UV Sky Polarimetry for Neutral Point Position Estimation

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INTRODUCTION

Polarization refers to the orientation of the oscillation of light waves and the relative phase between them. It is a key property of light that can be described using Stokes parameters, which provide a comprehensive way to quantify the polarization state [2]. The Ultraviolet Linear Stokes Imaging Polarimeter (ULTRASIP) is an instrument designed to capture the linear polarization properties of 355 nm light, particularly from the sky, which becomes linearly polarized due to scattering. This poster describes the basic construction of ULTRASIP and preliminary measurement of the sky polarization.

ULTRASIP

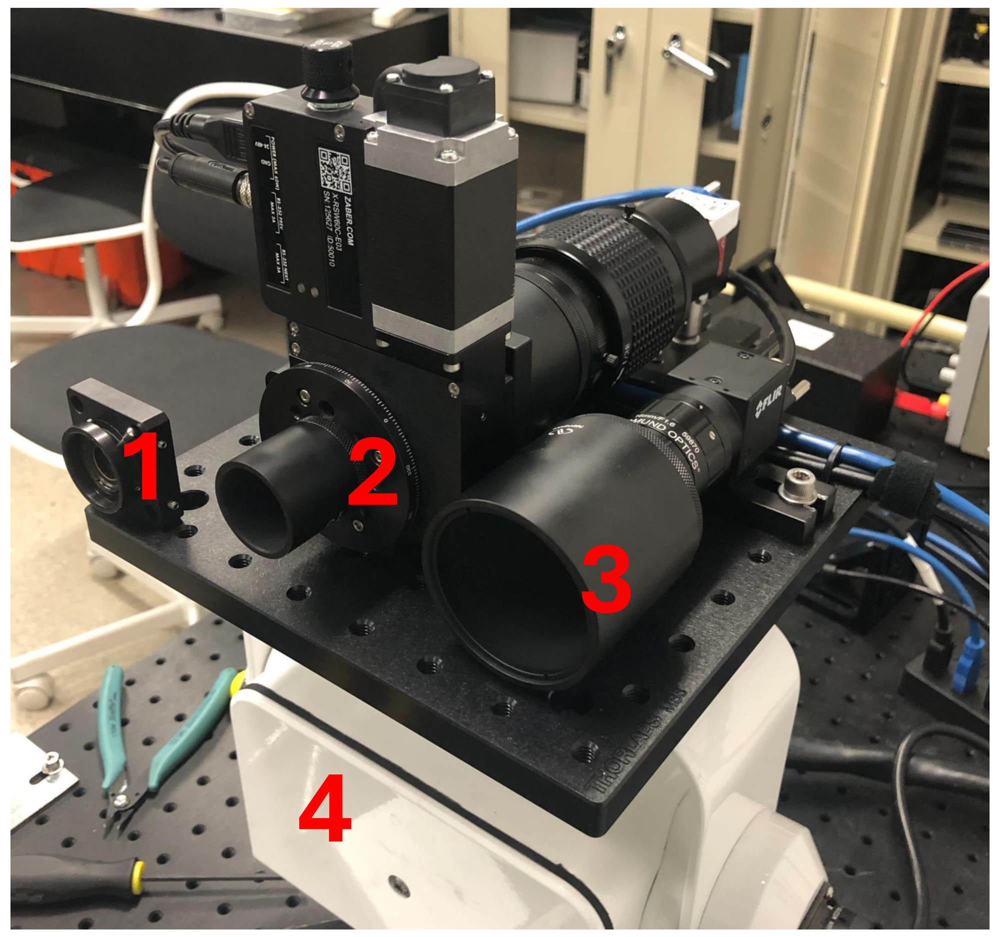

Fig. 1: Components of ULTRASIP

1) Pinhole solar aligner
2) Ultraviolet polarimeter
   - CMOS sensor
   - 355 nm +/- 10 nm bandpass
   - 25 mm lens
     - 22.32 arcsecond FOV per pixel
   - Rotating linear polarizer
3) Visible snapshot polarimeter
   - Polarizer and Bayer filter on focal plane
   - 16 mm lens
4) Precision Pan-Tilt stage

LINEAR STOKES PARAMETERS, AOLP, & DOLP

Linear Stokes parameters are a four number mathematical representation of the polarimetric state of light. (S_0 , S_1 , S_2) are the linear flux sums or differences for 0(H), 45, 90(V), and 135 degrees. Below are the linear Stokes parameters:

$$S_{linear} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \end{pmatrix} = \begin{pmatrix} P_H + P_V \\ P_H - P_V \\ P_{45} - P_{135} \end{pmatrix} = \begin{pmatrix} I \\ Q \\ U \end{pmatrix} = \begin{pmatrix} \leftrightarrow + \updownarrow \\ \leftrightarrow - \updownarrow \\ \nearrow - \nwarrow \end{pmatrix}$$

Furthermore, polarized light can be described using two additional properties: the angle of linear polarization (AoLP) and the degree of linear polarization (DoLP). AoLP, which ranges from 0 to 180°, indicates the orientation of light's oscillation. DoLP measures the extent of polarization, ranging from 0 to 1, with 1 representing fully polarized light.

$$AoLP = \frac{1}{2}\arctan\frac{S_2}{S_1} \qquad DoLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$

INSTRUMENT DEPLOYMENT

Standard cameras are not sensitive to polarization, so for ULTRASIP a linear polarizer is rotated in front of a SONY IMX487 Back-Illuminated Complementary Metal-oxide-semiconductor (CMOS) sensor housed in an Alvium camera (1800 U-812 UV). A 25 mm lens with a variable aperture is mounted in front of the camera and sensor the field of view (FOV) is 63648 arcseconds, with a 22.32 arcsecond FOV per pixel.


Fig. 2: ULTRASIP mounted on an altitude-azimuth motorized stage and cart for rooftop deployments

SKY POLARIZATION

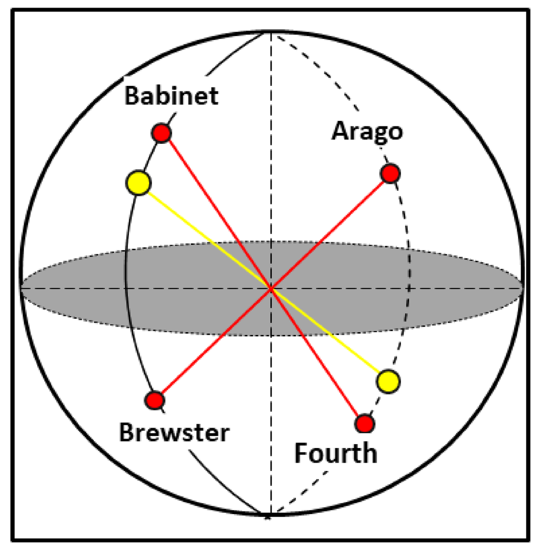

Fig. 3: The four neutral points [5]

In Rayleigh's model, the sky is polarized tangentially to the sun [**Fig. 4**]. This model assumes the absence of multiple scattering. Multiple scattering produces partially polarized light oriented perpendicular to the plane containing the zenith and observer's view direction [**Fig. 5**]. The incoherent addition of these two polarization patterns creates four positions in the sky where the DoLP is 0. Below is a visual representation of how the neutral points are formed [1]:

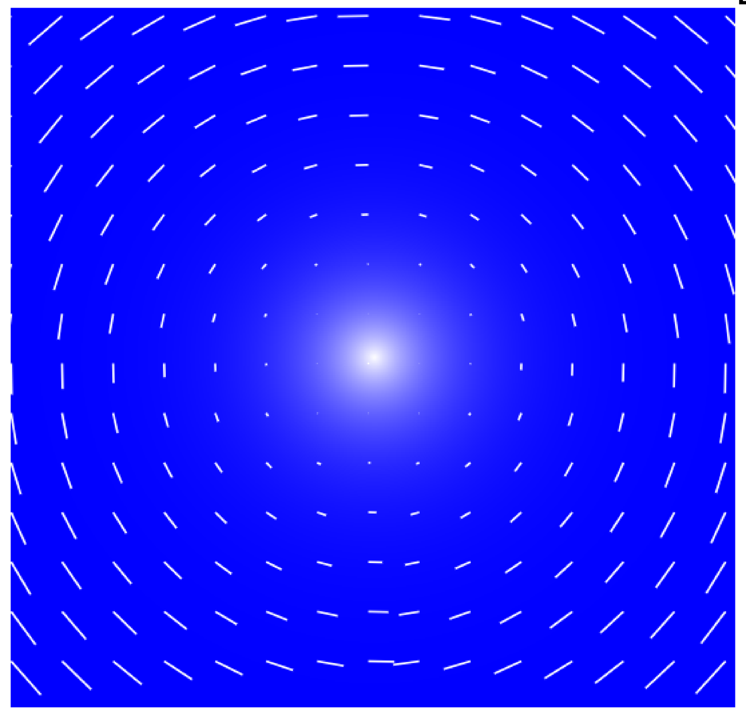
Fig. 4: Sky polarization Rayleigh model where DoLP correlates to the length of the line and AoLP correlates to the angle in the plane perpendicular to propagation.

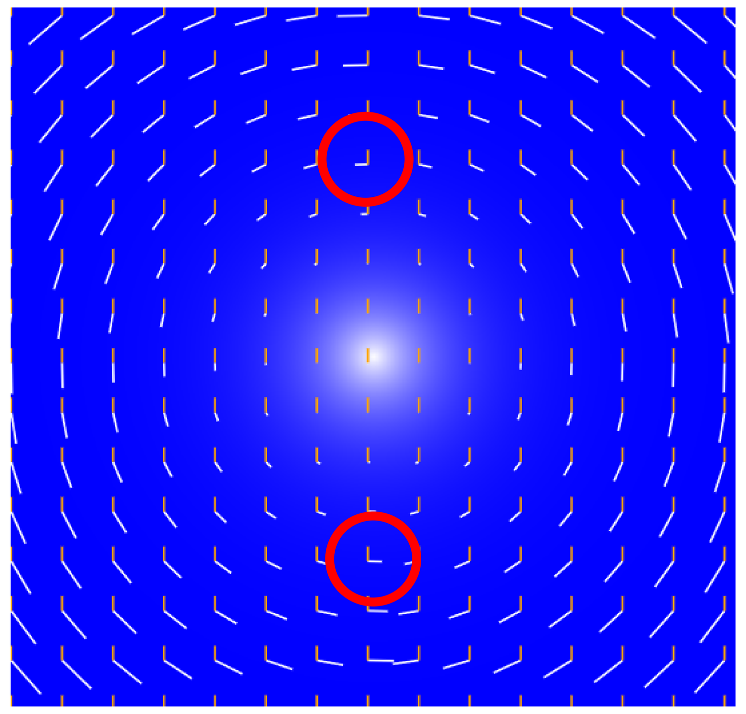
Fig. 5: The introduction of vertically polarized light. These orthogonal states cancel to produce the neutral point above and below the sun and anti-sun.

NEUTRAL POINT IMAGES

Position of the Sun: (Azimuth: 77.14°, Altitude: 29.64°)

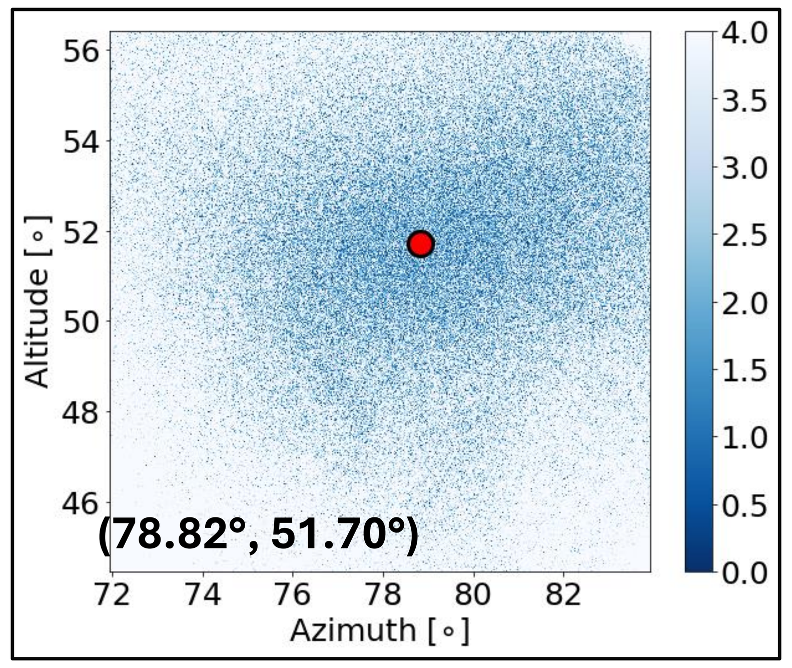

Fig. 6: Neutral Point DoLP [%]

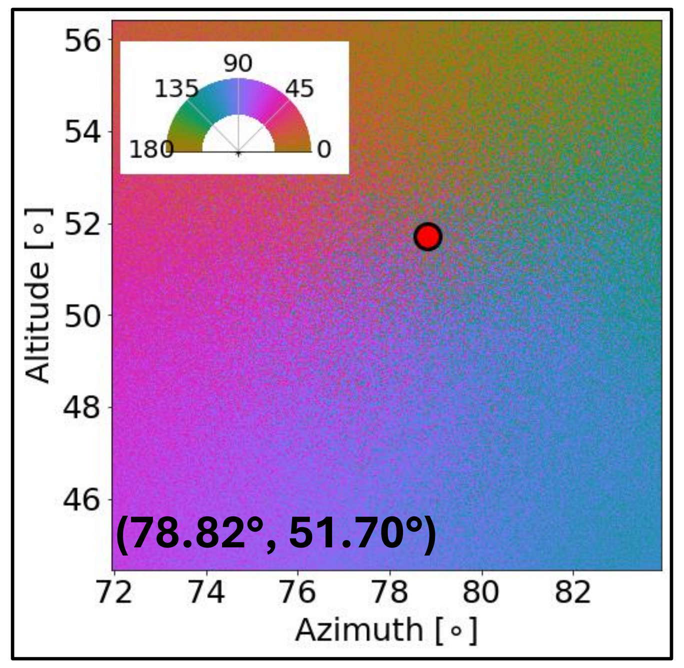

Fig. 7: Neutral Point AoLP [°]

NEUTRAL POINT ESTIMATION

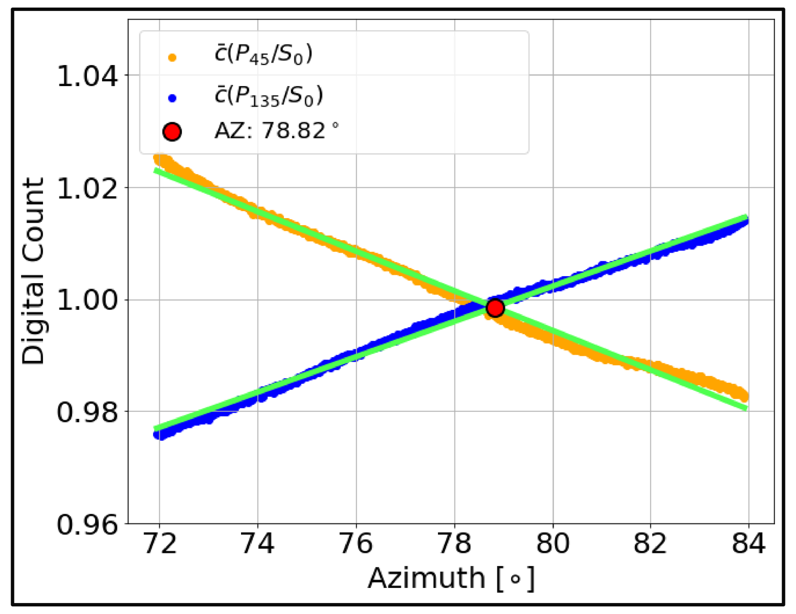

Fig. 8: Plotting of P_{45} (yellow) versus P_{135} (blue) to find azimuth angle.

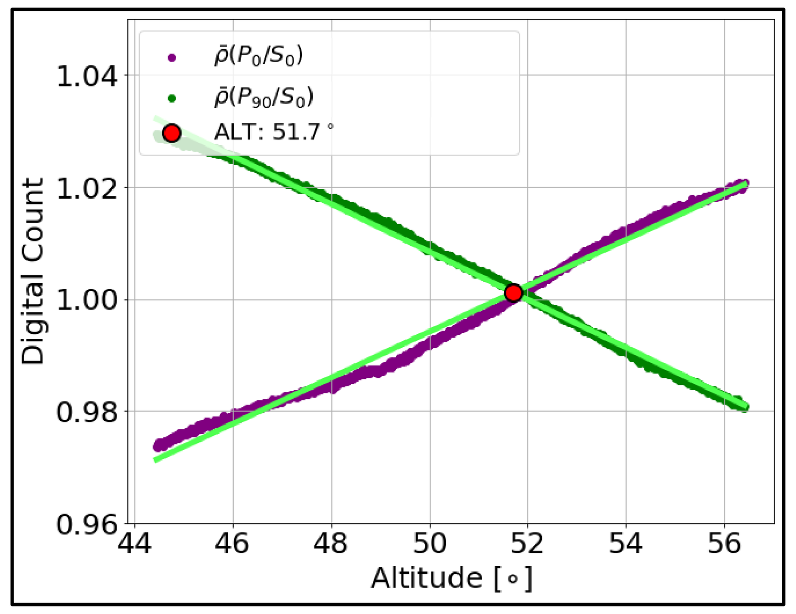

Fig. 9: Plotting of P_0 (purple) versus P_{45} (green) to find altitude angle.

Plotting the row and column averages of the flux images for each angle of the polarizer transmission axis against the pixel's spatial position is a method to estimate the position of the neutral point.

CONCLUSIONS

The ULTRASIP instrument has demonstrated its capability to locate neutral points in the sky, with the potential for real-time tracking. By monitoring changes in neutral point locations, this technique can be used to correlate neutral point position with aerosol loading, such as smoke from wildfires. Observing location changes to the sky's polarization neutral point that correlate with atmospheric aerosol loading conditions would provide evidence to support this technology for the ground-based monitoring of pollutants.

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