Project Summary Changes in Earth's climate system have directly caused abnormal wildfire activity within the western United States [1]. Resources to prevent, prepare for, and respond to this increase have become a national priority. The increase in wildfire activity and its effects have personally motivated my interest in wildfire science. My doctoral research will contribute to the scientific study of atmospheric propagation and aging of wildfire smoke, by developing a polarimetric imaging instrument to measure the polarization of UV light scattered by highly absorbing aerosols. My goal is to demonstrate that an imaging polarimeter fabricated from commercial-off-the-shelf components mounted on an unmanned aerial vehicle (UAV) can differentiate the dominant aerosols in wildfire smoke: black and brown carbon.

Sky Polarization Consider looking up at the blue sky on a perfectly clear day. To our human eyes, receptive to the visible electromagnetic spectrum, we will simply see a Rayleigh scattering dominant bright blue sky. However, insects *e.g.* flies, honeybees, desert ants, will be able to see the polarization signature of the sky and use it for navigation.

Polarization describes the orientation of electric field oscillations, which can have no preferential orientation (*i.e.*, unpolarized), oscillate in many orientations with a tendency towards a given orientation (*i.e.*, partially polarized), or only oscillate in a specific orientation (*i.e.*, polarized). Sunlight is unpolarized but atmospheric scattering creates partial polarization in many wavebands of the electromagnetic spectrum. Applying biomimicry of the polarimetric sensitivity of insect eyes to perform polarimetric studies of the sky, many scientific insights have been made on the atmospheric particulates disrupting this clear sky polarization pattern.

Aerosol Typing Pollution, dust, and smoke are common atmospheric particulates, called aerosols. These aerosols interact with sunlight through scattering and absorption, depending on the size of the aerosol and their optical properties *e.g.* index of refraction.

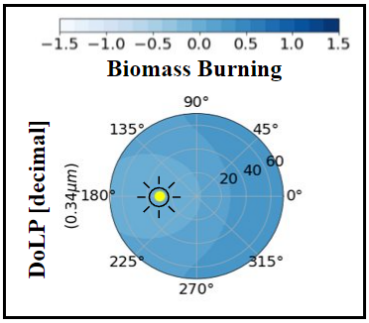


Figure 1: Biomass Burning DoLP simulated over the sky dome at 340nm. At backscattering geometries the DoLP peaks at 0.42. Therefore, a strongly polarized signal would be observed at solar noon looking down from a UAV [2].

The size of aerosols typically ranges between a few hundredths of a micron to tens of microns. At the lower end of this size range, scattering and absorption increase rapidly with decreasing wavelength. Absorption in the UV (100-400 nm) is particularly strong for aerosols originating from black and brown carbon, the dominant aerosols in wildfire smoke.

Current satellite-based aerosol retrievals utilize visible and infrared wavelengths because UV atmospheric absorption is high. Although the radiometric signal is lower in the UV than visible the UV polarization properties have significant benefits for aerosol typing. These polarization properties can be quantified by finding the degree of linear polarization (DoLP) of the scattered light. Performing aerosol retrieval sensitivity studies was the focus of my first publication [2]. In Figure 1 the absolute DoLP (decimals) at 340nm of a biomass burning aerosol (e.g. wildfire smoke) is plotted within the sky-dome with the sun (yellow circle) positioned at (-20°, 180°). My work and other UV sensitivity studies have shown the potential to improve aerosol typing using UV DoLP [2]. The results of this work lead me to my current research hypothesis. **Research hypothesis: UV polarimetric measurements will improve aerosol typing algorithms for black and brown carbon found in smoke.**

Current Methods When measuring atmospheric scattering either angular or polarimetric sampling is valuable for aerosol typing but the combination of both offers increased benefits. These polarimetric differences are caused by absorbed or scattered light. Multi-angle imaging provides sensitivity to the scattering properties of the aerosol. Adding polarimetry to multi-angle imaging increases this sensitivity, since the measured polarimetric signal is also dependent on the incident angle of the sunlight [3]. The combination of multi-angle polarimetric imaging also increases sensitivity to the refractive index of the aerosol, which is a crucial parameter for distinguishing aerosol types. This unique capability has driven investments in multi-angle

polarimetry for ground-based, airborne, and satellite instruments.

Intellectual Merit Designing, fabricating, and demonstrating a compact, low-cost UAV-mounted UV imaging polarimeter with sufficient accuracy for aerosol typing of black versus brown carbon is the goal of my doctoral research. *Hardware Conception* The proposed concept is novel in two ways. First, by utilizing the mobility of a UAV to take polarimetric measurements. The idea to make a UV polarimeter airborne on a UAV allows for a more cost-effective study than using a manned aircraft. This is feasible with the advanced precision pointing of UAVs. Mounted on a UAV the camera's roll, yaw, and pitch can be controlled. This precise rotation of the camera reference frame creates a sampling of unique polarization orientations at varying scattering geometries. The assumption that the surrounding plume is homogeneous enables polarimetric-angular sampling from the UAV motion. Secondly, the homogeneous assumption that this UAV-mounted UV polarimeter relies upon is strengthened in the UV region due to low land surface reflectance and high aerosol optical depth of smoke. The important advantage of this assumption is that rotating optical components and other polarization modulation technologies can be replaced with only a static polarizing filter in front of a UAV-mounted camera.

Algorithm Development In traditional multi-angle polarimetric imaging, evenly-spaced linear polarization states are measured at a static acquisition geometry. These samples are selected to constrain the reconstruction of Stokes parameters. My idea is to bypass the intermediate step of Stokes reconstruction and instead develop a computer-aided aerosol typing algorithm. This computational development is intended to alleviate the hardware complexity required for Stokes reconstructions while still providing the desired aerosol typing of wildfire smoke.

Calibration & Validation My university offers support to deploy UAVs on campus. The first measurement from my UV-UAV polarimeter will be on a clear day for comparison to the expected clear sky polarization pattern. This known polarization pattern provides ground truth for instrument calibration, characterizing measurement uncertainty, and aerosol typing algorithm development. Then, on a smoky or hazy day, the aerosol typing capabilities can be validated against satellite-based aerosol retrievals *e.g* NASA's Multi-Angle Imager for Aerosols (MAIA) satellite.

Field deployments The Federal Aviation Administration puts flight restrictions into place near ongoing wildfires. In 2018, Arizona had 570 sanctioned drone flights for wildfire monitoring. I plan to leverage the prestige of an NSF fellowship and propose a collaboration with the Arizona Bureau of Land Management for a piggyback UAV deployment of my instrument into a contained wildfire.

Data Management A data protocol will be developed to save all data and metadata as layers in Hierarchical Data Format (HDF) files. For public access, all polarimetric measurements and aerosol typing algorithms will be made available at a permanent, public-facing repository.

Broader Impacts Aerosols from wildfire smoke influence the Earth's temperature, precipitation, and the overall climate process. This work will provide unprecedented UV polarimetric measurements to study smoke propagation and aging that are needed for climate modeling and aerosol interaction studies [4, 5]. These models and studies help determine ways to combat climate change. Mitigating the effects of climate change is a global priority, due to its effects on weather patterns, the economy, global air quality, agriculture, and more. These effects are felt disproportionately by people of color and people of lower economic status, creating further societal divides.

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[1] J.Dashoff. In: (2021). [2] C.M.DeLeon et. al. In: (2021). [3] M. K. Kupinski et. al. In: (2019). [4] J. Shaw et al. In: (2014). [5] K. T. Junghenn Noyes et al. In: (2020).