# Characterization of a Low-Pressure High-Capacity $^{129}$Xe Flow-Through Polarizer


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# Two Basic Ways to Implement SEOP

**BATCH MODE ($^3$He): Slow spin-exchange rates (hours$^{-1}$), slow (He-Rb) alkali-metal spin-destruction rates.**

**FLOW-THROUGH MODE ($^{129}$Xe): Fast spin-exchange rates (minutes$^{-1}$), fast (Xe-Rb) alkali-metal spin-destruction rates.**

**Driehuys, *et al.* [Appl. Phys. Lett. 69, 1668 (1996)] introduces:**

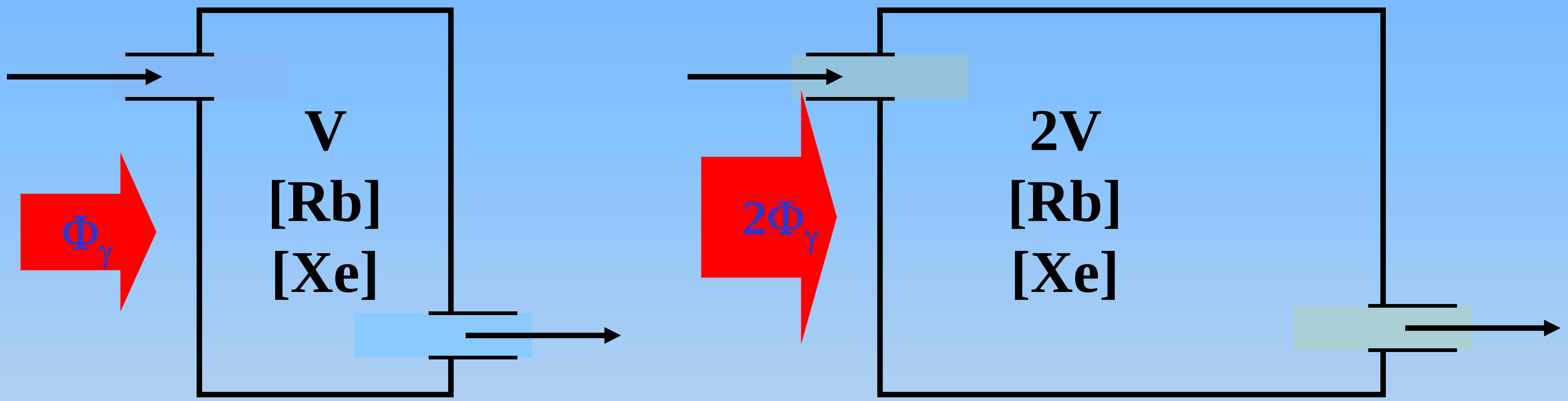
- **Flow-through mode.**
- **Lean Xe gas mixture.**
- **Broadening of Rb absorption line by high-pressure He.**
- **Cryogenic separation of Xe from gas mixture.**

# What to do with More Photons?

$$P_{\mathrm{Xe}}\Phi_{\mathrm{Xe}} \propto \langle P_{\mathrm{Rb}}\rangle[\mathrm{Xe}]V\gamma_{\mathrm{se}} \propto \langle P_{\mathrm{Rb}}\rangle[\mathrm{Xe}]\underbrace{V[\mathrm{Rb}]}_{\Phi_\gamma}\xi_{\mathrm{se}}$$

se physics

photon flux



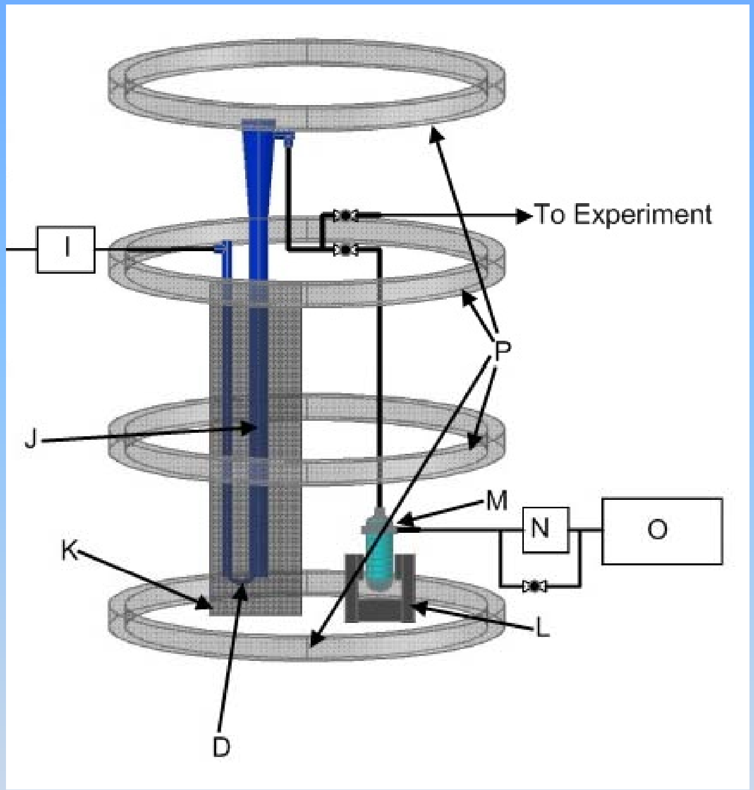

- Increasing volume instead of [Rb] avoids Rb-Rb spin destruction and makes it easier to handle heat load.

# The Utah Flow-Through Polarizer

**Diode-Laser Arrays offer increased power (tens to hundreds of watts) and can be spectrally narrowed.**

**Ruset, *et al.* [Phys. Rev. Lett. 96, 053002 (2006)] introduces:**

- **Long, narrow SEOP cell (≈ 2 m long by 4-5 cm diam)**
- **Low total gas pressure in addition to gas mixture lean in Xe.**
- **Xe polarization $P_{Xe}$ = 64% at 0.3 L/h Xe flow rate with laser power = 90 W, $T$ = 160 °C**




- **Our polarizer based on UNH design.**
- **$P_{Xe}$ = 25% at 0.4 L/h Xe flow rate with laser power = 30 W, $T$ = 140 °C.**
- **Can measure both $P_{Xe}$ and $P_{Rb}$.**

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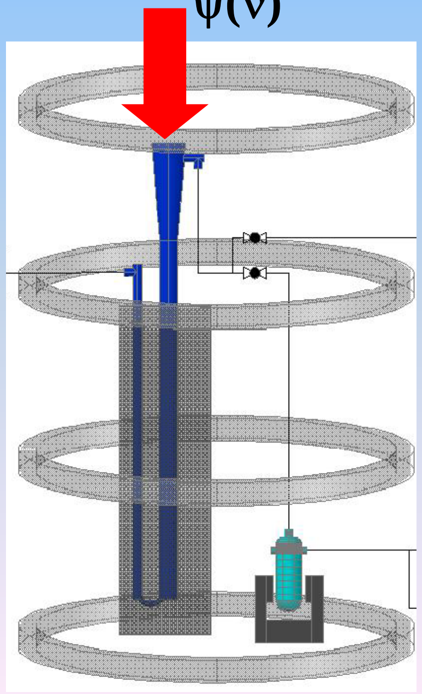
# Numerical Modeling

$$\frac{\partial\psi(\nu,z)}{\partial z} = -[\mathrm{Rb}]\sigma_s(\nu)\frac{\Gamma_{\mathrm{SD}}(z)}{\gamma_{\mathrm{opt}}(z)+\Gamma_{\mathrm{SD}}(z)}\psi(\nu,z) \quad \textbf{with} \quad \gamma_{\mathrm{opt}}(z) = \int_0^\infty \psi(\nu,z)\sigma_s(\nu)\,d\nu$$

$$P_{\mathrm{Rb}}(z) = \rho_{+1/2} - \rho_{-1/2} = \frac{\gamma_{\mathrm{opt}}(z)}{\gamma_{\mathrm{opt}}(z)+\Gamma_{\mathrm{SD}}(z)}$$

$$\frac{\partial P_{\mathrm{Xe}}(z)}{\partial z} = \frac{1}{v_l}\left[\gamma_{\mathrm{se}}(z)\left(P_{\mathrm{Rb}}(z)-P_{\mathrm{Xe}}(z)\right)-\Gamma_{\mathrm{Xe}}(z)P_{\mathrm{Xe}}(z)\right]$$

**ψ(ν)**

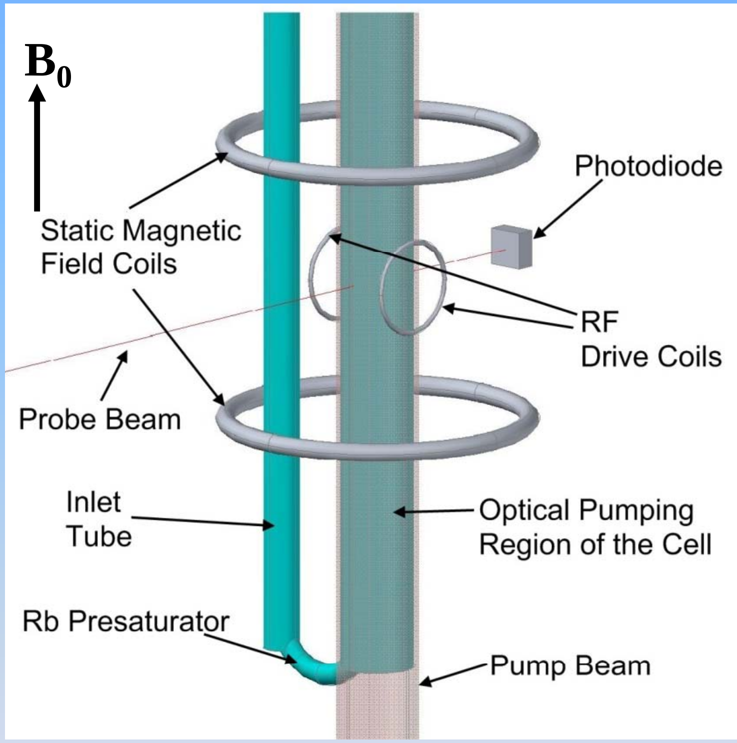


**axial depth (*z*)**

- **Model also adapted from UNH work.**
- **Model yields predictions for: $\gamma_{\mathrm{opt}}(z)$, $P_{\mathrm{Rb}}(z)$, $P_{\mathrm{Xe}}(z)$; axial distributions, avg'd over transverse slice.**
- **We measure $P_{\mathrm{Xe}}$ and $\boxed{P_{\mathrm{Rb}}(z)}$**

# Rb Polarimetry: Experimental Setup

## Optically Detected Electron Paramagnetic Resonance (ODEPR)*



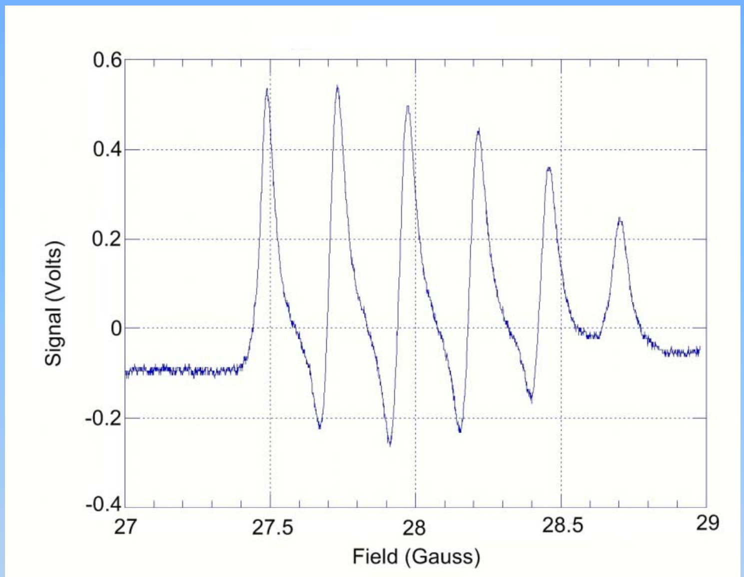

- **Angular momentum of Rb atoms in spin-temperature distribution:**

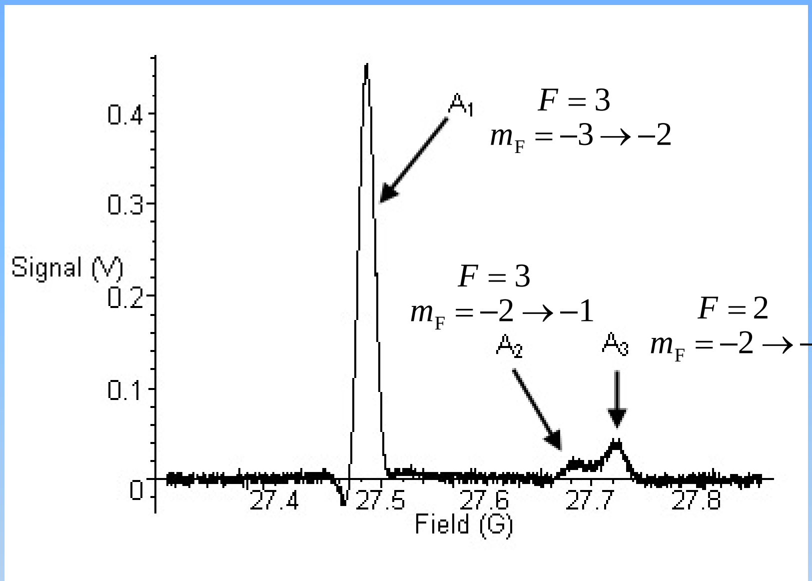
$$P_{\mathrm{Rb}} \propto e^{-\beta m_F}$$

- **Low-level RF creates steady-state precession of $^{85}$Rb atoms at low angle to $B_0$.**
- **Absorption of probe-laser light (detuned from $D_1$) is modulated at $^{85}$Rb Larmor frequency (about 13 MHz at 27-28 G).**
- **Field-sweep generates hyperfine spectrum.**

*Ben-Amar Baranga, et al., Phys. Rev. A **58**, 2282 (1998).

# Rb Polarimetry: ODEPR Hyperfine Spectra




**$^{85}$Rb spectrum at low Rb polarization.**

**$^{85}$Rb spectrum at high Rb polarization.**

$$P_{\mathrm{Rb}} = \frac{7r_{1/2,3} - 3}{7r_{1/2,3} + 3} \qquad P_{\mathrm{Rb}} = \frac{5r_{1/3} - 3}{5r_{1/3} + 3}$$

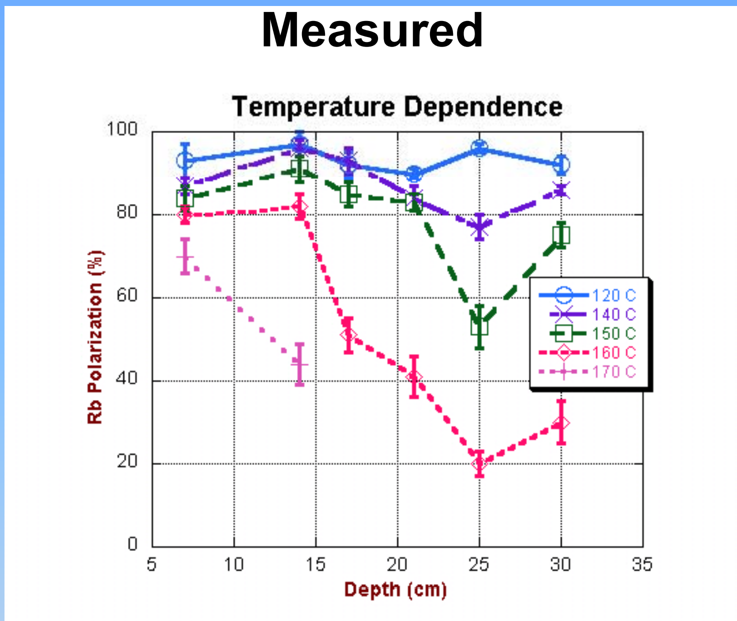
$$r_{1/2,3} \equiv \frac{A_1}{A_2 + A_3} \qquad r_{1/3} \equiv \frac{A_1}{A_3}$$

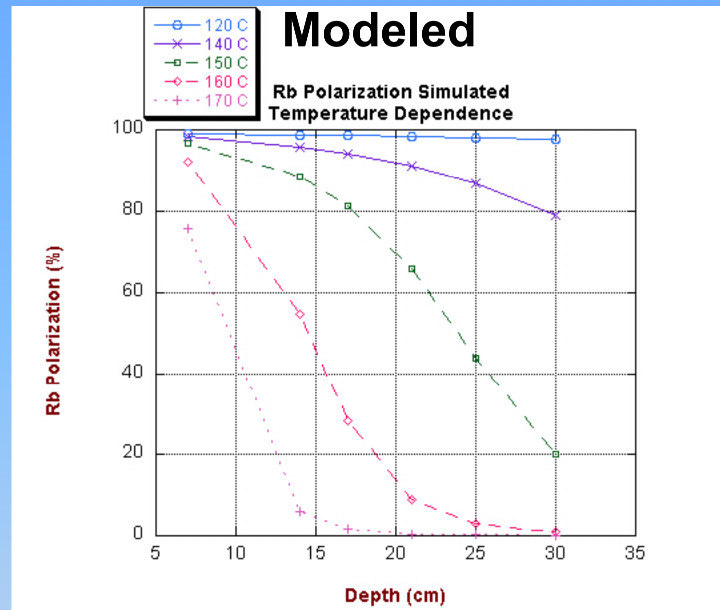
# Nominal Optimal Operating Parameters

**(unless varied):**

- Temperature: 140 °C.
- He:$N_2$:Xe 1000:500:10 sccm flow rates.
- Total gas pressure: 840 mbar at room temperature.

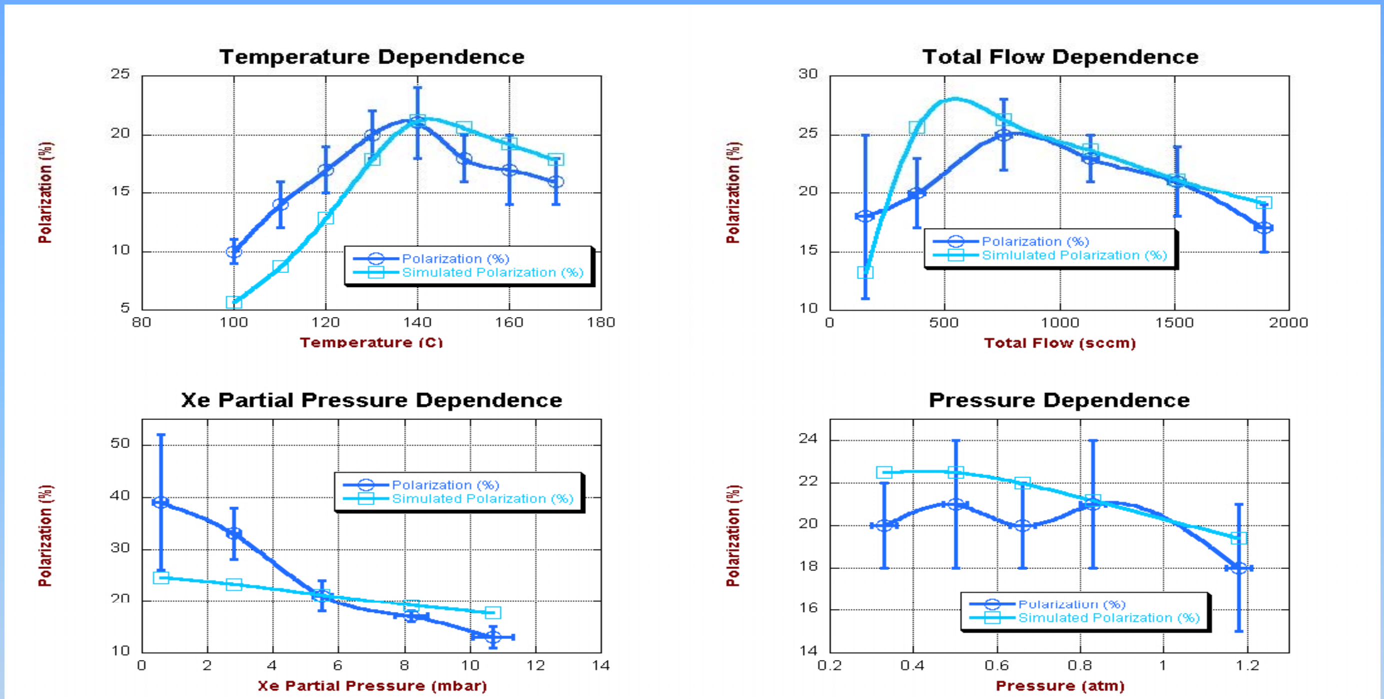
# Rb Polarization: Temperature Dependence




- $P_{\mathrm{Rb}}$ = 85-90% throughout optical pumping region at $T$ = 140 °C.
- Drop off is slower than predicted for higher temperatures. (Maybe actual [Rb] is smaller than vapor pressure curves predict.)
- In general $P_{\mathrm{Xe}}$ is not limited by low $P_{\mathrm{Rb}}$ for our optimal operating parameters.
- Anomalous region of depressed $P_{\mathrm{Rb}}$ at 25 cm.

# Measured/Modeled $^{129}$Xe Polarization




- Temp-dependence model gets trend right, but overestimates $P_{\mathrm{Xe}}$ unless spin-exchange rate is reduced by 40%.
- Total flow dependence is modeled well only if we assume short $^{129}$Xe wall-relaxation time (tens of seconds).
- Dependence on Xe partial pressure stronger than expected.
- Total pressure dependence is weak, as expected.

# Summary

**We have built and done initial tests on a flow-through Xe polarizer based on the UNH design.**

- $P_{Xe}$ = 25% at 0.4 L/h Xe flow rate with laser power = 30 W, *T* = 140 °C.
- We have modeled and measured: output $P_{Xe}$ AND $P_{Rb}$, the latter as a function of axial position in the cell.
- Modeling includes temp. dependence of spin-exchange rate, does a reasonable job of reproducing general shapes and trends.
- $P_{Xe}$ not apparently limited by $P_{Rb}$.
    - Yet $P_{Xe}$ not as large as predicted by model.
    - Anomalous regions where $P_{Rb}$ is depressed.

# Hyperpolarized Gas Research Group



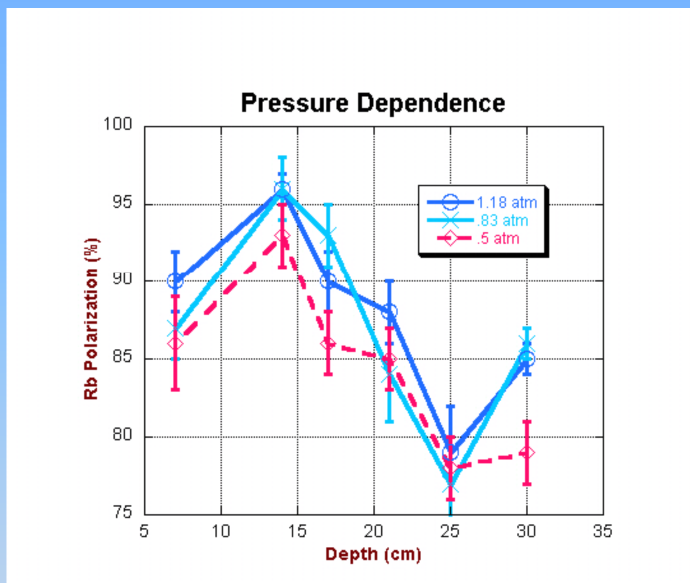
**<u>Faculty</u>**
**Brian Saam**
**David Ailion**
**Gernot Laicher**

**<u>Graduate Students</u>**
**Geoff Schrank (graduating Summer 2009)**
**Eric Sorte**
**Zayd Ma**

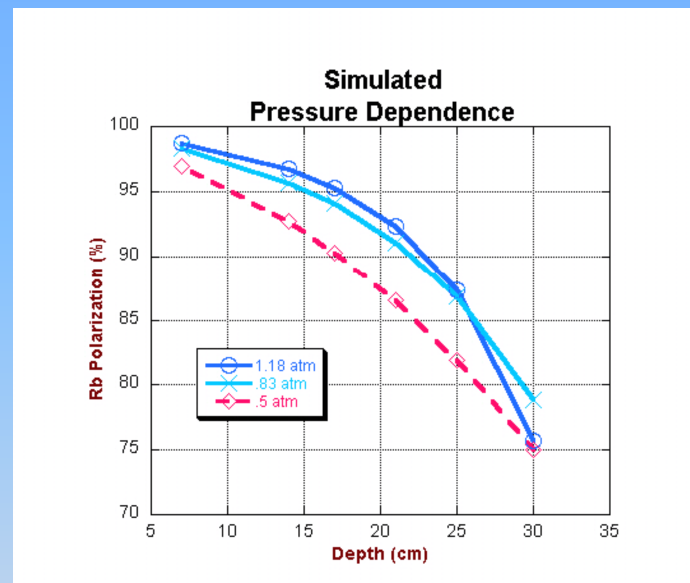
**<u>Undergraduates</u>**
**Allison Schoeck**
**Laurel Hales**
**Oliver Jeong (HS student)**

# Rb Polarization: Total Pressure Dependence

**Measured**

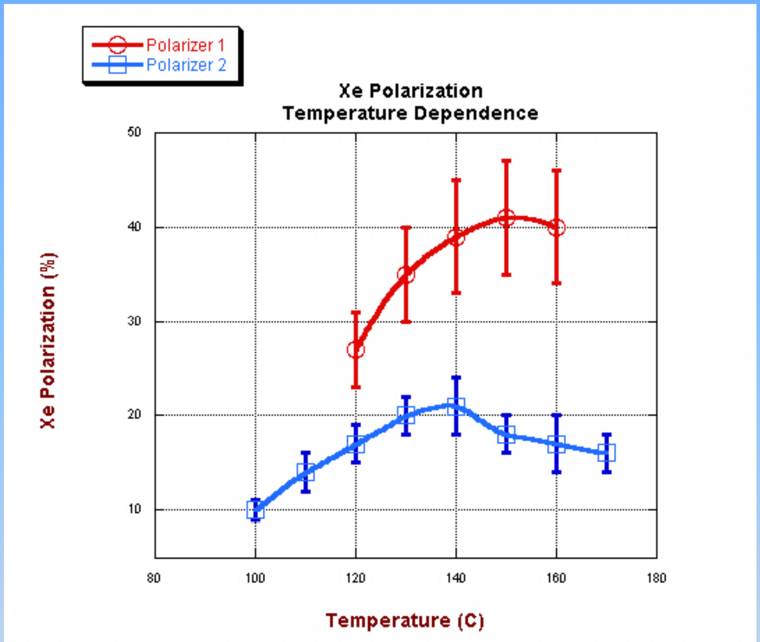


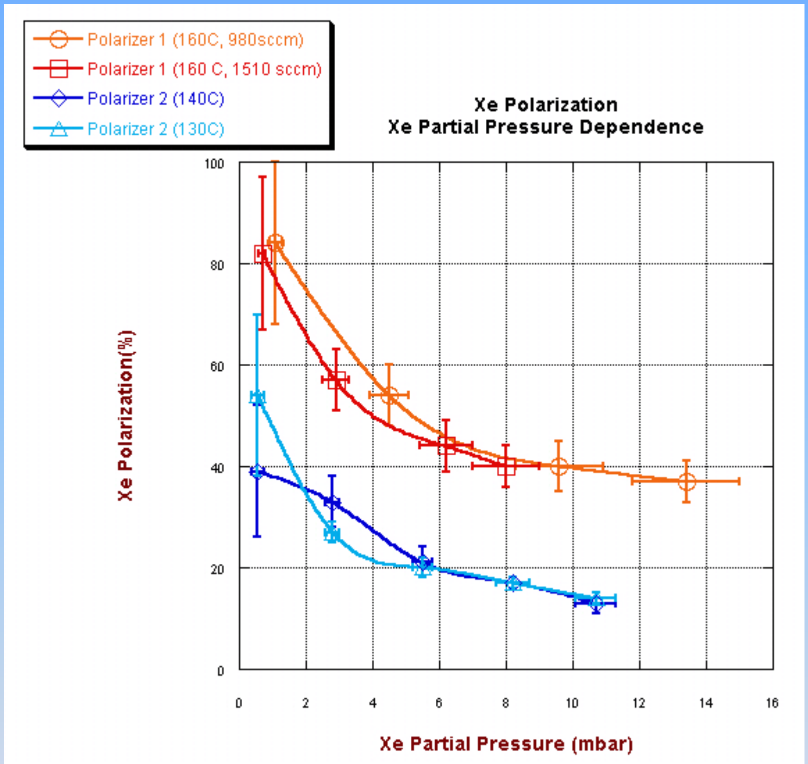

**Modeled**




- Pressure dependence is relatively slight (note scale change for $P_{Rb}$).
- Area of depressed $P_{Rb}$ more apparent.
- Lower total pressures have slightly lower $P_{Rb}$ (likely reflects lower laser absorption).

# Results with Higher Laser Power




➢ Red curves show results with 100-Watt diode-laser array.