We aim to decrease the long-term bias drift and increase the sensitivity of a $^{129}$Xe-$^3$He NMR gyro using direct $^{87}$Rb detection [1-4]. Our gyro in Fig. 1 uses two spin-1/2 noble gas species, $^{129}$Xe and $^3$He, that each measure the same magnetic field in the same volume, operating as a co-magnetometer and resulting in a measurement that is independent of any external static magnetic fields. A bias field of $B_x \approx 0.5$ μT results in a detected frequency ratio of $(\omega_{He} + \Omega)/(\omega_{Xe} + \Omega)$, where $\Omega$ is a rotation of the apparatus about the $z$ axis; in this way, we can use our technique to create a gyroscope for inertial navigation systems. If apparatus is kept completely still and all systematics are accounted for, a deviation of the frequency ratio from $\gamma_{He}/\gamma_{Xe}$ would indicate the $^{129}$Xe and $^3$He nuclei undergoing exotic spin couplings, e.g., a coupling to a gravitational field.

Spin-1/2 noble-gas nuclei have the benefits of long coherence times and high magnetic-field sensitivity. The nuclear-spin shot noise can be achieved if an alkali-metal vapor, such as $^{87}$Rb, serves as the magnetometer for the spin-1/2 noble gas baths. This is a result of a Fermi-contact interaction causing an enhanced magnetic field over the classical dipolar field generated by the noble-gas nuclei, characterized by a factor $\kappa_0$ that is ~6 for $^{87}$Rb-$^3$He and ~490 for $^{87}$Rb-$^{129}$Xe. While this enhancement improves the ability of the $^{87}$Rb magnetometer to detect the noble gases, the $\sim 10^2$ difference in $\kappa_0$ causes fields experienced by the $^3$He and $^{129}$Xe due to polarized $^{87}$Rb to be significantly different, leading to long-term bias drift instability in the NMR gyro.

To remove the effect of $\kappa_0$ on the noble gas precession, co-magnetometer phase accumulation can be performed “in-the-dark” without optically pumping the alkali-metal vapor (shown in Fig. 2). However, even in-the-dark, the $^{87}$Rb is “backpolarized” by the $^{129}$Xe, so the $^{87}$Rb-$^{129}$Xe interaction must be actively decoupled or else $^{87}$Rb polarization instabilities manifest and cause uncontrolled noble-gas frequency shifts. During the in-the-dark evolution, we use fast repetition $^{87}$Rb $\pi$ pulses to decouple $^{87}$Rb-$^{129}$Xe interaction by a factor of 10$^4$. We are also able to rotate the $^{87}$Rb $\pi$ pulses at a frequency that is the sum of the $^{129}$Xe and $^3$He precession frequencies, in order to null out the effect of the $\pi$ pulses on the $^{129}$Xe and $^3$He frequency ratio.

Our $^{87}$Rb decoupled SERF magnetometer has a sensitivity of 40 ft/sqrt(Hz). The decoupling techniques described herein have produced an NMR gyro with a single-shot resolution of ~20 nHz and achieved a long-term bias drift of ~7.7 nHz at 7 h.

Supported by DARPA and NSF.

References: