High-Precision Faraday Rotation Spectroscopy and Atomic Beam Polarizability Measurements in Lead

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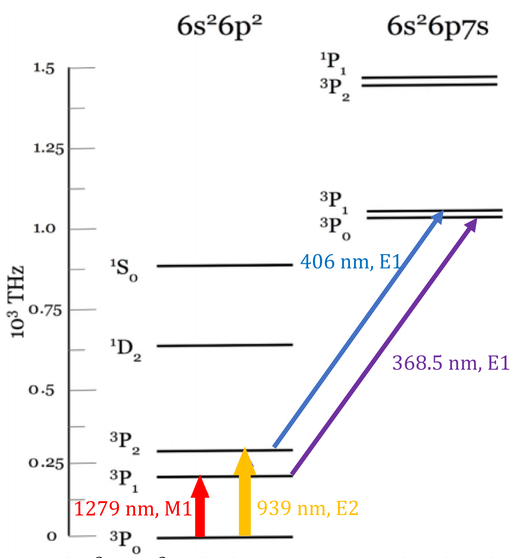
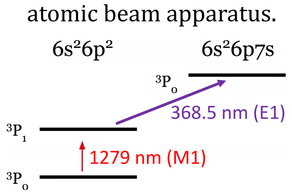
Background

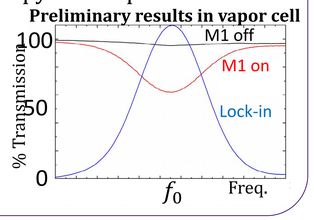
- Heavy, multivalence elements are good testbeds for atomic theory; optical rotation scales with Z^3.
- Previous work with Group IIIA In [1] and Tl [2] tested *ab initio* multi-valence wavefunction models (Safronova group).
- New focus is on Group IV Pb. Extra valence electron complicates atomic wavefunction calculations. Pb also very important for PNC measurements and probing weak interaction with nucleus.
- Modest improvements → big impact.

Energy Levels of Pb

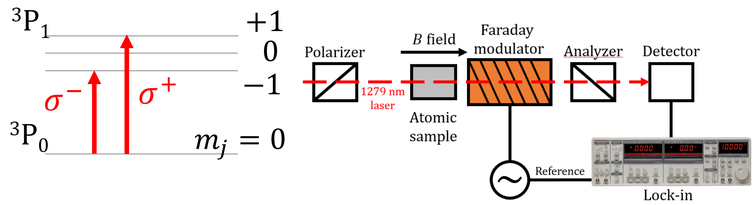


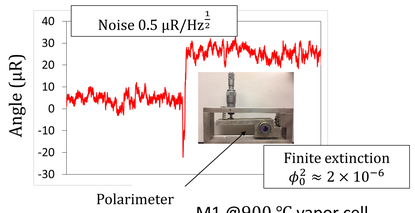
- **Recently:** $^3P_0 \rightarrow {}^3P_2$ (E2) transition amplitude relative to M1 in a vapor cell [3].
- **Currently:** $^3P_0 \rightarrow {}^3P_1$ (M1) in an atomic beam unit → use polarimetry with μRad resolution, measure atomic polarizabilities, stark-induced M1 transition due to mixing of P states with S and D levels.
- **Future:** two-step spectroscopy to $6s^26p7s$ states with atomic beam apparatus.



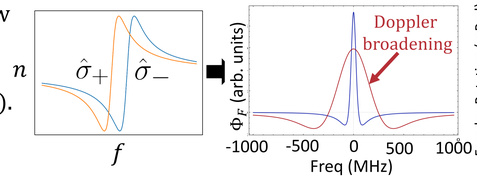


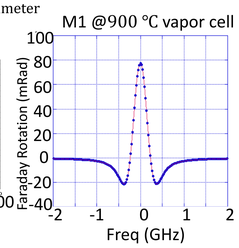
Faraday Rotation Spectroscopy (FRS)



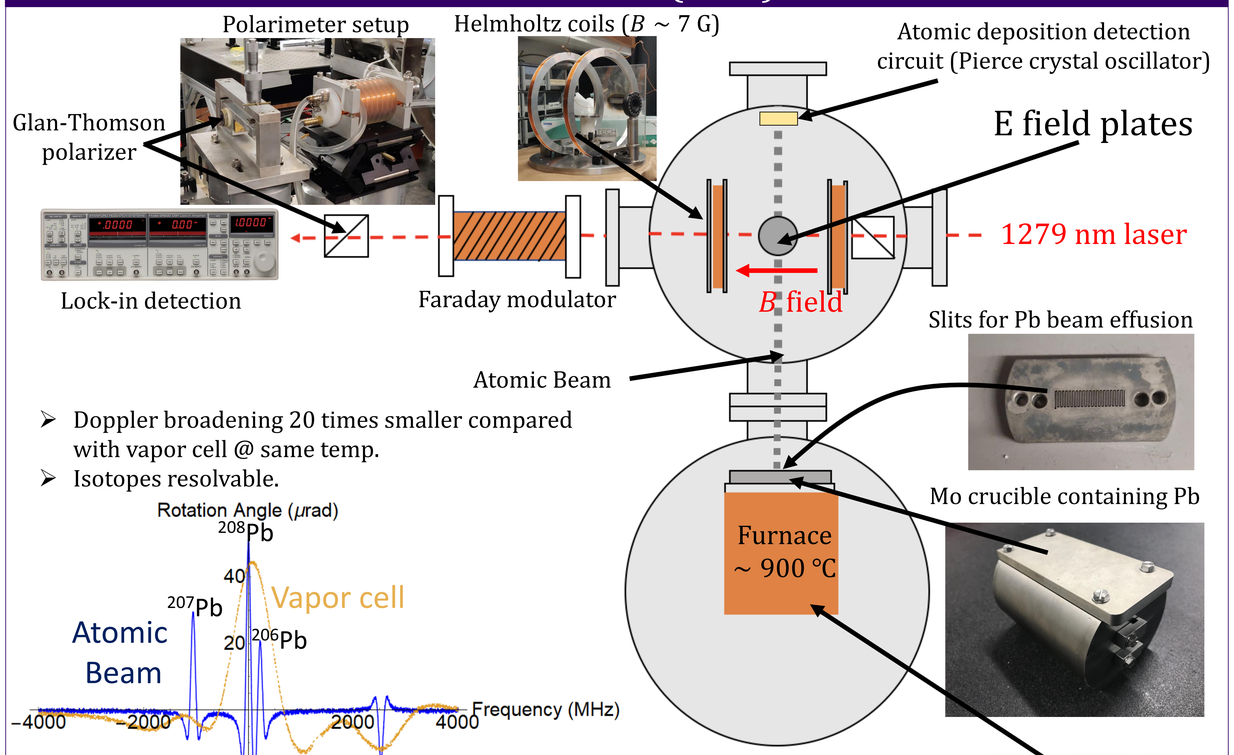


- Applied B field splits m_j sublevels for $^3P_1$.
- Refractive indices for σ^- and σ^+ are now different.
- Lock-in signal is proportional to this difference $\Phi_F \propto \mathrm{Re}(n_+(f)) - \mathrm{Re}(n_-(f))$.
- Actual signal depends on Doppler broadening.

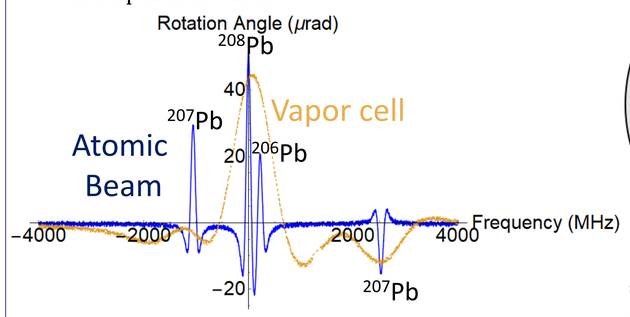




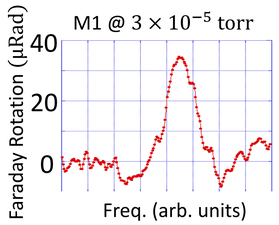
Atomic Beam Unit (ABU) for Pb



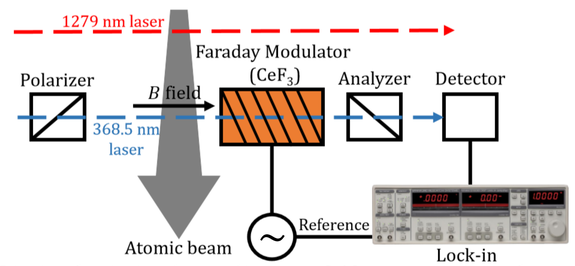
- Doppler broadening 20 times smaller compared with vapor cell @ same temp.
- Isotopes resolvable.



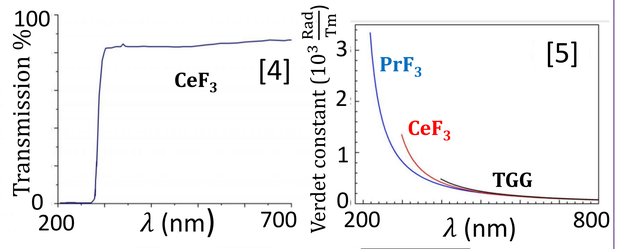
- Reduction in systematic thermal effects from heating of Quartz cell.
- Optical depth with ABU 2500 times smaller than in vapor cell at same temperature.
- Rotation signals of 30 μRad are still resolvable!

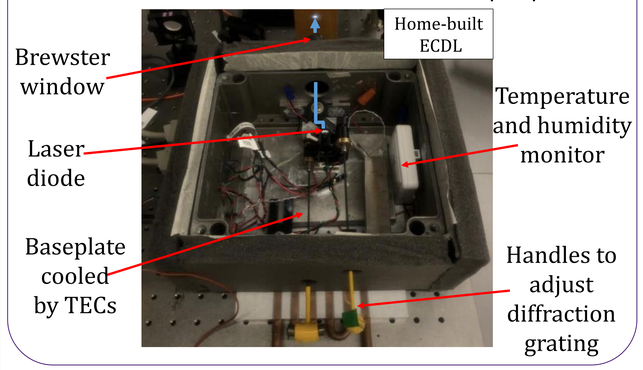


Pb Spectroscopy in UV



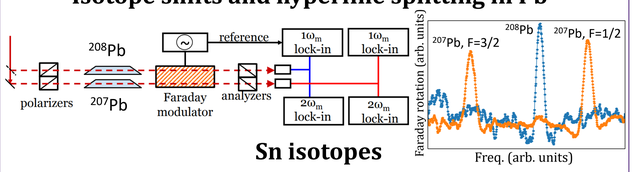
- Limit of existing laser diodes ~369 nm – too long for $6s^26p^2\ {}^3P_1 \rightarrow 6s^26p7s\ {}^3P_0$ (E1) transition.
- Lasing frequency ↑ as diode temperature ↓. Need −2 °C!
- H_2O condensation avoided by flushing box with N_2.
- Lasing power @ 368 nm ~ 15 mW.
- FRS feasible @ 368 nm – use CeF_3 Faraday glass.





Future Goals

Isotope shifts and hyperfine splitting in Pb



Sn isotopes

- Low vapor pressure (Sn @ 900 °C ~ Pb @ 540 °C).
- 7 stable even isotopes (^{112}Sn, ^{114}Sn, ^{116}Sn, ^{118}Sn, ^{120}Sn, ^{122}Sn, ^{124}Sn)→ King plot linearity test.
- Several transitions at accessible wavelengths.

[1]- *Phys. Rev. A* 97, 022507 (2018)
[2]- *Phys. Rev. A* 89, 012511 (2014)
[3]- *Phys. Rev. A* 100, 052506 (2019)
[4]- Data from *Cry-Link*, https://www.scintillator-crylink.com/scintillator-products/cef3.
[5]- P. Molina *et al.*, *Opt. Express* **19**, (2011)