# SPACE OBSERVATIONS OF THE SUN AT TAO

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## 1. Introduction

Many of the recent progress in Solar Physics have been the result of extensive observations from outside the terrestrial atmosphere. More than twenty years have passed since the solar observation from outside the terrestrial atomosphere was started by TAO staff in close collaboration with the Institute of Space and Aeronautical Science(ISAS) of the University of Tokyo.

Balloon projects so far conducted since 1967 contain spectroscopy of the Sun in Infrared(IR) and Ultraviolet(UV) regions, the study of the fine structure of the solar atmosphere in visible region, and the measurement of the solar X-ray bursts. The last two programs will be continued by using a larger 30 cm aperture telescope from Balloon and X-ray modulation collimator with better spatial resolution (15") and high time resolution from the Astro-A satellite to be launched next year respectively.

Rocket observation by TAO staff was started in 1958 as one of the IGY programs. The measurements of the absolute intensity and the center to limb variations of the Sun in the vacuum ultraviolet region have been successfully performed from 1971 to 1975, and further experiments will be hopefully expected.

The astronomical observation from Japanese satellite was started in 1971, and the solar radio emissions were measured by the first satellite for the scientific study -Shinsei-. The study of solar flares, particularly in the soft X-ray region, was successfully performed by a Bragg type spectrometer on the Tansei-4 satellite which was launched in this February as a test flight for the Astro-A satellite. The Astro-A is the seventh scientific satellite of ISAS to make detailed study of solar flares mainly in the X-ray region during periods of enhanced solar activity, and will be launched coming February.

Table 1 contains a list of all successful experiments from Balloon, Rocket, and Satellite with general view of each experiment, a list of planned experiments in the near future, and a long range plan.

Table 1

List of successful Observations of the Sun from Space performed by TAO

Balloons

Infrared region

| Date of launch | Instrumentaion | Pointing accuracy | Spectral resolutin | Spectral range | Maximum height | References |
|---|---|---|---|---|---|---|
| 1968 Sept. 5 | Czerny-Turner type scanning monochrometer Detector PbS | 1° | 10A | 0.98μm～ 2.19μm | 24 km | 1 |
| 1970 Sept.14 | Imaging tele-scope and the monochromator | 0.1° | 0.5A | 0.73μm～ 1.36μm | 27 km | 2 |
| 1972 Sept.20 | nearly same system | 1' | 0.5A 1.0A | 1.15μm～ 2.47μm | 27 km | 3 |

Visible region

| Date of launch | Instrumentation | Pointing accuracy | spatial resolution | Spectral band | Maximum height | References |
|---|---|---|---|---|---|---|
| 1971 Sept.14 | Imaging tele-scope ( φ=5cm), camera and TV system | Test for pointing and focusing by TV technique, thermal effects | | about 400A centered at 5300A | 26 Km | 4, 5, 6 |
| 1973 Sept.15 | Imaging tele-scope(φ=10cm) and same system | 1" | 1" | same as before | 28 km | |
| 1976 Sept. 2 | nearly same system | " | " | " | " | |
| 1977 Sept. 2 | nearly same system | " | " | " | " | |

Ultraviolet region

| Date of launch | Instrumentation | Pointing accuracy | Spectral resolution | Spectral range | Maximum height | References |
|---|---|---|---|---|---|---|
| 1971 Sept.16 | Imaging tele-scope(φ=5cm) scanning mono-chromator | 10" | 7A | 2750A～ 2850A | 34 km | 7, 8, 9 |
| 1975 Sept.11 | Piezoelectric scanning Fabry-Perot Interference spectrometer | 1" | 0.14A | 2780A～ 2820A | 38 km | |

X-ray region

| Date of launch | Instrumentation | Spatial resolution | Spectral (energy) range | Maximum height | References |
|---|---|---|---|---|---|
| 1969 Sept.27 | Modulation collimator Detector; NaI scintillation counter | 1.32' (FWHM) | 20 keV∼ 60 KeV | 35 km | 10 |
| 1970 July 26 | nearly same system | | | 36 km | |

Rockets

| Date of launch | Instrumentation | Spatial resolution | Spectral resolution | Spectral range | Result | References |
|---|---|---|---|---|---|---|
| 1971 Sept.1 | Double-dispersive trichromator | 1.3' | 8.3A | 1629A 1684A 1739A | Abs. I and CLV | 11 |
| 1973 Feb.19 | Single dispersive, Ion Chamber | Whole disk | 78A | 1550A∼ 1950A 1216A | Abs. I Abs. I | 12 |
| 1975 Sept.24 | Grating-spectrometer | 50" | 3.3A | 1630A∼ 2000A | CLV | 13 |

Satellites

| Date of launch | Instrumentation | Spectral range | Spectral resolution | Name | References |
|---|---|---|---|---|---|
| 1971 Sept.28 | Superheterodyne receving set | 8 MHz 5 MHz | 180kHz(3db) 150kHz(3db) | Shinsei | 14 |
| 1980 Feb.17 | Bragg type spectrometer LiF crystal | 1.8A∼1.98A 3.12A∼3.24A Time resolution 6 sec. | 0.007A | Tansei-4 | 15 |

List of planned experiments in the near future

(1) A 30 cm aperture Balloon-borne telescope will be launched in 1981.

(2) A X-ray modulation collimator with high spatial resolution (15") and A set of Bragg type spectrometers with spectral resolutions of 0.00068A and 0.000042A will be launched by the Astro-A in 1981.

Long range plan

UVSAT project

A satellite for observing stars and the Sun in the vacuum ultraviolet region and extreme ultraviolet region is under consideration to be launched in 198?.

2. Experiments and related results

The spectroscopic observation in IR region from Balloon was started in 1968. A very simple Czerny-Turner type scanning monochromator with a PbS detector was used. Two other successful flights were performed in 1970 and 1972 by the improved monochromator with a 0.5A spectral resolution combined with small imaging telescope. By these experiments more than 1500 absorption lines were recorded. Paschen series, Brackett series of Hydrogen and many metal lines were identified. From these experiments we have studied a pointing technique of the observation from Balloon. The balloon gondra itsself is directed by means of a servo-controlled wire-twisting system with a geomagnetic sensor, which was developed by the staff of balloon engineering section of ISAS. The pointing accuracy is about 1°, and this system was used for almost of all experiments as a coase pointing.

Direct photography for Solar surface by balloon-borne telescope was started in 1971 to study the fine structures in the Solar atmosphere. The first step of the project was to test for a fine pointing and focusing by the TV technique which was developed by ISAS staff and temperature measurement of the instrumentation with a 5 cm aperture telescope. After the first successful flight, several flights of 10 cm aperture telescope were performed almost once a year from 1972 to 1977. More than 1000 photographs were obtained by these flights.

The results obtained from the data are as follows;

(1) The life time of facular granules with the average size of 2" is about 4 hours and they flucture in intensity with a time scale of approximately 20 min.

(2) Center to limb variation of the excess brightness of facular granules was obtained.(Fig.1) This result shows that facular is 600K~1000K hotter than the photosphere, if the diameter of facular granules is assumed to be 600~150km respectively.

(3) It is found that the soft X-ray bright points as observed with the Skylab do not correspond spatially to the facular granules near the polar region.

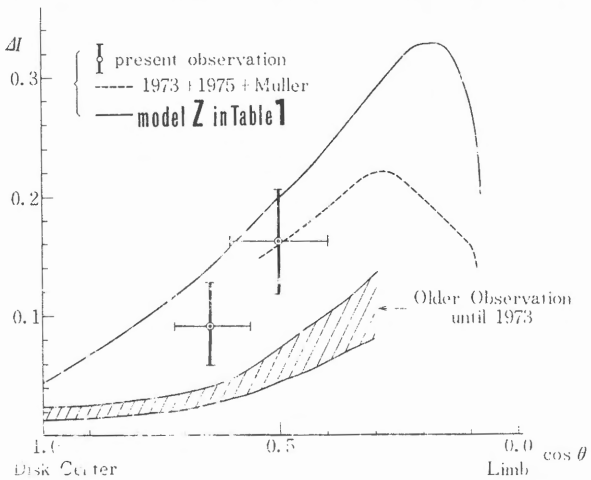



Fig.1. The excess brightness against cosθ, θ being an angle between the sun's normal and the line of sight.

The resonance lines of MgII of 2802.7A and 2795.5A have been used for the study of the Solar chromosphere, and many observations of these lines were done by using balloons, rockets, and satellites worldwidely. The first preliminary experiment with a small grating monochromator was successfully performed in 1971 in collaboration with the staff of Mechanical Engineering Laboratory. The spectral resolution was 7A and the pointing accuracy was 10". In order to obtain better spectral resolution a Farby-Perot interference spectrometer was launched in 1975. The spectrometer consisted of a Piezoelectric scanning Farby-Perot interferometer and a grating as predisperser. The measured resolution was 0.14A. The spectrometer was calibrated absolutely, and the pointing accuracy was about 1". The result is shown in figure 2.

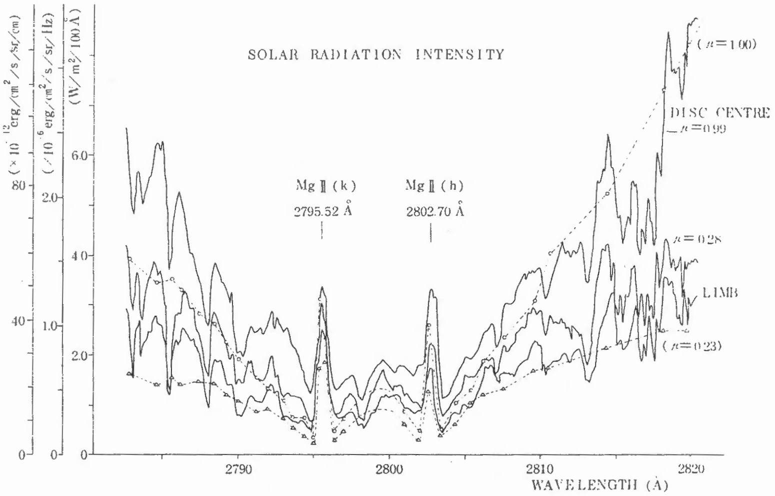
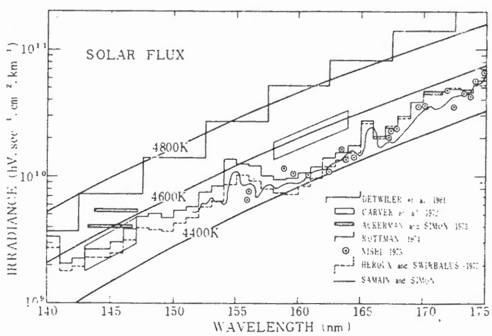
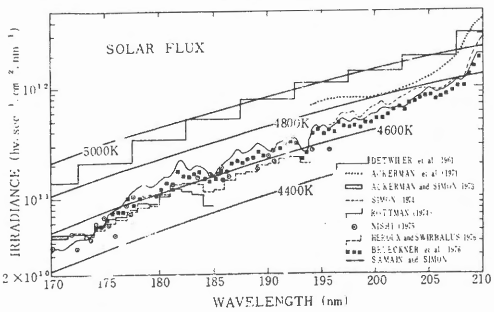



Fig.2. Solar UV spectrum observed by a balloon-borne FP-grating spectrometer. Brief level plots from Kohl and Parkinson(1976) are shown for comparison.

The measuments of size and location of the Solar X-ray burst (20-60 keV) were performed by the balloon-borne modulation collimator in 1969 and 1970. The device has been developed for the measuments of the celestial X-ray sources by the staff of ISAS. The collimator consisted of three grids made of parallel wires, and the angular resolution was 1.32'(FWHM). The X-ray detector was a scintillation counter with NaI(Tl) equipped with a veto-counter of a plastic scintillator. The observable energy range of the detector was from 20 keV to 60 keV. From these experiments it became clear that the size of the X-ray sources was remarkably small (less than 1'), much smaller than the $H_\alpha$ flare size. The finer experiments of the same kind is on schedule for the Astro-A satellite which will be launched next February.

The observation of the solar spectrum from rocket was begun in 1958 as one of the IGY programs. The rocket technique was still on a progressing stage at that time, and the upper limit of launch height was about 50 km, and the pointing technique was not performed yet. Since the rockets could be flown higher than 200 km, the observation of the solar spectrum in the vacuum ultraviolet region (1216A~2000A) became feasible together with the construction of laboratory for the basic experiments of spectroscopy in VUV region. In order to study the physical situation of the solar surface between upper photosphere and lower chromosphere the measurements of the absolute intensity and the center to limb variation were planned. Three flights were successfully performed in 1971, 1973, and 1975.
The results are shown in figure 3.
Our result of the absolute intensity of solar spectrum in this wavelength region seems to nicely coincide with others shown by Samain and Simon (16). Those of the center to limb variation seem to be in good coincidence with the Samain's (17) from 1730A to 2000A but not down to 1630A. It may not be fair to compare ours with others simply, because the spectral and spatial resolutions are different. One thing which we can notice is that the HSRA model can not fit these results. Should we continue to do the extensive calculation taking into account of the effects of many lines like Bonnet, Samain, and many others have tried? Or should we see the fine structures in the spectrem shown by the HRTS performed by Brueckner? And we should also think of the results of flux variations in accordance with the solar activity obtained by recent long-term observation from satellites. The continuous observations with high resolutions and accuracy in the future are quite hopeful.



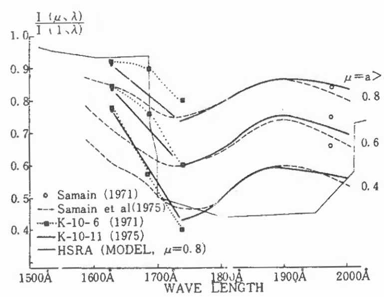




Fig.3.
Comparison of various solar irradiation flux measurements from 140nm to 210nm (from Samain and Simon (16)) and center to limb variation of the Sun.

Solar radio emission in 5 MHz and 8 MHz was measured by the first Japanese scientific satellite Shinsei-, and about ten type III bursts were observed during four months in 1971. The data were compared with those obtained by the IMP-6 USA satellite, and a normalized time profile of type III burst was obtained. On the hypothesis that the time profile corresponds to the one of electron flux, it is shown that the similarity of time profile is maintained even if the electron velocity decreases with the travel distance, provided that the time is normalized at the time of maximum flux.

A test satellite Tansei-4- for the Astro-A satellite, which is on schedule to launch next February, was successfully performed this year. The instrumentation and some results are reported by K.Tanaka in detail. Since the sensitivity of the Solar Bragg Spectrometer is very high, we have big hope and large expectation for the data analysis and for the further observations with the Astro-A which has high spectral resolutions.

3. Planned experiments in the near future

A Balloon-borne telescope for the observation of the fine structure on the Solar surface will be launched next year. The telescope system consists of a 35 cm aperture plane mirror which is used for the fine pointing, a 30 cm aperture main mirror for imaging, a diagonal small mirror which locates at the focus of main mirror to take out a part of solar image, and an enlarging lens system for fine focusing and making the solar image of 44 cm in diameter, two cameras one for white light (5300A, $\Delta\lambda \sim 400$A) and another for UV light (3835A or 3933A $\Delta\lambda \sim 20$A), and the TV system to be used for pointing and focusing.

A satellite named Astro-A is on schedule under various tests to be launched next February. The satellite body is an octagonal pillar with a cirumscribed diameter of 106 cm and a height of 85 cm. Four solar paddles are deployed after the satellite achieves orbit. The satellite will spin at a rate of 5rpm, and the spin axis will be controlled to point 1.2° ± 0.5° from the center of the Sun. The prime object of the satellite is to make detailed study of solar flares mainly in X-ray bands by observing various aspects with good spatial, spectral and temporal resolutions. The physical instruments aboard the satellite are as follows:

(A) Solar X-ray imaging telescope (SXT)
(B) Solar hard X-ray monitor detector (HXM)
(C) Solar $\gamma$-ray detector (SGR)
(D) Soft X-ray crystal spectrometer (SOX)
(E) Solar soft X-ray monitor detector (FLM)
(F) Particle and X-ray monitor detector (PXM)
(G) Plasma impedence probe (IMP)

(H) Plasma electron temperature probe (TEL)

TAO has three instruments responsible for the Astro-A, and they are SXT, HXM, and SOX. Here the discription of the SOX is reported.

The SOX will obtain high resolution spectra from highly ionized iron emitted by the hot thermal plasmas produced in flares. The following types of features can be obtained with a time resolution of 6 seconds.

(1) line intensities in the range 1.72-1.99A
(line of Fe XX-Fe XXVI and Fe $K_\alpha$)
(2) line profiles in the range 1.83-1.89A
(3) continuum intensities around the lines
(4) degree of polarization

These may be reduced in order to determine the electron temperature, ion temperature, ionization temperatures, and emission measures. These quantities combined with radio, hard X-ray, and soft X-ray continuum data will hopefully explain the heating mechanisms producing flares. A spectral scan is made automatically by the crystals fixed to the satellite utilizing the satellite spin (5 rpm). This method has been successfully tested by the satellite -Tansei-4-. Two crystal spectrometers independently measure overlapping spectral ranges. Characteristics of the two spectrometers are shown in Table 2.

Table 2 : Characteristics of the crystal spectrometer (SOX)

| | SOX-1 | SOX-2 |
|---|---|---|
| crystal | $SiO^2$(1011) | $SiO^2$(1340) |
| 2d | 6.69A | 2.36A |
| integrated reflectivity | $79 \times 10^{-6}$rad | $23 \times 10^{-6}$rad |
| rocking curve FWHM | 22" | 6" |
| angle ($\alpha$) fixed to the satellite | 16.111° | 52.01° |
| crystal size | 44 x 133mm | 40 x 53mm |
| effective area (A) | 6.4$cm^2$ | 8.2$cm^2$ |
| sensitivity | $4.9 \times 10^{-2} cm^2 s$ | $1.8 \times 10^{-2} cm^2 s$ |
| ARc $\eta/\omega$ | | |
| wavelength range | 1.72 - 1.99A | 1.83 - 1.89A |
| scan step | min max | min max |
| | 0.0001-0.0011A | 0.00002-0.0023A |
| spectral resolution | 0.00068A | 0.000042A |

The detectors are NaI(Tl) scintillation counters with 5cm apperture. The signals are handled in two modes : in PC-mode those pulses within the lower and upper discrimination levels are simply counted and read out every 15.6ms. The wavelength resolution is determined by the sampling time which corresponds to $\Delta\phi$=0.47° in the satellite spin angle ($\phi$). The measured wavelength ($\lambda$) is related to the satellite spin angle ($\phi$) by :

$$\lambda=2d\ (\sin\alpha\cos\delta+\sin\delta\cos\alpha\cos\phi)$$

Where $\alpha$ is the fixed angle of the crystal (Table 2) with respect to the spin axis and $\delta$ is the off-set angle of the spin axis to the flare position ($\delta$ ranges from 0.7 to 1.7 degrees). In PH-mode, 16 channel pulse-height analysis is performed for each signal with a time resolution of 250ms. This mode is mainly used for detector calibration. A $^{109}Cd$ source emitting 22 KeV X-ray is used for the calibration. The amplifier gain, discrimination levels, and high voltage values are selectable by commands. The instrument performance is effectively limited to the maximum count rate of 200 KHz due to plus pile-up.

4. Long range plan

There is a long range plan -UVSAT- project, but this is not definite yet as far as the budget situation is concerned. The plan consists of two parts; the one is a VUV telescope for the observation of stars and the other is a EUV telescope for the Sun. The explanation of the second one is reported. The main aim of this plan is to understand the energy transport on the solar surface, where the physical state is the boundary condition in space and time from which the analysis of the solar interior and its evolution must start. What is the ordinary process to convert energy from the nuclear source at the core of the Sun to the photosphere, layer by layer, and uphill beyond the temperature minimum into the chromosphere and corona? By what extraordinary process can some of this energy be converted into various phenomena like sunspots, flares, flare-related nonthermal process, loop and surge prominences, and less active features like plages etc.. To study above mentioned questions the observation with simultanious heliograms of photosphere, chromosphere, transition region, and corona with high spatial resolution (2") and high temporal resolution (1 sec.) from a satellite is greatly hoped. The design of the satellite is not clear yet, but an Aplanatic Gregorian telescope ($\phi$=12cm, f=1.5m, F/12.5) is combined with a 50cm stigmatic spectrograph of 11A/mm spectral resolution. Multi-Anode Microchannel Array (MAMA) and CCD are used for detectors. The selected lines for the observation are 624.9A (MgX), 770.4A(NeVIII), 997.0A(CIII), 1031.9A(OVI), 1215.7A(HI), 1335.7A(CII), 1600A, and 5000A. For the long range plan the fundamental experiment devices should be prepared, and several rocket flights should be also planned.

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