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Development of an Infrared Camera Using a Hawaii-2RG Detector for Solar Polarimetry

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Abstract. Solar polarimetry in near-infrared wavelengths is promising because the magnetic field information of the chromosphere can be obtained in addition to that of the photosphere. To realize the infrared polarimetry with a large format detector, we developed an infrared camera with a Hawaii-2RG (H2RG) array of Teledyne, which has 2048×2048 pixels, focusing on the wavelengths 1.0 – 1.6 μ. It is required to synchronize the polarization modulation and data acquisition by the camera for the polarimetric data acquisitions. However, it was difficult when using the high-speed mode of H2RGs. We introduced a MACIE interface board and new assembly codes (both by Markury Scientific) to realize the synchronization, and now it is possible to carry out the polarimetry with frame rates as high as 30 – 120 frames sec^{-1}. Here we present the operation scheme of the camera with a polarization modulator, and show some results of an experimental run of the polarimetry observation.

1 Introduction

The He I 10830 Å line is one of the most important targets of the solar polarimetry in near-infrared wavelengths (e.g., Lagg 2007). The solar group of National Astronomical Observatory of Japan has been operating a regular full-disk, full-Stokes polarimetry observation at some wavelengths including He I 10830 Å (Sakurai et al. 2018). Such an observation gives information of the magnetic field in filaments (e.g., Hanaoka & Sakurai 2017). Filament eruptions and coronal mass ejections are caused by the evolution of the magnetic field in and around filaments, and therefore, observation of the magnetic field evolution in and around filaments will give a hint to predict eruptive events. However, currently we are using a small format infrared camera, and the efficiency of the observation is not very high to track the evolution of the magnetic field.

Then we started to develop a large format, low noise infrared camera with a Hawaii-2RG (H2RG) detector (Teledyne) focusing on the wavelengths 1.0 – 1.6 μ, with the support of a Japanese Kakenhi grant, “Project for Solar-Terrestrial Environment Prediction”. With this camera, we realized the synchronization of the polarization modulation and the image acquisition with a H2RG under the “fast readout mode”, which is suitable for a photon-rich target like the Sun. This development is in principle only for the experimental purpose using an engineering model chip. However, such a development allows for efficient polarimetry by future advanced telescopes, and will contribute to the study of the space weather phenomena. Here we present the system of the camera and an example of experimental polarimetric

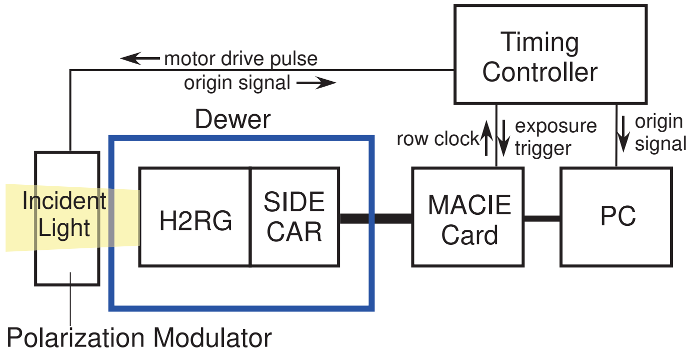

Figure 1. Outline of the camera system. A H2RG and a SIDECAR is installed in a dewer to be cooled. A/D-converted data are transferred to a PC via CameraLink. A timing controller governs the synchronization between the polarization modulation and the data acquisition through various timing signals.

observation of the Sun.

2 Overview of the H2RG Camera System

A H2RG of Teledyne is a HgCdTe array, which has 2048×2048 pixels with a pixel size of 18 ×18 μm. There are some choices for the cut-off wavelength, and we chose the 1.7 μ cut-off. Its fullwell capacity is about 100,000 e^-. With the low-speed mode (100 kHz), the readout noise is as low as ~15 e^-, and therefore, H2RG have been widely used in night astronomy. It can be operated with the high-speed mode (5 MHz) as well, and with the 32-channel readout, the frame rate can be as high as 33 frames s^{-1}, with sacrificing the noise level to some extent (~70 e^-). With this high frame rate, H2RGs can be used for solar polarimetry, where it is required to gather many photons within a short time and to reduce the crosstalk caused by the seeing effect.

Polarization modulation in solar polarimetry should be done at high-speed, and image acquisition with a camera needs to be synchronized with the polarization modulation. However, it was difficult to synchronize H2RGs and polarization modulation under the high-speed mode. To cope with this problem, we, jointly with Kyoto University, introduced a MACIE card fabricated by Markury Scientific. A MACIE card interfaces between a SIDECAR ASIC focal plane electronics (it sends out A/D-converted signals) and a Personal Computer via CameraLink, instead of a SAM card of Teledyne. A MACIE has a function to send out and receive timing signals, which can be used for the synchronization with the polarization modulator.

The configuration of the camera system is shown in Figure 1. The overall timing is controlled by the row clock (line sync) of about 70 kHz, a frequency corresponding to the period time of the processing of each row of the detector. The stepping motor drive pulses are produced by dividing this clock. After the origin signal from the rotating waveplate is detected, 16 exposure triggers are sent out from the timing controller during a rotation of the waveplate. With this trigger signal, the MACIE card makes the SIDECAR start the readout of the

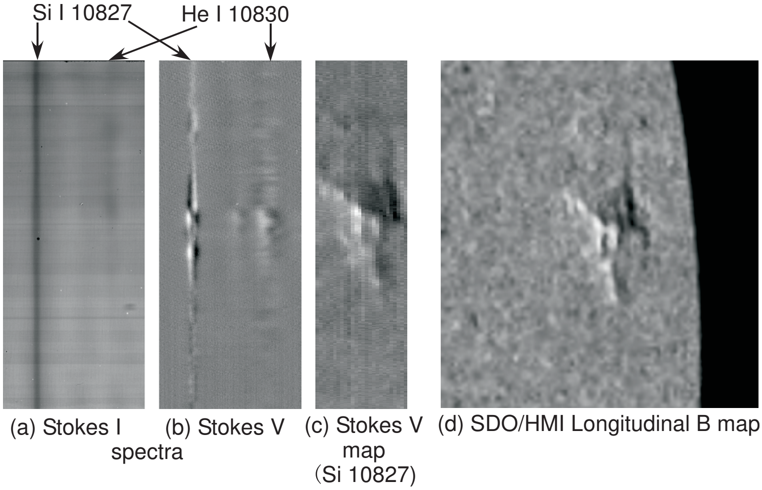

Figure 2. Example results of the experimental observation on 2018 November 20. Panels (a) and (b) show the Stokes I and V spectra of the wavelength ranges including the Si I 10827 Å and He I 10830 Å lines. Panel (c) shows a Stokes V map of the blue wing of the Si I 10827 line, covering NOAA 12727. The field of view is $3'.7$ (along the slit) $\times 52''$. Panel (d) shows a map of the longitudinal magnetic field taken with SDO/HMI. A part of the full-disk map including the field of view of panel (c) is shown.

signal from H2RG.

For the SIDECAR, a new assembly code prepared by Markury Scientific has been installed to realize the synchronization, etc. With this code, very high duty cycle, > 99%, has been achieved. It means that there is virtually no dead time, and most of the photons coming into the detector are used to produce signals. In addition, this code enables the vertical windowing. Reducing the width of the window from 2048 makes the frame rate higher. Now it is possible to carry out the polarimetry with high frame rates such as 30 – 120 frames sec^{-1}.

3 Verification Experiment with the Hida Domeless Solar Telescope

We carried out an experiment for the polarization measurement of the Sun to verify the performance of the camera system using the Domeless Solar Telescope (DST) of Hida Observatory, Kyoto University (Nakai & Hattori 1984) in November 2018. The DST is a 60 cm vacuum solar telescope, and we installed the camera into the vertical spectrograph. The length of the slit is 5 cm (corresponding to $5'$); the H2RG (37×37mm) covers $3'.7$ along the slit with a spatial sampling with $0''.11$ pixel^{-1}. The dispersion is 0.39 Å mm^{-1} (7mÅ pixel^{-1}) at 10830 Å (2nd order). The polarization modulator (Hanaoka 2012), which is a rotating waveplate with 1/4-λ retardation at 1.6 μ and about 1/3-λ retardation at 10830 Å. A linear polarizer (analyzer) was installed in front of the slit. The waveplate made 1.9 rotations s^{-1}, and 16 exposures were made during every rotations.

There was no sunspot; we measured polarization of a weak plage region (NOAA12727). In Figure 2, examples of Stokes I and V spectra including the Si I 10827 line showing photospheric magnetic field and the He I 10830 line showing chromospheric magnetic field are shown. The data were taken with 16-sec integration; during this time 480 images (16 exposures $\times$ 30 rotations) are acquired. In the Stokes V spectra, we can find remarkable Zeeman polarization in Si I 10827 line, and also weak Zeeman signals both in the blue (10829.1 Å) and red (10830.3 Å) components of the He I 10830 line. We took such spectral data at 26 slit positions separated every $2''$; as a result, we obtained the polarization data of the field of view of $3'.7 \times 52''$.

A Stokes V map of Si 10827 of this field of view is also shown in Figure 2. It shows photospheric longitudinal magnetic field of the weak plage region. A bipolar magnetic polarity distribution can be found in the plage region. In Figure 2, a magnetogram obtained with the Helioseismic and Magnetic Imager (HMI; Scherrer et al. 2012) of the Solar Dynamics Observatory (SDO; Pesnell et al. 2012) including the same area is also shown. The HMI magnetic field map corresponds well to the Stokes V map recorded with the infrared camera.

In this experiment, it was proven that the new infrared camera works well as a polarimetry instrument. On the other hand, some problems, such as noise from the cryocooler, have been revealed. Now we are working to remove the problems, and preparing to use the camera in regular observations.

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