

## Achromatic Polarization Modulation

### Introduction

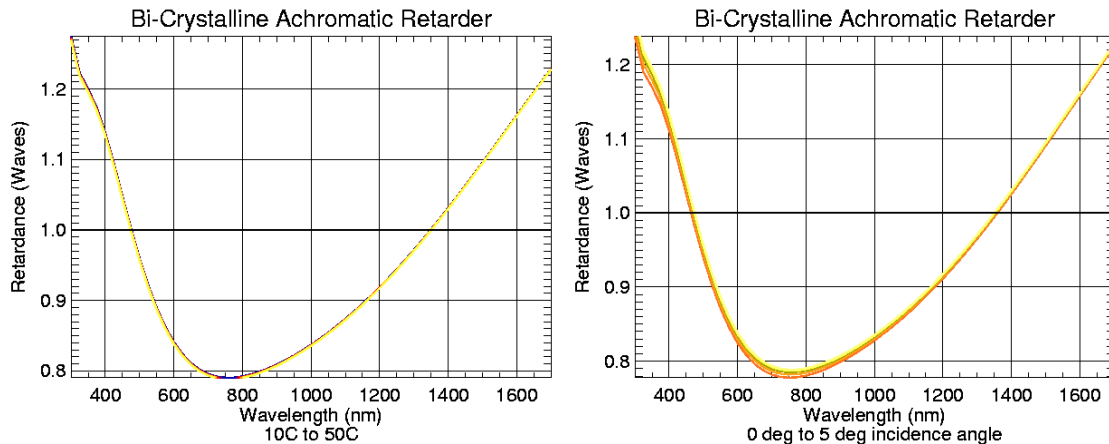
Design goals for the ATST Visible Spectro-Polarimeter call for wavelength diversity; polarimetry at multiple wavelengths simultaneously over the range of 300nm to 1700nm. Many techniques for polarization modulation are available, such as piezo-elastic modulators, ferro-electric liquid crystals, nematic liquid crystals, Pockel's cells, or rotating retarders. Some techniques span a small range of wavelengths, some can modulate well at specific divergent wavelengths simultaneously, but none can handle any arbitrary set of wavelengths simultaneously. If this wavelength diversity goal could be met, there would be an additional benefit by reducing the number of modulator types needed by ATST.

### Proposed modulator

An achromatic bi-crystalline rotating retarder can be designed for use at the Gregory focus of the ATST. The design uses two birefringent crystals. Crystal thickness is in the 2mm to 3mm range each. Size can be large, 50mm to 75mm diameter, ability to handle flux is high, temperature sensitivity is good, and field of view is good. A wavelength range from about 450nm to 1600nm can be modulated with reasonable efficiency using a single crystal pair. Extension for use from 300nm to 1700nm can be achieved through a Panchratnam configuration of three such crystal pairs.

### Performance

Retardance verses wavelength for a crystal pair is show in Figures 1 and 2. The design is optimized for two wavelengths, 475nm and 1350nm. Curves are shown relative to one wave, but could be relative to any fraction of a wave.



Figures 1 and 2. Achromatic bi-crystalline retardance verses wavelength for a single pair of crystals. Figure 1 shows temperatures of 10°C to 50°C. Figure 2 shows angles of incidence from 0° to 2.5°.

The largest concern is spectral fringing. The 2mm to 3mm thickness is small enough so that if used as two elements, spectral fringes are broader than most spectral lines. Extremely broad band anti-reflection coating is possible and could reduce fringing to about a percent. Another concern is use of a rotating retarder at the Gregory focus with the polarization analyzer at the coudé room and the time varying polarizing optics in between. Since there will be calibration optics at the Gregory focus (perhaps including an achromatic bicrystalline retarder), it will be possible to calibrate the polarimeter for all telescope geometries.

For a rotating retarder, 0.35 waves of retardance nicely balances modulation efficiencies for Q, U, and V. Missing that value by  $\pm 20\%$  compromises modulation efficiency for some Stokes parameters and some wavelengths. One solution is to optimize the retarder over a smaller wavelength range. Another is to use a Pancharatnam configuration. Figure 3 shows the polarimeter response matrix for a simple polarimeter consisting of a rotating 0.35 wave bi-crystalline retarder followed by a polarization analyzer, either single beam or dual beam. A dual beam Pancharatnam design is included.

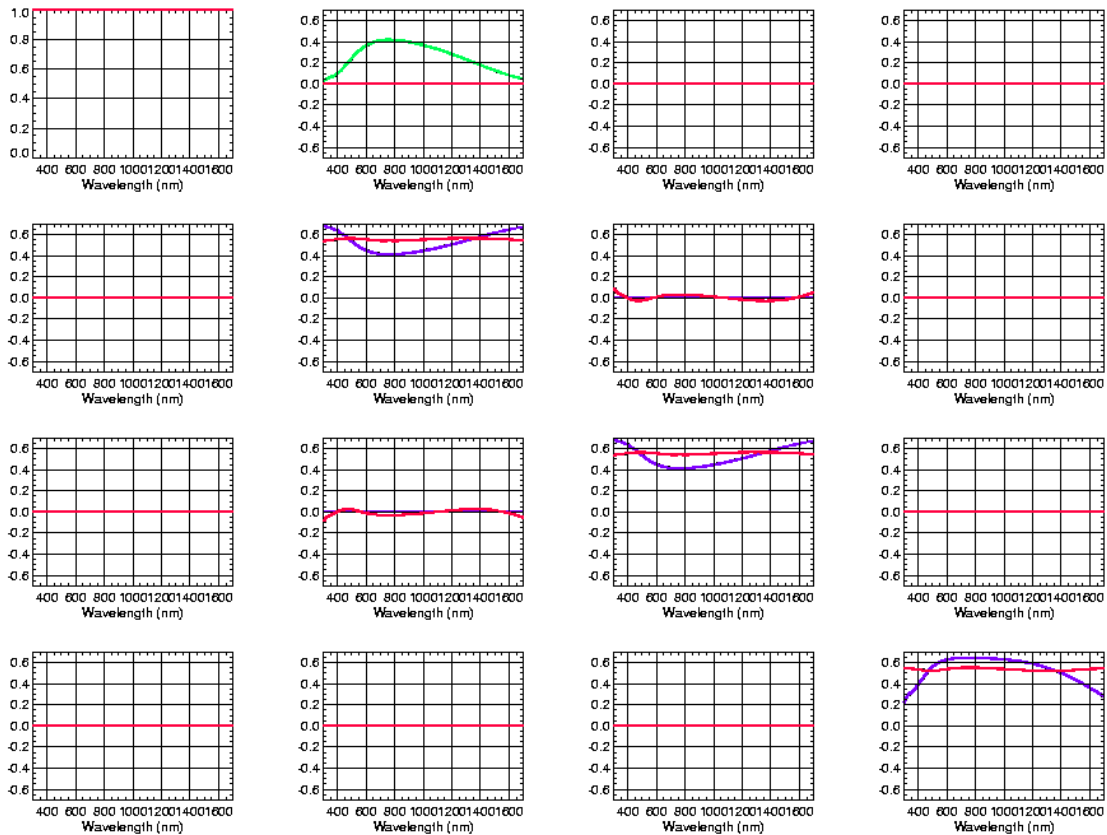


Figure 3. Polarimeter response matrix for rotating retarder. Red is for a Pancharatnam configuration of three bi-crystalline retarders. Blue is a dual beam with for a single bi-crystalline retarder, and green is single beam for a single bi-crystalline retarder.

***Discussion***

The modulation rate could be high so that benefits of a charge caching detector could be realized. It would also be possible to put ferro-electric liquid crystals before the polarization analyzers for various wavelengths to encode polarization in only four modulation states. Traditional CCD cameras could be accommodated with a slower rotation rate. In conclusion, it is possible to achieve the goal of spectro-polarimetry and wavelength diversity for an arbitrary set of lines between 300nm and 1700nm using a rotating bi-crystalline achromatic retarder.

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