# High-Resolution Doppler-Free Polarization Spectroscopy for Novel Doppler Lidars for Environmental and Atmospheric Sciences


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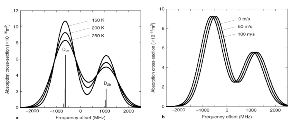
## 1. Introduction

➤ **LIDAR** (*light detection and ranging*) remote sensing has become one of the most powerful tools in atmospheric and environmental research, which is not only replacing conventional sensors but also creating new methods with unique properties that could not be achieved before.

➤ **Resonance fluorescence Doppler lidar** is one of the most sophisticated lidar technologies. By inferring the Doppler shifted and broadened atomic absorption spectroscopy (e.g., Na, K, Fe in the upper atmosphere) with narrowband lasers, it measures temperature and wind simultaneously in the Earth's upper atmosphere between 75 and 120 km above the ground.


Doppler Effect in Na $D_2$ Line Resonance Fluorescence

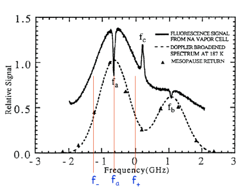


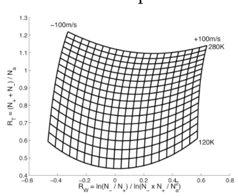

Na $D_2$ absorption linewidth is temperature dependent

Na $D_2$ absorption peak freq is wind dependent

➤ **Locking laser frequency** to desired atomic absorption lines is crucial in Doppler lidar and enables 3-frequency ratio technique to achieve high-resolution lidar measurements.

➤ **Three-frequency ratio technique** is to tune the stabilized laser frequency with acousto-optic modulator (AOM) to generate two wing frequencies. The ratios of sky-return signals at the peak and two wing frequencies are then used to infer the temperature and wind of the atmosphere.



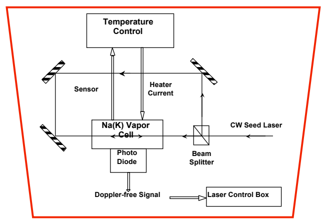



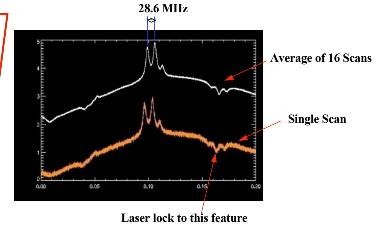

➤ **High-resolution Doppler-free spectroscopy** is the key for locking laser frequency. Saturation fluorescence, saturation absorption and polarization spectroscopy are the three major Doppler-free approaches.

➤ **Current state-of-the-art Na and K Doppler lidars** utilize saturation fluorescence spectroscopy to lock the cw seed lasers to the Doppler free features of Na $D_2$ and K $D_1$ lines, and then amplify the laser to lidar pulses with pulsed amplifier or laser. However, this scheme suffers low signal-to-noise ratio, dither, and chirp problems from fluorescence, laser locking, and pulsed amplification, resulting in large bias & uncertainty in measurements.

➤ **Our Objectives** are to innovate the Doppler lidars by introducing saturation absorption and polarization spectroscopy and applying them to lock pulsed laser frequency directly. This chirp-free and dither-free frequency locking will help achieve a bias-free iron (Fe) resonance fluorescence Doppler lidar that has been proposed to NSF Major Research Instrumentation Program as the most advanced mobile Doppler lidar in atmospheric and environmental research.

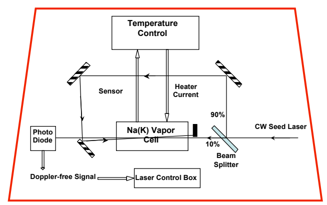
## 2. Saturation Fluorescence Spectroscopy

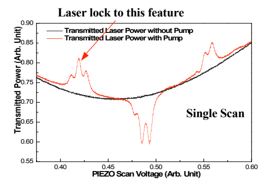



Saturation Fluorescence Spectroscopy Setup for Current Na and K Doppler Lidars (left) and the Measured Spectrum of K (D1) with Doppler-free Features (right).

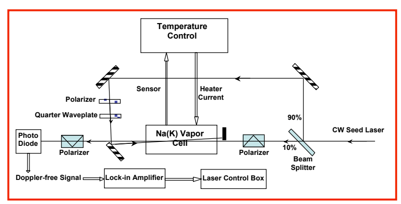
## 3. Saturation Absorption Spectroscopy




Saturation Absorption Setup and the Spectrum of K (D1) with Doppler-free Features

## 4. Doppler-Free Polarization Spectroscopy




Very sensitive! Great SNR! Dither free - producing first derivative spectroscopy naturally without dithering laser frequency!

Signal structures are sensitive to polarization configurations.

Polarization Spectroscopy Setup with Na or K Vapor Cell

## 8. Conclusions and Outlook

➤ Doppler-free polarization spectroscopy promises a revolution to Doppler lidars — dither-free and chirp-free laser frequency locking, leading to bias-free measurements of wind and temperature that are crucial in understanding atmospheric dynamics, general circulation, and global climate change.

➤ Pulsed laser frequency locking using Doppler-free spectroscopy is very challenging but doable. We seek collaborations to address the challenge, aiming for a major advancement in lidar remote sensing field.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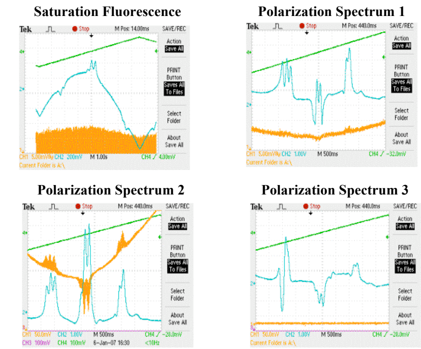
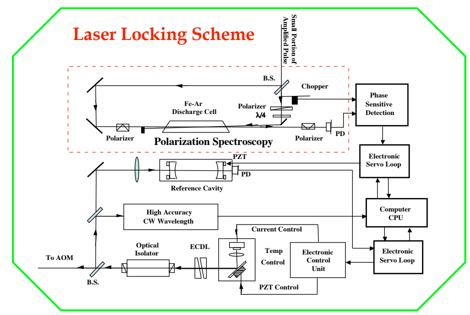
➤ Lidar Group Web Page: http://cires.colorado.edu/science/groups/chu/

## 5. Initial Results with Potassium $D_1$ Line

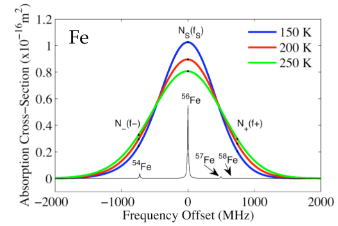



Measured Spectrum of K (D1) with Doppler-free Features

## 6. Proposed Fe Doppler Lidar to NSF




## 7. Major Challenges and Issues




➤ Simulation of the Doppler-free feature

➤ Simulation of signal shape with the polarization configuration

➤ Measurement of isotope shifts for Fe (54, 56, 57, 58) 372/374 nm

➤ Directly locking laser pulse frequency (rather than cw seed laser) to the Doppler-free feature of 372 nm Fe absorption line

➤ (Fe excited state lifetime ~ 61ns, laser pulse duration ~250-300ns)