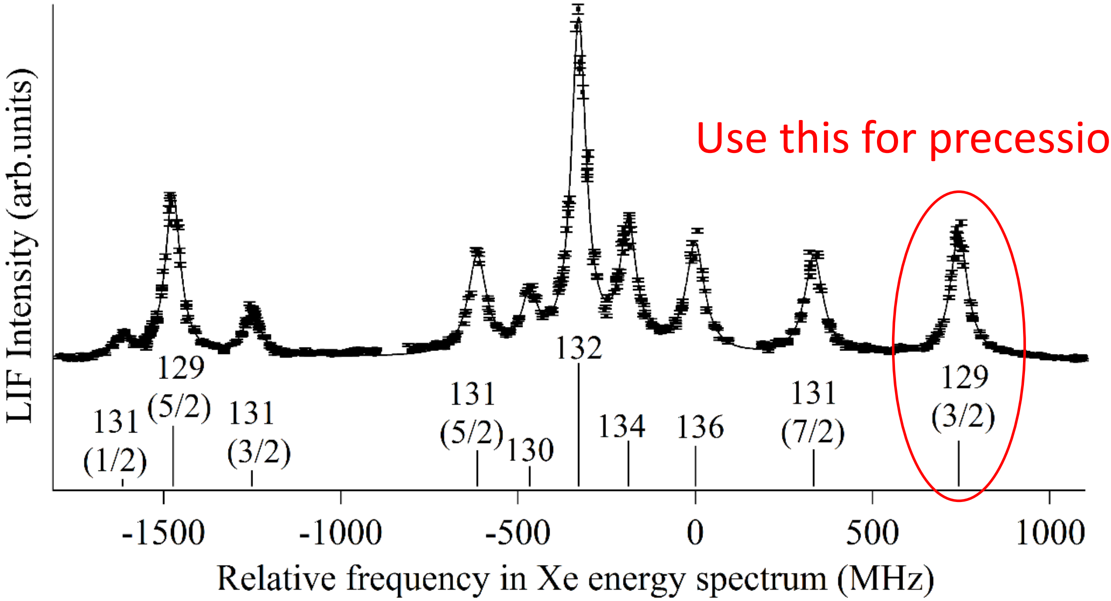
More information in a poster by E. Altiere and E. Miller

Xe Spectroscopy

Experimental condition

- Doppler-free spectroscopy with a **UV Fabre-Perot cavity** inside a **vacuum chamber**
- Xe 0.8 Torr + O_2 0.8 Torr
- Pressure broadening of Xe: 29 MHz/Torr





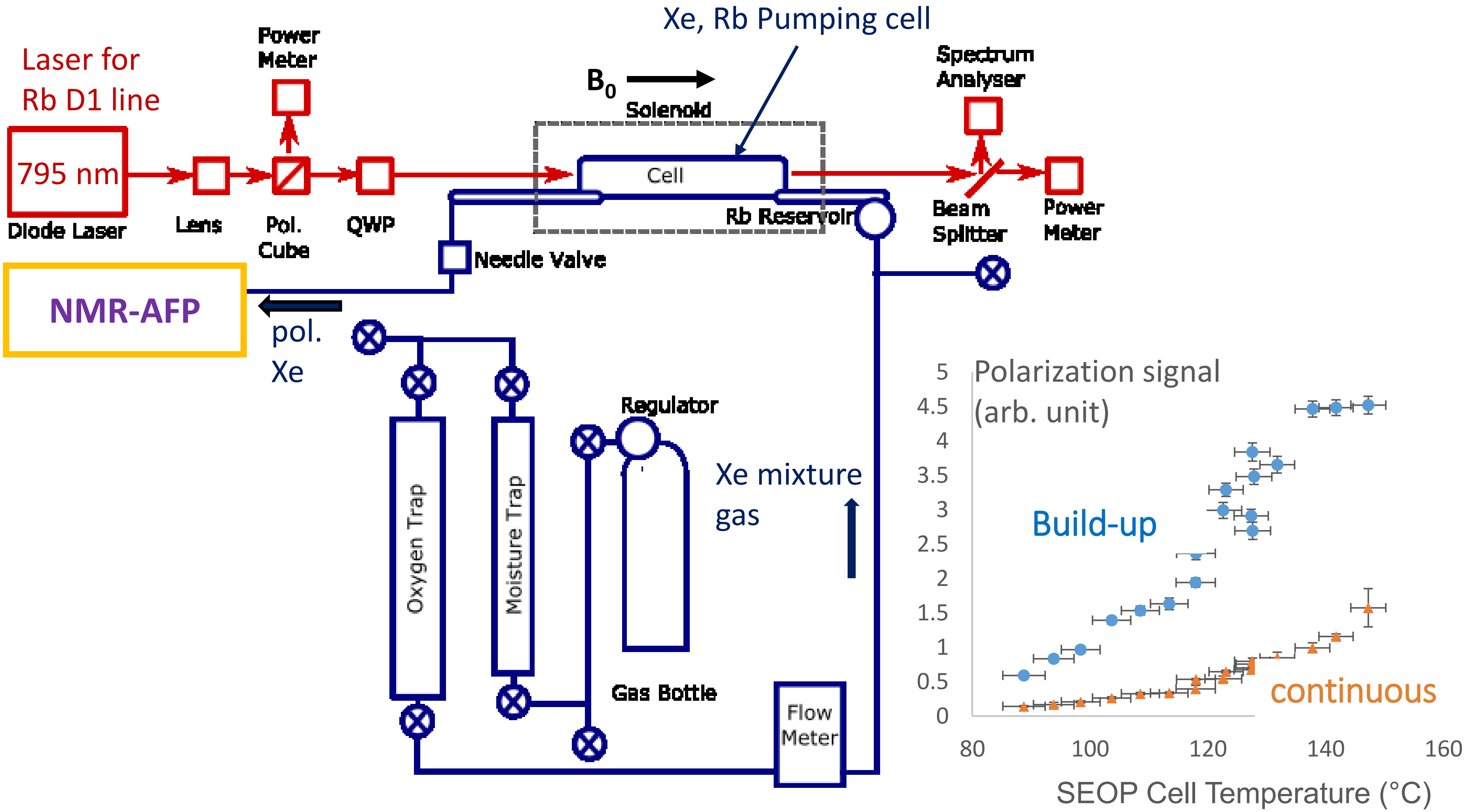
Use this for precession detection

2216 MHz between F=3/2 to F=5/2 of ^{129}Xe

UBC comag team, Submitted to Phys. Rev. D

More information in a poster by E. Altiere and E. Miller

Spin Exchange Optical Pumping (SEOP) of Xe



P_{129Xe} = **<u>11.5%</u>** (With build-up time 10 min) and **<u>5.4%</u>** (continuous flow)

Towards Xe precession: S/N estimation

Photon counting rate from ^{129}Xe (F=3/2) emission

Current conditions (200 mW, 800 mTorr natural Xe + 800 mTorr O^2): $2.1*10^8$ /sec

- Pressure broadening
- Natural linewidth

See Florian Kuchler's talk about Xe pressure @afternoon

UCN regime (200 mW, 1 mTorr isopure ^{129}Xe, no O^2): $1.8*10^7$ /sec

- Noise equivalent power of APD: 20 fW/√Hz
- Precession frequency 10 Hz (10 msec for 1 points)

⇒ S/N > 10 : **precession signal can be detected**.

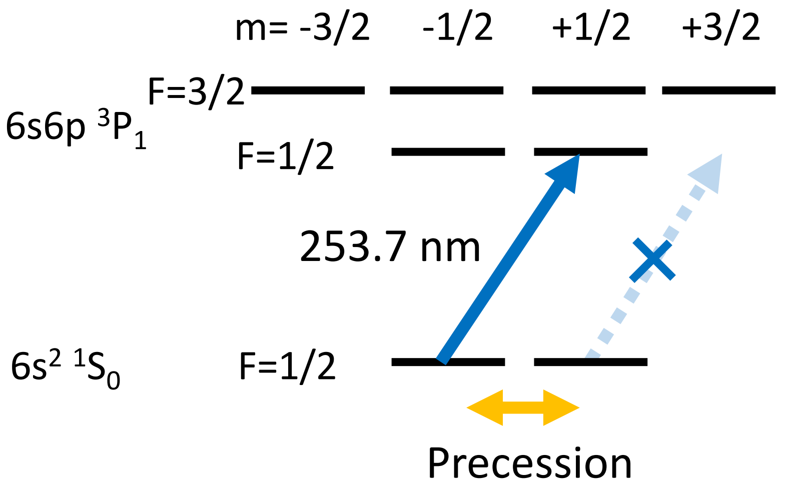
For better S/N: increase UV power intensity ***I*** (transition rate $W_T \propto I^2$)

UBC comag team, Submitted to Phys. Rev. D

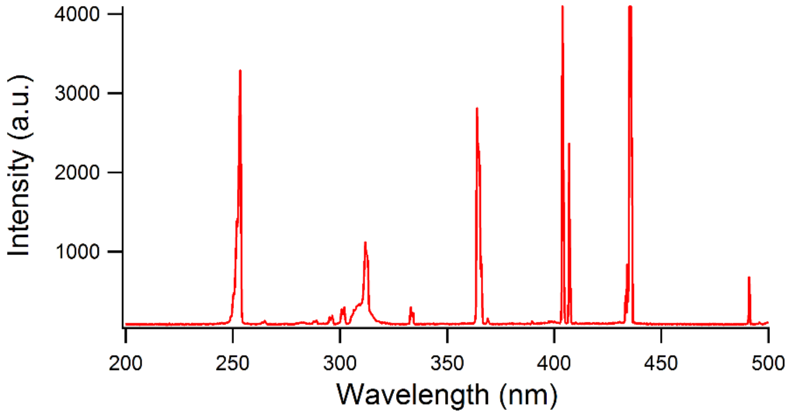
More information in a poster by E. Altiere and E. Miller

Hg light source and transition

^{199}Hg states

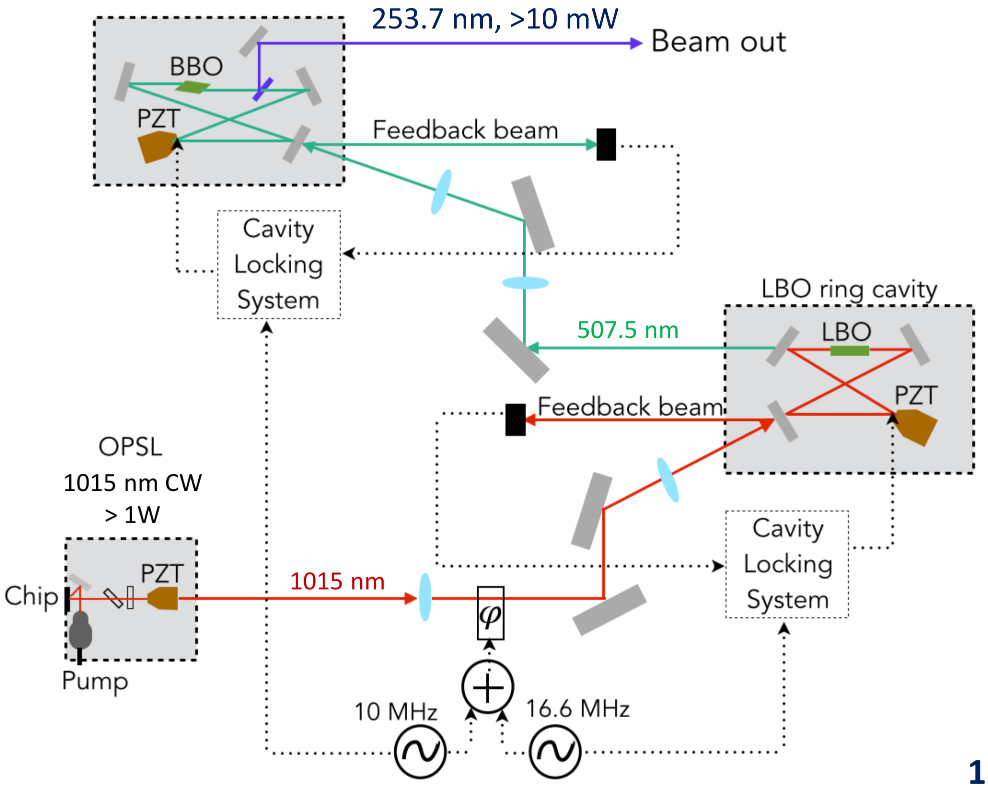


^{204}Hg-enriched discharge lamp



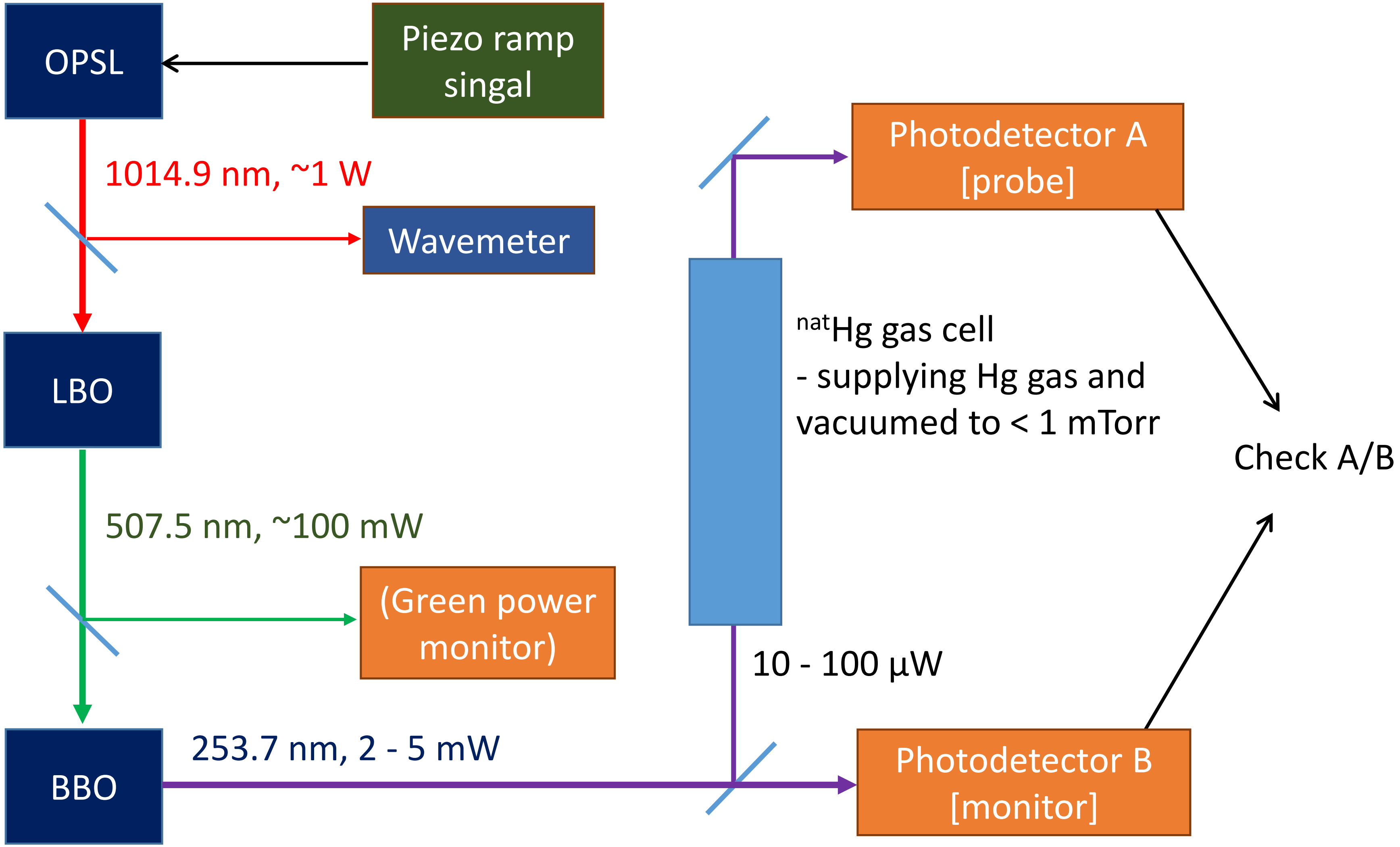
Two types of 254 nm light source are used for our experiments.

Laser light source (sister of Xe laser)



Hg spectroscopy

Hg spectroscopy was performed for resolving the ^{199}Hg transition



OPSL

Piezo ramp singal

1014.9 nm, ~1 W

Wavemeter

LBO

507.5 nm, ~100 mW

(Green power monitor)

BBO

253.7 nm, 2 - 5 mW

Photodetector A [probe]

^{nat}Hg gas cell
- supplying Hg gas and vacuumed to < 1 mTorr

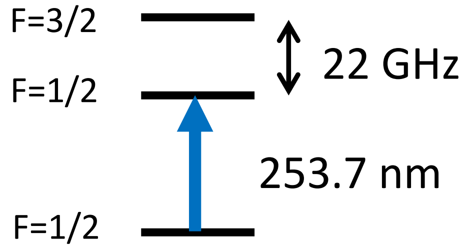
10 - 100 µW

Photodetector B [monitor]

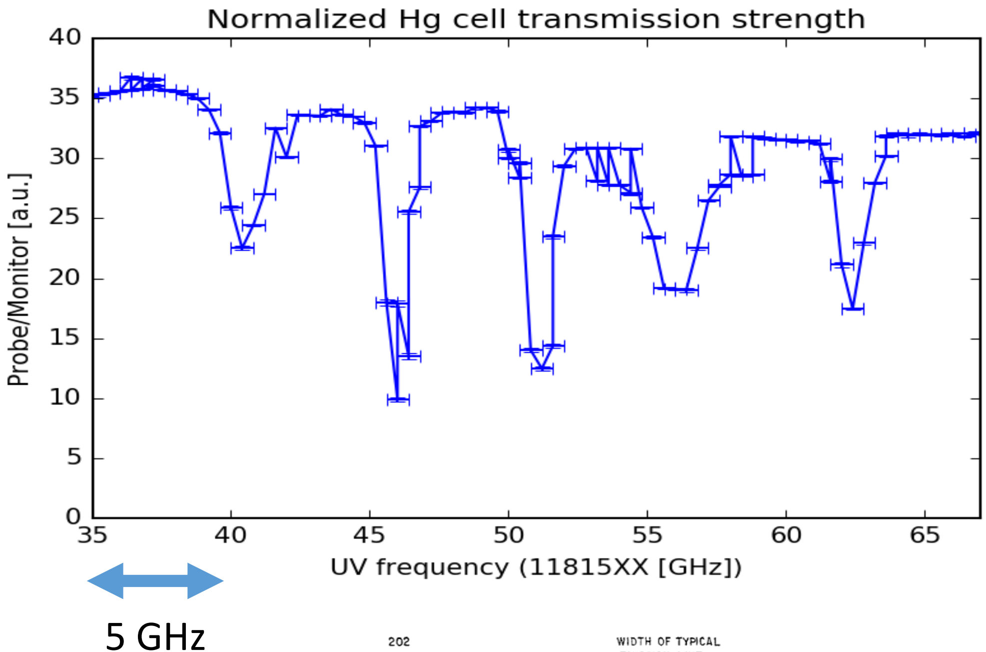
Check A/B

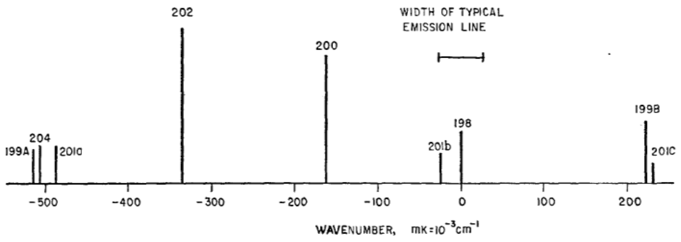
Hg spectroscopy

199Hg states

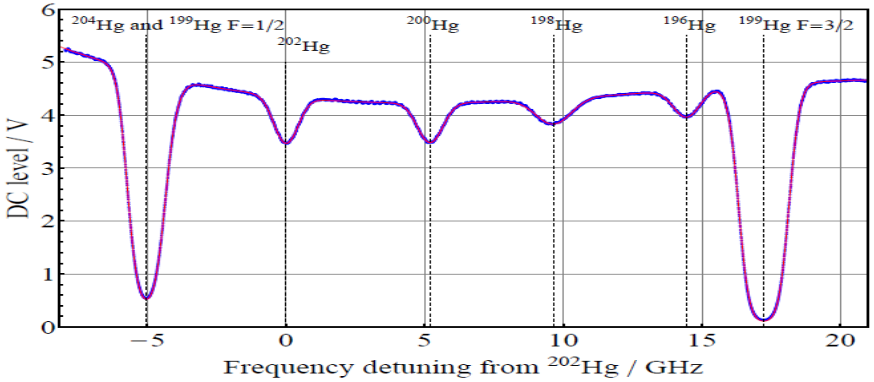


- Two ^{199}Hg peak were identified (Frequency separation > 20 GHz)



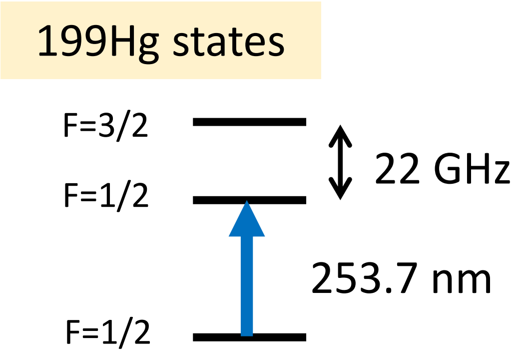


Schweitzer, JOSA (1963)



Fertl, thesis (2013) (Enriched cell)

Hg spectroscopy



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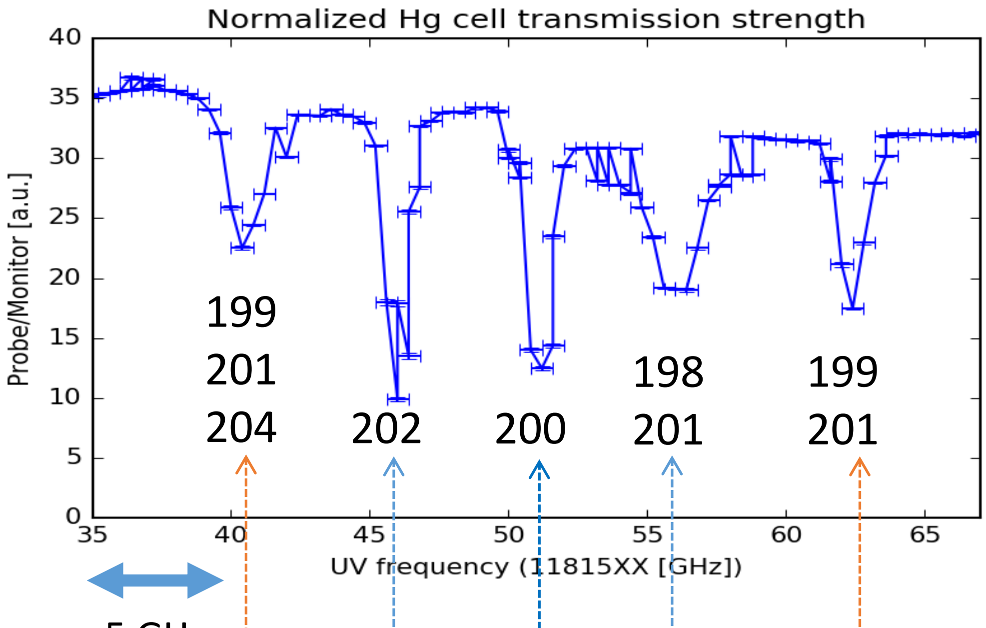
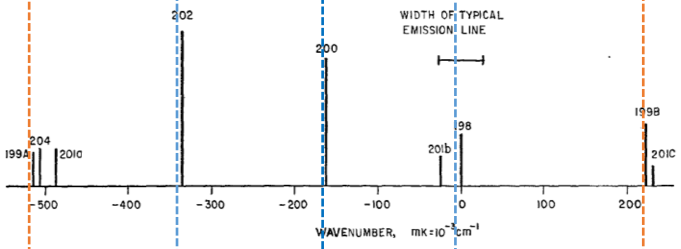
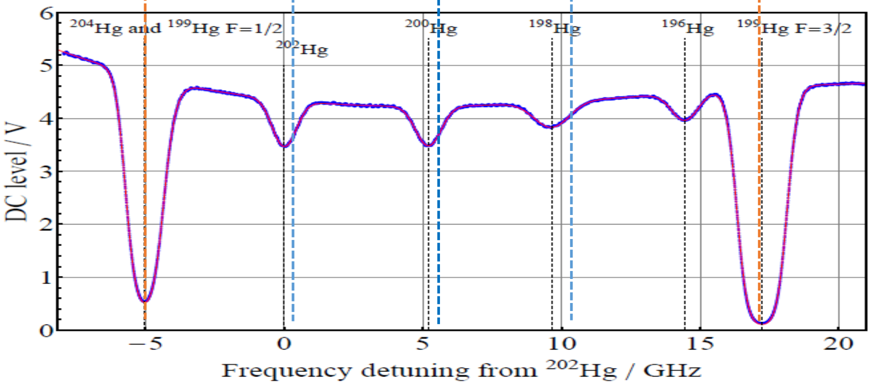


5 GHz



Schweitzer, JOSA (1963)



Fertl, thesis (2013) (Enriched cell)

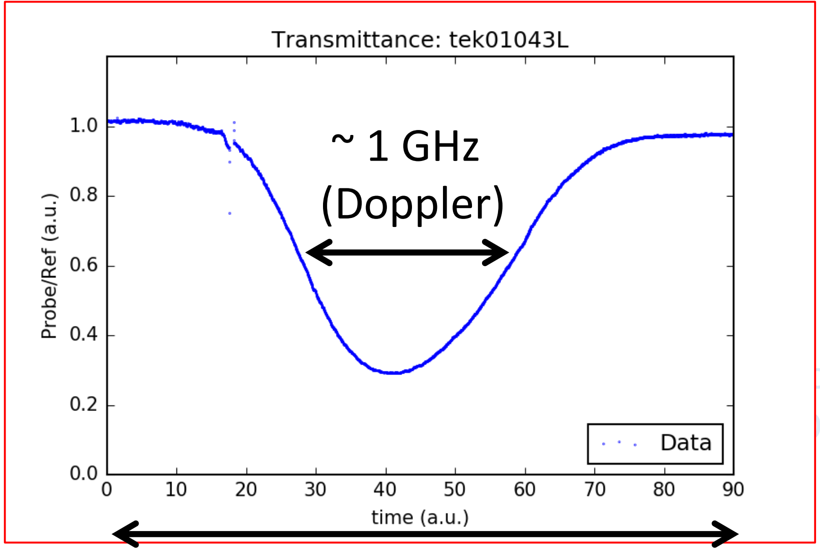
Hg spectroscopy

Three overlapping peaks

^{199}Hg F=1/2 → F=1/2

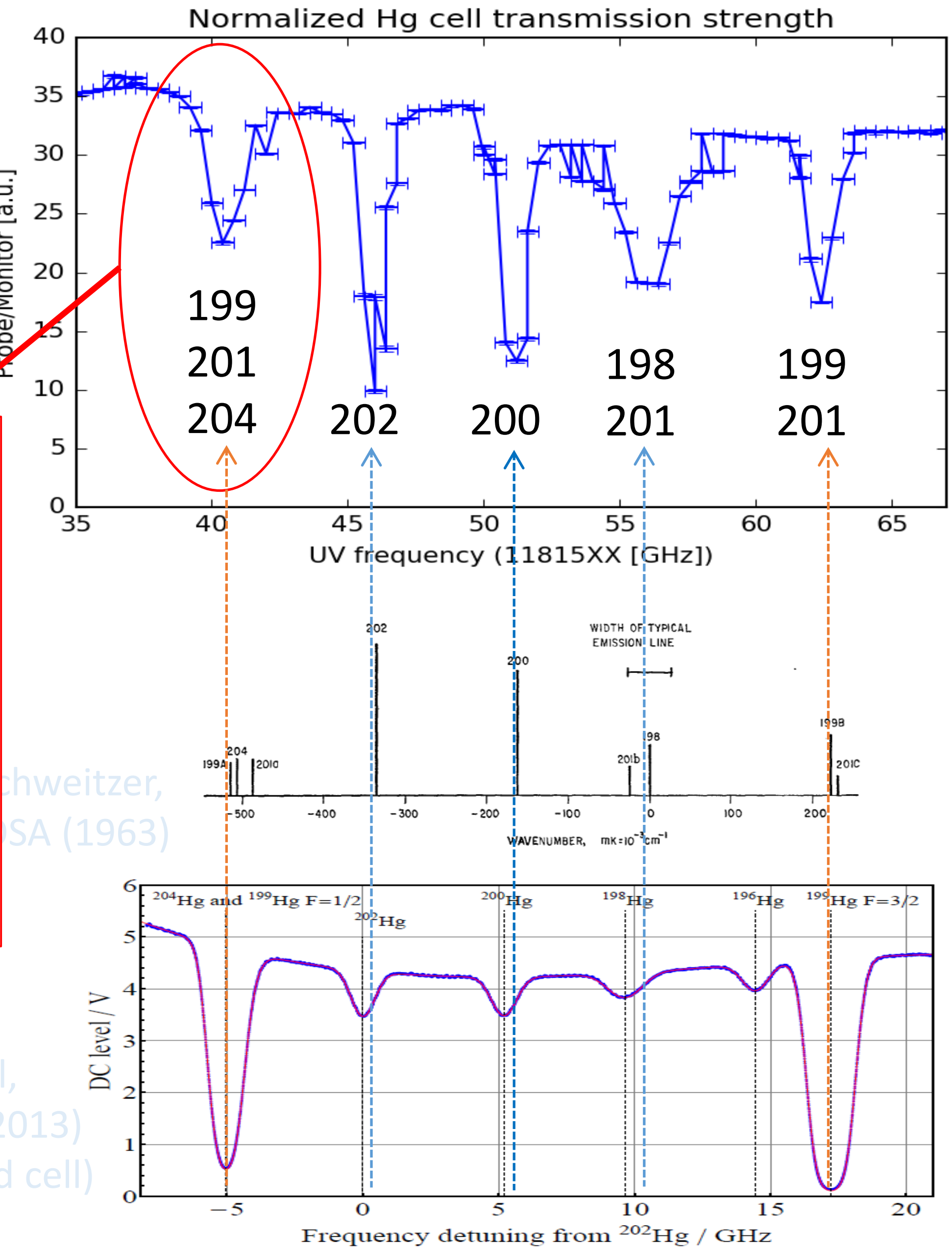
^{204}Hg

^{201}Hg F=3/2 → F=5/2



~ 4 GHz

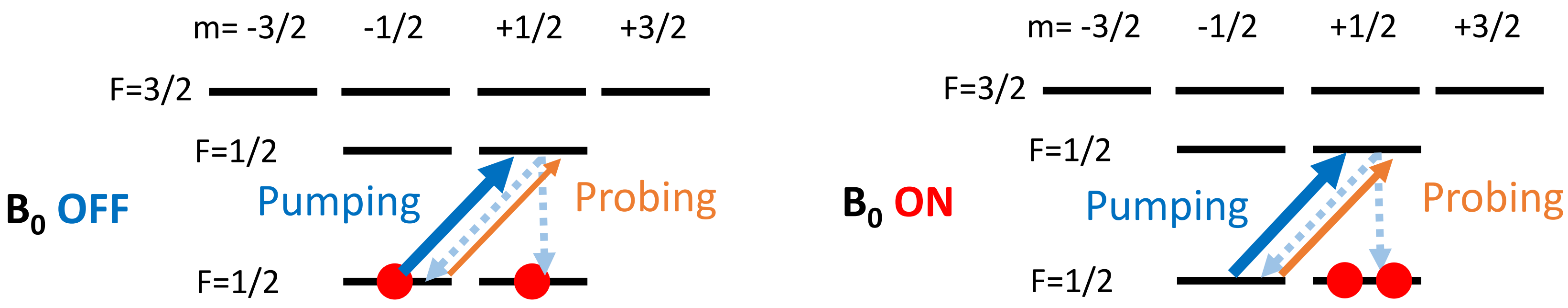
Target peak spectrum was obtained with good S/N (~ 100).

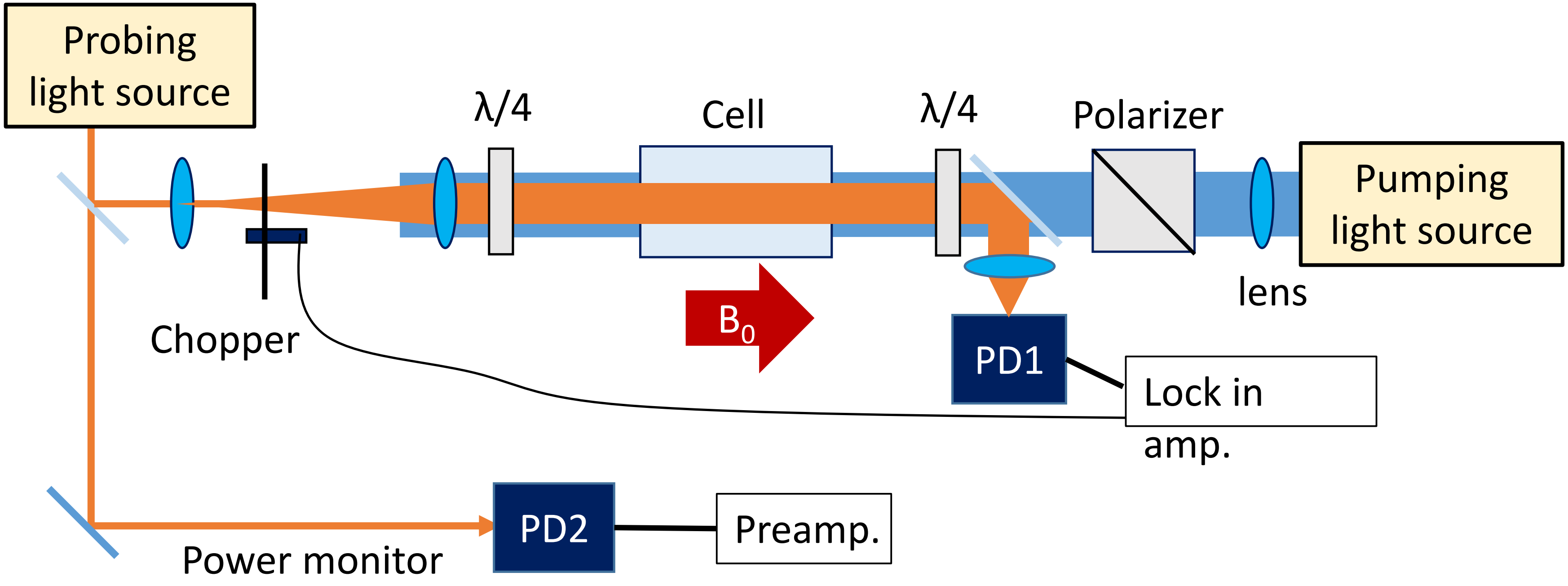


chweitzer,
SA (1963)

Fertl,
thesis (2013)
(Enriched cell)

Proposed optical pumping





Summary

- We are working towards Xe/Hg Dual comagnetometer for monitoring the B0 field and field gradient same time
- Both of ^{129}Xe and ^{199}Hg peaks employed for precession monitor were identified via UV laser spectroscopy.

To Do list before combining Xe-Hg system

1. Preparing UV light sources (Xe 252 nm, Hg 254 nm).
   : Done
2. Observe/Identify a transition for monitoring the spin precession (especially **Xe**).
   : Done
3. Obtain highly spin-polarized atoms.
   : On going
4. Observe spin-precession and estimate field sensitivity.
   : Precession

Next step

Xe: Low pressure (< 1 mTorr) spectroscopy, Coaxial detection

Hg: Optical pumping → Precession measurement

Acknowledgement

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