First Asia-Pacific Solar Physics Meeting
ASI Conference Series, 2011, Vol. 2, pp 355–365
Edited by Arnab Rai Choudhuri & Dipankar Banerjee

The early years of solar research in Japan

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Abstract. The early years of solar research in Japan are described in the order from the solar core to the corona. The contents are as follows; solar neutrino problem, helioseismology, solar dynamo, photosphere, sunspots, chromosphere, flares, prominence, corona, total solar eclipses, radio observations, space observations, observatories, archival solar data, and prospect.

Keywords : Sun: general – history and philosophy of astronomy

1. Introduction

The Sun is a rotating self-gravitational plasma sphere with a fusion reactor in its core. The Sun has two faces of the quiet and dynamic states. All living beings on earth are keeping their lives by the favour of the quiet Sun like "the Sun as a mother", but recent solar satellites show many scale sizes of dynamic activities like "the Sun as youth". The Sun has revolved about 23 times around the centre of our Galaxy, and thus we may call the solar age to be 23 if we count it like a person. In the earlier phase of the 20th century, the solar problems were mainly on the quiet Sun, but nowadays the central problems of the research have shifted to its dynamic activity.

2. Solar neutrino problem

Measured solar neutrino fluxes at neutrino observatories are found to be about a third or half of the expected value from the standard solar model, and it had been one of the unsolved problems late in the 20th century. It was proposed that neutrinos could change from one type to another if they had mass. The definitive evidence of neutrino oscillation came in 2001 from Super-Kamiokande collaboration (Fukuda et al. 2001) and Sudbury Neutrino Observatory collaboration (Ahmad et al. 2001). However, there

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might occur another problem of the solar chemical composition involving the helium abundance (Nakahata 2011)

3. Helioseismology

Oscillatory motions in the solar atmosphere have revealed the superposition of many modes with discrete eigenfrequencies of the acoustic mode. Ando & Osaki (1975) had theoretically studied the spectra of eigenfrequencies, which were in good agreement with the observation (Deubner, Ulrich & Rhodes 1979). Non-radial oscillation of the solar atmosphere and convection were extensively studied by Unno and his colleagues (Unno et al. 1979; Osaki & Shibahashi 1986; Sakurai Takeo 1966).

4. Solar dynamo

The behaviour and phenomena occurring inside the Sun were vigorously studied by Yoshimura (1972, 1975a,b, 1981, 1983, 1993), who made a lot of simulations by solving the dynamo equation under a working hypothesis of global convection and provided theoretical models of such things as the 11-year sunspot cycle, the butterfly diagram of sunspots, the reversal of magnetic field, 55 years' cycle, Maunder minimum type variation, variability of solar constant, dynamo wave propagation. Recent dynamo models have been constructed (Choudhuri et al. 1995; Hotta & Yokoyama 2010), taking into account the results of helioseismic observations.

5. Photosphere

Radiative transfer on line formation and continuum had been extensively studied in 1950s for understanding the underlying mechanism and for deriving physical quantities of the photosphere . One example of very important research is "Line Formation of a Normal Zeeman Triplet" (Unno 1956), which has provided a useful method for estimating the magnetic field in the solar atmosphere.

The angular diameter of the Sun observed with a meridian circle (Yoshizawa 1996) or derived from an eclipse observation (Kubo 1993) have been reported and should be compared with the measurements made in future for studying the change of solar diameter with time.

6. Sunspots

The oldest record on sunspots, which appeared in AD 851, is reported in a historical book (Montoku-Jitsuroku) in Japan. Goryu Asada (1734-1799), an astronomer in the Edo period, observed sunspots by a telescope in 1769 and found that the solar rotation period was about 30 days and sunspots did not appear near polar regions. Tobei Kunitomo (1778-1840), an artisan for making guns, observed the Sun in 1835 for 157 days by his hand-made Gregory-type reflector. His mirror is still shining and is nearly parabolic (Tomita et al. 1998). Continuous observations of sunspots were made in 1888 by Prof. S. Hirayama. From the recorded data of sunspot sketches made at NAOJ, including Greenwich sunspot data, Yoshimura & Kambry (1993) derived differential rotations for more than 100 years from solar cycle 12 to cycle 22 in order to study a periodic long-term modulation of the surface rotation.

Makita (1963) derived a sunspot model in which the temperature distribution is lower than Michard's because his measurements seem to be less affected by scintillation. Ichimoto (1998) studied the Evershed flow using 85 lines. The magnetic field of sunspots was measured at Solar Tower Telescope of NAOJ (Tanaka et al. 1939a,b), at 65-cm coudé-type solar telescope at Okayama Observatory of NAOJ, and at Solar Flare Telescope. Hagino & Sakurai (2004) studied the helicity deduced from the observations with Solar Flare Telescope and confirmed a rule of negative (positive) helicity in northern (southern) hemisphere. Their measurements suggest the process generating helicity to be of random/turbulent nature involving convective motions.

7. Chromosphere

A close relation between Hα fine structure and its evolution due to magnetic field change was studied by Tanaka (1974) and Kurokawa et al. (1986). Kitai (1983) showed the "Ellerman bomb", seen also as "moustache", to be locally heated (ΔT=1500K) and condensed atmosphere with upward mass motion of 6 km s^{-1}. Suemoto, Hiei & Nakagawa (1990) observed K line profiles and detected chromospheric bright regions, corresponding to the upper region of central dark parts of the granulation, which is seen in Hinode images. A chromospheric model (Hiei 1963; Tanaka & Hiei 1972; Makita 1972; Kurokawa et al. 1974) and the turbulent velocity in the chromosphere (Suemoto 1963) were derived from flash spectra, and the temperature structure in the transition region of chromosphere-corona was studied by Kanno, Tsubaki & Kurokawa (1971) and Suemoto & Moriyama (1964).

Nagasawa (1955) derived electrical conductivity at the low chromosphere and umbra. Theoretical models of spicule were studied by i) Unno & Kawabata (1955) as a direct manifestation of the passage of a hydrodynamic shock wave, ii) Uchida (1961) as a shock wave propagating into the corona, and iii) Suematsu et al. (1982) as phenomena occurring as a result of sudden pressure enhancement at their roots. Propagation and dissipation of waves in the chromosphere were studied by i) Ono, Sakashita & Ohyama (1961) as an initially non-uniform medium in the presence of a gravitational field, ii) Saito (1964) as transport of mechanical energy, and iii) Kato (1966) as isothermal medium with no magnetic field.

8. Flares

A method of precise determination of electron density from the Stark effect of higher Balmer lines was studied by Suemoto & Hiei (1959), who found that a flare is composed of many filamentary structures of sizes a few times 10 km. From Hα filtergrams with high spatial/time resolution and magnetic field measurements, Tanaka & Zirin (1985) found that flares occurred near a magnetic shear region, which is later confirmed by data of Yohkoh and Hinode satellites. Ichimoto & Kurokawa (1984) reported that chromospheric brightening and a red asymmetry of Hα line occurred at the onset of a flare due to the downflow of high energy electrons. Kurokawa, Takakura & Ohki (1988) found a close relation between Hα brightening and X-ray emission, and concluded that the fast electron beam is the main heating mechanism of Hα flare in the impulsive phase.

Spectroscopic studies of white light flares (WLF) were made by Hiei (1982), Fang, Hiei & Okamoto (1991), Ding, Fang & Okamoto (1994), Hu et al. (1995). There are three types of WLF brightenings: i) impulsive, ii) gradual, and iii) wave-like brightenings, which correspond to downflow of high energy electrons, energy supply from high temperature plasma, and X-ray irradiation of flare loops.

Tanaka et al. (1982) observed X-ray lines of Fe XXVI and Fe XXV in a X-2.2 class flare with Hinotori satellite and derived time profiles of line intensities, line widths, and plasma parameters, and reported that Fe XXVI intensity reached maximum 1 minute earlier than Fe XXV line, T_e became $4{\times}10^7$K, and line width was 250 km s^{-1} at the onset. Nakajima et al. (1983) detected a flare which shows 7 pulses of peak intensities in microwave, hard X-ray, and γ-ray line emissions with a little time difference each, and found that the association of particle acceleration took place successively within a few seconds. Kai, Kosugi & Naitta (1985) studied flux relations between hard X-rays and 17-GHz microwaves for impulsive/extended flares for placing a strong constraint for flare models.

Nagai (1980) derived a model of hot loops associated with a flare from gas dynamics in the loop. An evaporating X-ray loop at a flare was detected from data of SKYLAB (Hiei & Widing 1979). Uchida (1968) studied Moreton waves as propagation of hydromagnetic disturbances in the solar corona. Suzuki, Sakurai & Ichimoto (2006) studied structure of magnetic fields before CMEs, and Hiei, Hundhausen & Sime (1993) studied the largest CME observed with Yohkoh.

Masuda et al. (1994) found a loop-top hard X-ray source in a compact solar flare as an evidence for magnetic reconnection. Tsuneta (1996, 1997) discussed structure and dynamics of magnetic reconnection regions and proposed a new MHD image of heating/acceleration of a flare. Shibata et al. (1992) detected the new phenomenon of X-ray jets caused by magnetic reconnection, and Yokoyama & Shibata (1998) studied the reconnection model of X-ray jets. An interesting flare theory of high-β disruption was proposed by Shibasaki (2001). A model of flares known as the CSHKP

(Carmichael; Sturrock; Hirayama; Kopp-Pneuman) model was proposed by Hirayama (1974). Tajima & Shibata (1997) wrote a book on plasma astrophysics.

9. Prominence

Hirayama (1985) reviewed observational studies of prominences (emphasizing topology of magnetic fields measured by Hanle and Zeeman effects), spectroscopic characteristics of quiescent prominences, flow patterns at prominence-corona interface, prominence evolution, prominence activities, and surges. Tsubaki, Ohnishi & Suematsu (1987) found a periodic oscillation of a period of 160 s and an amplitude of around 1km s^{-1} in a quiescent prominence. Bright soft X-ray arcades and coronal holes associated with the disappearance of prominences (DB) were studied by Watanabe et al. (1992) and Hiei et al. (1998), who suggest that magnetic reconnection occurred near DB and coronal matter moved up with DB.

Sakurai (1976) discussed the screw-mode instability for the onset of ascending motions of three types of arch-, loop-, and gigantic arch-prominences, and concluded that the motions of all types of eruptions were reproduced by perturbing a model sequence with decreasing pitch angles of the helical magnetic field lines. Sakai & Koide (1992) discussed filament eruptions moving up with X-point before impulsive phase of flares. A beautiful prominence is studied with Hinode satellite, and Okamoto et al. (2007) found Alfvén waves propagating in the prominence.

10. Corona

The ionization theory of the solar corona was first studied by Miyamoto, whose paper was published in Japanese (1943) and later translated in English (1949).

From the coronal images taken at total solar eclipses, Notsuki (1936) derived fine structures of streamers and polar plumes, Saito & Hata (1964) reported 3-dimensional structure of streamers, and Takeda et al. (1994) discussed spatial distribution of loops of Fe x 6374Å, Fe xiv 5303Å, Ca xv 5694Å.

From the coronagraph data observed at Norikura observatory, i) Nagasawa (1961) studied a relation between 5303 line intensity and sunspot groups, ii) Singh et al. (1999) and Minarovjech et al. (2003) studied coronal intensity oscillations of 5-minute period, iii) Sakurai et al. (2002) found coronal waves of 1-3 mHz range and the existence of possibly sound waves of 100 km s^{-1}, although the existence of Alfvén waves is inconclusive.

Magnetic field configurations in the corona (Sakurai & Uchida 1977; Sakurai 1981) and magnetic helicity injection into the corona (Kusano et al. 2002) have been studied. Coronal heating (Uchida 1963; Yamazaki, Hashimoto & Ono 1969) and

Table 1. Expeditions of solar eclipses in Japan.
T : Total solar eclipse, A : Annular eclipse, P : Partial eclipse.

1883/10/31	A	Miyagi, Japan	1962/2/5	T	Lae, New Guinea
1887/8/19	T	Niigata,Tochigi, Japan	1963/7/21	T	Hokkaido, Japan
1896/8/9	T	Hokkaido, Japan	1965/5/30	T	Manue, South Pacific
1898/1/22	T	near Bombay, India	1966/11/12	T	Arequipa, Peru
1901/5/18	T	Sumatora	1970/3/7	T	Mexico
1915/8/11	A	Ogasawara, Japan	1973/6/30	T	Mauritania
1918/6/9	T	Izu islands, Japan	1974/6/20	T	New guinea
1929/5/9	T	Mallay, Sumatra	1976/10/23	T	Australia
1932/8/31	T	USA	1980/2/16	T	Kennya
1934/2/14	T	Rosop island	1983/6/11	T	Indonesia
1936/6/19	T	Hokkaido, Japan	1988/3/18	T	Ogasawara, Japan
1941/9/21	T	Okinawa, Japan	1991/7/11	T	Hawaii and Mexico
1943/2/5	T	Hokkaido, Japan	1994/11/3	T	Chili and Paraguay
1948/5/9	A	Rebun island, Japan	1995/10/24	T	India
1950/9/12	P	Hokkaido, Japan	1997/3/9	T	Caribbean sea
1955/6/20	T	Ceylon	1999/8/11	T	Turkey
1958/4/19	A	Tanegashima, Japan	2006/3/29	T	Turkey
1958/10/12	T	Suwarrow, South Pacific	2009/7/22	T	Iwo Island, Japan

heating due to small X-ray intensity fluctuations and nano-flares (Shimizu 1995; Katsukawa & Tsuneta 2001) were reported.

11. Total solar eclipses

Observations at total solar eclipses were carried out as shown in Table1. “Grazing incidence method” for taking flash spectra is unique. Suemoto & Hiei (1962), applying the magnifying power of a prism/grating (Wood 1934), took the chromospheric lines not affected by chromospheric scale height by using this method. Another unique observation is to detect velocity of solar wind by taking continuous spectrum of K-corona from 360 nm to 470 nm, which shows a little dip near 385 nm and 430 nm. If solar wind moves upward, the continuous spectrum of K-corona shifted due to Doppler effect. Ichimoto et al. (1994) observed solar wind velocity of 80 km s^{-1} by using this method. Infrared brightness of F-corona was successfully observed from a balloon at an altitude of 30.5 km at the Indonesia total solar eclipse in June 1983 (Isobe et al. 1985). An excess in infrared brightness had been found, but the results are debatable.

12. Radio observations

Radio emission from the Sun was first detected in Japan in 1938, and the early history of radio observations was reported by Tanaka (1984). Tanaka et al. (1951) had measured microwave sky-background temperature to be 0-5 K. It would have been a great discovery if he stressed the existence of the background radiation. In 1965 Wilson and Penzias discovered the 3 K microwave background radiation, which led to the Nobel prize of 1978 to them.

Akabane & Hatanaka (1957) observed the polarization of solar radio outbursts related to optical flares. Kakinuma & Swarup (1962) derived a model for the radio sources of microwave. Kai (1962, 1986) studied the characteristic of spectral Type I-IV radio bursts and a relation of microwave flux/hard X-ray. Enomé & Tanaka (1970) inferred coronal magnetic fields from the microwave data. Kosugi, Ishiguro & Shibasaki (1986) reported the polar cap brightening observed at millimeter wavelengths.

Theory of solar bursts (Takakura & Kai 1961), transfer of the gyroresonance radiation (Kawabata 1964), and excitations of Type II/III solar radio bursts (Uchida 1960) have been discussed. Scientific results and instruments of Nobeyama Radio Observatory are discussed in *Proc. of Nobeyama Symp.* 1998 and *Proc. of Nobeyama Symp.* 2004.

13. Space observations

Solar space observations in Japan started from rockets (Nishi & Suemoto 1971) and balloons (Hirayama 1972) in 1971. Solar satellites Hinotori (P.I.: Y. Tanaka and K. Tanaka, size: 1m×1m×0.8m, weight: 188 kg, M-3S rocket) was launched in 1981, Yohkoh (P.I.: Ogawara and Uchida, size: 1m×1m×2m, weight: 390 kg, M-3SII rocket) in 1991, and Hinode (P.I.: Kosugi/Sakao and Tsuneta, size: 1.6m× 1.6m×4.0m, weight: 900 kg, M-V rocket) in 2006. They were launched from Uchinoura, in southern part of Japan. Yohkoh and Hinode projects involved Japan-U.S.-UK. collaborations. Scientific results and details of instruments are published in special issues of journals and conference proceedings. Hinotori: 1983, Sol. Phys., 86. Yohkoh: (i) 1991, Sol. Phys., 136, No.1; (ii) 1991, The Yohkoh (Solar-A) Mission, eds. Z. Svestak, Y. Uchida Y.; (iii) 1992, PASJ, 44, No.5; (iv) 2002, Proc. COSPAR Colloq. Series Vol.13. Hinode: (i) 2007, PASJ, 59, No. SP3; (ii) 2007, Sol. Phys., 243; (iii) 2007, Science 318, no. 5856, p. 1571 (iv) 2008, Sol. Phys., 249; (v) 2008, The Hinode Mission, ed. T. Sakurai.

14. Observatories and solar observing facilities

National Astronomical Observatory of Japan (NAOJ) was founded in 1878. Observing instruments now are i) Solar Flare Telescope for measuring vector magnetic field and observing Hα flare, ii) A 10 cm aperture telescope for automatic recording of sunspots and faculae. At Norikura Corona Observatory, a 10 cm aperture coronagraph was installed at a height of 2876 m (Notsuki 1951) in 1949 for visual measurement of Fe xiv 5303Å line intensity, and was modified in 1997 for automatic observation. In 1971, a 25 cm Coudé-type coronagraph was set up for spectroscopic and polarimetric observations of corona, prominences and limb flares. The observatory was closed in 2010.

Nobeyama Solar Radio Observatory of NAOJ, established in 1968, has i) Radio Heliograph at 17GHz and 34GHz, and ii) antenna for measuring flux/polarization at 1, 2, 3.75, 9.4, 17, 35, 80 GHz. Toyokawa Solar Radio Observatory was opened at 1949 and joined NAOJ in 1988.

Kwasan Observatory, University of Kyoto, was opened in 1929 and moved to Hida Observatory in 1968, where there are i) 60 cm Domeless Solar Telescope and ii) Flare Monitor Telescope.

15. Archival solar data

At NAOJ
· sunspots sketch and white light images; 1923~now
· Ca K-line spectroheliograms (full sun); 1913~1974
· Hα spectrohelioscope; 1947~1967
· Hα filtergrams; 1957~now
· Intensity of Fe xɪv 5303Å emission line; 1949 ~2009
At Kwasan Observatory
· photographic plates of whole Sun(not regular); 1957~1962
· Hα filtergrams of whole sun; 1992~2010
· high resolution Hα filtergrams of whole sun; 2003~now
· Ca K-line spectroheliograms (not regular); 1937~1968
Radio data
- Observing frequencies (TYKW: Toyokawa, NBYM: Nobeyama)
· 1GHz: TYKW/NBYM 1957.3~
· 2GHz: TYKW/NBYM 1957.6~
· 3.75GHz: TYKW/NBYM 1950.11~
· 9.4GHz: TYKW/NBYM 1956.5~
· 17GHz: NBYM 1978.1~
· 35GHz: NBYM (no daily flux values)
· 80GHz: NBYM (no daily flux values)
- Data acquisition
· digital data: (0.1 sec) 1987.11~
· daily total flux values: 1950.11~

16. Prospects

The Sun deepens our knowledge of the characteristics of Nature and always gives us new information when the observation is carried out with higher quality. The unsolved solar problems confronting us today can be divided into two classes: those which are expected to be solved within 10–100 years, and the others which are hoped to be solved within 100–1000 years. The coronal heating, and the heating/particle acceleration of a flare/solar wind, and the prediction of occurrences of such activities belong to the former group. During the last 4.6 billion years, the Sun has displayed unexplained activities such as Maunder minimum type variations, which belong to the latter. It is therefore important to accumulate some data for more than 100–1000 years in order to make clear the solar variability and the generation of magnetic fields. Fortunately the sunspot sketches drawn by Galilei are preserved. The data on sunspots sketches and numbers at least should be preserved. Also, the data of absolute solar constant, magnetic field, and reliable solar radio fluxes should also be kept for many years. What data should we leave for the future?

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