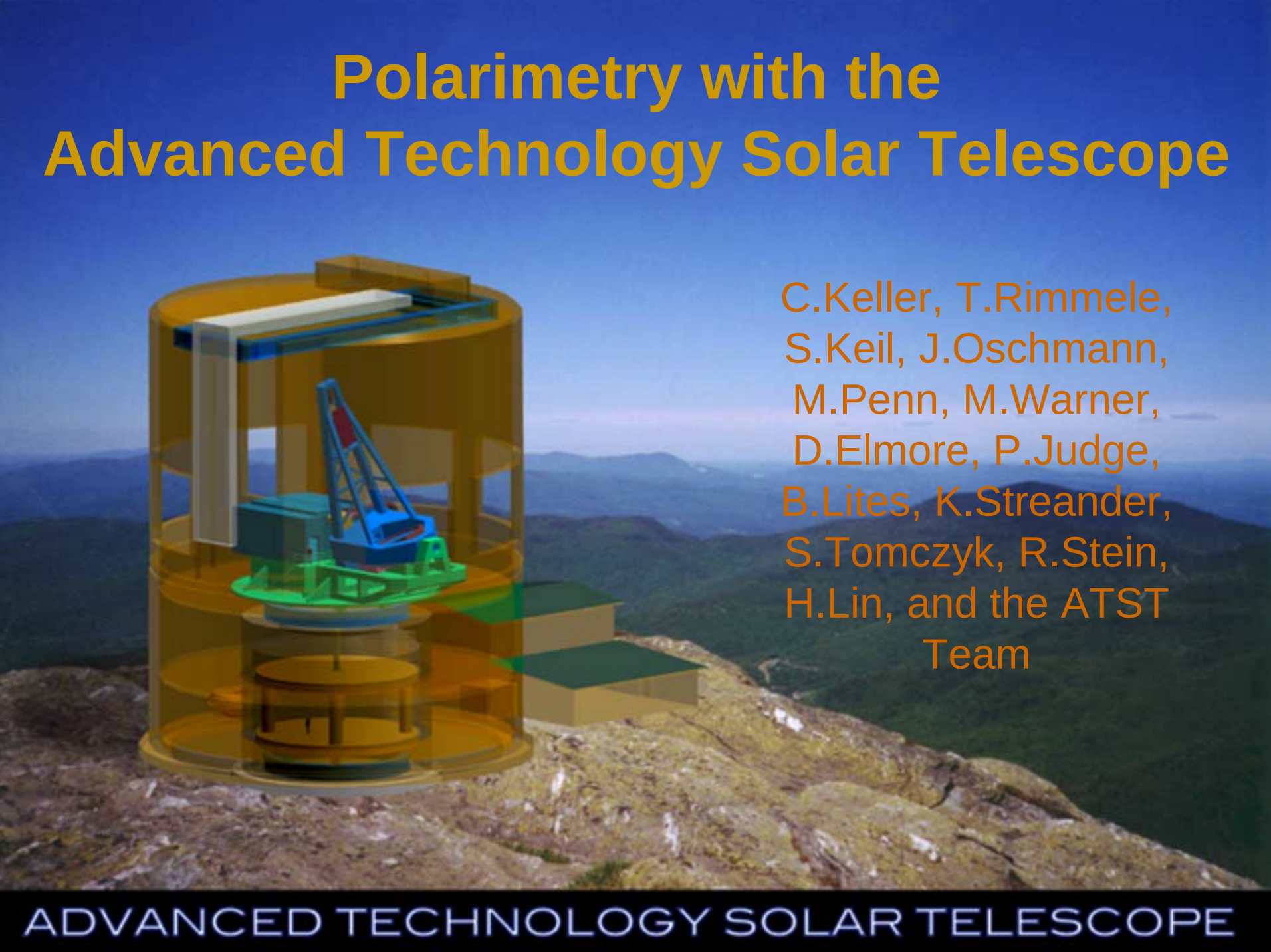
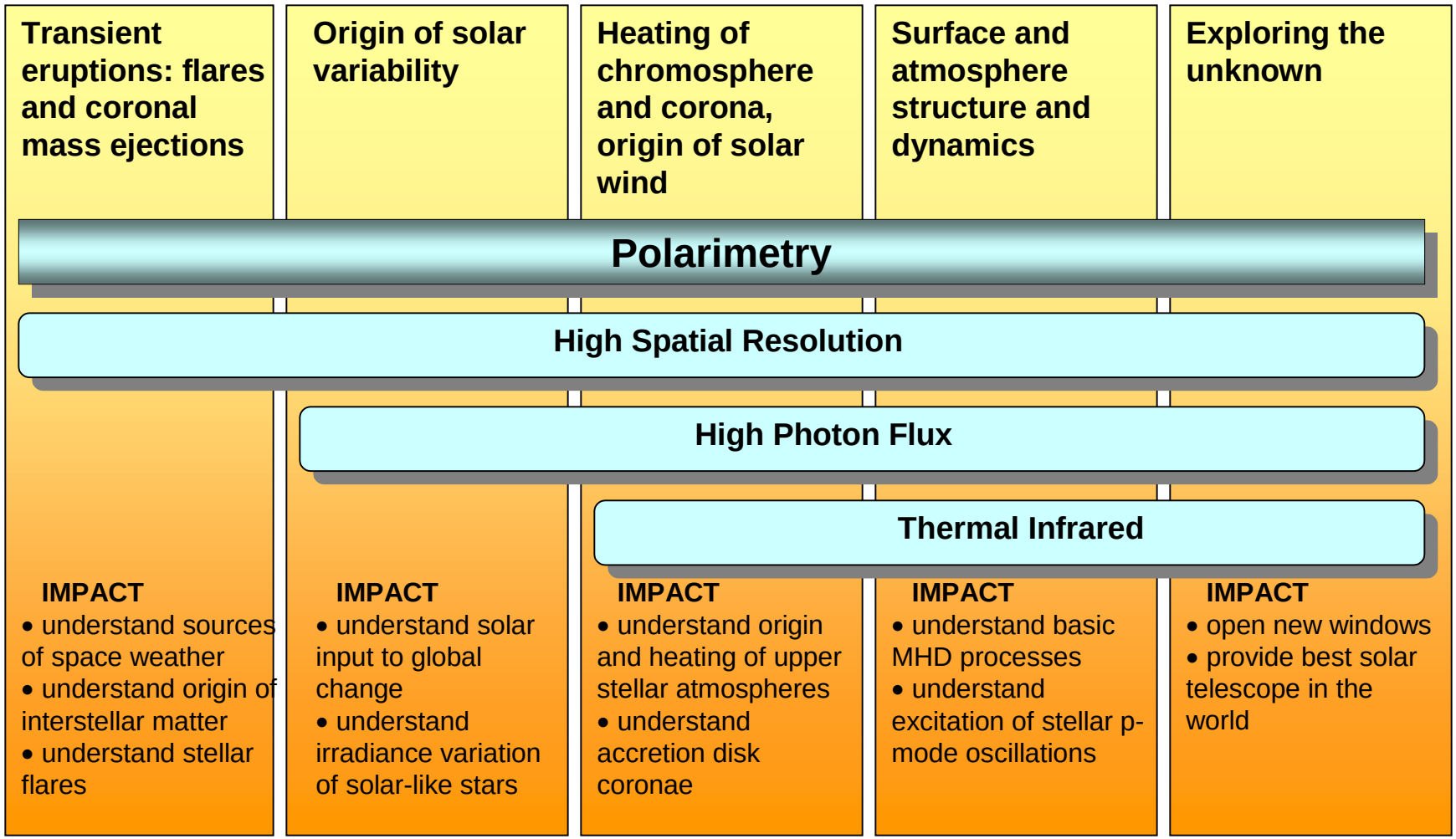
Polarimetry with the Advanced Technology Solar Telescope



C.Keller, T.Rimmele, S.Keil, J.Oschmann, M.Penn, M.Warner, D.Elmore, P.Judge, B.Lites, K.Streander, S.Tomczyk, R.Stein, H.Lin, and the ATST Team

ADVANCED TECHNOLOGY SOLAR TELESCOPE

ATST Science Overview

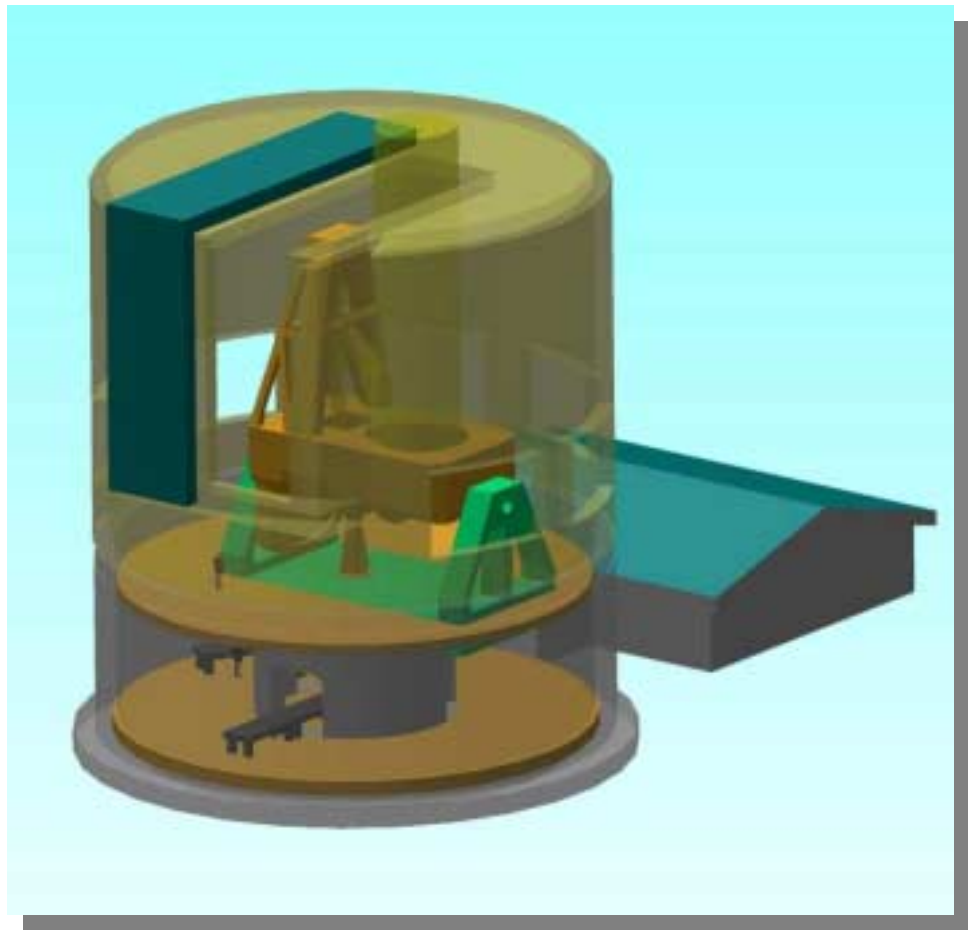


Telescope Requirements

Parameter	Requirement
Aperture	4 m
Spatial Resolution	diffraction limited within isoplanatic patch (over >2 arcmin after MCAO upgrade)
Adaptive Optics	Strehl ratio: >0.3 (goal of > 0.5 during good seeing)
Fielf-Of-View	3 arcmin (goal of 5 arcmin)
Wavelength Coverage	300 nm - 28 μm
Polarization Sensitivity	10^{-5}
Scattered Light	< 1% (10-20”) of continuum intensity $< 10^{-5}$ at R = 1.1 (at IR wavelengths)
Coronagraph	in the NIR and IR
Flexibility	e.g., combine various post-focus instruments
Adaptability	e.g., try out new ideas, bring your own instrument

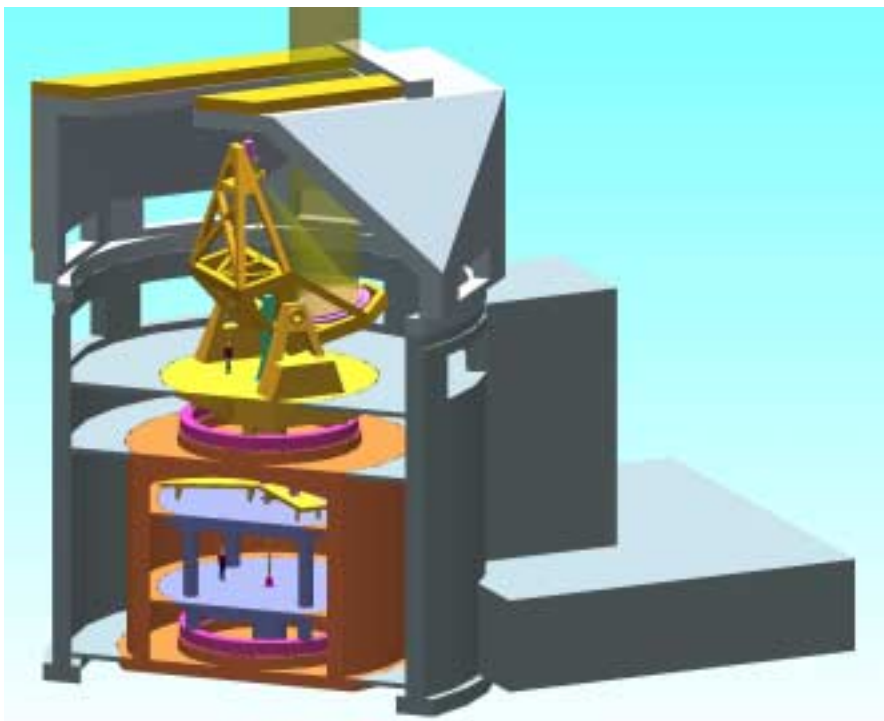
Baseline Concept

- 4-m Gregorian Off-Axis
  - Unobstructed Aperture
  - Clean PSF
  - Scattered light control
  - IR Emmisivity
  - Easy access to prime focus, heat stop, secondary
  - Internal seeing control easier
- Alt-Az mount
  - Design heritage: least risk and cost
  - Gravity vector changes in only one plane
  - Equatorial is about 20% more expensive
- Conventional adaptive optics (but plan for MCAO upgrade)
- Internal seeing control
- Contamination control

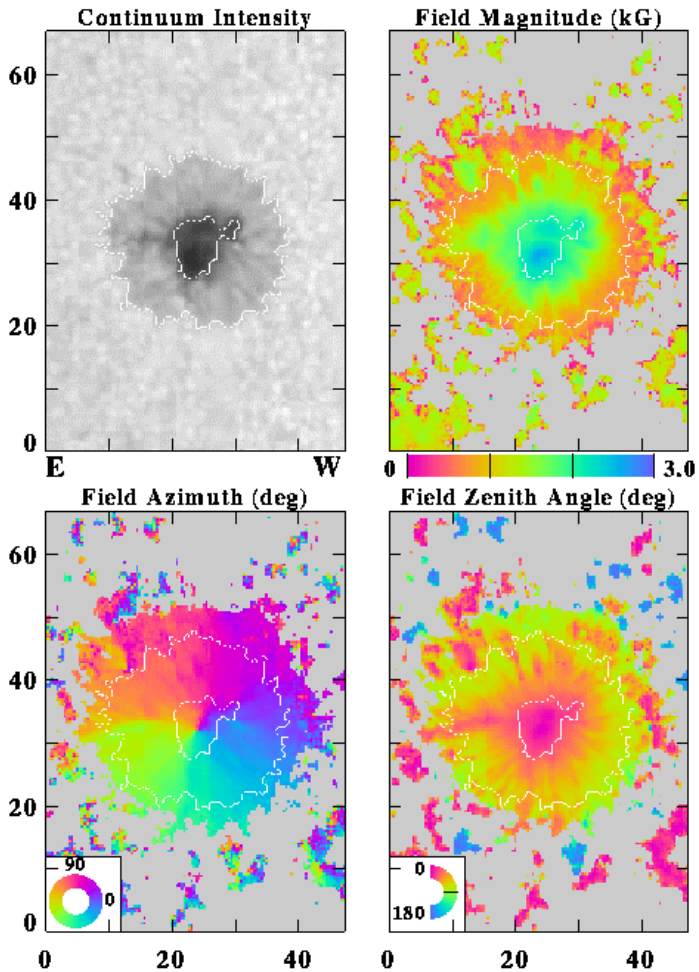


ATST Polarimetry

- ATST will be the premier facility for ground-based solar polarimetry from 0.35 to 28 μm at a resolution down to 0.025 arcsec (at 500 nm)
- 4-m aperture will provide large photon flux to enable very sensitive polarization measurements



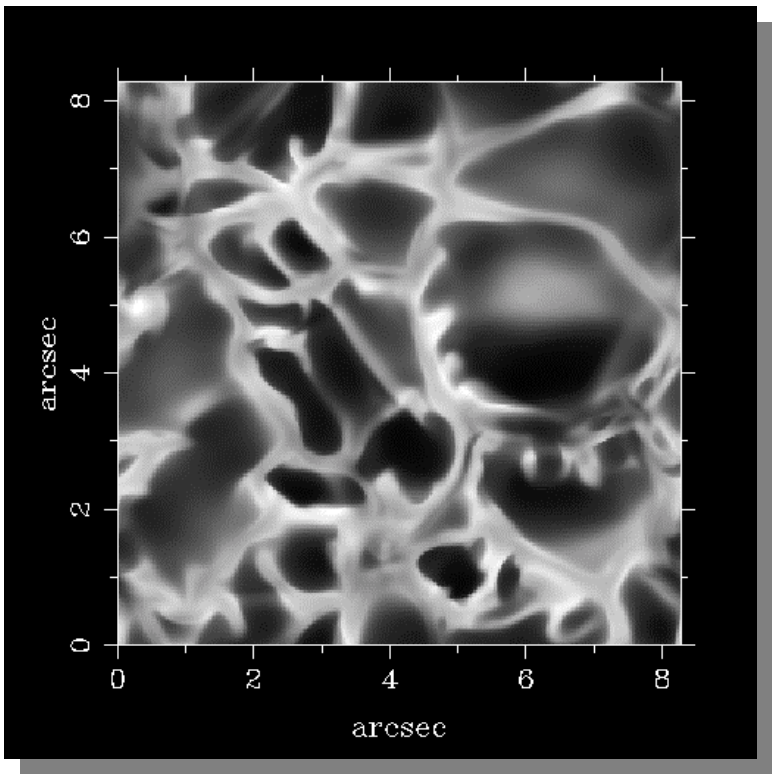
High Photon Flux



Data courtesy Bruce Lites and ASP team

- 20mÅ spectral resolution, SNR of 2000 in polarized Stokes parameters, 10% efficiency (optimistic), 5 spatial positions, 600 nm
- need 5 minutes at diffraction limit (independent of aperture) ➔ unacceptable
- evolution at scales of 0.1 arcsec within 15 s
- need at least 4-m telescope to achieve SNR of 2000 within 15 s at 0.1 arcsec resolution
- Most polarimetry with ATST will not be performed at the diffraction limit

What Would ATST Do?



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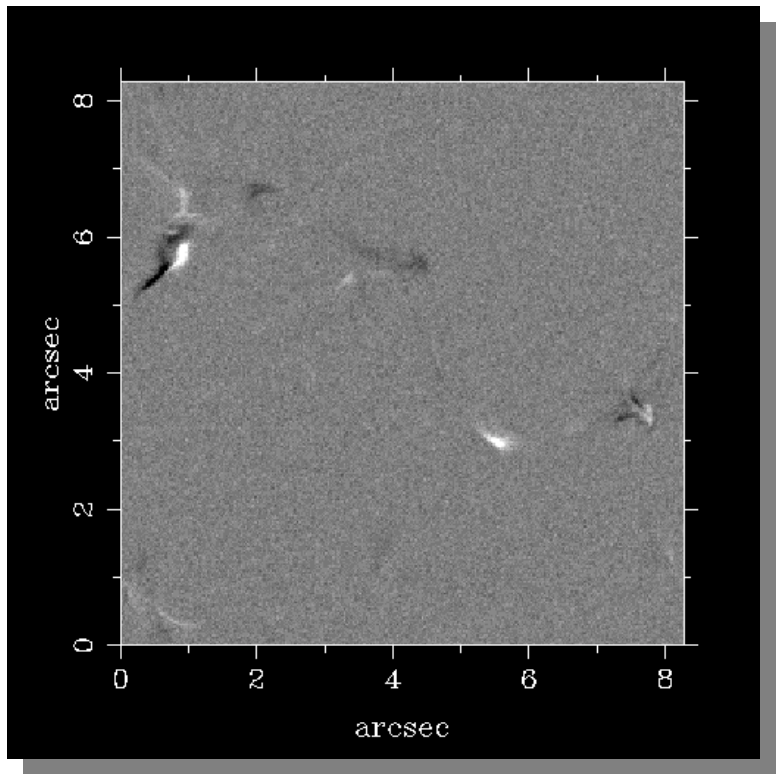
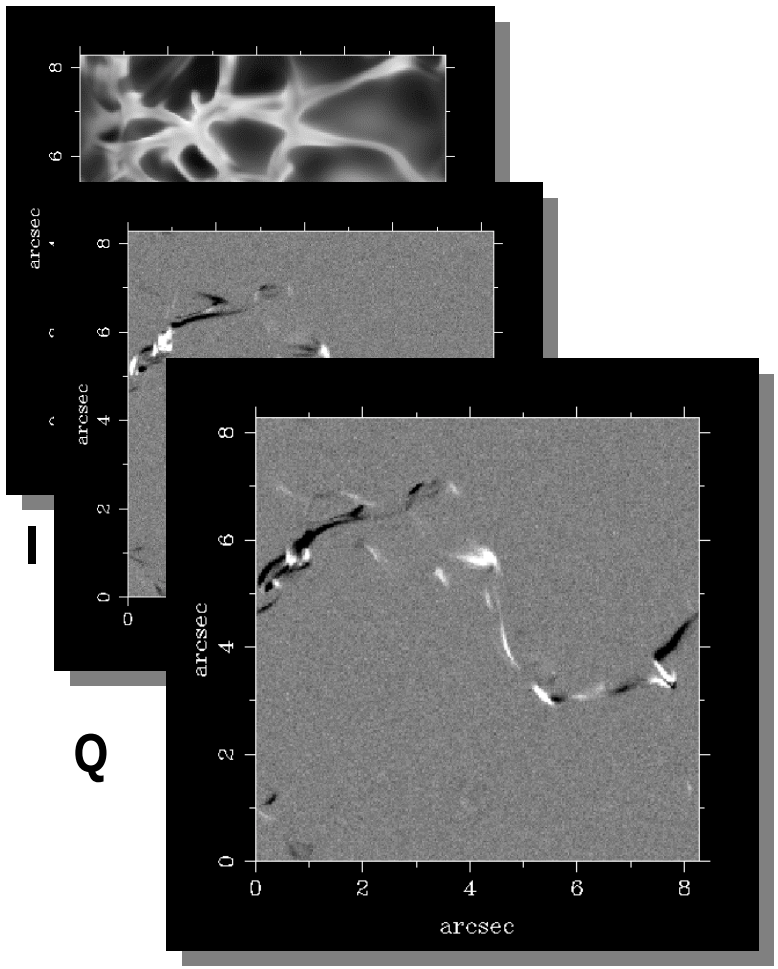
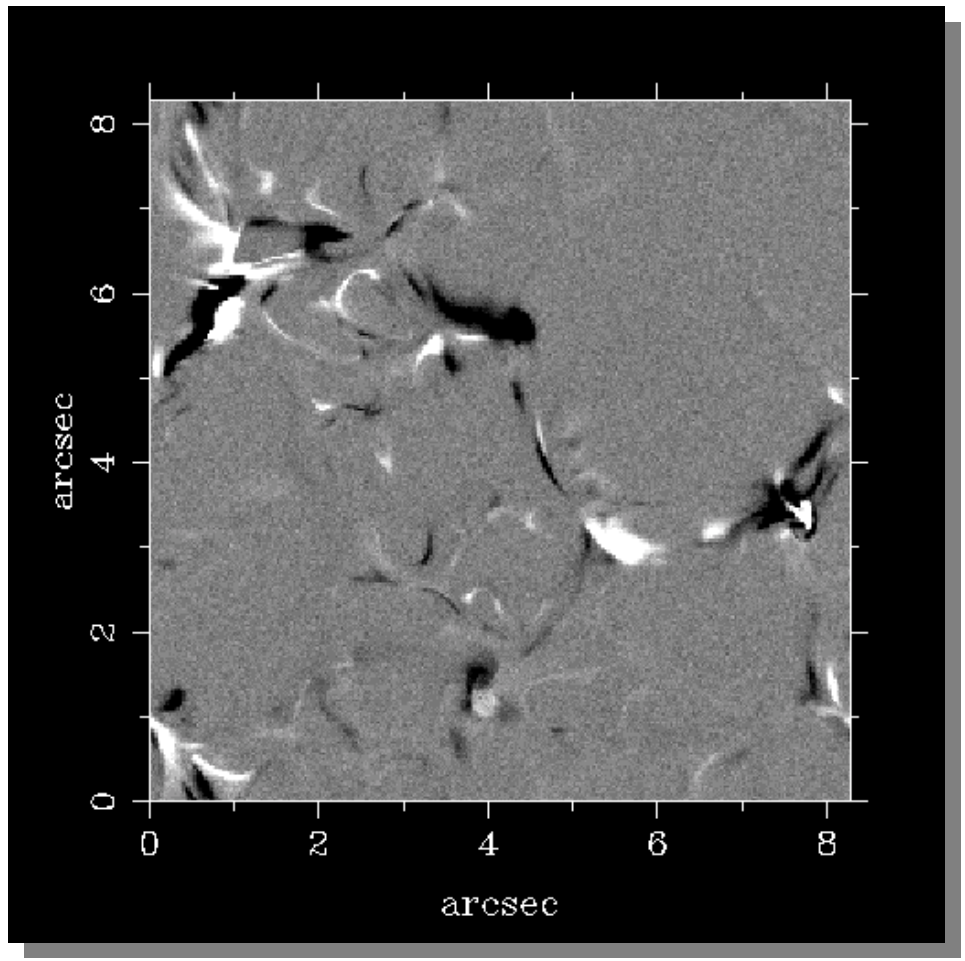


V

- Assume 10% total efficiency, 4-m aperture, no diffraction, no seeing, tunable filter with 2.2 pm rectangular filter profile, 1-second exposure time
- For 2.5 Mx/cm^2 rms fields (Stein & Nordlund simulation), no Q/U detectable
- For 25 Mx/cm^2 (fudge factor of 10), all four Stokes parameters show signals

Tunable Filter Simulation





ATST Polarimetry Requirements

- Polarization sensitivity: amount of fractional polarization that can be detected above a (spatially and/or spectrally) constant background. It refers to a relative measurement. ATST sensitivity requirement: 10^{-5}
- Polarization accuracy: absolute error in measured fractional polarization, an absolute measurement. ATST accuracy requirement: $5 \cdot 10^{-4}$
- Instrumental polarization requirements:
  - **<** 1% instrumentally induced polarization at all wavelengths and all points in FOV before polarization modulation
  - Instrumental polarization calibration: should be known to an accuracy of at least $5 \cdot 10^{-4}$
  - Instrumental polarization stability: change no more than $5 \cdot 10^{-4}$ within 15 min

Off-Axis Instrumental Polarization

- Mueller matrix for f/2 primary, f/30 Gregorian at 600 nm, simple aluminum coating:

$$\begin{pmatrix} 1.0 & 0.004472 & 0.0 & 0.0 \\ 0.004472 & 0.999998 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.998424 & 0.049914 \\ 0.0 & 0.0 & -0.049915 & 0.998422 \end{pmatrix}$$

- Cross-talk and instrumentally induced polarization need to be corrected for
- For alt-az mount, instrumental polarization rotates with respect to image
- How do we measure it?
- How do we compensate for it?

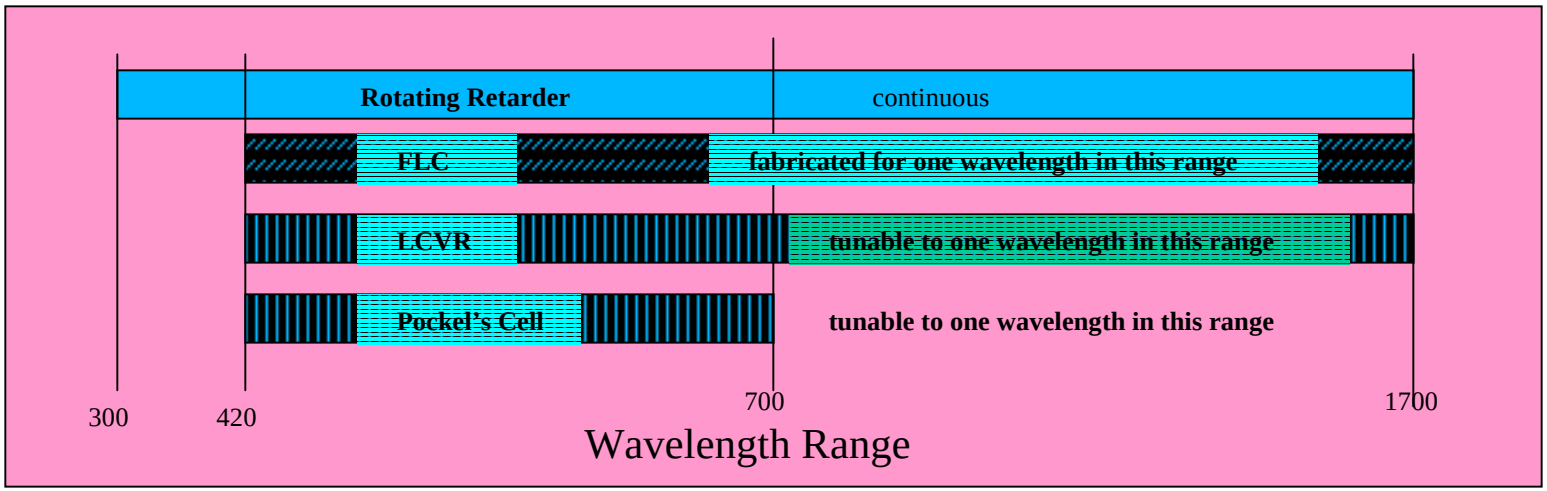
Instruments from Building Blocks

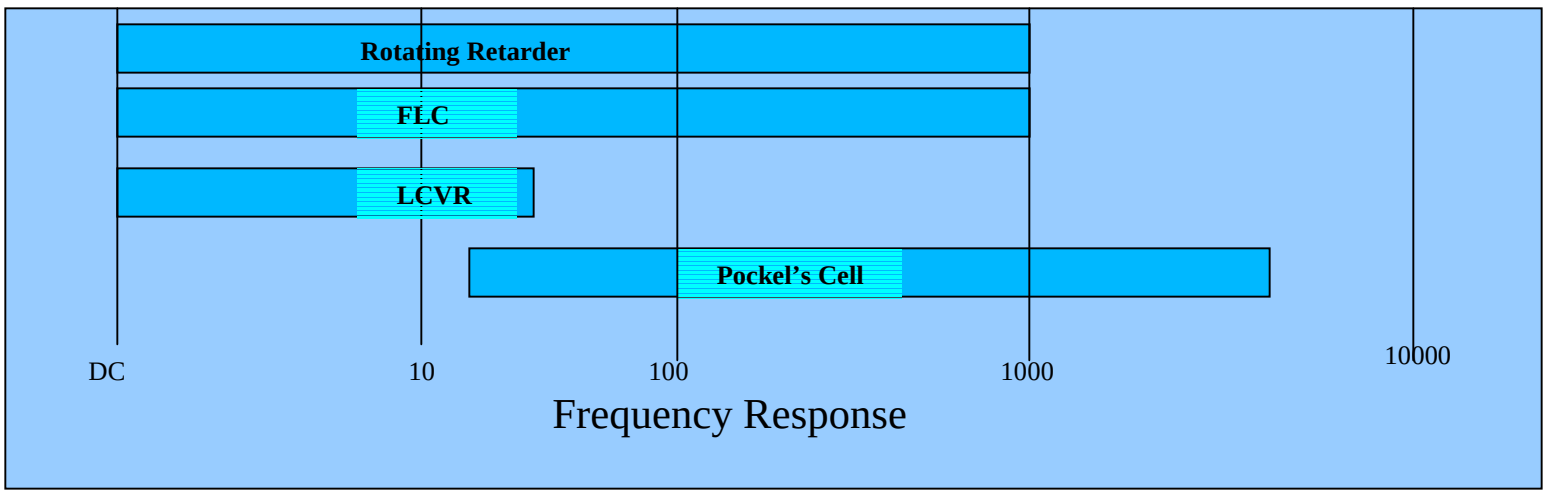
Instrument	Fore-Optics	Dispersing System	Detector
Broad-band imager		Interference Filters	Visible
Visible Spectro-Polarimeter	Visible Polarization Analyzer	Medium-dispersion spectrograph	Visible or Special
NIR Spectro-Polarimeter	NIR Polarization Analyzer	Medium-dispersion spectrograph	NIR
Visible Tunable Filter	Visible Polarization Analyzer	Visible Tunable Filter	Visible
NIR Tunable Filter	NIR Polarization Analyzer	NIR Tunable Filter	NIR
Thermal IR Spectrograph	Thermal IR Polarization Analyzer	Thermal IR Spectrograph	Thermal IR
Visible/NIR High-Resolution Spectrograph		Visible/NIR high-resolution spectrograph	Visible/NIR

Polarimeters for ATST

- Visible Spectro-Polarimeter (ViSP)
  - 380 to 900 nm
  - 0.05 arcsec resolution in normal mode, 0.025 arcsec in high-resolution mode
  - Rapid modulation (500 Hz)
  - At least 3 wavelength bands simultaneously
  - Works together with NIRSP
  - Led by HAO (Steve Tomczyk)
- Near-IR Spectro-Polarimeter (NIRSP)
  - 1000 to 2500 nm
  - 0.05 arcsec resolution
  - Works together with ViSP
  - Led by IfA Hawaii (Haosheng Lin)
- Mid-Infrared and Thermal IR Polarimeters
  - mid-IR and thermal IR instruments will include polarimeters

Modulator Comparison

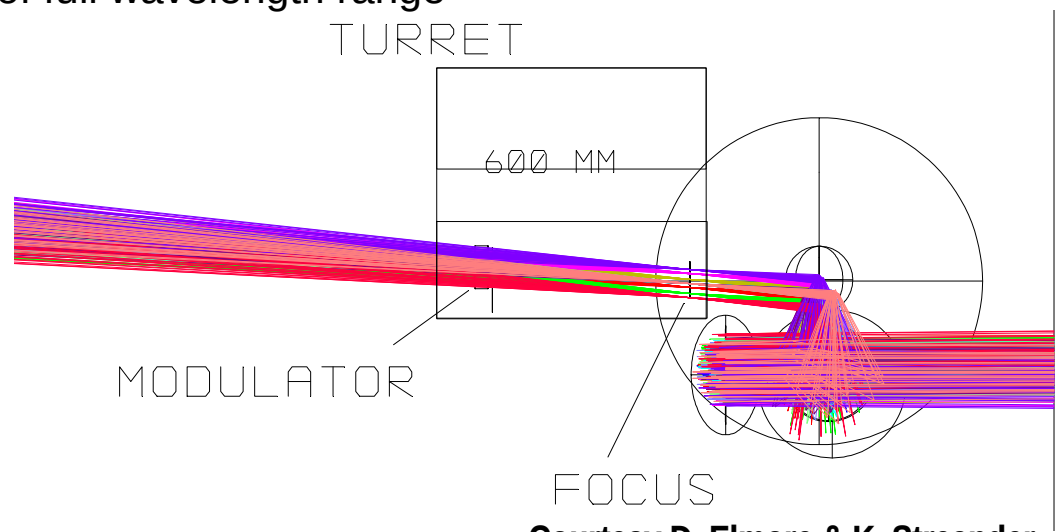




Courtesy D. Elmore & K. Streander

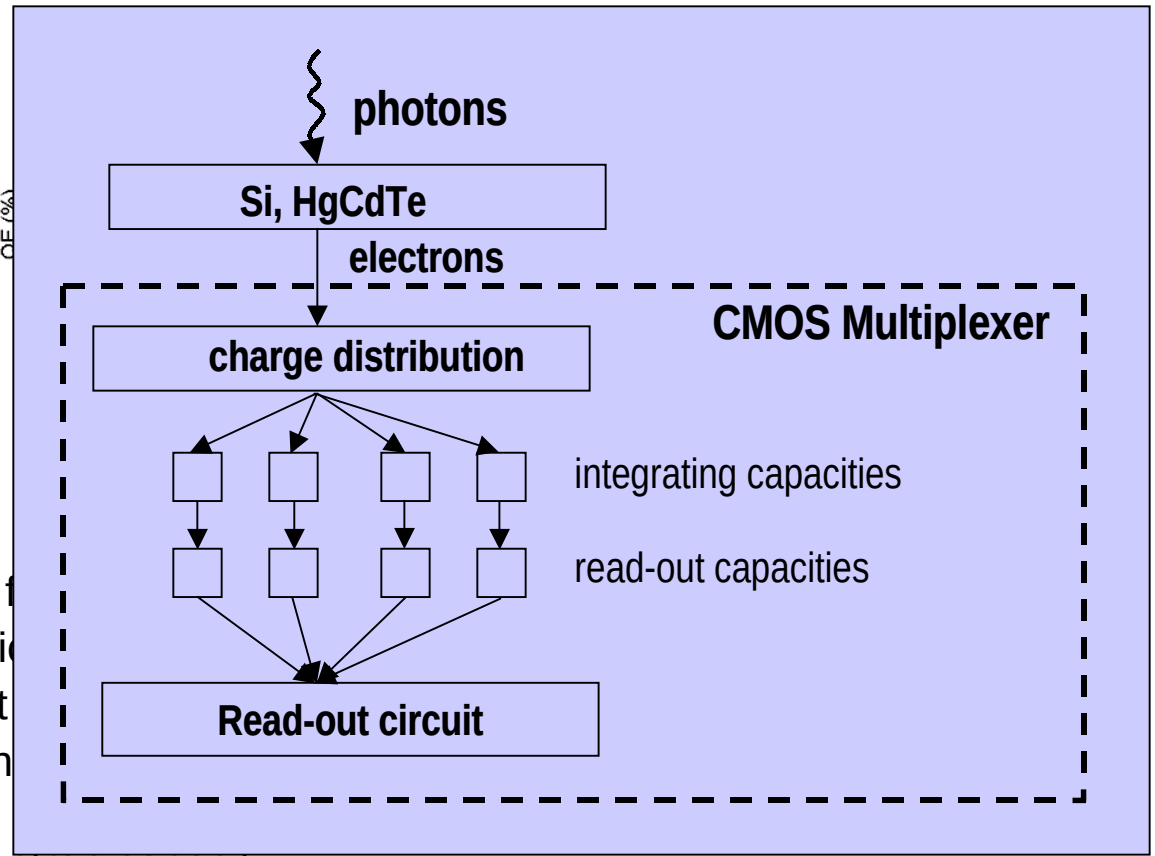
Current Modulator Concept

- Turret
  - At least 6 positions (rotating retarder, clear,LCvis, LCir, Far IR modulator, and user slot)
  - Standard mechanical mounts with drive and status connections
- Rotating Retarder
  - Most general polarization modulator
  - Only modulator capable of full wavelength range
- LCVRs
  - One optimized for visible
  - One optimized for IR



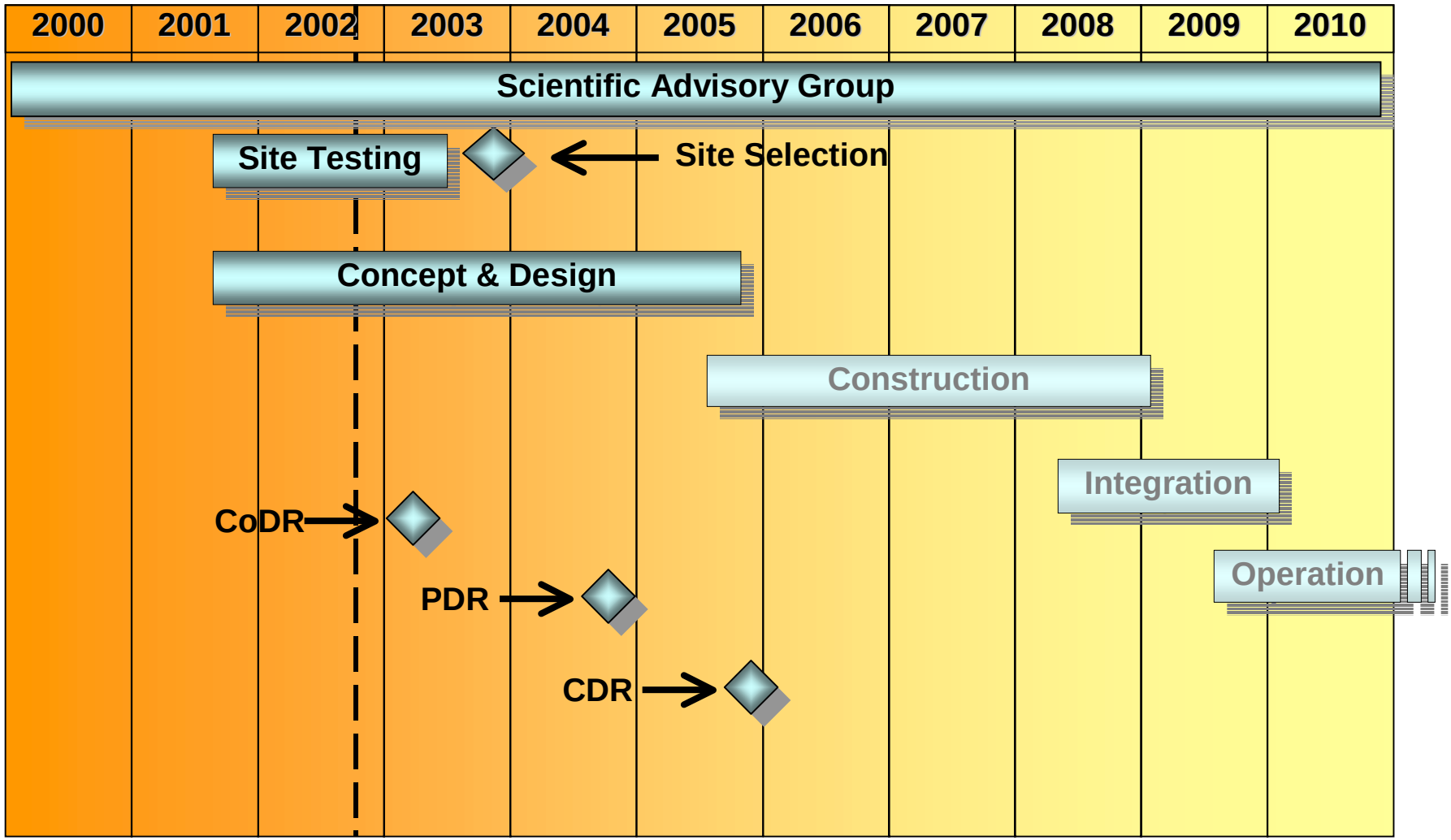
Courtesy D. Elmore & K. Streander

A New Detector Concept for Polarimetry



- CMOS Hybrid technology f
- CMOS multiplexer with sili
- Advantages of CMOS, but
- 8 capacitors per pixel, tran
  read out
- 18 µm pixel has 6 mio. electron capacity
- $500k for new CMOS multiplexer design, about $100k for a camera
- Same multiplexer could be used for the visible and the IR

Timeline


2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Scientific Advisory Group
Site Testing
Site Selection
Concept & Design
Construction
Integration
Operation
CoDR
PDR
CDR

Conclusions and Future Work

- ATST will be a great facility for solar polarimetry
- Polarimetry is likely to be the normal mode of operation for the ATST
- Need to work on integrated simulations of observations to better defined the requirements and analyze trade-offs
- How and where do we modulate the polarization at different wavelengths (simultaneously)?
- How do we demodulate? Do we need new detectors?
- How do we measure/correct for the instrumental polarization?

more at http://atst.nso.edu