Outline

1. Liquid Crystal Polarimeters
2. SOLIS VSM
3. S5T

Introduction

- many systems in operation
- variety of liquid crystyal types and arrangements
- often combinations of variable liquid crystal retarders and fixed retarders
- example: circular polarimeter with nematic liquid crystal
- example: circular polarimeter with ferro-electric liquid crystal

Liquid Crystal Polarimeters

Introduction

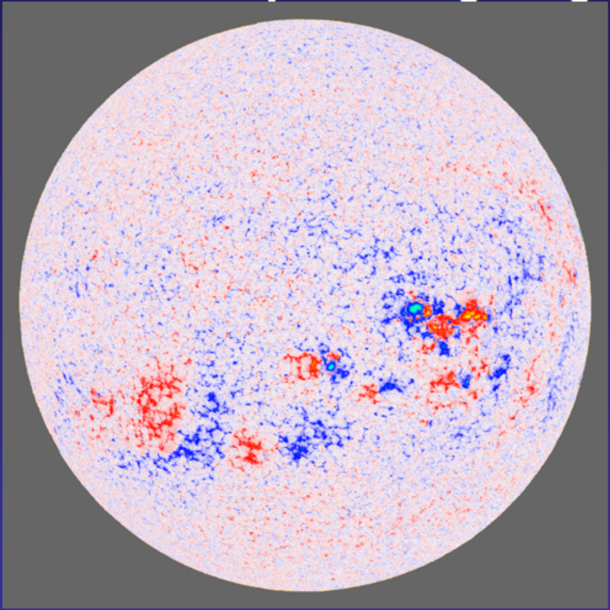
- no moving parts
- nematic liquid crystals
  - change retardance with applied electric field
  - relatively slow (<50 Hz)
  - electrically tunable for different wavelengths
- ferro-electric liquid crystals
  - flip fast axis orientation with applied electric field (2 states only)
  - fast (<10 kHz)
  - fixed retardation and optimum wavelength
- often combinations of variable liquid crystal retarders and fixed retarders

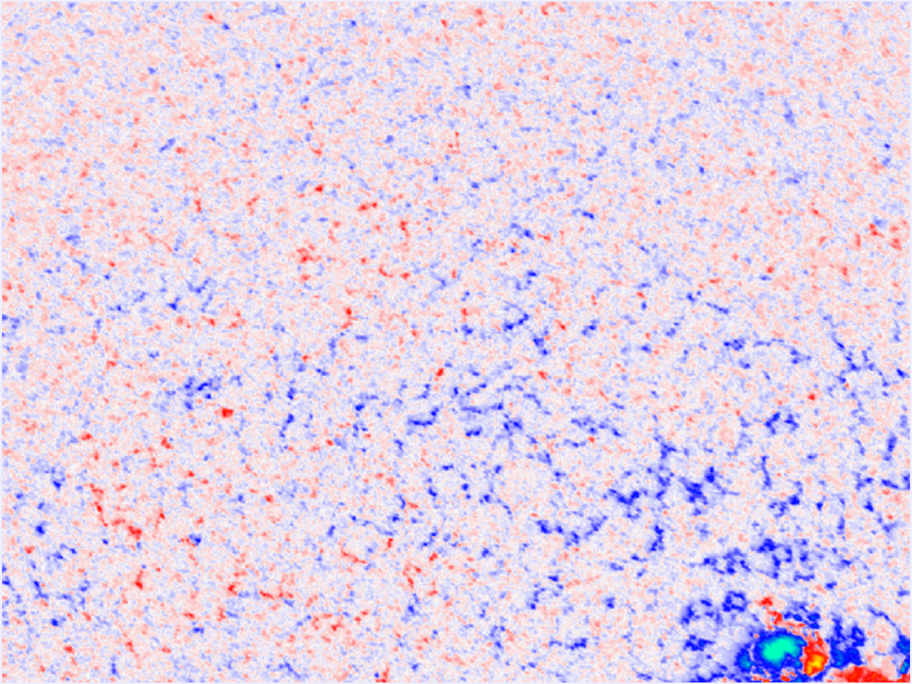
SOLIS Vector-Spectromagnetograph (VSM)

Introduction

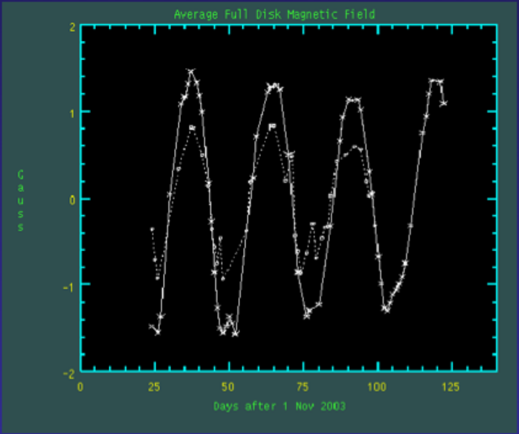
- SOLIS = Synoptic Optical Long-term Investigations of the Sun
- 3 instruments: Vector SpectroMagnetograph, Full-Disk Patrol, and Integrated Sunlight Spectrometersun-as-a-star spectrometer) attached to single equatorial mount
- located on top of old Kitt Peak Vacuum Telescope
- solis.nso.edu
- VSM operates in four different observing modes at three different wavelengths:
  1. photospheric full-disk longitudinal magnetograms in FeI 630.15 and 630.25 nm
  2. photospheric full-disk vector-magnetograms in FeI 630.15 and FeI 630.25 nm
  3. chromospheric full-disk magnetograms in CaII 854.2 nm
  4. full-disk HeI 1083.0 nm line characteristics

Full-Disk Photospheric Magnetogram

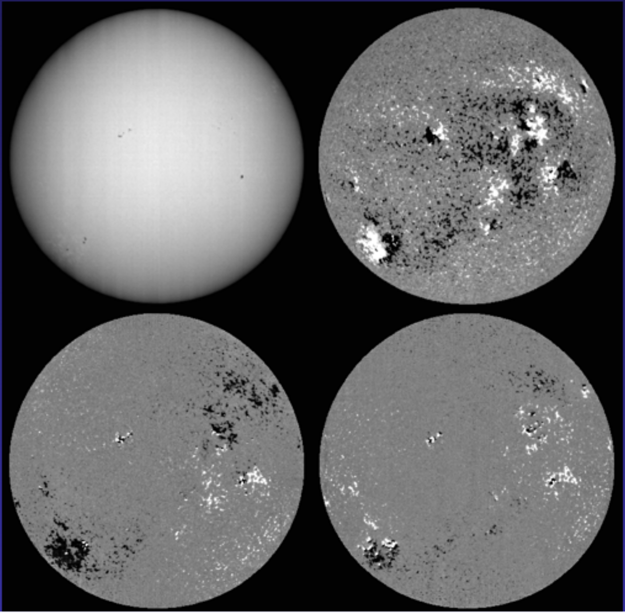




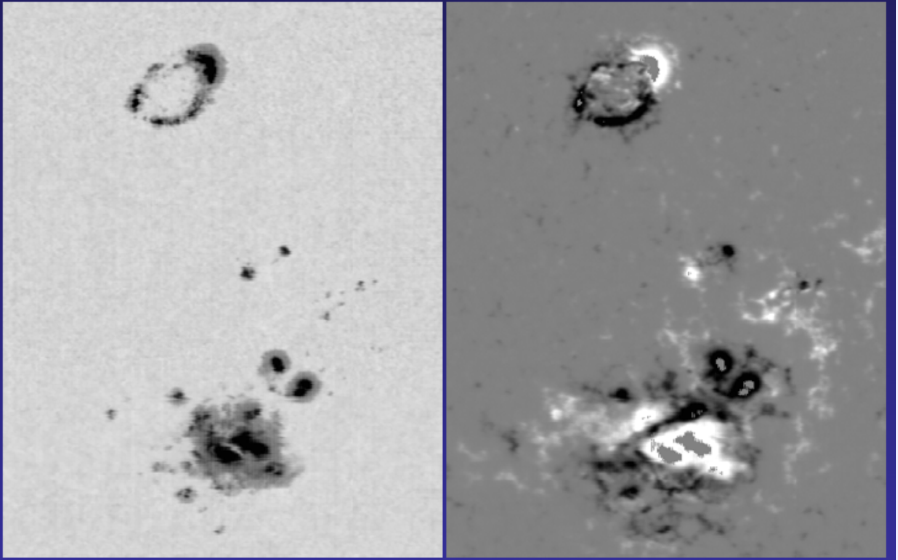
Sun-as-a-Star Magnetic Field



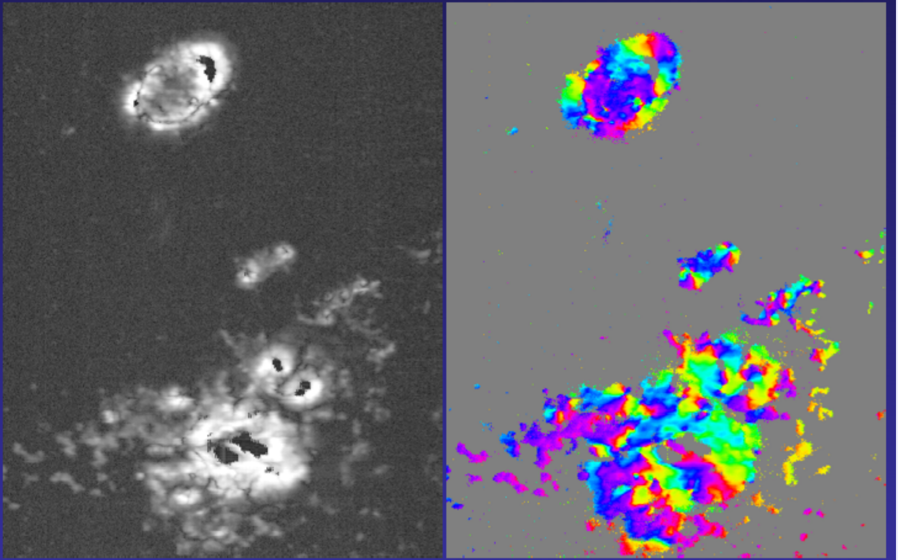
Full-Disk Vector-Polarimetry



More Vector-Polarimetry



More Vector-Polarimetry



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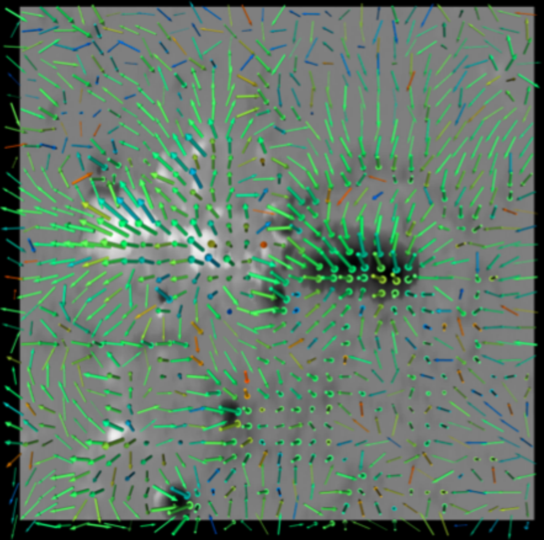
Field Vector, Filling Factor, and Helicity

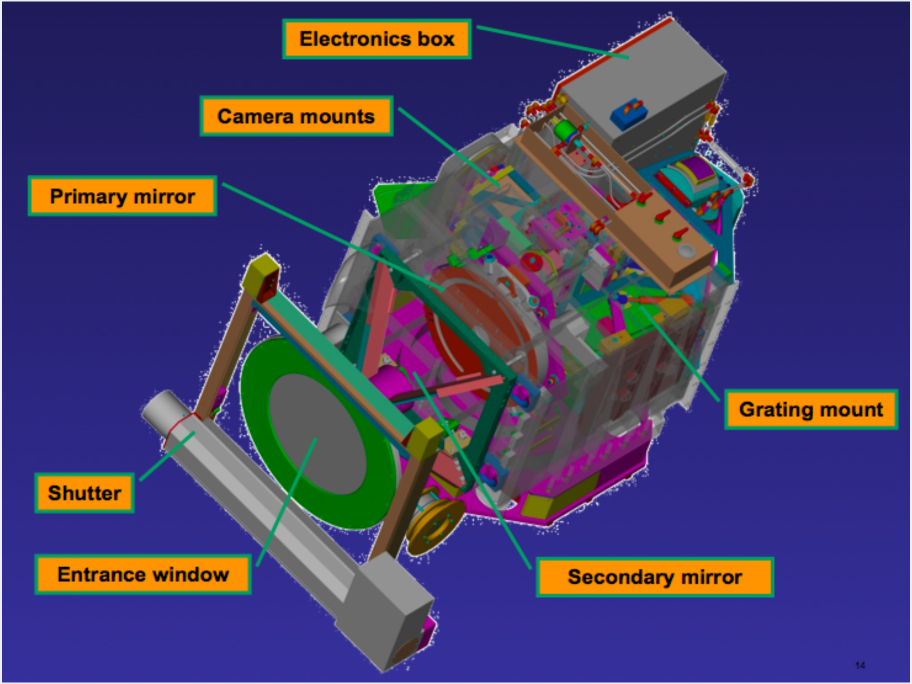


Specifications

Parameter	Specification
Effective pixel size	1 arcsec by 1 arcsec (1.125 by 1.125 arcsec initially)
Angular coverage	2048 arcsec by 2048 arcsec
Geometric accuracy	0.5 arcsec rms after data reduction
Scan rate	0.2 to 5.0 seconds/arcsec
Timing accuracy	Better than 1 second
Time stamping	Better than 1 ms
Spectral resolution	238,000 (at 630 nm)
Wavelengths	630 nm, 854 nm, 1083 nm
Polarimetry	• FeI 630.15 and FeI 630.25 nm: I,V,Q,U • CaII 854 nm: I,V • HeI 1083.0 nm: I
Polarimetric sensitivity	0.0002 at 0.5 seconds/arcsec scanning rate
Polarimetric accuracy	Better than 0.001

Technical Challenges

Challenge	Solution
Compact instrument no longer than 2.5 m	**Folded f/6.6 beam**
Good and stable spatial resolution	**Helium-filled, active M2**
High guiding accuracy of better than 0.5 arcsec rms	**Guider in slit plane, active secondary mirror**
Low instrumental polarization of less than $1 \cdot 10^{-3}$	**Axially symmetric design**
Fixed image size, low distortion from 630 to 1090 nm	**Quasi RC with correctors**
Stable high spectral resolution of 200,000	**Large, active grating**
Highest possible throughput	**Silver, multilayer coatings, CMOS hybrid cameras**
Energy densities of up to 0.2 MW/m^2	**Copper-silicon carbide plate**
High data rate of up to 320 Mbyte/s	**DSP array, Storage Area Network**


Electronics box
Camera mounts
Primary mirror
Grating mount
Shutter
Entrance window
Secondary mirror
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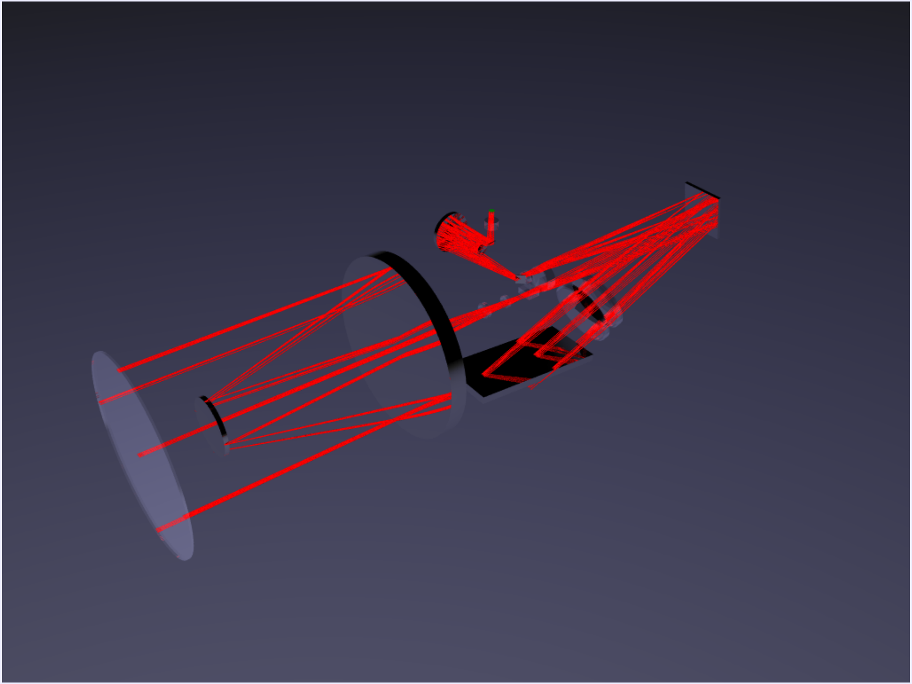
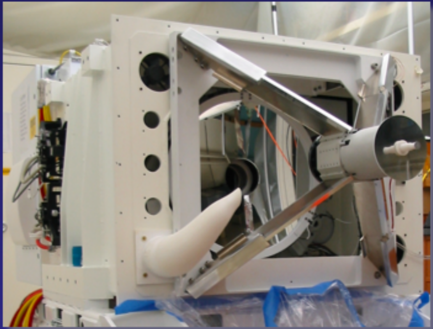
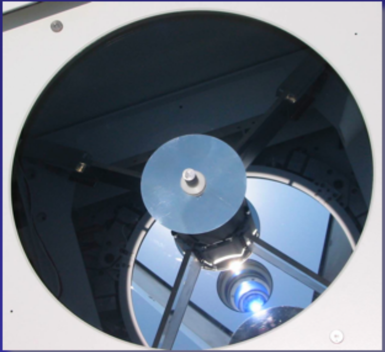


Telescope

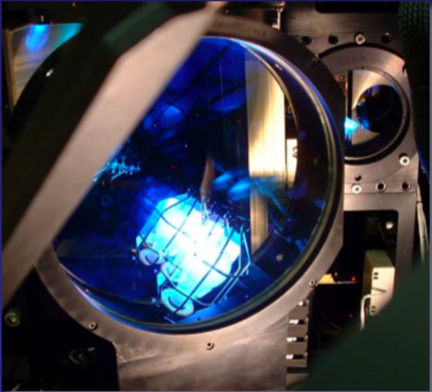
- Helium-filled f/6.6 Ritchey-Chrétien with field corrector lenses
- Entrance window provides environmental protection
  - 6-mm thick oversized, fused silica to minimize edge effects
  - ‘Floats’ in RTV to minimize stress birefringence





- 575-mm f/1.4 ULE primary mirror
- Single crystal silicon secondary
  - 40 Hz tip/tilt closed-loop bandwidth piezo platform
  - Slow closed-loop focus control
  - Cooled by helium flow

Folded Littrow Spectrograph

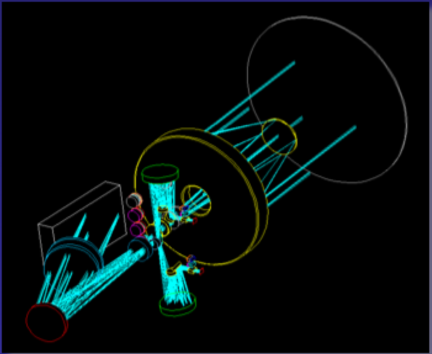


Grating

- 79 lines/mm on 204 mm by 408 mm fused silica blank
- Almost no instrumental polarization
- Rotates for different wavelengths
- Active adjustment in 2 axes to compensate for flexure

Littrow lens

- Air-spaced doublet
- Athermal design
- Moves to adjust for different wavelengths
- Dual Offner reimaging optics



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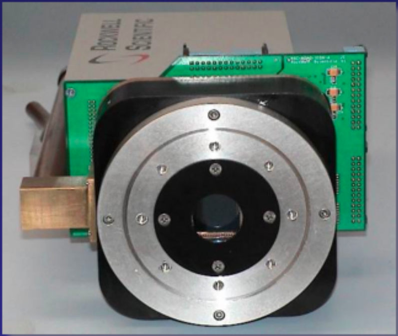
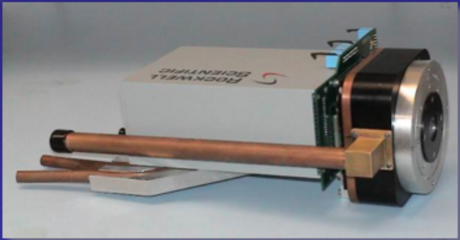
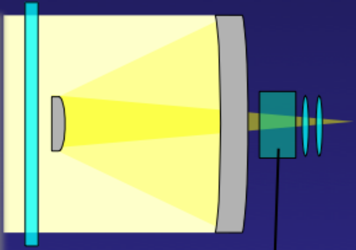
CMOS Hybrid Cameras



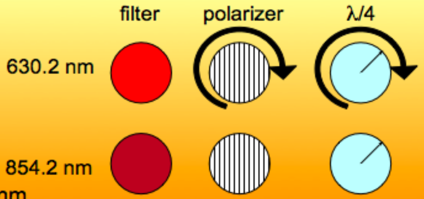
- Interim replacement for cancelled PixelVision & SITe CCD cameras
- Made by Rockwell Scientific
- 1024 by 1024 18 μm pixels
- 92 frames/s at 1024 by 256
- > 2,000,000 e- full well depth
- Silicon on CMOS multiplexer
- Quantum efficiency 85% at 630 and 854 nm, 5% at 1083 nm



Polarization Calibration



- 'Polarization-free' optics before polarization calibration
- Polarization calibration occurs as early as possible
- interference filters to limit solar flux
- rotating polarizers and retarders at 630 nm, fixed at 854 nm



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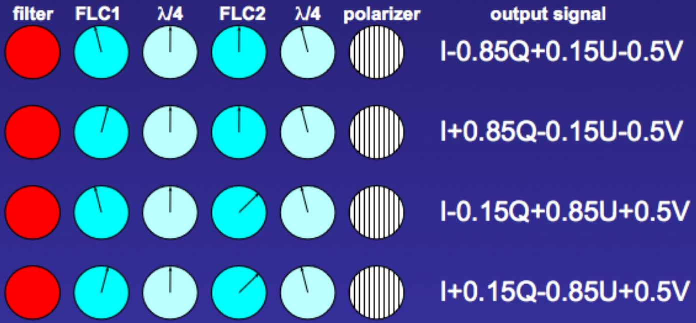
Polarization Modulation

- Ferroelectric liquid crystal (FLC) variable retarders (all λ/2 at 630 nm)
- Fixed λ/4 (at 630 nm) and λ/6 (at 854 nm) polymer retarders
- All true zero-order retarders to cope with fast f/6.6 beam
- Full vector modulation similar to Gandorfer and Rabin schemes
- Exact position angles optimized based on measured FLC properties
- After modulation, both polarization states pass the same low-polarization optics
- Solar-B spectropolarimeter and Diffraction-Limited Spectro-Polarimeter (DLSP) at Dunn Solar Telescope are based on VSM concept



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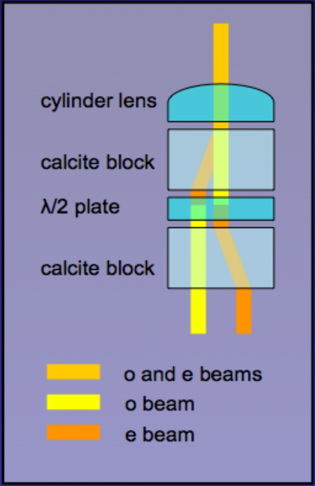
Polarization Analysis



- Modified Savart plate
- Crystal astigmatism is a major issue for an f/6.6 beam, corrected by cylinder lens
- Provides high quality polarizing beam-splitting for fast beam and large field of view
- Different beamsplitters for 630.2 nm and 854.2 nm
  - Calcite splitting is wavelength dependent
  - Can use simple mica retarder

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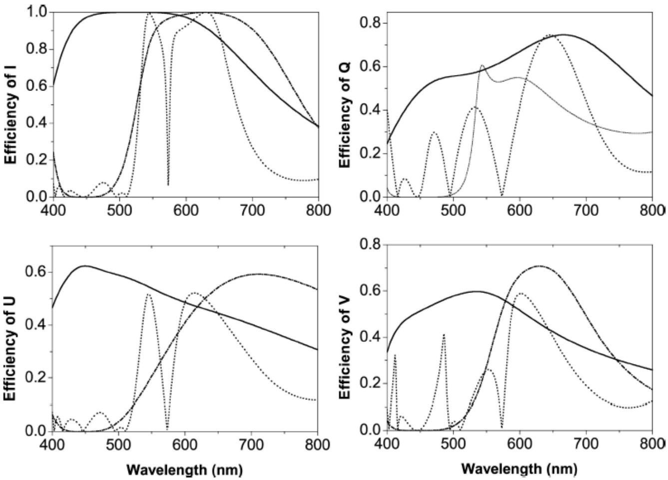
Separation of Polarization Modulation and Polarizer

- FLC and retarders located behind spectrograph entrance slit
- polarizing beamsplitters located in front of cameras
- spectrograph and associated optics built to minimize instrumental polarization between modulators and polarizing beam splitters
- advantages of VSM approach: no moving parts for polarization analysis, switching of polarization states can occur rapidly, and both polarization states are detected simultaneously after having passed through the same optics

Instrumental Polarization

- only entrance window, primary and secondary mirrors not calibrated
- all other optical elements after polarization calibration optics
- still try to minimize polarization introduced because coupling of instrumental polarization and non-linearities camera read-out electronics are difficult to calibrate
- static birefringence of window due to remaining stress from the annealing process, measured at less than 2 nm
- telescope design is axially symmetric and therefore 'polarization free', but symmetry only valid optical axis
- simulation at 0.25° (solar limb) shows I to Q cross talk of $4 \cdot 10^{-5}$ and a V to Q cross talk of $8 \cdot 10^{-5}$

Achromatic Liquid-Crystal Polarimeter



- Yunnan Liquid crystal Polarimeter

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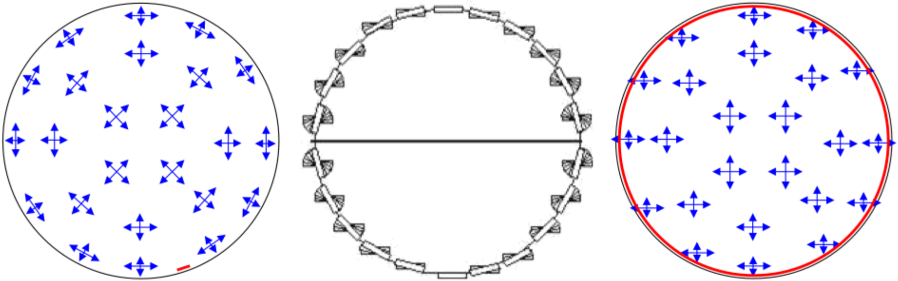
Properties

- Small Synoptic Second Solar Spectrum Telescope
- daily scattering polarization observations
- 420-465 nm
- 18 fibers around limb
- 10^{-5} polarization sensitivity
- 1% stability (>10 yrs)
- VPH-grating spectrograph
- high-speed 8196 by 96 pixel CCD camera
- located on SOLIS Mount, Kitt Peak, USA

Theta Cell



- Large aperture telescope.
- Large magnification.

- Small aperture telescope.
- Small magnification.