The New Solar Telescope in Big Bear: Polarimetry I

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**Abstract.** We present here the near-term polarimetry plans for the 1.6 m clear aperture, off-axis telescope in Big Bear. The first scientific data were taken in the Summer of 2009 at the Nasmyth focus, and first observations corrected by adaptive optics were taken in the Summer of 2010. The first polarimetry for this telescope will be done in the near infrared at 1.56 μm, which is close to the photospheric opacity minimum. We show and explain reasons for the general layout of the polarimetric hardware for the telescope.

1. General Introduction

The 1.6 m clear aperture, off-axis telescope in Big Bear Solar Observatory (BBSO) can be envisioned as a 1.7 m daughter of a 5.5 m parent. The primary mirror (PM) is 1.7 m off-axis, which leaves the secondary (SM) well-away from the path of the incoming light. The telescope is called the NST, or New Solar Telescope. Two schematics of the telescope are shown in Figure 1. On the left, one can see the parent-daughter relationship and how far off-axis the PM is. On the right, one can see the full light path from its entrance from above to the vertical bench in the Coudé Lab where the adaptive optics (AO) resides to the horizontal bench for the spectro-polarimeters. The heat stop before the elliptical secondary defines a round field-of-view (FOV) of about 100″ and a downstream field stop that reduces the FOV to about 50″ square to accommodate the requirements of the current IR polarimetric setup. After the secondary, the light comes to the first set of polarization optics, which contains a calibration optics and the modulation system. The tertiary mirror (M3) sends the light down the declination axis of the Gregorian NST. During the Summer of 2009, the first scientific observations were made at the Nasmyth Bench affixed to the optical support structure of the NST (Cao et al., 2010a). Observations from the Nasmyth Bench are limited because of space and weight considerations. Basically, one is limited to imaging with a narrow band filter with tip-tilt corrections. Without adaptive optics, speckle reconstruction (Wöger et al., 2008) of the images was required for diffraction limited imaging with a 15 s cadence, and really useful polarimetry was precluded as well as AO. Over the next winter, light was fed down the Coudé axis to the Coudé Lab below with care taken to ensure a uniform temperature along the light path. This uniformity was accomplished primarily by exhausting the heat from the dome and along the optical path, while keeping the Coudé Lab at a uniform temperature. The Coudé Lab has a uniform temperature and is isolated with an entrance window. Along the vertical bench in the Coudé, the AO-76 system (Cao et al., 2010b) was mounted, after re-design of the optical system to make it appropriate for the NST. Diffraction...
tion limited imaging was achieved in the Coudé Lab with a combination of AO (with 97 actuator deformable mirror defining 76 sub-apertures) and speckle reconstruction. With AO alone, diffraction limited imaging was confined to the isoplanatic patch. Still, the AO corrected imaging was sufficient to motivate the next step for the NST, which is polarimetry. Polarimetry will be done first in the near infrared (NIR) because AO-76 provides a sufficient Strehl ratio there to allow us to perform the subtractions of consecutive images and be left with a signal of the magnetic field. This is not true for visible light under nominal seeing conditions. We are in the process of upgrading the AO to a 349 actuator deformable mirror (AO-308) with which polarimetry can be done in the visible.

2. Polarimetry for the NST

The current polarimeter for the NIR is quite different from its predecessor (Cao et al. 2006) that was used on the now replaced 0.6 m BBSO solar telescope. The BBSO NIR polarimeter, InfraRed Imaging Magnetograph (IRIM), and its optical system are shown in Figure 2. The optical design, calibration procedure and implementation of the IRIM are discussed in detail in Cao et al. (2010c). The left panel shows the M3 complex and the right panel shows the full light path of the polarimetry. We decided it was best to put the modulator as far forward as possible – namely before M3. Thus, the polarimeter consists of a well-separated modulator and analyzer. As well, we put two calibration elements before M3, which are composed of a quarter waveplate and an analyzer. Thus, there are three optical mounts before M3, and each can be slid in and out of the beam. In the same figure, one can see the wavefront sensor for alignment, as well as control of the active PM. Calibration needs to be done several times a day to account for changes in crosstalk induced by changes in polarization of optical elements as the telescope rotates through the day. We chose not to
utilize an image de-rotator because it would introduce oblique reflections that would greatly complicate the polarimetry. The essence of the calibration is to create purely-polarized light from the unpolarized sun light. The outgoing beam from the calibration unit can be one of the pure Stokes signals - Q, U, or V. For this purpose, elements 1 and 2 in the left panel of Figure 2 should have the capability of being angularly positioned with increments of 45°. The two calibration elements do not need to rotate continuously. Considering they are a birefringent material and a linear polarizer, their fast axis or polarization axis should be located at an angle of 45°*n (n is some integer) from the reference axis, which is determined from the geometry of the telescope. The position angles of elements 1 and 2 will be determined independently. The calibration elements are inserted in the beam several times a day to determine the off-diagonal Müller matrix elements, and their evolution at the camera. Modeling done by Don Mickey (2009, private communication) says these off-diagonal elements should not be too large to handle, and would be much small than what would result if the modulation were done further downstream. Elements 1 and 2 will be used for calibration purposes only. Thus, they should be inserted in the beam only when calibration is needed. Elements 1 and 2 are loaded on separate linear stages so that they can be controlled independently.

Element 3 is used for the actual measurements of the sun’s magnetic field. Element 3 is rotated continuously with its rotation integrated to the frame rate of the IR camera. A frame should be acquired while the plate rotates from 0° to 22.5° and then from 22.5° to 45° and so on. One rotation of the plate will result in the acquisition of 16 frames. There is a negligible time gap between adjacent frames.

The analyzer consists of two Wollaston prisms (see right panel of Figure 2) for which the first is a polarizing beam splitter, while the second makes the beam parallel. Simulations done by Don Mickey. The rotating waveplate is the modulator and Wollaston prism is the analyzer. The modulator is a 0.35λ wave plate rotating in about one second. Again, in order to reduce polarization crosstalk induced by oblique reflectors, the modulator is placed ahead of M3. IRIM itself consists of a pre-filter with a 2.5 nm bandpass, Lyot filter with 2.5 Å
Figure 3. Idealized I, Q, U and V for each of the eight unique positions of the rotating waveplate modulator. V, Q and U represent the modulated pattern of the idealized Stokes signals. The dot-dashed curve is a simulated curve assuming a typical Stokes signal from the Sun ((I, Q, U, V)=(1.00, 0.05, 0.05, 0.10))

bandpass centered on 1.56 μm, an IR Fabry-Pérot filter (with 0.1 Å width peaks separated by about 5.5 Å ) and a Rockwell (now Teledyne) 1024×1024 CMOS camera (Cao et al. 2010d) capable of taking 30 frames per second. IRIM is in the process of being upgraded to dual Fabry-Pérot system, which will increase the light throughput by about an order of magnitude with the replacement of the Lyot filter with its low transmission. At that time, a faster IR camera will be required to optimize magnetic field measurements. The current IRIM should be capable of determining the full Stokes profile once a minute with a relative precision of 10^{-3}.

In Figure 3, we sketch the determination of I, Q, U and V using the 0.35 λ rotating waveplate. I is the intensity and is given by the sum of eight measured components illustrated in Figure 3. The Stokes components are a more complicated combination of the eight components, V (=1-2-3-4+5+6+7+8), Q (=1-2-3+4-5+6-7+8), U (=1+2-3+4+5-6+7-8), where V is the line-of-sight component of the field, while Q and U yield the transverse components of the field.

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References
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