Progress on a ^{3}He-^{129}Xe Co-magnetometer

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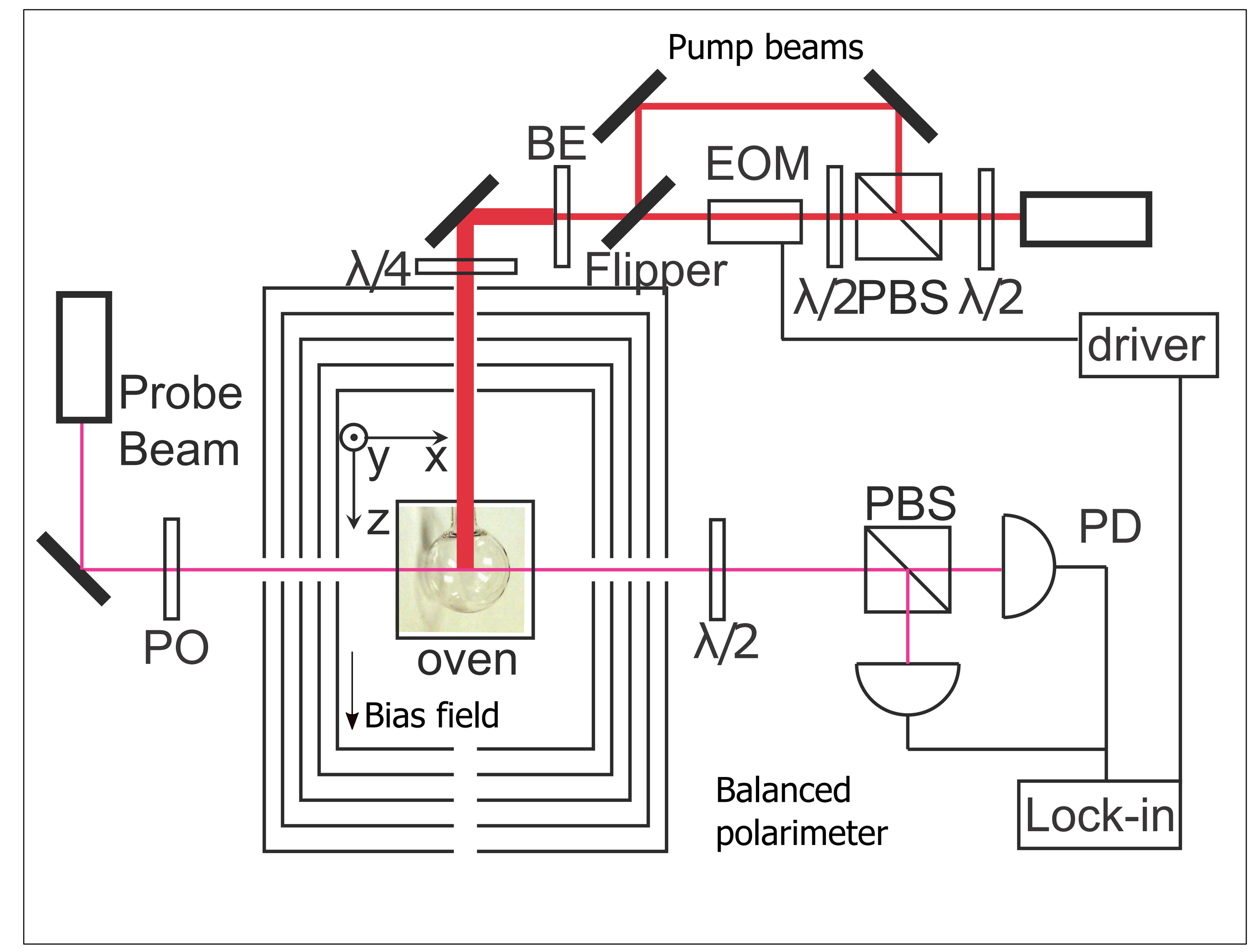
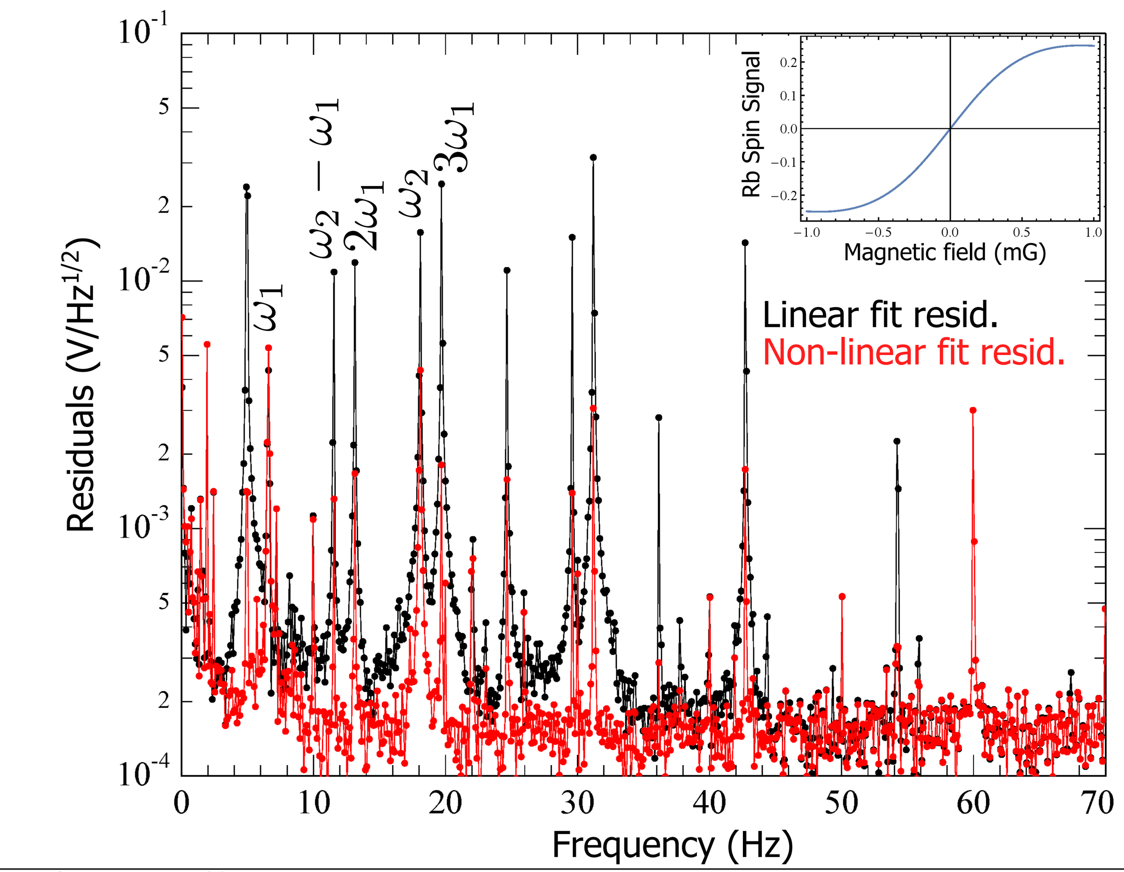
The ^{3}He-^{129}Xe co-magnetometer is a natural choice for precision measurements (including nuclear spin gyros, EDM and spin-gravity experiments) because both noble gases are spin-1/2 nuclei and have long coherence times. We use ^{87}Rb as a sensitive probe of a ^{3}He-^{129}Xe co-magnetometer through their Fermi-contact interactions, which enhance the dipolar magnetic fields by a factor of 5.6 for ^{3}He 490 for ^{129}Xe. In turn, these interactions cause noble gas precession frequency shifts due to the ^{87}Rb polarization. We actively depolarze the ^{87}Rb in the noble gas frames using magnetic field pulse sequences.

Our results presented here are from attempts to suppress the Fermi-contact shifts of the nuclear spin precession frequencies while retaining sufficient detection sensitivity, and also mitigate the effect of the pulse sequences themselves on the nuclear spin precession. To achieve this, we are experimenting with two modes of co-magnetometer operation, (1) "in-the-dark" (with no Rb pumping/detection during noble gas evolution) and (2) continuously detected. For detection of the ^{3}He-^{129}Xe, a 795 nm σ_+/σ_- pump beam syncronized with a single-axis ^{87}Rb π pulse train is used. The pulse train effectively depolarizes the Rb along the bias field with respect to the noble gases, while keeping sufficient Rb polarization for detection, but has a few drawbacks in both modes of operation. These single-axis pulse effects can be supressed by applying specific x and y channel π pulse trains.

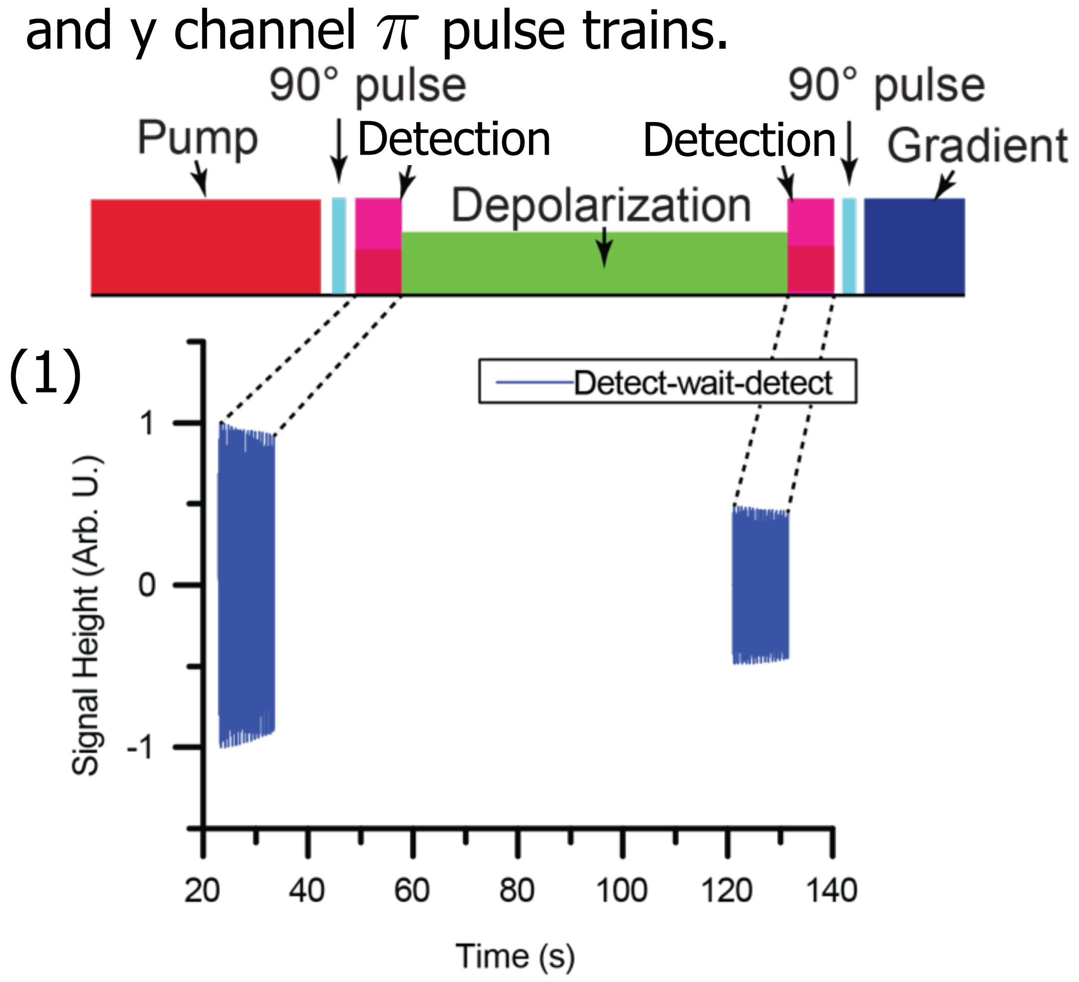


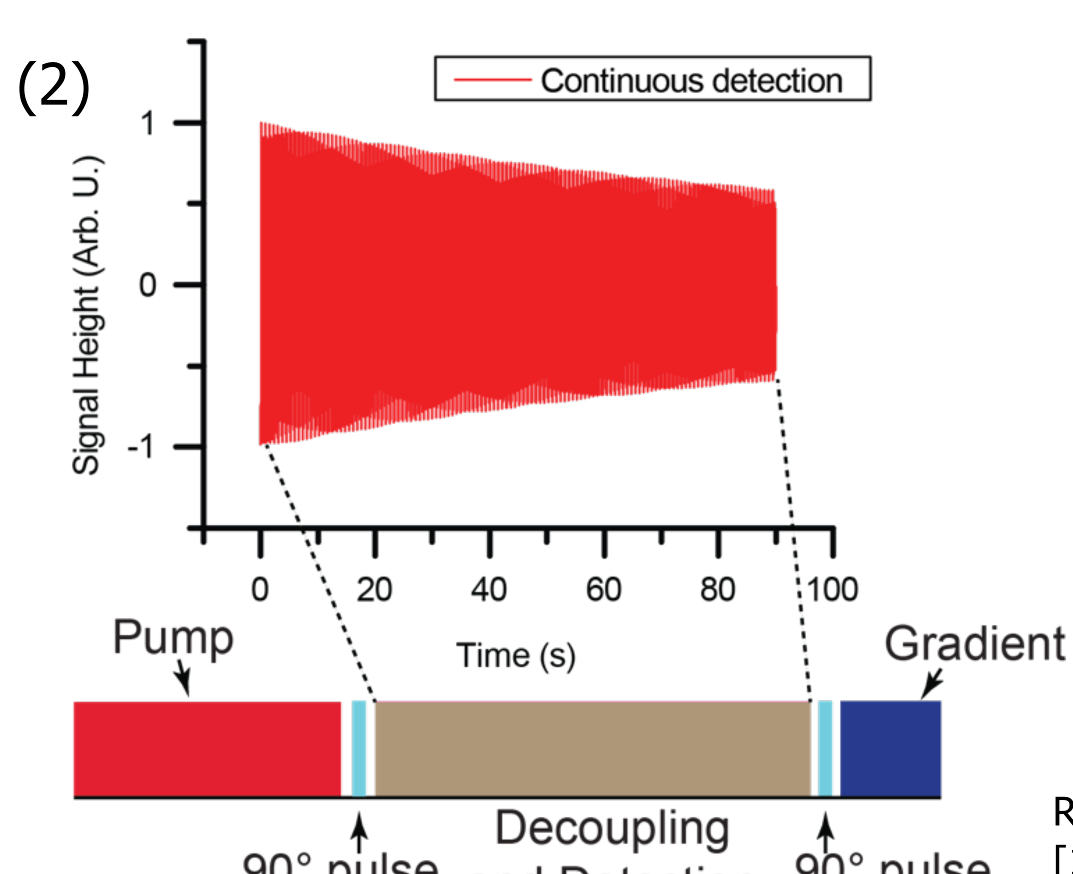


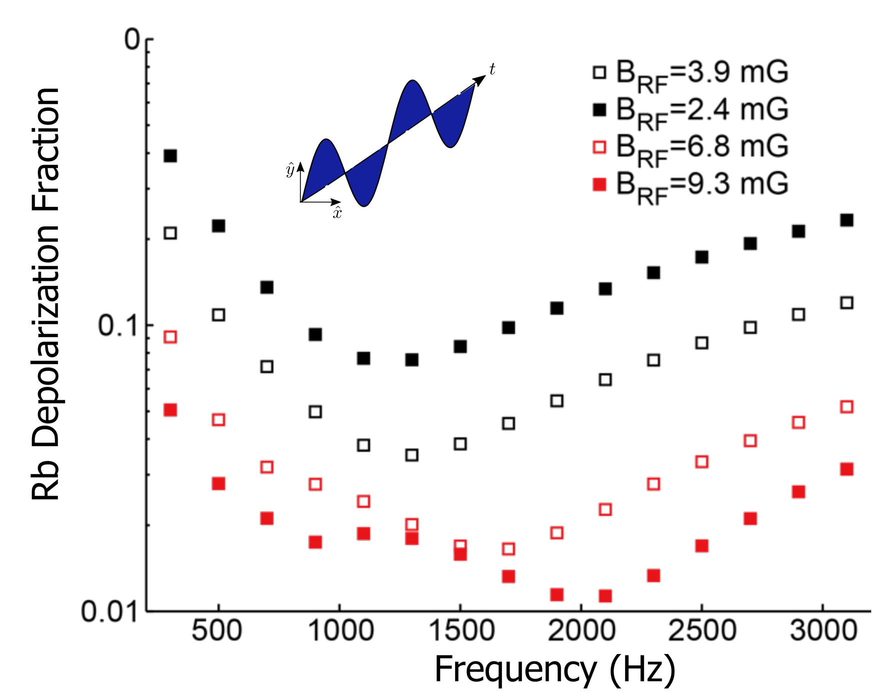
The ^{3}He and ^{129}Xe signals are so large that we run out of linear dynamic range of the Rb response. Thus previous iterations used low ^{3}He and ^{129}Xe polarizations. Detection is no longer limited by high ^{3}He and ^{129}Xe polarizations, by using a non-linear fitting routine.

$$S = A\frac{B_y}{B_y^2+\Gamma^2} = A'B_y(1-\frac{B_y^2}{\Gamma^2}+\frac{B_y^4}{\Gamma^4}+...)$$

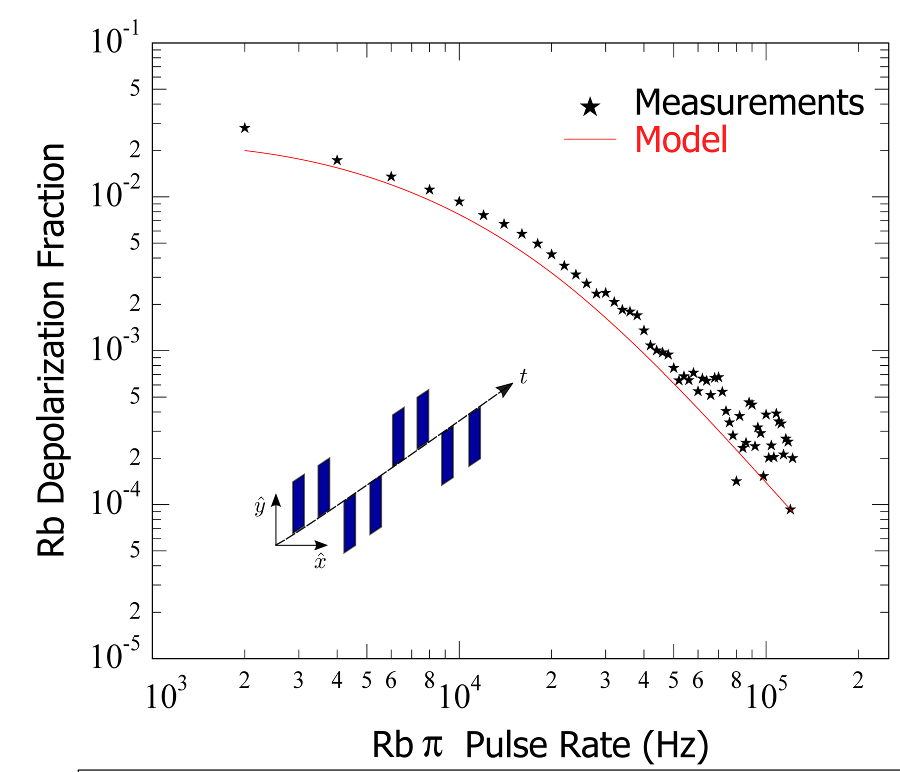
Inset: Non-linear Rb response to large signals.



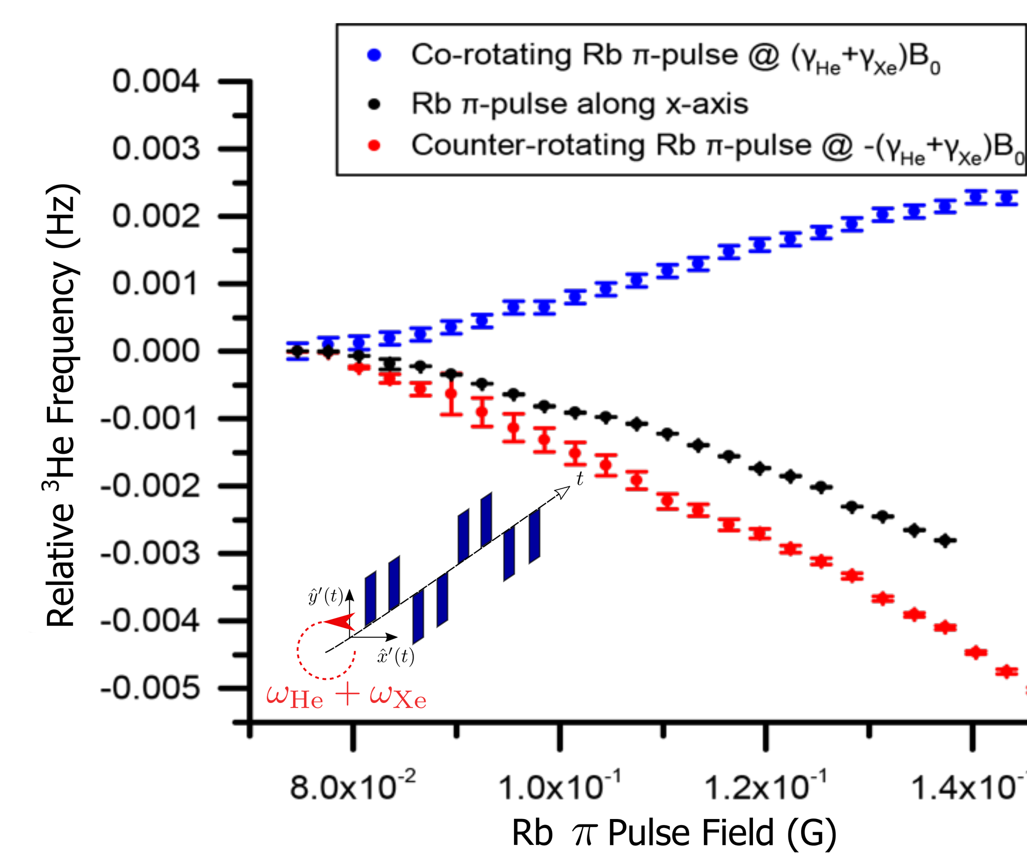




Decoupling of the Rb-Xe Fermi-contact interaction by a factor of 100 using sine wave depolarization in a 2.4 mG bias field.

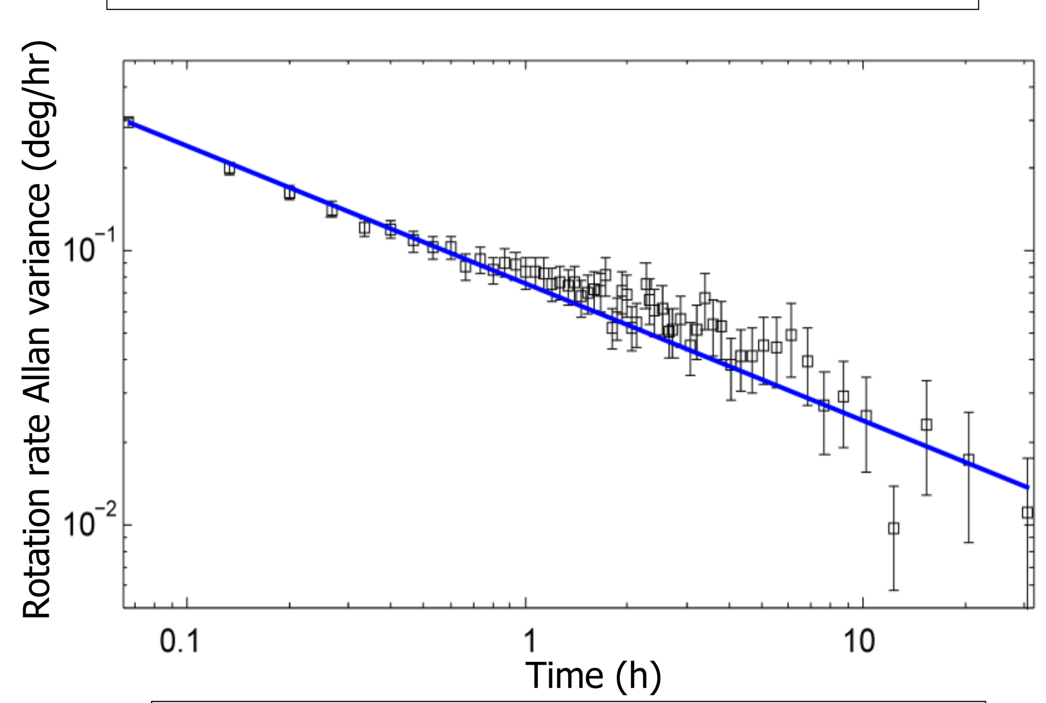


Decoupling of the Rb-Xe Fermi-contact interaction by a factor approaching 10^4 using sufficiently high repetition rate Rb π pulses. Model includes alkali-alkali spin exchange.

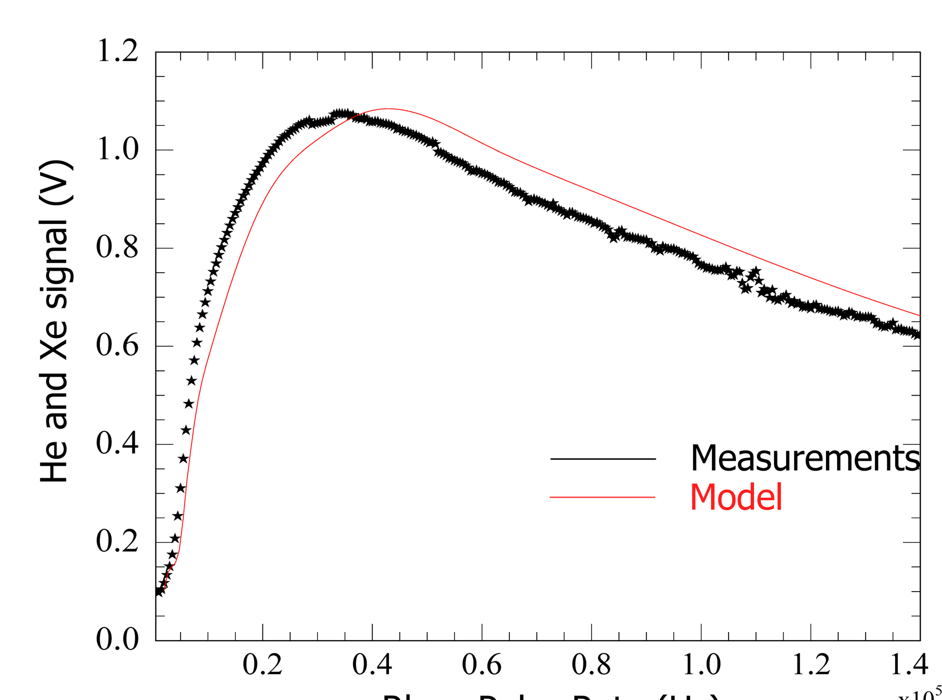


One drawback of the single-axis pulse train is that it causes different frequency shifts on the ^{3}He and ^{129}Xe. However, by using Rb π pulses with a pulse axis slowly rotating at the sum of the ^{3}He and ^{129}Xe (see inset), the change in the ^{3}He-^{129}Xe frequency ratio caused by the pulses can be zeroed out.

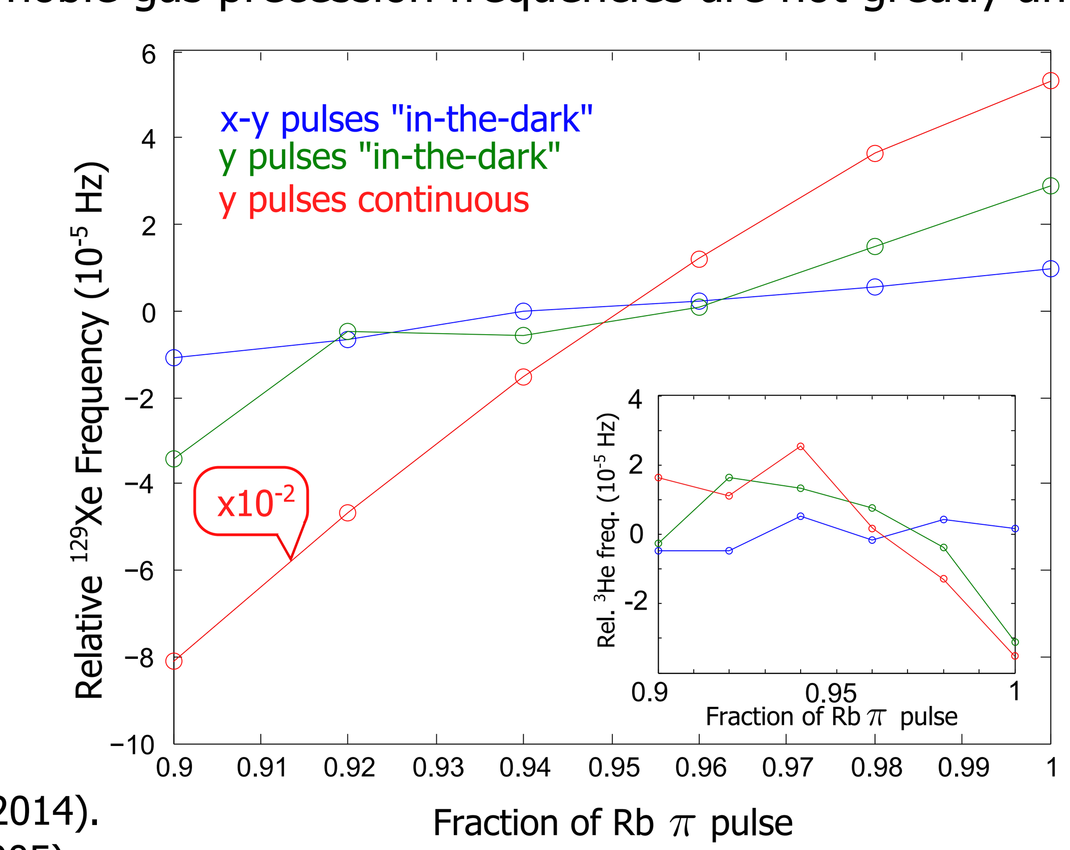
Another drawback of the single-axis and slowly rotating Rb pulse train is that it does not depolarize the ^{87}Rb along the direction of the pulses, leading to backpolarization of the Rb from the ^{129}Xe. By alternating x and y pi pulses, the ^{87}Rb is effectively depolarized along all axes, and the noble gas precession frequencies are not greatly affected from the pulses.

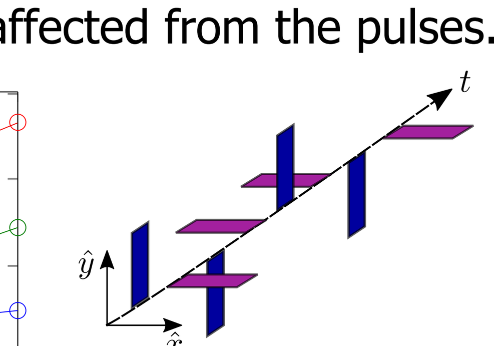


Pulsed detection has demonstrated bias stability of 7.7 nHz at 24 hours, using a sine wave for Rb depolarization.



The sensitivity of the Rb detection increases as the pulse repetition rate exceeds the Rb precession π rate in the bias field.





The effect of alternating x and y direction in this way creates a sense of rotation and counter-rotation, and 'slips' can be introduced for any additional frequency ratio correction. However, this particular pulse sequence must be operated "in-the-dark."

References

[1] New Classes of Systematic Effects in Gas Spin Comagnetometers, D. Sheng, A. Kabcenell, M. V. Romalis, Phys. Rev. Lett. **113**, 163002 (2014).
[2] Nuclear spin gyroscope based on an atomic comagnetometer, T. W. Kornack, R. K. Ghosh, M.V. Romalis, Phys. Rev. Lett. **95**, 230801 (2005).
[3] NMR Dectection with an Atomic Magnetometer, I. M. Savukov and M. V. Romalis, Phys. Rev. Lett. **94**, 123001 (2005).