

Long-term synoptic observations of the Sun at the National Astronomical Observatory of Japan

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Abstract. The National Astronomical Observatory of Japan started regular synoptic solar observations about 100 years ago. At the beginning, Ca K spectroheliograms and white-light photographs were taken, and various other types of observations have been added. These historical data have been digitized and are now open at our web site (<http://solarwww.mtk.nao.ac.jp/en/solarobs.html>). Currently we are operating high-resolution imaging observations in the H α line, the green continuum, and the G-band. Besides various kinds of imaging observations, magnetic field measurements have been carried out for about 30 years. We recently started to conduct full-Sun spectropolarimetry observations in the lines of He 10830 Å/Si 10827 Å and Fe 15648 Å. These near infrared observations show the magnetic field evolutions in both the photosphere and the chromosphere. In this paper, we present our data, which are expected to contribute to studying the long-term change of the solar activity.

1. Introduction: NAOJ History of Solar Observation

Long-term solar variability is not only an important clue to study the stellar dynamo, but also it is a source of the change in the solar system's environment, including the earth's climate. To study the long-term variation of the solar magnetic activity, synoptic solar observations are essentially important. Sunspot records using telescopes date back to about 400 years ago, and the sunspot relative number has been used as a canonical index of the solar activity. However, the sunspot relative number shows only one aspect of the solar activity. Two-dimensional, full-disk information of the upper solar atmosphere and the solar magnetic field is more important, and both utilizing old data and ensuring to continue the current observation for long time are required to understand the long-term variability.

The Tokyo Astronomical Observatory, the predecessor of the National Astronomical Observatory of Japan, started the regular solar observation in the 1910's in Tokyo, Japan. Photographic and hand drawing observations were continued until the 1990's, and now the observations are carried out with electric devices. The accumulated analog data had been difficult to be distributed, and therefore digitization of the plates, films, and hand drawings was started about ten years ago. The project to digitize analog records was led by Prof T. Sakurai, and was carried out with some funds from the Japan Society for the Promotion of Science and Nagoya University, and recently it was completed.

About nine solar cycles are covered by various types of observations, and the following data, not only digitally acquired data but also digitized old analog data, are available online now.



- Sunspot relative numbers: 1929–
- Sunspot drawings: 1939–1998, digitized
- Full-disk white-light images: 1918–1998 digitized photographs, 1997– electronic data
- Full-disk Ca K images: 1917–1974 digitized photographs
- Full-disk H α images: 1949–1964 digitized drawings, 1957–1992 digitized photographs, 1991– electronic, 2011– high-resolution with off-band images
- Full-disk magnetograms: 1993–2006 imaging polarimetry at Fe 6303 Å, longitudinal B and Doppler, 2010– spectropolarimetry, He 10830 Å/Si 10827 Å and Fe 15648 Å lines
- Full disk He 10830 Å: 1991–1998 spectroheliograms, electronic
- Active region H α images: 1990–2007, electronic, partly with polarimetry
- Active region magnetograms: 1982–1995 spectropolarimetry at Okayama, 1992–2007 imaging polarimetry at Mitaka, Tokyo
- Coronal green-line images: 1978–1991 digitized photographs, 1997–2009 electronic
- Coronal green-line intensities: 1951–2009

In the following section, we will briefly introduce the observations for various types of the targets to promote data use for synoptic solar physics. A review of scientific results from the old observations is found in [1].

2. Data

2.1. Full-disk Chromosphere

The full-disk Ca K observation was started in 1917 with a Grubb 30-cm sidelostat and a Toepfer double-prism spectroheliograph, and was continued until 1974. Basically one scan was carried out per day, and Ca K images were recorded on photographic plates (–1960) and 35mm films (1960–). In total, 8585 images were recorded on 8524 observing days. They show magnetic activity of the Sun before the magnetograph observations became available, as shown in Figure 1(a). Furthermore, Ca K activity is considered to be closely related with the UV irradiance of the Sun. The Ca K data during recent 100 years taken at some observatories (Kodaikanal from 1905, Mt. Wilson from 1915, and Arcetri from 1930) have been already digitized, and some attempts to reproduce the correct Ca K activity have been made (see [2], and references therein). Our data will contribute to more accurate estimation of the Ca K activity in the 20th century (Figure 1(b)).

Since 1949, the full-disk H α observation was carried out with hand drawing using a spectrohelioscope. In 1957 photographic observation was started with a OPL Lyot filter with a 0.75 Å passband, and later on CCD imaging with a Halle Lyot filter succeeded it. Recently we started high-resolution imagings, with a 2k \times 2k camera and a 0.25 Å passband Zeiss Lyot filter, and the obtained images are comparable to those taken by the Global High Resolution H α Network (see http://swrl.njit.edu/ghn_web/). In addition, now we are taking images at several wavelengths around the H α line (center, ± 0.5 Å, ± 0.8 Å, and $+3.5$ Å). Those data show flares and filament activities not only with brightness changes but also with Doppler velocities. H α data give us three dimensional information of mass motions, and this fact makes that the H α observations are unique and difficult to be substituted with simple imaging observations in other wavelengths.

2.2. Full-disk Photosphere

White-light photographic imaging observation was started in 1918, and now we are taking white-light images with a CCD camera. Sunspot relative number derivation was started in 1929 [3]. Sunspots were formerly counted on the hand-drawn sketches, but now the images taken by the

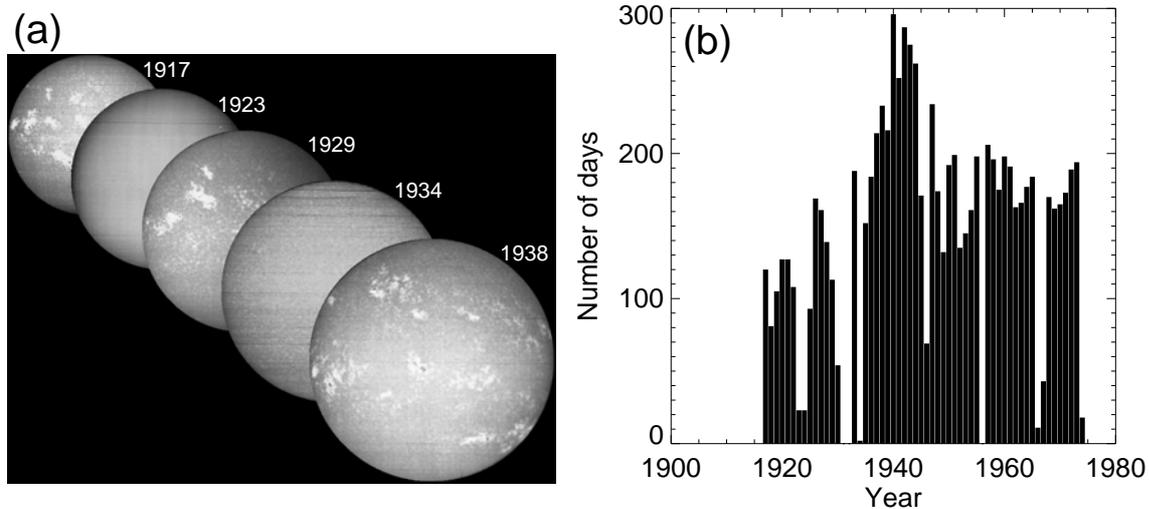


Figure 1. (a) Some samples of the Ca K spectroheliograms taken by NAOJ during the early 20th century. Solar activity cycle can be seen in these images. (b) Annual number of Ca K observing days. During 1917–1974, the Ca K spectroheliograms were taken on 8524 days.

CCD camera is used for automatic pick-up of sunspots [4]. Recently we are working to replace the current system with a new imaging system, which takes G-band (CH 4305 Å) images as well as green continuum images.

2.3. Magnetic Field

NAOJ is the only institute which continues regular solar magnetic field observations in Japan. In 1982, vector magnetic field measurements of active regions was started at the Okayama Observatory of NAOJ with a spectropolarimetry instrument [5]. In 1992, imaging polarimetry at Fe I 6303 Å line was started with the Solar Flare Telescope [6] at Mitaka, Tokyo. In 2002, polarimetry in the H α line was added to study polarization signals in the chromosphere. These active region polarimetry was continued until 2007, and then, we have installed a full-disk near-infrared spectropolarimeter on this telescope, and from 2010 it has been under operation (see [7]; full description is now in preparation by Sakurai *et al.*). Observing wavelengths are as follows, and sample Stokes maps are shown in Figure 2.

- He I 10830 Å: This line shows the polarization signals in the chromosphere. In addition to the Zeeman polarizations in sunspots and plages, prominences show atomic and Hanlé polarizations, and they contain information of the magnetic field in prominences. A nearby line, Si I 10827 Å, which show the photospheric magnetic field, is observed simultaneously with the He line.
- Fe I 15648 Å: This line shows the photospheric magnetic field. This line has a large Landé factor, and with the long wavelength, it shows much larger Zeeman splitting than usual lines used in the solar polarimetry. Therefore, we can estimate the magnetic field strength down to a couple of hundred gauss directly from the separation of Zeeman split components, regardless of the filling factor of the magnetized area.

This infrared polarimeter is intended to obtain basic magnetic information of both the chromosphere and photosphere for long time. Such an instrument, which regularly measures full-disk, full-Stokes signals in He I 10830 Å and Fe I 15648 Å, is unique, and is expected to contribute to the solar dynamo study.

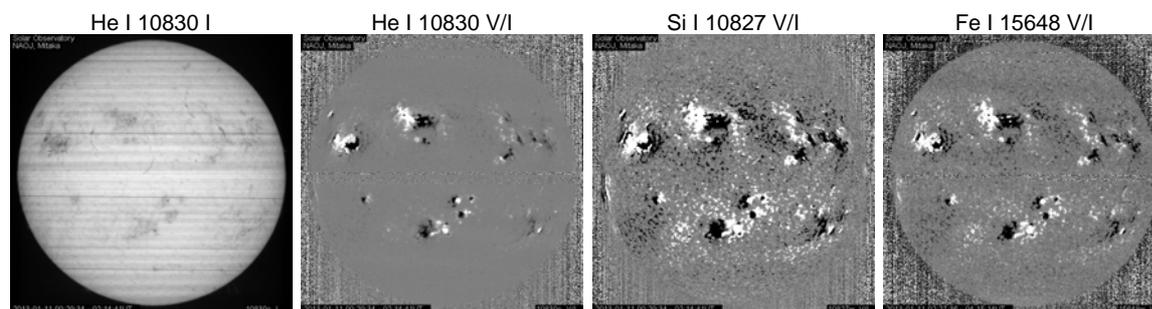


Figure 2. Sample Stokes I image of the He I 10830 Å line and Stokes I/V images of the He I 10830 Å, Si I 10827 Å, and Fe I 15648 Å lines taken with the infrared spectropolarimeter on 2013 Jan 11. The celestial north is to the top.

2.4. Corona: Coronagraphs and Solar Eclipses

The observation with a coronagraph was started in 1949 in the central mountain area in Japan, and until the shut-down in 2009 the Norikura Corona Observatory was operated by NAOJ with some coronagraph systems. The long-term coronal activity variation has been monitored for about 60 years. Latitudinal distribution of the green line (Fe XIV 5303 Å) brightness was also measured; basically it shows similar variation to that seen in sunspot butterfly diagrams, but coronal observations cover to the poles, where the sunspots do not appear. Such coronal observations show synoptic magnetic features before the space observations of the corona became available.

The expeditions for eclipse observations have been dispatched since the 19th century. The total eclipses still provide us unique chances to observe the corona, particularly in the visible wavelengths. In recent eclipses including the very eclipse on 2012 November 14, we collaborated with amateur astronomers to raise the probability to succeed in taking images of the corona under good weather conditions and to obtain data at more than one site [8].

3. Future Prospect

The solar and heliophysics community in Japan is proposing to establish a framework of the cooperation for the ground-base synoptic solar observations. There are various plans to construct or upgrade telescopes and establish data circulation networks. We will promote these projects collaboratively to continue the synoptic observations in the future.

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