

Features of Solar Telescopes at the Hida Observatory and the Possibilities of Coordinated Observations with Solar-B

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Abstract. At the Hida observatory, two solar telescopes, Domeless Solar Telescope (DST) and Flare Monitoring Telescope (FMT), have been operated for studying solar fundamental structures and active phenomena which affect interplanetary environment. In addition, a new telescope named Solar Magnetic Activity Research Telescope (SMART) was built from 2002 through 2003 to obtain simultaneously $H\alpha$ image and the vector magnetogram of the full solar disk with high spatial and temporal resolution. In this paper, we give an outline and scientific purposes of these three telescopes, with emphasis on the SMART, and discuss about possibilities of coordinated observations with Solar-B.

1. Introduction

The studies of solar periodic variations and explosive phenomena which are related to magnetic fields are important for us not only to understand the origin of solar activity itself, but also to develop researches in astrophysics and solar terrestrial physics. We need develop observational technologies and instruments by which we can elucidate the mechanism of solar activity to forecast it.

Furthermore, such solar researches are also helpful to develop other basic science, such as nuclear physics, plasma physics and magnetohydrodynamics, because the Sun is the unique star with which we can observationally study the phenomena relevant to their fundamental physics.

To promote the progress of these researches, we have recently built a new telescope named Solar Magnetic Activity Research Telescope (SMART) and have installed a vector magnetograph on the vertical vacuum spectrometer of the 60 cm Domeless Solar Telescope (DST) and have updated the tower cooling system of the DST to improve the seeing condition. We summarize outlines and scientific purposes of these telescopes working at Hida Observatory, Kyoto University, to develop their efficient use in the future coordinated observations with Solar-B.

2. 60 cm Domeless Solar Telescope (DST)

The DST has functions both of the filtergraph and spectrograph observations (Nakai & Hattori 1984).

In the filtergraph observation, we can simultaneously observe the photosphere in G-band around 4308 Å and the chromosphere in $H\alpha$ line for FOV of

380×380 arcsec with high spatial resolution (~ 0.18 arcsec around 600 nm) and high cadence (1–2 sec).

For the spectroscopic observation, we can use two kinds of spectrograph, “Vertical Spectrograph (VS)” and “Horizontal Spectrograph (HS)”. The former has a very high dispersion $1.6 \text{ m}\text{\AA}/\text{pix}$ and resolution $(\lambda/d\lambda)=1290000$ in the 5-th order spectrum around 630 nm. The latter is used for multi-wavelength spectroscopy in which we can simultaneously observe in multiple wavelengths between UV and near infrared. A Stokes polarimeter which is installed on the VS enables us to make precise measurements (photometric error $< 0.04\text{--}0.07\%$, error of the polarimeter itself $< 0.7\%$, error of compensation for instrumental polarization $< \text{about } 0.5\%$) of solar vector magnetic field by using the whole line profiles of various Fraunhofer lines.

In 2003, we renewed the cooling panel system of the DST tower to suppress the turbulence rising from the tower surface. By exchanging the material of panels from stainless-steel to aluminum, their reflectance to sunlight were raised, and the thermal conductivity was also raised, so the cooling efficiency by the cooling medium was improved significantly. Moreover, the cooling chiller was made able to work at all seasons even if outside temperature becomes -10 degrees, so, the seeing condition with the DST is expected to be improved over all seasons.

3. Flare Monitoring Telescope (FMT)

The FMT observes full solar images simultaneously and continuously in the following five different wavelengths with four Fabry-Perot filters and one multi-layer coating filter (Kurokawa *et al.* 1995):

- (1) $\text{H}\alpha$ line center image (passband: $0.42 \text{ \AA}$)
- (2) $\text{H}\alpha - 0.8 \text{ \AA}$ (blue shifted) image (passband: $0.5 \text{ \AA}$)
- (3) $\text{H}\alpha + 0.8 \text{ \AA}$ (red shifted) image (passband: $0.5 \text{ \AA}$)
- (4) $\text{H}\alpha$ prominence image with occulting disk (passband: $3 \text{ \AA}$)
- (5) $6100 \text{ \AA}$ continuum image (passband: $60 \text{ \AA}$).

Since it can record the full solar disk and limb image simultaneously in three wavelengths of $\text{H}\alpha$ line with 2 sec time cadence, the FMT is very useful for the study of their vector velocity fields of solar eruptive phenomena, which affect the solar-terrestrial environment (Morimoto & Kurokawa 2003).

This telescope has also detected many Moreton waves in the chromosphere which accompanied solar flares (Narukage *et al.* 2002; Eto *et al.* 2002).

4. Solar Magnetic Activity Research Telescope (SMART)

The SMART is designed to observe the full solar disk with much higher spatial resolution than FMT, so that we can study in detail energy buildup processes of magnetic active phenomena on the whole solar disk.

It mainly obtains “chromospheric filtergram” around $\text{H}\alpha$ absorption line, and “photospheric vector magnetogram (filter-type)” with $6302.5 \text{ \AA}$ Fe I ab-

sorption line, and “photospheric continuum image” around 430 nm (G-band), in various FOV and resolution.

The SMART is composed of the following 4 refractors;

- T1: 20cm diameter, H α filtergraph (whole solar disk) with Lyot filter (FWHM: 0.25 Å), FOV=2300'' $\times$ 2300'', pixel resolution=0.58''
- T2: 20cm diameter, Filter Vector Magnetograph (whole solar disk mode/partial region mode) with Lyot filter (FWHM: 0.125 Å), FOV=2000'' $\times$ 2000'' or 500'' $\times$ 500'', pixel resolution=1.0'' or 0.25''
- T3: 25cm diameter, H α filtergraph (partial region, high resolution) with Lyot filter (FWHM: 0.25 Å), FOV=1000'' $\times$ 1000'', pixel resolution=0.25''
- T4: 25cm diameter, Filter Vector Magnetograph with Fabry-Perot filter (FWHM: 0.101 Å), FOV=400'' $\times$ 400'', pixel resolution=0.10'' or two-color filtergraph, FOV=1000'' $\times$ 1000'', pixel resolution=0.25''

5. Details of SMART

5.1. Characteristics of Optical Elements and Detectors

In the SMART, we have adopted newly-designed high quality optical elements and detectors as follows;

- (1) Wedge-shaped Prefilters
By rotating two wedge-shaped glass plates, we can select any positions on the Sun, even if the telescope itself points the solar disk center.
- (2) Lyot Filters
We developed the Lyot filter which has the large effective aperture of 50 mm ϕ in order to make the wide field filtergraph which has a high-speed wavelength tuning ($> \pm 2$ Å/10 sec) and small wavefront error (RMS $< \lambda/25$ for each element).
- (3) Fabry-Perot Filters
Since the single etalon filter with the large peak-interval of the transmission profile needs to make the thickness very thin, it is very difficult to guarantee the uniformity of the filter. We are developing the tandem(double)-type filter system whose each etalon's thickness is not so thin, so that its transmission profile has high uniformity of center-wavelength and of FWHM, and has low rate of unnecessary light.
- (4) Large format CCD Camera
We introduced the large format CCD chips which have the large number of pixels (4096 $\times$ 4096) and the high sensitivity (full-well: 200000e $^-$), so that we can get high spatial resolution and wide FOV and high S/N. Moreover, we introduce high-speed readout interface: USB2.0 (~ 480 Mbps). So, time resolution is about 3 sec for a high resolution full-disk observation.

5.2. Designed Characteristics of SMART Polarimeters

The target of the photometrical error of polarimeters in the SMART is less than 0.1 %. These targets correspond to $\delta B_l < 6\text{--}7$ G, $\delta B_t < 15\text{--}50$ G when $B_l, B_t < 500$ G. The target of the time resolution is less than 30 sec. These targets are not easy to be realized because of technical restrictions of optical elements and

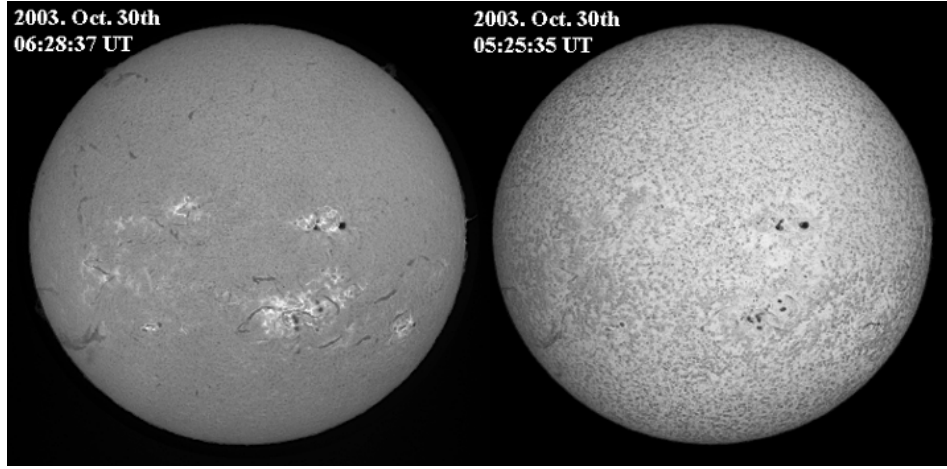


Figure 1. $H\alpha$ line center image (left) and $H\alpha - 0.50 \text{ \AA}$ image (right) observed by the 20 cm refractor (T1) of the SMART.

detectors in telescopes or polarimeters, but we tested the performances of various devices from various sides. Since we will report the details about polarimetry accuracy and these devised points in another paper, we indicate only particular items we considered.

- (1) Coating on wedge-shaped prefilters
Specification: Retardation at each point on the filter surface $< 0.3 \text{ nm}$
- (2) Anneal of glass materials for lens
Specification: Retardation at each point on the lens $< 0.3 \text{ nm}$
- (3) High quality rotating wave-plate
Specification: Error in retardation $< 0.2 \text{ deg}$, error in rotation-angle $< 0.05 \text{ deg}$
- (4) Wavelength shift in FOV due to oblique incidence of rays to the filters
Specification: $|\delta\lambda| < 0.021 \text{ \AA}$, ($|\delta v_{\text{Doppler}}| < 1.0 \text{ km s}^{-1}$)
- (5) Simultaneous record of two images of orthogonally polarized light by using Fabry-Perot channel
- (6) Four wavelengths observation in a line which can suppress various errors

5.3. Current Status of SMART

$H\alpha$ (chromospheric) image obtained by T1 seems to be close to its target of spatial resolution (Fig. 1).

On the other hand, we find that the spatial resolution for photospheric vector magnetogram obtained by T2 is not as good as expected (Fig. 2a). After examination of the source of problem, it was found that Lyot Filter ($6302.5 \text{ \AA}$) has unacceptable aberration. We are now performing a repair work. In Figs. 2b to 2d, we display each components of “vector magnetogram” obtained in the testing phase; they are neither compensated for the “instrumental polarization” nor calculated with “inversion method”, yet. Figure 2b stands for V -map which

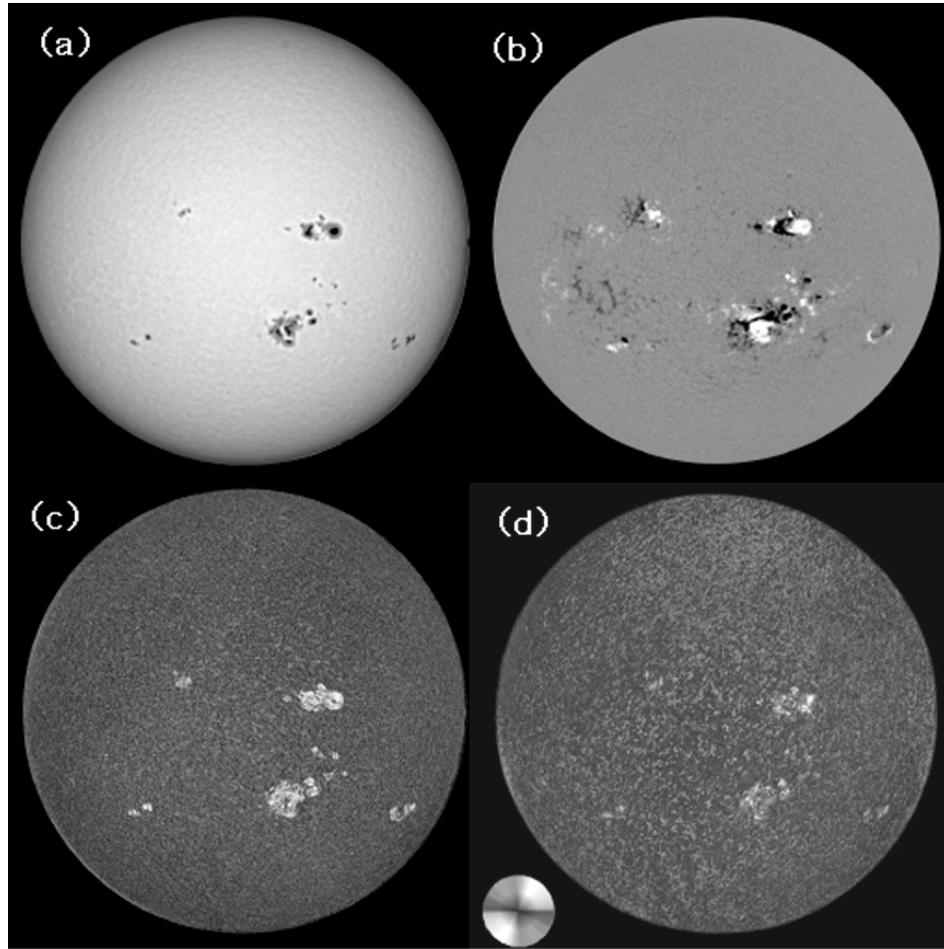


Figure 2. “Vector magnetogram” by the SMART/T2 on October 30, 2003. (a) Intensity map, (b) V -map, (c) $(Q^2 + U^2)^{0.25}$ -map, and (d) azimuth angle map.

is averaged four V -values from different 4 wavelengths in the line. This map corresponds to the map of longitudinal magnetic fields. Figure 2c stands for $(Q^2 + U^2)^{1/4}$ -map which is averaged at two wavelengths. This corresponds to the map of transverse magnetic fields. Figure 2d stands for $(1/2) \arctan(U/Q)$ -map which is averaged at different four wavelengths. This corresponds to the map of azimuth angle of magnetic fields. In the next step, we will measure the amount of systematic errors on these magnetograms due to the instrumental polarization, so that we can measure more accurate vector magnetic fields of the solar origin.

Similarly, we are carefully examining whether the images obtained by T3 and T4 fulfill our specifications.

6. Possibilities of Coordinated Observations with Solar-B

The DST observes the photosphere and the chromosphere with much higher spectroscopic resolution over wider wavelength region in faster cadence than Solar-B. With this advantage, the DST can cooperate with the Solar-B in precise determinations of physical parameters, such as vector magnetic field, velocity field, temperature and density, of various fine structures.

The FMT observes five kinds of full disk images simultaneously and continuously. Those images can be seen on real time on the web at present. So, for example, we can know the beginning of a filament eruption on the whole solar disk about one hour before the solar X-ray flare occurs. Then, this telescope can be expected to work as a role of monitor which offers important informations about current solar activity, when the Solar-B decide the target region to observe.

The SMART will regularly offer the information about the photospheric gas motion (by T4/G-band), the photospheric vector magnetic field (by T2 and T4/6302.5 Å), and the change of chromospheric structures of the whole solar surface (by T1, T3, T4/H α), only a small part of which the Solar-B will observe. So, the SMART will supply the Solar-B with detailed informations of earlier evolutional stages of active phenomena, such as emerging magnetic flux, shearing magnetic structures etc.

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