Progress Toward a Transversely Pumped NMR Gyroscope

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Atom Trainers

Novel NMR Gyro

- No first order time averaged longitudinal polarization
- Physics scale factor

Previously reported:

- ARW ~ 10 uHz/rt Hz
- Bias < 1 uHz
- Hz bandwidth

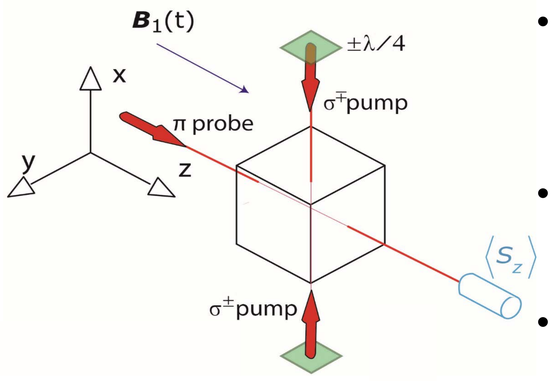
Scale Factor

$$f_k = \gamma_k(B + B_{Rb}^{[1]} + B_{k'}^{[2]}) + Q + f_{rot}$$

f_k = precession frequency of isotope k
γ_k = k's gyromagnetic ratio
B_{Rb} = longitudinal alkali field seen by k
$B_{k'}$ = longitudinal field produced by k' seen by k
Q = quadrupole interaction with glass cell
f_{rot} = spin dependent effect to be measured

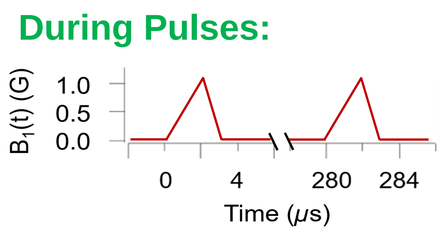
$$f_{rot} = \frac{\rho f^{131} - f^{129}}{1+\rho} \quad \text{where} \quad \rho = \frac{\gamma_{129}}{\gamma_{131}}$$

Implementation

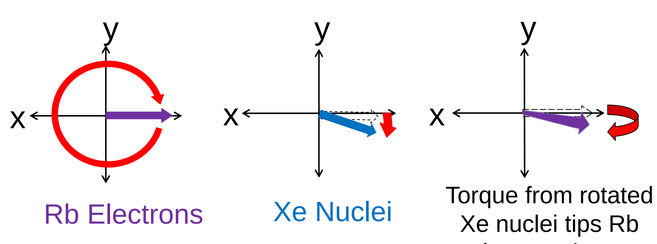


- NMR bias field (B_1): sequence of 2π Rb pulses; since $0\pi \equiv 2\pi$, the Rb magnetometer operates at zero field
- Rb atoms are optically pumped transverse to B_1 and can co-precess with the Xe nuclei
- The NMR is driven by collisions, not oscillating fields

During Pulses:



z Bias Field



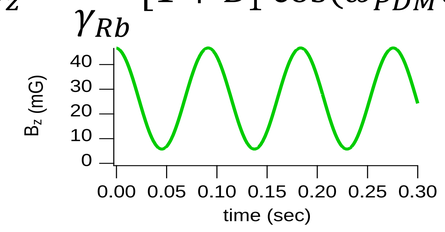
"Hybrid" Operation

Bloch Equation for Xe:

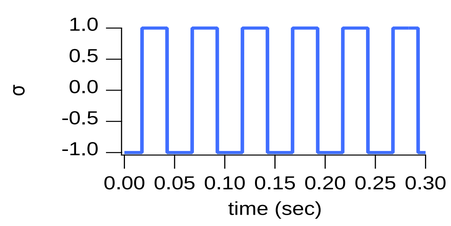
$$\frac{d}{dt}K_+ = -(i\gamma_K B_z + \Gamma_2)K_+ + \Gamma_{SE}S_+$$

Bias Pulse Density Modulation (PDM) — **Pump Polarization Modulation (PM)**

$$B_z = \frac{f_{2\pi}^0}{\gamma_{Rb}}[1 + B_1\cos(\omega_{PDM}t)]$$



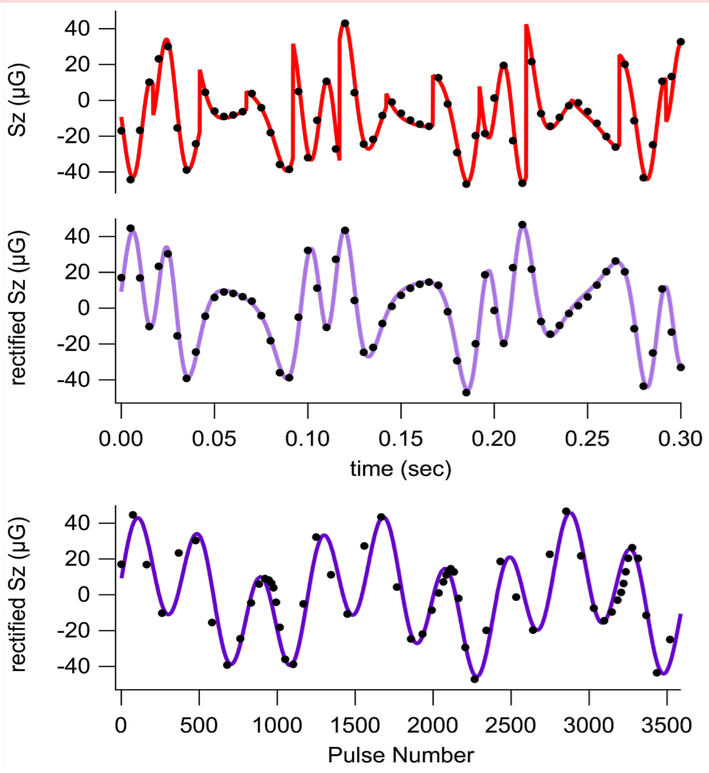
$$S_+ = sign[\cos(\omega_{PM}t)]$$



Resonance Condition: $\omega_d^K = p^K\omega_{PM} + q^K\omega_{PDM}$ where $p, q \in Integers, p\ is\ odd$

We Use

$\omega_d^{129} = \omega_{PM} + \omega_{PDM}$
$\omega_d^{131} = \omega_{PM} - \omega_{PDM}$

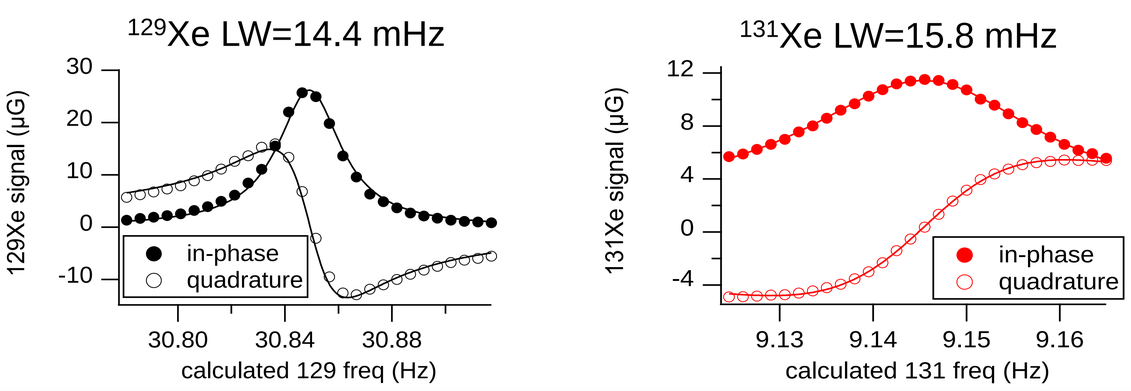


Faraday rotation signal

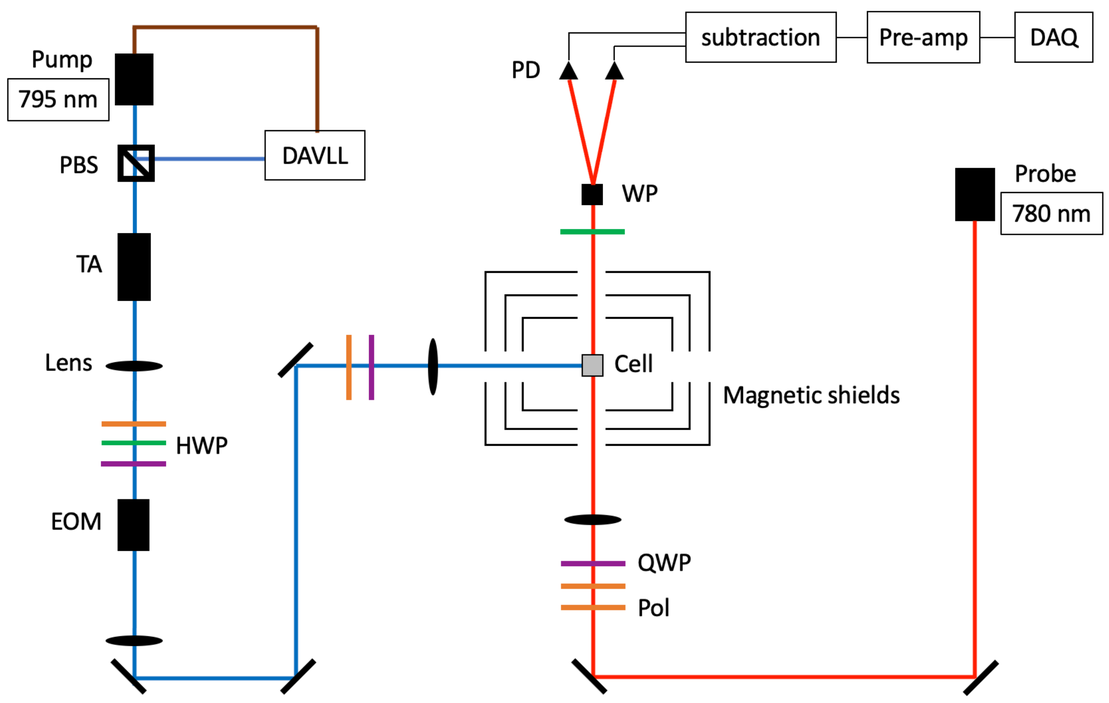
Faraday rotation * σ

Faraday rotation * σ vs pulse number

(pulse repetition rate changes in time)



Development of New Apparatus



Change	Purpose
• Rotating table	• Measure Earth's rotation to evaluate accuracy of measurements
• Single sided on-resonant pumping • DAVLL	• Eliminate AC Stark
• Tapered amplifier	• Reduce optical pumping gradients
• Smaller cell with higher Xe pressure • Smaller laser beams	• Sensitivity at shorter length scales (for axion search)
• New shield, shim coils, and coil rig	• Improved magnetic field uniformity • Better stray field suppression

[1] T.G. Walker & M. S. Larsen, Advances In Atomic, Molecular, and Optical Physics, Vol. 65 (2016) [2] M.E. Limes, et al., ArXiv e-prints, 1805.11578 (2018)