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Polarimetry with the ATST

Christoph U. Keller

National Solar Observatory, 950 N. Cherry Ave., Tucson, AZ 85719, USA

Abstract. The Advanced Technology Solar Telescope (ATST) will be the premier facility for ground-based solar polarimetry from 0.3 to 28 μm at an angular resolution as high as $0.''025$ in the visible part of the spectrum. The 4-m aperture will also provide a large photon flux to enable very sensitive polarization measurements at reduced angular resolution. I present some general thoughts on polarimetry with the ATST and discuss specific issues such as the instrumental polarization of an off-axis telescope design.

1. Introduction

Since most observations of the Sun rely on remote optical observations, it is imperative to use all information carried by photons. In particular, the polarization carries information about anisotropies seen by the emitting atoms and molecules. These anisotropies can be induced by a variety of mechanisms including electric and magnetic fields, particle beams impacting on atoms, or simply due to the anisotropic illumination of the scattering atoms and molecules. Because of the inhomogeneous nature of the solar atmosphere, one expects to observe polarization everywhere on the Sun, although sometimes at very small levels that might be impossible to observe due to the finite number of photons. It is therefore no surprise that polarimetry is a crucial capability of the Advanced Technology Solar Telescope (ATST, e.g. Keil, Rimmele, & Keller 2002). One may even go as far as saying that polarimetry will be the standard ATST observing mode (Elmore, private communication).

Spatial structures in the solar photosphere associated with purely hydrostatic phenomena are expected to exist down to scales of the order of the pressure scale height and the photon mean free path, which are about 70 km ($=0.''1$ at disk center) in the lower photosphere. One might therefore think that a 1-m solar telescope would provide adequate spatial resolution in the visible. However, dynamic structures and, in particular, structures due to magnetic fields will occur at much smaller scales. Since the fundamental astrophysical processes at these small scales are crucial for our understanding of the Sun at large, the ATST must be able to observe polarization at the highest possible spatial resolution.

Polarimetric observations of the Sun are mostly photon-noise limited, in particular at high spatial resolution. The number of photons per wavelength interval, per time interval, and per angular resolution element is independent of the aperture size at the diffraction limit. Photospheric intensity patterns can move with apparent speeds of up to 7 km/s. For features $0\farcs1$ or smaller in size, one must collect photons for only a few seconds to avoid spatial smearing. Thus, the total number of available photons collected with diffraction-limited spatial resolution (linearly) decreases with increasing aperture. To obtain the necessary signal-to-noise ratio at a given spatial resolution, the required aperture is larger than what is required by diffraction alone. For instance, a diagnostically accurate measurement of the vector magnetic field at $0\farcs1$ resolution and 5-second maximum integration time requires a 4-m aperture, despite the fact that a 1.5-m telescope would provide adequate spatial resolution. Therefore, polarimetry will be performed most often at spatial resolutions that do not approach the diffraction limit. This and other issues of polarimetry close to the diffraction limit with large solar telescopes have been discussed by Keller (2002a).

In the following, I will provide an overview of polarimetry with the ATST. Section 2 summarizes the science cases that require polarimetry. More details can be found in the ATST Science Requirements Document (Rimmele 2002). Section 3 discusses the need for integrated science simulations to verify, and if necessary adjust, the science requirements. Section 4 summarizes the reasons for looking at ATST as a system when designing the polarimetry capabilities. Section 5 discusses telescope design aspects, while Section 6 deals with post-focus instruments for polarimetry.

2. Science cases and requirements

As can be seen from Fig. 1, polarimetry is a crucial aspect of basically every science case. Among the most prominent solar phenomena to be investigated with polarimetry are:

- Magnetoconvection in weak magnetic fields to understand the magnetic field generation by local dynamos, which might produce the ubiquitous magnetic fields that permeate the solar atmosphere;

- Emergence and disappearance of strong magnetic fields to understand the global solar dynamo;

- Magnetoconvection in strong magnetic fields that leads to fine-structure in sunspots (e.g. penumbral filaments and umbral dots);

- Evolution, structure, and dynamics of magnetic fluxtubes, the building blocks of solar magnetic fields;

- Interaction of magnetic fields and mass flows and the build-up of free magnetic energy in the corona to understand transient eruptions such as flares and coronal mass ejections;

- Dynamics and structure of the inhomogeneous upper solar atmosphere and its connection with photospheric magnetic fields to understand the heating of the upper chromosphere and the corona;

- Formation, structure, dynamics, and eruption of prominences;

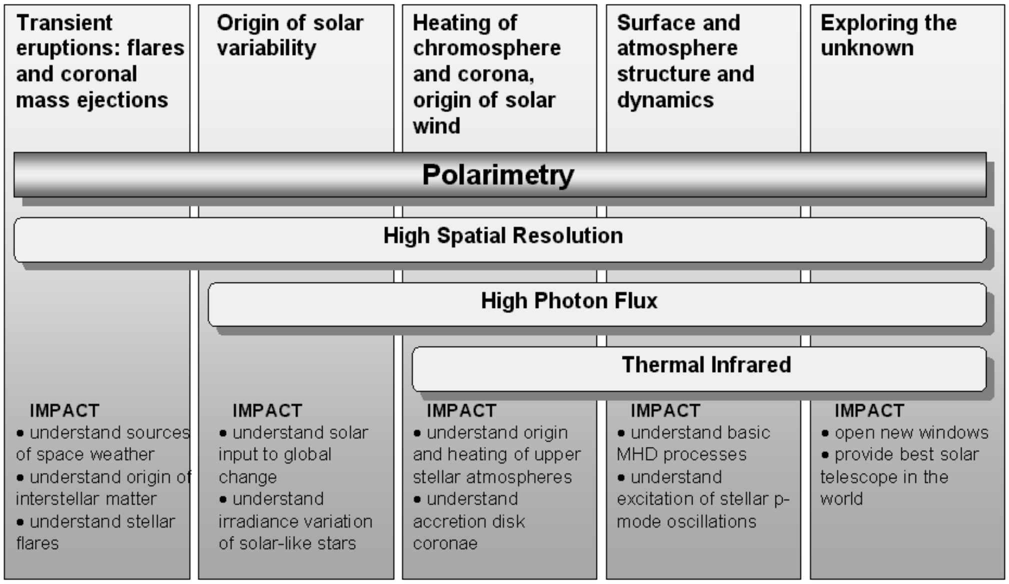

Figure 1. Solar science addressed by the ATST, the technical advances that provide the capabilities to address these science issues, and their impact on other areas of astrophysics. Polarimetry is required in all of these areas.

Based on these science cases, technical requirements for the ATST telescope and instrument system have been deduced. In general, polarimetry should have a minimal influence on any core telescope capabilities or the telescope performance. Therefore, optical aberrations and loss of throughput due to polarimetry optics need to be minimized. Table 1 summarizes the quantitative requirements as far as polarimetry is concerned. Several expressions used in this table need to be defined. The *polarization sensitivity* is the amount of fractional polarization that can be detected above a (spatially and/or spectrally) constant background. It refers to a relative measurement. The *polarization accuracy* is the absolute error in the measured fractional polarization. It refers to an absolute measurement. In many cases the instrumental effects due to the telescope and the instrument can be described by Mueller matrices, which have the general form

$$\begin{pmatrix} I\rightarrow I & Q\rightarrow I & U\rightarrow I & V\rightarrow I \\ I\rightarrow Q & Q\rightarrow Q & U\rightarrow Q & V\rightarrow Q \\ I\rightarrow U & Q\rightarrow U & U\rightarrow U & V\rightarrow U \\ I\rightarrow V & Q\rightarrow V & U\rightarrow V & V\rightarrow V \end{pmatrix} . \qquad (1)$$

The various terms are grouped into three categories:

- $I \rightarrow X, X = Q, U, V$: instrumentally induced *polarization*;
- $X_1 \rightarrow X_{2\neq 1}, X_1 = Q, U, V$: instrumentally induced *cross-talk*;
- $X \rightarrow X, X = Q, U, V$: instrumentally induced *depolarization*.

Table 1. ATST preliminary polarimetry requirements.

item	requirement
Wavelength coverage	full ATST range
Field of view of	minimum of 3 arcmin, goal of full ATST FOV
Polarization sensitivity	1×10^{-5}
Polarization accuracy	$< 5 \times 10^{-4}$
Instrumentally induced polarization	<1% at all wavelengths and all points in FOV before polarization modulation
Instrumental polarization calibration	to an accuracy of at least 5×10^{-4}
Instrumental polarization stability	change no more than 5×10^{-4} within 15 min

In the following, I will refer to all these effects together as *instrumental polarization.*

Since the scientific requirements have not yet been finalized, although unlikely, the polarimetry requirements in Table 1 might need to be updated. Furthermore, the requirements are sometimes not compatible among each other or cannot be fulfilled simultaneously. These incompatibilities must then be resolved by designing multiple systems that each fulfill parts of the specifications.

3. Integrated science simulations

To ensure that the functional requirements are in agreement with the scientific requirements, it is imperative to perform integrated science simulations where a theoretical or numerical model of the Sun is used as a starting point. Radiative transfer calculations then provide the simulated spectra emitted by the artificial solar structure. The spectra are in turn degraded with models of the telescope and the instrument. The degradations need to include optical and electronic effects as well as the photon noise. Such simulations are also very helpful if science requirements need to be adjusted due to technical or financial constraints or to decide between two technically and financially comparable solutions. On the theoretical solar physics side, these simulations will help answer the questions of what parameters should be extracted from the observations and how these parameters can be used to validate a theory or differentiate between competing theories.

As an example, I show a first attempt at modeling observations of turbulent small-scale magnetic fields with the ATST. State-of-the-art numerical MHD simulations (Stein & Nordlund 2000; Stein in these proceedings) are used as a starting point. The magnetic field vector in these simulations was increased by a factor of 10 to lead to a reasonable polarization signal. With this factor of 10 included, the mean density of the unsigned longitudinal flux was 25 Mx/cm^2, which is a reasonable upper limit for turbulent magnetic fields. These simulations represent the most realistic models of the weak magnetic fields that can be observed everywhere in the solar photosphere. Figure 2 shows the four

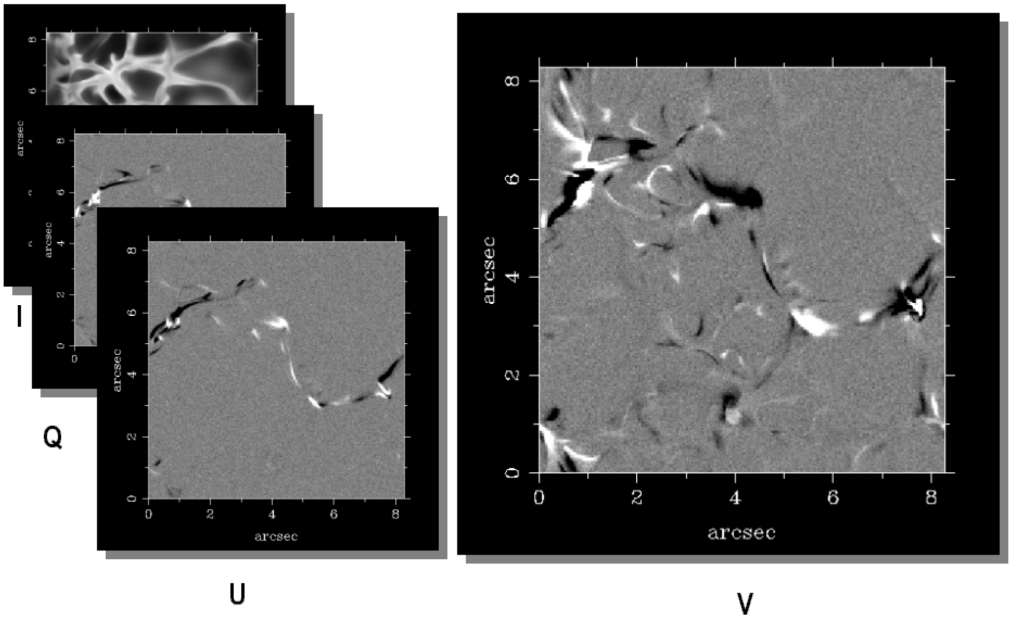

Figure 2. Simulation of narrow-band tunable filter polarimetry with ATST based on numerical MHD calculations. Spatial smearing due to diffraction and adaptive optics limitations has not yet been included.

Stokes parameters as observed through a tunable narrow-band filter. They were obtained with one-dimensional LTE polarized radiative transfer calculations in the FeI 630.15 and 630.25 nm spectral lines. The following simplifications and assumptions were made:

- Zeeman effect only
- no telluric lines
- 4-m unobscured aperture
- 10% total efficiency of telescope, instrument, and detector
- no degradation of spatial resolution, i.e. no diffraction or seeing
- no degradation of spectral resolution due to filter
- filter with 2.2 pm rectangular filter profile
- 1-second total integration time
- perfect polarimeter

Further work must include the effects of diffraction, remaining wavefront aberrations, a more realistic filter profile, as well as effects related to a polarimeter (see Judge et al. in these proceedings for an example of how to model a specific polarimeter implementations). All these effects will reduce the polarization signal and will add random and systematic noise. Observations with ATST will therefore never achieve the quality of Figure 2.

Other integrated science simulations are needed, in particular for observations of magnetic fluxtubes and sunspot fine-structure. Coronal polarimetry simulations can be found in the work by Judge et al. in these proceedings.

4. Systems aspects

Interfaces between post-focus instruments and the telescope need to be designed such as to provide optimum science data while maximizing the possibility of attaching new instruments once the telescope has been built. Therefore, the post-focus instruments, at least partially, drive the telescope design, and vice versa. Some of the telescope parameters influenced by instruments in general are: optical configuration (e.g. f-ratio of optical beam), location of instruments on telescope (e.g. image rotation, changing gravity vector), auxiliary telescope optics (e.g. polarization calibration), and controls (e.g. close interaction between instruments and telescope).

For polarimeters, the coupling to the telescope is even more intimate since accurate solar polarimetry, as implied by the scientific requirements for ATST, mandates that polarimetry post-focus instrumentation and the telescope are designed as a system. All optical elements, and in particular mirrors with oblique reflections inside the telescope or in front of static image-forming optics change or even produce polarization. This artificially introduced polarization is often many orders of magnitude larger than the expected solar signal. In addition, diffractive or interfering optical elements that are used in many post-focus instruments, such as spectrograph gratings or birefringent filters, are highly polarizing. This requires that the polarization analysis be done, at least, in front of the post-focus instruments. Modern solar telescope designs even place the polarization analysis as early in the optical train as possible where the optics is (almost) axially symmetric (e.g. THEMIS and the designs for LEST and GREGOR). Other designs (e.g. SOLIS Vector-Spectromagnetograph) have polarization calibration optics in the axially symmetric part to accurately calibrate the instrumentally induced polarization due to the optics after the polarization calibration. We therefore have to expect that at least some components of the polarimetry instrumentation will be located within the telescope, possibly far away from the post-focus part of the polarimeter.

A good polarimeter design minimizes statistical and systematic errors, which are due to the combined telescope – post-focus instrument system. Among these errors and potential solutions to overcome them (in parentheses) are

- Photon noise (maximize total efficiency);
- Atmospheric seeing and scintillation, guiding and tracking errors (simultaneous polarization measurements or very rapid polarization modulation);
- Instrumental polarization due to telescope and instrument optics (minimize, compensate, calibrate);

- Polarized and unpolarized scattered light from atmosphere and optics (minimize, calibrate);
- Polarized ghost images (careful optical and coating design);
- Variable sky background (rapid switching between source and sky measurements);
- Limited calibration accuracy (careful designs of calibration approach and data reduction procedures);
- Detector-induced errors (careful characterization and modeling of detectors).

Some of these error sources are discussed in more detail in the following sections. Extensive information on these and other potential sources of errors and mitigating measures can be found in Keller (2002b).

Since error sources are often distributed over the whole system, it is crucial to keep track of the individual elements that contribute to the overall error. The use of error budgets is therefore not only necessary for standard optical issues such as total delivered image quality but also for polarimetry-related issues. As an example, let us consider the influence of non-linearities in the detector and instrumentally induced polarization. Both are expected to be at or below the 1% level, and one might neglect them for most measurements. As it turns out, these two effects couple in a non-linear fashion for polarimetry (see Keller 2002b for details) to produce artificial spectral signatures at the 1×10^{-4} level in the measured polarized spectra. To meet the required polarization sensitivity of 1×10^{-5}, one must therefore track both the instrumentally induced polarization error as well as the non-linearity of the detector and combine them to estimate the achievable polarization sensitivity.

While it is crucial to design polarimeters and telescope as a system, telescope and polarimeter designs will be carried out by different groups. I therefore split up the rest of the paper into telescope and instrument-related sections. Nevertheless, it is important to realize that systems engineering is absolutely essential for successful polarimetry with the ATST because of the intimate "polarimetric" coupling of all system components.

5. Telescope design considerations

This section deals with the aspects of polarimetry that are directly related to the telescope. While the first set of instruments will most likely not include polarimeters for all wavelength regimes, the telescope needs to be designed with polarimetry at all wavelengths in mind.

As far as polarimetry is concerned, the telescope design must consider the following:

- Minimize telescope polarization before polarization analysis;
- Adequate locations in the beam for the polarization analysis optics, which is often rather limited in diameter (5 to 10 cm);

- Adequate means to determine any remaining telescope-induced polarization with sufficient accuracy (polarization calibration);
- Polarization optics is often only useful over a limited wavelength range; therefore, different options may be available for different wavelengths;
- Seeing destroys the axial symmetry even of an axially symmetric telescope on the optical axis; particular attention needs to be given to calculating the influence of adaptive optics and seeing on diffraction-limited polarimetry;
- Rotation of the polarimetry coordinate system will occur due to the telescope mount configuration. The instrumental polarization rotates with respect to the solar image due to the alt-azimuth mount;
- Illumination changes on the primary and secondary mirrors will lead to changes in the instrumental polarization;
- The optical properties of the coatings will change in time. Therefore, the instrumental Mueller matrix will change in time;
- The instrumental Mueller matrix changes across the field-of-view, which is the case with any telescope.
- Light scattered in the telescope has a different instrumental polarization than light reflected in the telescope.

To measure solar polarization accurately, it is important to minimize the instrumental polarization. Although the latter can be determined quite accurately, instrumental polarization often couples with other instrumental effects such as unknown offsets and non-linearities in detectors. As a rule of thumb, it is very hard to measure polarization accurately at levels below one percent of the instrumental polarization. Modern observations of polarized light from the Sun often work at or below the 10^{-4} level, which requires instrumental polarization levels well below the 1% level.

Due to the limited space available, we concentrate here on the instrumental polarization induced by an off-axis telescope and ways to deal with this unwanted telescope property.

5.1. Instrumental polarization of an off-axis telescope

Every telescope introduces some polarization, although the amount may be very small. Rotationally symmetric telescopes are often called *polarization-free* because, theoretically, they would not introduce any net polarization at the very center of the field of view, although they do introduce a very small amount of depolarization. For points away from the center, even a rotationally symmetric telescope will introduce polarization (for an extended treatment of this issue see Sen & Kakati 1997). Furthermore, seeing destroys the rotational symmetry even on axis (Sánchez Almeida 1994). Therefore no telescope design should be considered to be free of instrumental polarization.

Oblique reflections off and transmission through optical surfaces such as mirrors introduce polarization and cross-talk between the Stokes parameters. The accurate modeling of these reflections is not easy because of oxide and occasional oil layers on mirrors and their associated interference effects. Similar issues occur with oblique transmissions through glass surfaces with multi-layer coatings. The difficulty of modeling these instrumental effects of telescopes is the reason why instrumental polarization is often measured directly and not modeled in a self-consistent way.

The most likely optical configuration for the ATST is an off-axis Gregorian. Such a telescope would not feature axially symmetric optics in front of the location where the polarization analysis is performed due to the oblique reflections off the primary and secondary mirrors. The choice of coating and the diameter of the primary parent have a considerable influence on the amount of instrumental polarization. An off-axis design therefore needs to be particularly well studied in terms of accurate polarimetry. Instrumental polarization typically increases with the square of the inclination on the reflective surface. Beams at the outer edge of the primary and secondary parents will therefore show considerably more instrumental polarization as compared to beams closer to the optical axis of the parents.

Assuming an f/2 off-axis parabolic primary mirror configuration based on a 12-m parent with an f/30 Gregorian focus after the secondary mirror, I calculated the theoretically expected instrumental polarization for the center of the field-of-view for various wavelengths. The instrumental Mueller matrix for a simple aluminum coating at 400 nm in prime focus is

$$\begin{pmatrix} 1 & 0.002387 & 0 & 0 \\ 0.002387 & 0.999902 & 0 & 0 \\ 0 & 0 & -0.99955 & -0.02666 \\ 0 & 0 & 0.02666 & -0.999452 \end{pmatrix} . \tag{2}$$

In the Gregorian focus, the corresponding instrumental Mueller matrix is

$$\begin{pmatrix} 1 & 0.004472 & 0 & 0 \\ 0.004472 & 0.999998 & 0 & 0 \\ 0 & 0 & 0.998424 & 0.049914 \\ 0 & 0 & -0.049914 & -0.998422 \end{pmatrix} . \tag{3}$$

There are really only two numbers that are of concern: (1) the I to Q instrumentally induced polarization and (2) the V to Q crosstalk. The other elements in the Mueller matrix are either too small to be of concern or are directly related to these two numbers due to the symmetry properties of the Mueller matrices. Fig. 3 shows the variation of the I to Q and V to Q elements as a function of wavelength.

It is not surprising that the change between prime and secondary foci is no more than a factor of 2. The levels of instrumental polarization are much larger than the required polarization accuracy of 5×10^{-4}, and a factor of 2 does not change this. Therefore, the instrumental polarization needs to be calibrated independent of whether the polarization modulation and/or calibration occurs in prime focus or in the Gregorian focus. I conclude that there is no need to locate any polarimetry optics at or close to the crowded prime-focus area.

Despite the instrumental polarization being larger than the required polarization accuracy, it is worth noting that the expected instrumental polarization

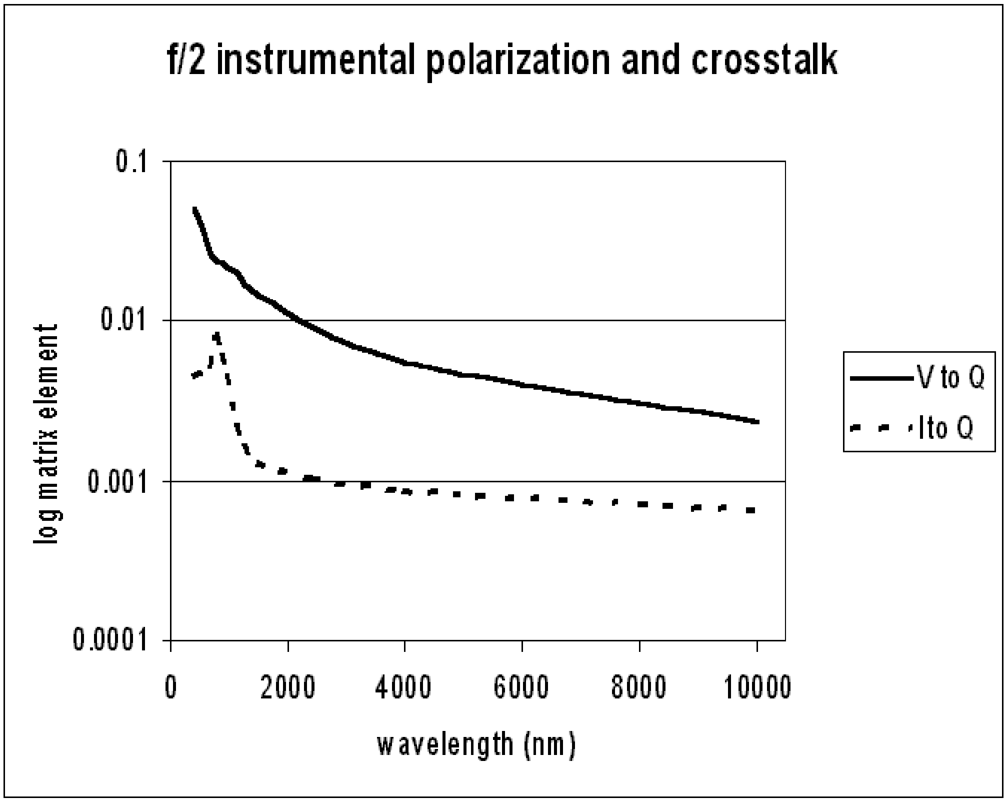

Figure 3. Wavelength dependence of telescope instrumental polarization for a Gregorian configuration with an f/2 primary mirror and aluminum coatings.

values are at least an order of magnitude smaller than those of most conventional solar telescopes, which exhibit oblique reflections (e.g. the McMath-Pierce and Dunn Solar Tower telescopes). Solar telescopes that are optimized for low instrumental polarization (e.g. THEMIS) have their dominant contribution of instrumental polarization from their entrance windows, i.e. birefringence due to mechanical stresses. The instrumental polarization induced by the window is comparable to that of an off-axis, all-reflective telescope. However, the latter has the major advantage that the instrumental polarization is fixed with respect to the telescope pupil and that it can be considered constant over several days. This makes accurate calibrations much easier.

5.2. Instrumental polarization calibration strategies

While some polarimetric measurements will be limited in sensitivity and accuracy by photon noise, many observations will be limited by systematic errors due to the polarizing telescope. As seen above, it is indispensable to accurately calibrate the instrumentally induced polarization and cross-talk. These calibrations have to be performed at regular intervals since the instrumental polarization changes with the change in coatings over time (e.g. growth of an aluminum oxide layer on aluminum coatings).

Ways to measure the instrumental polarization include

- Sun as a light source: use continuum and/or specific spectral lines, use symmetry properties of Stokes profiles;
- Sky polarization (Socas-Navarro, private communication);
- Artificial sources either inside the telescope (Collados & Martinéz Pillet, private communication) or far away from the telescope (Lites, private communication).

Since it is almost impossible to measure all elements of the Mueller matrix at all wavelengths of interest, we will have to rely on some model of the telescope. The free parameters of this model, which are likely to depend on wavelength and time, will then need to be adjusted to fit the measured instrumental polarization.

6. Instrument design issues

Polarimeters for ATST must pay careful attention to several issues. Optics and detectors must be highly efficient, i.e. light losses in polarization modulators must be minimized; multilayer coatings on optical elements are required; and array detectors with quantum efficiencies close to unity and high-speed readout are needed to make use of all the photons that hit the detector within the maximum possible integration time (a few seconds at most). Since array detectors have rather limited full-well capacities (typically a few 100,000 electrons per exposure), an array detector needs to be read out often and quickly. A realistic goal is to achieve an overall efficiency of the combined telescope and instrument of 30%. Furthermore, there is no time for scanning in space or wavelength, which makes the use of integral field units such as fiber fed spectrographs, image slicers, lenslet arrays etc. a necessity. Nevertheless, most polarimetry will not be carried out at the diffraction limit, at least in the visible part of the spectrum, because of photon starvation close to the diffraction limit.

The current suite of initial ATST instruments envisions polarimeters in three wavelength bands:

- A Visible Spectro-Polarimeter (ViSP) in the 300 to 1100-nm range that can reach the diffraction limit of the telescope, but will normally operate at a spatial resolution of $0\overset{\prime\prime}{.}05$. The design and development is carried out by the High Altitude Observatory (HAO).
- A Near-Infrared Spectro-Polarimeter (NIRSP) that covers the 1000 to 2500-nm range at the diffraction limit of the telescope. The design and development is carried out at the Institute for Astronomy in Hawaii with help from HAO.
- The mid-infrared and thermal infrared instruments covering the 2.5 to 28-μm range will include polarimeters. Some of the design and development work is done at NASA's Goddard Space Flight Center.

6.1. Building-block approach

Traditionally, solar observers build up their own "instrument" from the optical elements and systems offered by an observatory. Other instruments are "canned" instruments that are tightly integrated into the telescope. ATST will offer a combination of these approaches with the possibility to build up instruments from (fairly major) building blocks. Polarimeters can be separated into three building blocks:

- A polarization analysis component that transforms the polarization information into intensity variations (spatial and/or temporal) and that might include calibration optics;
- A dispersing element such as a tunable filter or a spectrograph;
- A detector system that is often a specialized imager whose characteristics are well matched to the polarization analyzer.

The polarization analysis is a building block unique to polarimetry and is discussed in more detail in the following paragraphs. The dispersing element is a conventional element whose requirements are barely influenced by polarimetry. I therefore do not discuss this any further. Finally, the detector design is often heavily influenced by the polarimetry requirements. Here I present a new detector concept that would be ideal for most solar polarimetry between 0.3 and 5 μm.

6.2. Polarization analysis

There are various options for the polarization analysis including rotating waveplates, Pockels cells, nematic and ferro-electric liquid crystals, and piezo-elastic modulators. Different approaches might be favored for different wavelength ranges. These analyzers typically require video-frequency CCDs or specially masked CCDs that incorporate fast charge shuffling because the modulation rate has to be faster than typical changes in seeing. The modulation frequency is often in a range where sensors for controlling the adaptive optics operate. Coupling between the polarimetry and the adaptive optics system might lead to a degradation of the performance of both, and particular care has to be taken in assessing the cross-talk between the polarimetry and the adaptive optics systems. Depending on the type(s) and location(s) of the polarization analyzer(s), additional polarization calibration optics are required to accurately determine instrumentally induced polarization and the characteristics of the polarization analyzer(s) themselves.

6.3. New detector concept

The most crucial ingredient in any future polarimeter for a large solar telescope is a high-speed, high-sensitivity array detector that is suitable for polarimetry. The Zurich Imaging POLarimeter (ZIMPOL) I and II represent the first detector concepts that were specifically designed for solar polarimetry (Povel 1995).

New developments in hybrid detector arrays have opened the possibility to build the perfect array detector for polarimetry as envisioned by Lites (1991). The HyViSI hybrid CMOS silicon arrays from Rockwell Scientific combine the advantages of a backside-illuminated CCD with the flexibility, speed, and cost-efficiency of a CMOS imager. The HyViSI arrays are based on the same CMOS hybrid technology as the well-known Rockwell infrared arrays. Silicon is used instead of HgCdTe, which makes the arrays sensitive to visible and ultraviolet light. The same read-out multiplexer can be used for either infrared or HyViSI arrays. 1024 by 1024 pixel HyViSi cameras are available as a commercial product. 2048 by 2048 arrays are in the engineering phase.

A typical CMOS multiplexer contains two capacities, one of which is used for integrating the charges of the current exposure, while the other holds the charges from the previous exposure that is concurrently read out. Instead of only 2 capacities, one could imagine 8 capacities within every pixel. Figure 4 shows an outline of one pixel of such a device.

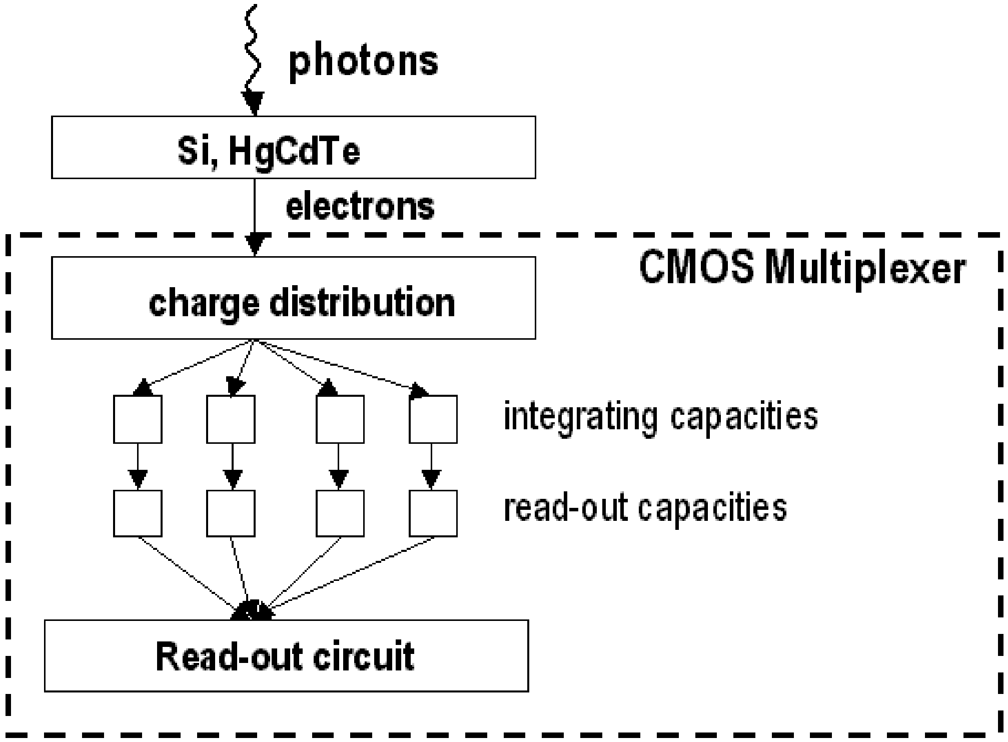

Figure 4. Schematic layout of a single pixel of a new CMOS hybrid array detector that is capable of measuring all four Stokes parameters. It has a 100% geometric fill factor and very high quantum efficiency. The photosensitive layer can be chosen to cover either the 300 to 1100-nm or the 1000 to 5000-nm wavelength ranges.

Since an 18-μm pixel can hold about 6,000,000 electrons, a full-well depth of more than 500,000 would still be possible for every 18-μm pixel and every polarization modulation state. Larger pixel sizes would offer even larger full-well depths. The charges from the silicon would then be sent to one of four capacities in synchrony with the polarization modulation. Before the next image is exposed, the four integrating capacities would transfer their charges to the four read-out capacities. The cost for the design of such a new CMOS multiplexer is on the order of \$500,000. The multiplexer could be hybridized with either silicon to cover the 300-nm to 1100-nm wavelength range, or with HgCdTe to cover the 1000-nm to 5000-nm infrared wavelength range. Since the ATST Design and Development phase does not include funds for such a novel detector, a consortium of interested parties should be performed to pursue such a development.

7. Conclusions

ATST will be a great facility for solar polarimetry, and polarimetry is likely to be the normal mode of operation for the ATST. Further work on integrated science simulations is needed to better define the science requirements and analyze engineering trade-offs. Major questions that need to be answered soon include:

- How and where do we modulate the polarization at different wavelengths (maybe even simultaneously)?
- How do we demodulate? Do we need new detectors?
- How do we measure/correct for the instrumental polarization?

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