Numerical Modeling of Polarization due to Rayleigh Scattering in the Earth's Atmosphere

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Motivation

In ground-based astronomy, incident light scattered throughout the Earth's atmosphere can contribute to errors in imaging. Knowing the degree and angle of linear polarization of locations in the sky due to atmospheric scattering is useful in filtering out this interference from the polarized light observed from bodies of interest. Polarimetry also has applications in meteorology, as understanding the polarization properties of the sky is useful in characterizing the atmosphere.

Background

The radiative transfer equations developed by Chandrasekhar [1] describe the intensity and degree of linear polarization from light transmitted via Rayleigh scattering using the Stokes parameters *I* which describes intensity, and *Q* and *U* which describe linearly polarized radiation. From these parameters, the degree of linear polarization (DoLP) and angle of polarization (AoLP) can be found using Equations 1 and 2 [2].

$$(1) \quad DoLP = \frac{\sqrt{Q^2 + U^2}}{I}$$

$$(2) \quad AoLP = \frac{tan^{-1}(\frac{U}{Q})}{2}$$

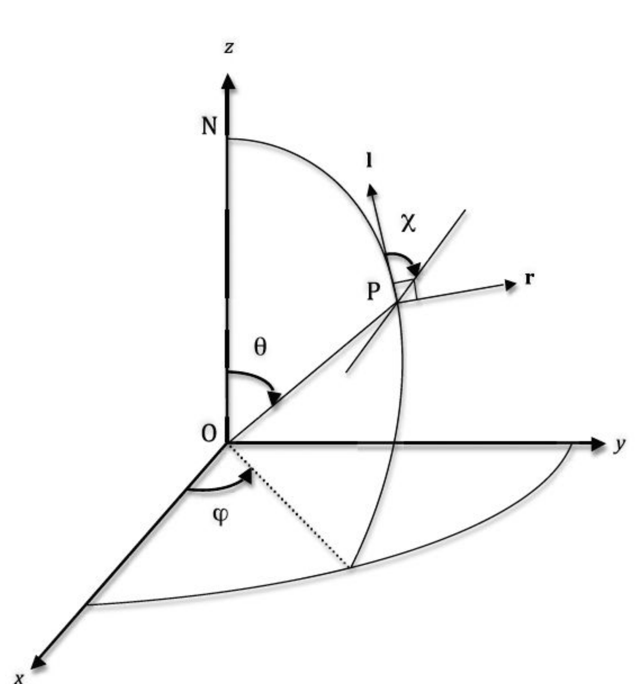

Fig 1: AoLP as defined in this context, not equivalent to position angle (PA) [4]

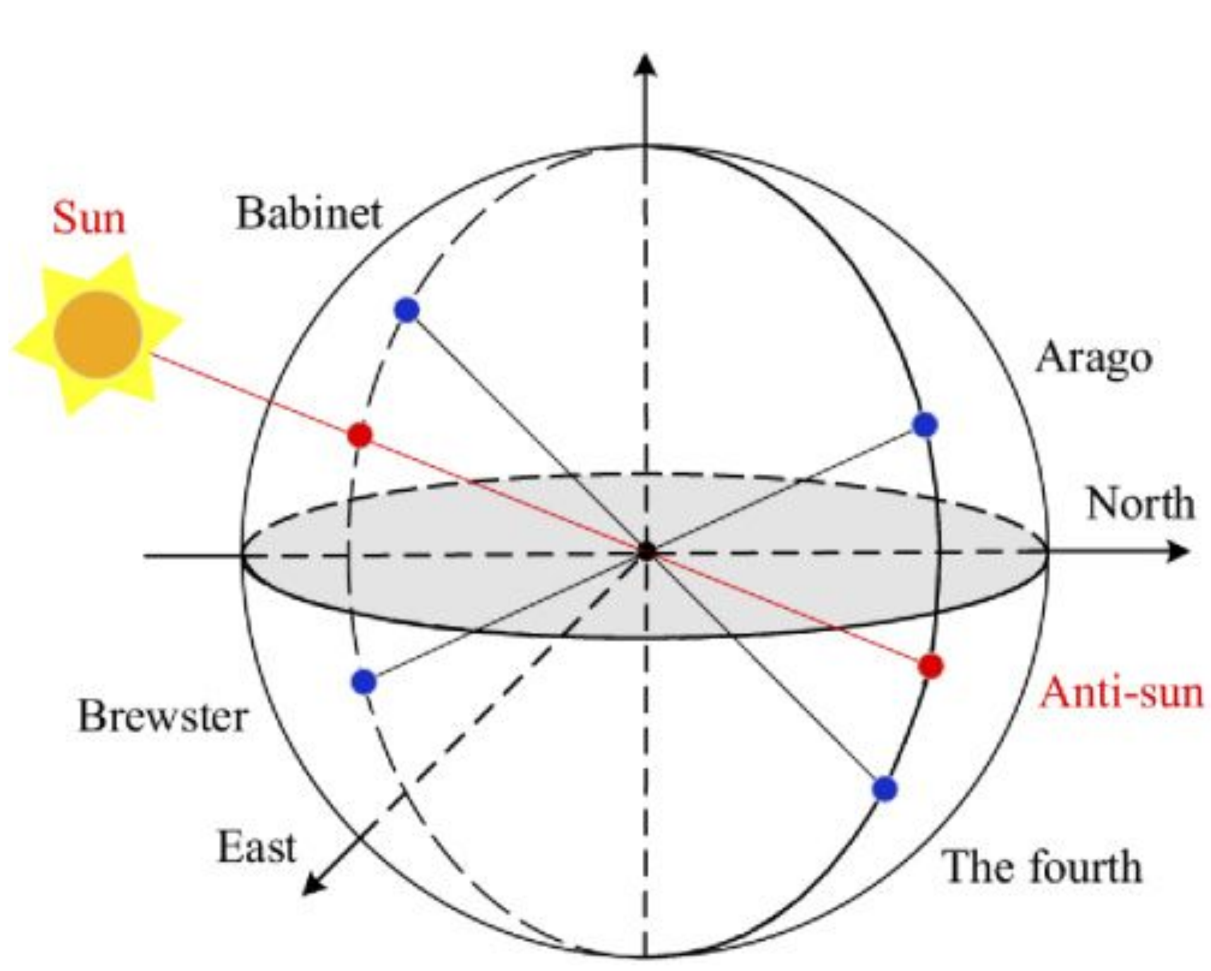

Fig 2: Neutral Points – locations at which DoLP = 0 – are marked in blue. [5]

Results

Maps of DoLP & AoLP

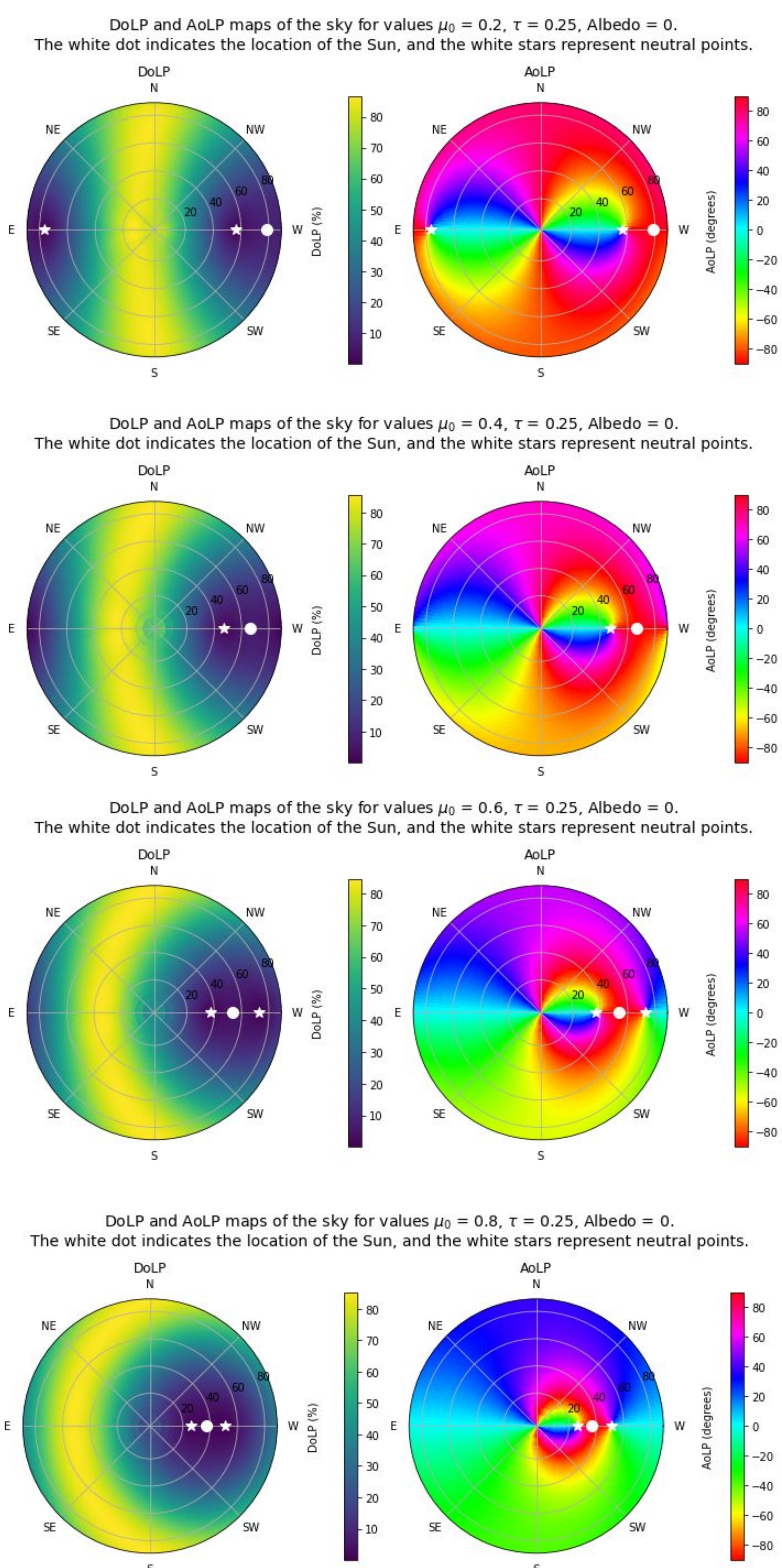

Fig 3: Sky maps of DoLP (left) and AoLP (right) values for different values of μ_0 with atmospheric conditions A = 0 and τ = 0.25.

Other Documentation

Scan the code below to see an animation of our DoLP map, or to download a digital version of this poster.

Methods

We used tabulated calculations [3] of the Stokes parameters I, Q, and U for various points in the sky described by terms μ and φ, which describe the cosine of the polar angle to the outward normal and the relative azimuth angle respectively. The values of the Stokes parameters at these locations vary for different atmospheric conditions of surface reflectance *A*, optical thickness τ, and direction of incident light μ_0.

With the Stokes parameters known, values of DoLP can be calculated for these points as well. We created a Python program to automate calculations of these values and cubic interpolations between them to generate maps of DoLP and AoLP values throughout the sky.

Conclusion

The produced maps of DoLP values display expected behavior of linearly polarized light as the Sun travels across the sky. Animations of this movement were also produced using imagemagick's "convert" tool. This program shows promise as an imaging tool for evaluating interference due to Rayleigh scattering.

Future Directions

- Generate maps displaying Position Angle, the definition of AoLP relevant to observational astronomy
- Use the source code made to generate the tabulated Stokes parameter values [2] for the purpose of more accurate interpolation
- After achieving improved interpolation, analyze behavior of neutral points as sun approaches zenith
- Compare with observed images from WHISPER team to further evaluate accuracy

References

1. Chandrasekhar, S. 1960, Radiative Transfer (New York: Dover).
2. Coulson, K. L., Dave, J. V., & Sekera, Z. 1960, Tables Related to Radiation Emerging from a Planetary Atmosphere with Rayleigh Scattering (Berkeley, CA: Univ. California Press).
3. Natraj, V., Li, K., & Yung, Y. L. 2009, ApJ, 691: 1909-1920.
4. Natraj, V. & Hovenier, J. W. 2012, ApJ 748:28.
5. Fa, Z., Wang, X., Jin, H., Wang, C., Pan, N., & Hua, D. 2021, Opt. Express Vol. 29: Issue 4, 5665-5676.