Sodium Guide Star Magnetometry

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Abstract

An experiment was devised to test the theory set forth in Higbie et. al.[3] proposing to measure Earth's magnetic field using a Sodium Guide Star. We expanded a Frequency Addition Source of Optical Radiation (FASOR) system operating at the Na D_2a-line to a 4 inch beam and used an Acousto-Optic Modulator (AOM) to pulse the beam near the Larmor frequency of the Na atoms. By sweeping the pulse frequency over the Larmor resonance we were able to see an enhancement in the return signal. The frequency of the resonance is directly proportional to the magnetic field strength and can be used to remotely monitor magnetic field strength and fluctuations in the Earth's mesosphere.

Background

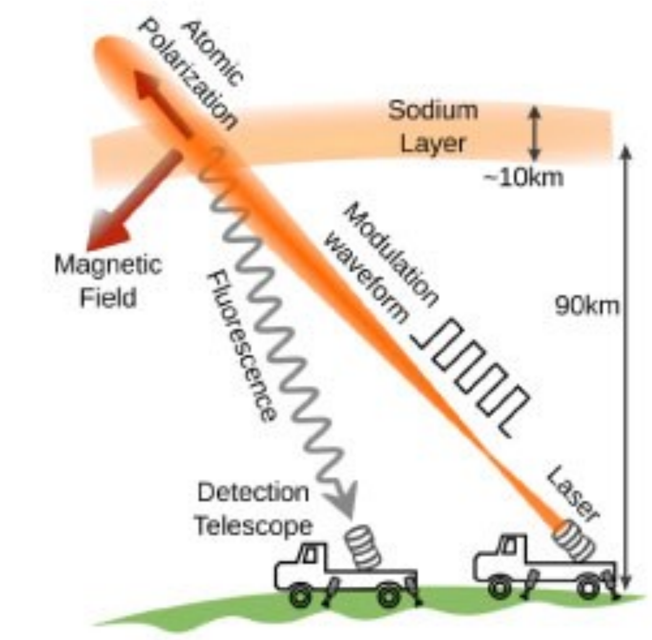
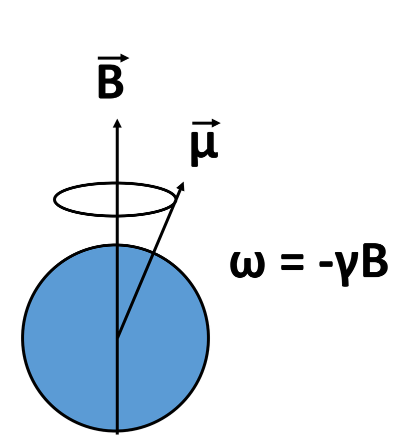


Figure 1: Diagram[3] of the experiment.

Na lasers have been used for years at several major observatories to create laser guide stars for Adaptive Optics (AO). Our goal was not to look at the return wavefront from the guide star, but rather to measure the variance in the return flux with relation to pulse frequency. The sodium atoms are given a magnetic moment via the circularly polarized FASOR beam. This magnetic moment causes the atoms to precess in the earth's magnetic field. Pulsing the FASOR at the precession frequency thus yields an enhanced return. The Larmor precession frequency is directly proportional to the magnetic field strength as shown in Figure 2. We can use the frequency of the enhanced return signal to find the field strength at a given time and to monitor fluctuations in the Earth's magnetic field.

Figure 2: A particle's magnetic moment (**μ**) precesses in a magnetic field (**B**). The precession frequency (**ω**) is directly proportional to the magnetic field strength



Results

Using the four inch beam we were able to create a tight Gaussian spot on the sodium layer about 4m in diameter shown in Figure 3. Comparing this to standard stars we found our guide star to have a photon flux of 110 $s^{-1}cm^{-2}$.

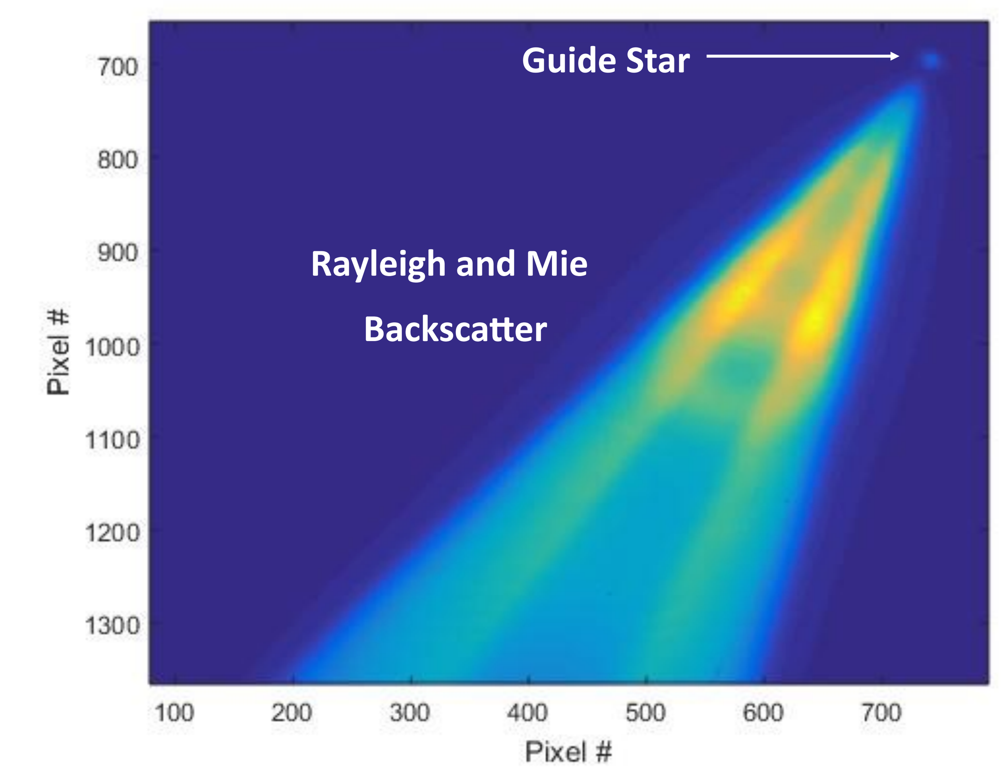


Figure 3: The Guide star viewed through the Kuiper 61" Telescope on Mt. Bigelow

To analyze the return signal from the guide star we dithered between two pulse frequencies separated by a 30 kHz and looked at the difference in signal strength. When the difference is zero we know that the center frequency is at the peak of the Larmor resonance. As we scanned through a range of center frequencies we were able to see a large positive signal and a large negative signal as shown in Figure 4. This shows that we were able to find a resonance from the sodium atoms precessing around the magnetic field. To track variances in the magnetic field the modulation will be optimized for a high zero-crossing slope while a servo tracks the drift in Larmor frequency. This drift directly corresponds to a change in field strength.

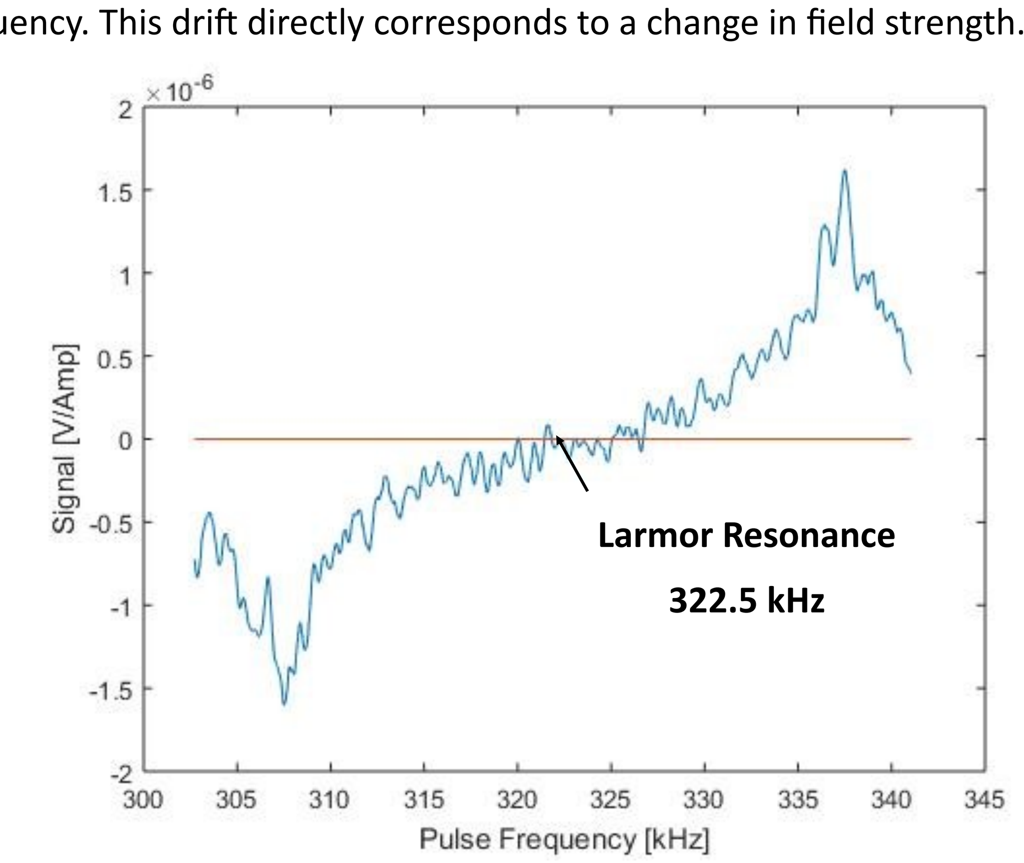


Figure 4: By taking the difference in signal strength from two frequencies separated by 30 kHz we were able to find a magnetic resonance from the sodium atoms.

Conclusions and Future Work

- Using our setup we found the magnetic field at the time of measurement to be 46.1 μT which is only slightly larger than the predicted field strength of 45,5 μT (WMM2010 model).
- Fluctuations in the signal can be monitored using a servo to lock onto the zero crossing between the negative and positive peaks.
- We plan to correlate the signal with ground based measurements to show that this is a viable alternative to current measurement techniques.
- We believe the signal can be monitored during daylight hours with a sufficiently narrow spectral filter. This would allow continuous monitoring of the field.

Experimental Setup

We used an AOM to allow us to pulse the laser through the Larmor frequency resonance. The two waveplates allow us to circularly polarize our beam in order to give a magnetic moment to the sodium atoms. The combination of two beam expanders allows us to create a 4 inch beam which gives us a 4m spot within the sodium layer.

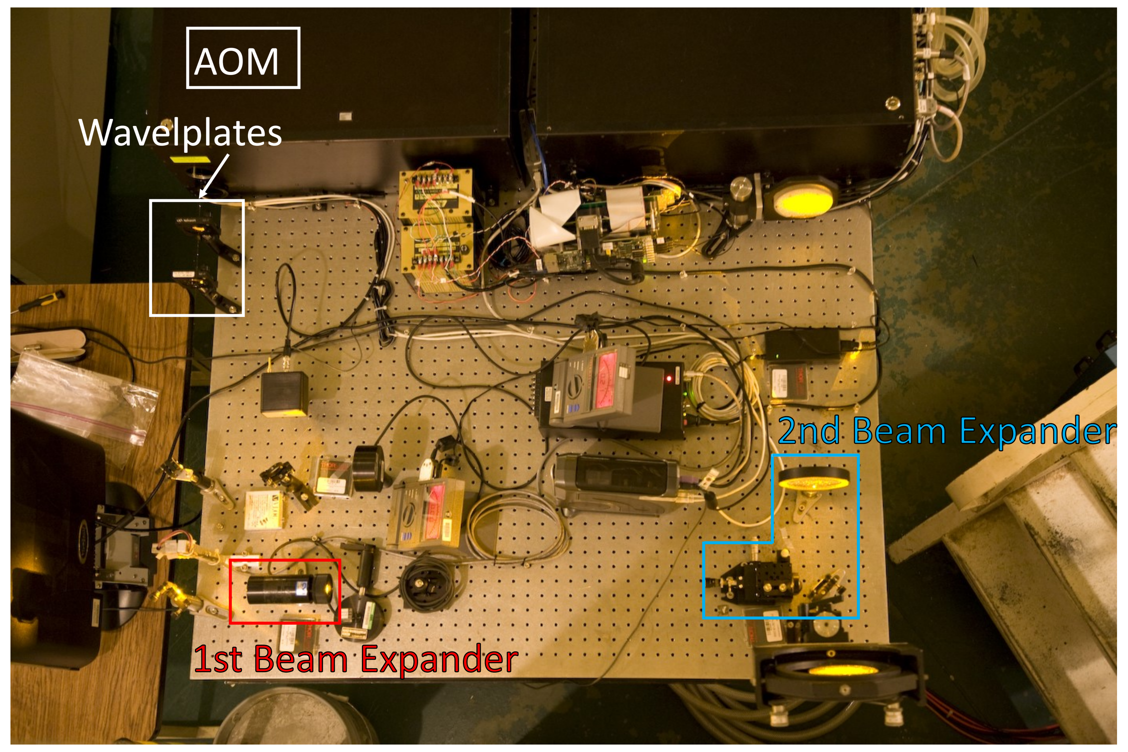


Figure 5: Optics table layout

Works Cited and Acknowledgments

1. Affiliated with the University of Arizona
2. Affiliated with FASORtronics LLC
3. Higbie James M., et.al, "Magnetometery with mesospheric sodium", PNAS, March 1, 2011, Vol 108 no. 9, p. 3522.
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