H α Solar Telescope at Hiraiso and Its Initial Observations

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A new H α solar telescope for the forecast of solar activity and the research on energetic phenomena of the sun has been constructed at Hiraiso Solar Terrestrial Research Center in Japan (Regional Warning Center of IUWDS). Its main features are (1) high resolution digital full-disk H α images with a 2 K by 2 K CCD, (2) real-time data processing with an automatic frame-selection technique, (3) spectroscopic observation with an automatic wavelength shift of H α Lyot filter. Because of these advanced features, continuous observations of the sun with this system will provide more reliable data for the forecast of solar activity and its influence on the space environment.

1. Introduction

An H α solar telescope has been constructed at Hiraiso for the forecasting operation and the research on various energetic phenomena on the sun. This telescope system is the initial step toward the prediction and monitoring of solar energetic phenomena with high quality data so that we can establish a "space weather forecast" to support various activities in space. In addition, the construction of this telescope is one of the topics of STEP activity in Japan.

The H α line is an absorption line at 6563 Å. Due to its high opacity, chromospheric structures and dense and cool material in the upper atmosphere of the sun can be observed in H α monochromatic images taken using a very narrow band filter or a spectrograph. H α images give us many important clues to the activity of sunspot regions. For example, filamentary dark features seen in H α monochromatic images reflect the distribution of the solar magnetic field and their ascending motions often precede the onset of flares. Thus, careful observations of H α fine structures and velocity fields give us important information for daily forecast of flares and other active phenomena as well as for research of their mechanisms.

In monitoring observation for forecasting flare activity, sufficient spatial resolution to recognize arch filament systems (AFS) and fibrils in full-disk observation is required. The appearance of AFS gives us information on the growth of active regions and fibril loci are useful in judging the complexity of magnetic field structures. The width of individual arch filaments is 1000–3000 km (Bruzek, 1967), equivalent to 1.5–4 arcsec. To recognize these structures, a resolution of 1 arcsec/pixel is required. A higher resolution of 0.5 arcsec/pixel is necessary to resolve these structures completely in close-up mode. In actual observations, the image quality changes rapidly owing to terrestrial atmospheric turbulence. Thus, frame selection technique to pick up the best image from many captured images is necessary to minimize deterioration in image quality.

Chromospheric velocity fields provide a lot of information to deduce the activity of sunspot groups. During emergence of magnetic flux, characteristic mass motions in the AFS are observed. It is well known that filaments often erupt before the onset of large flares. To measure the chromospheric velocity fields, the central wavelength of a Lyot filter must be automatically controlled around H α line-center.

To satisfy these requirements, we have been continuing efforts to update the telescope system since its initial construction in the spring of 1992. Currently, the main characteristics of this telescope are (1) full-disk imaging with a 2 K by 2 K pixel format, (2) real time frame selection to obtain images of higher

resolution, and (3) spectroscopic observation with automatic control of the filter wavelength. In this paper, an overview of the telescope system including its current status is briefly reported.

2. System Overview

A schematic drawing of the optics as of November 1994 is given in Fig. 1. The telescope is a 15 cm refractor with an equatorial coude mounting made by Carl Zeiss Co. Ltd. The primary lens is an achromatic doublet with a focal length of 2250 mm. The primary solar image with a diameter of 20.9 mm is made at the fixed optical bench on the polar axis of the coude-type equatorial mounting.

We developed a telescope control and imaging system for automatic and flexible operations after its initial construction (Fig. 1). The offset mechanism of a photoelectric guider enables us to change the field of view on the solar disk. The actuator for the offset guiding is a pulse motor driven micrometer with an encoder, installed on the photoelectric guider. A flat field lens for the calibration of CCD sensitivity and a shutter plate for measuring the dark current of the detector can be inserted into the optical path in front of the filter optics automatically. A camera for close-up mode observation and an assembly of relay-lens and camera for the full-disk mode is switched by the linear stage with a pulse motor. These devices are controlled by a personal computer (PC1) via a GPIB interface. Wavelength scanning devices of Lyot filter (0.25 Å passband) controlled by another personal computer (PC2) enables us to perform two dimensional spectroscopy in $H\alpha$.

To suppress the atmospheric turbulence around the telescope, an observation room has a removable sliding roof instead of a dome with a slit. The surface of buildings is painted white to reflect solar heat.

3. Imaging System

A major upgrade of the imaging system for our telescope was done in July 1994. Table 1 gives some principal parameters for this imaging system.

Before July 1994, the imaging system is composed of a CCD video camera, image capture board, post-focus optics, and so on. Two relay lens systems create solar images of different sizes on the CCD

Fig. 1. Schematic diagram of the optical configuration of $H\alpha$ Solar Telescope at Hiraiso.

cameras in full-disk and close-up observations. The detail of the system before July 1994 was described by Akioka *et al.* (1994). A new imaging system installed in July 1994 consists of digital CCD cameras, a relay lens, a field lens and mechanical stages, and so on. Figure 2 is a schematic drawing of the new imaging system. For the close-up mode observation, a CCD camera of 1360×1037 (Megaplex 1.4 fabricated by Eastman Kodak Co. Ltd.) is located at the primary focus of the telescope and direct images are taken with its 6.8 micron pixels. The lens-camera assembly for full-disk mode consists of a field lens

Table 1. Typical plate scales and observation intervals for full-disk and close-up observations.

Mode	Plate scale (arcsec/pix)	Field of view (arcmin)	Interval (min)
<i>Before July 1994</i>			
Full-disk	4.2	44.3×33.2	10
Close up (wide field)	0.83	8.9×6.6	30
Close up (Narrow field)	0.83	5.3×5.3	2
<i>After July 1994</i>			
Full-disk	1.15	38.9×39.4	10
Close up	0.64	5.5×5.5	2

Fig. 2. The imaging package for the H α Solar Telescope. Full-disk camera, a relay lens and a field lens are assembled on a small base plate on the focusing stage. Light comes from the left side of the drawing.

(D: 46 mm, f: 135.6 mm), a relay lens (f: 55 mm F2.8 micro Nikkor), and a 2 K by 2 K CCD camera (Megaplug 4.2). If the F ratio (ratio of focal length to effective aperture) is less than 18, the passband of the Lyot filter will broaden incorrectly due to the tilted rays passing through the birefringent elements. Therefore, the field lens is located on the focal plane to make a pupil on the stop of the relay lens. To reduce the effective aperture, the diameter of the pupil is reduced by a fan-like stop of micro Nikkor lens instead of the primary lens itself.

Plate scales and typical observation intervals are listed in Table 1. The output from the two CCD cameras is digitized with an 8 bit or 10 bit A/D converter equipped in the cameras. A mechanical shutter before CCD chip enables automatic adjustment of exposure duration depending on the change in image intensity caused by the change in atmospheric transmission. After exposure, digital video data from the CCD camera are transferred to the main memory of the workstation. Frame selection and other real-time data processing are carried out on a UNIX workstation. After that, data files are compressed and saved on the hard-disk of the workstation.

The frame selection technique is important in obtaining better resolution images, because other wavefront correction techniques are not useful for extended objects such as the Sun. Some observatories

Fig. 3. Example of images taken with the full-disk mode on September 4, 1994. A small frame in the lower right is a cut-out image from the full-disk data showing the details of the full-disk images. The cut-out area of the small frame is 7.4×5.7 arcmin..

are trying to develop more reliable and faster techniques (see von der Luhe (1991) for a general review). In our imaging system, frame selection works on a UNIX workstation. To select an image, many trial images are taken in a short period and the averaged image contrast in a limited area are calculated in real-time by the following equation,

$$\text{Averaged Contrast} = \sum |I(i+1, j) - I(i, j)| / \sum (I(i, j)).$$

Here, $I(i, j)$ stands for the intensity of the image at the (i, j) -th pixel. The image with the highest contrast is finally selected and stored on data recording media. The area for the contrast calculation and the number of trials can be changed easily with observation support software. It takes 5 seconds to make the trials for 20 images in the close up mode, including camera set-up, data transfer, contrast calculation and writing on hard-disk.

Fig. 4. Examples of the close-up mode observation on September 4, 1994. The left hand side panels are taken at the H α line center, and the right hand side ones in H α + 0.7 Å, with a narrow band Lyot filter. The field of view is 5.5×5.5 arcmin..

Validity of this algorithm were examined with the laboratory test with the imaging system and software actually operated on the telescope. Here, we compared an in focus image and an out-of-focus image and calculated the contrast value as we defined. The area used for this calculation is made of 384 by 30 pixels. In the typical results of 20 trials, the contrast value was 0.0068 for the out-of-focus image, and 0.011, for the in focus image. The difference mainly comes from the edge of features. So, this method is valid to discriminate between clear images and blurred images.

4. Examples of Observations

Figure 3 is an example of images taken with the full-disk mode. A small frame is extracted from the original full-disk image to show the detail of an active region observed with the full-disk mode. Notice tiny fibrils and filaments clearly seen even in the full-disk image. Such a high resolution digital image of the whole solar disk is very essential for flare forecasts. Furthermore, as the accurate coordinates of a feature can be obtained using the position of the solar limb, alignment with data from other instruments is easy.

Figure 4 is an example of data obtained in the close-up mode. Images in $H\alpha$ line center and in the red wing ($H\alpha + 0.7 \text{ \AA}$) taken nearly simultaneously are shown. A dark jet-like ejection or surge with a small bright point can be seen near the sunspot at the lower left part of the region. We can study the velocity field of $H\alpha$ features by comparing images taken in different wavelengths along $H\alpha$ line. When the wavelength is set on the far wing (e.g. offset of larger than $5 \text{ \AA}$), clear sunspot images in continuum are also available.

5. Concluding Remarks

The new $H\alpha$ telescope at Hiraiso is now in operation and enables us to obtain high quality full-disk images with 4 million pixels and an $H\alpha$ velocity maps in real time. This telescope system provides more detailed information such as the complexity of magnetic structures, emergence of new magnetic flux, and change in filament structures over the full solar disk and allows us to give more reliable flare forecasts. In addition, some collaborative data analyses with data obtained with other instruments are in progress on several topics. Furthermore, we are constructing a data base of active regions and active events observed with this system. Part of this database are available via the internet.

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