OBSERVATIONS OF SOLAR RADIO EMISSION AT MICROWAVE FREQUENCIES

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Summary:

Outline of the equipment used for radio observations at Toyokawa station which are in operation since the beginning of IGY is described together with the method of tabulation. Percentage variation of the S-component versus frequency is calculated for the first half-year period of IGY, which shows a peak near 4000 Mc/s. Left-hand polarization of S-component prevails in this period at frequencies below 3750 Mc/s and there are many cases where the sense of polarization reverses between 3750 and 9400 Mc/s. Experiment has been made for detecting liner polarization at a frequency of 3750 ± 5 Mc/s, but we have yet no data to show the existence of linear polarization for both S-component and outstanding occurrences.

I. Introduction.

In Vol. 4, authors described in detail the equipment used for solar radio observations at 9400, 3750, 2000 and 1000 Mc/s[1]. At that time, the radio telescope for 2000 Mc/s was incomplete. However, not only it was completed before the beginning of IGY but also some alterations were made for a continuous observation of polarization at 9400 and 3750 Mc/s. The authors will summarize here the whole equipment concerning the IGY data published monthly at Toyokawa station. Though tabulation is made on standard forms supplied by the World Data Center, a short account will be given for those who have no forms at hand.

A remarkable result obtained by spectral observations at microwave frequencies is that we found the reversal of polarization in outstanding events. On this subject, however, refer to the paper by T. Kakinuma on page 71. In this paper, some results concerning frequency spectrum of steady flux will be described. The results will be more reliable than those obtained by collecting the data from different observers.

II. Item of Observations.

The observations made at Toyokawa station are summarized in Table 1.

We have another radio telescope of 1.2 metre dish for use at 3750 Mc/s. This is to be used for the eclipse observation on 19 April 1958 at Hachijojima, 300 km south of Tokyo.

Table 1 Observations at Toyokawa station.

Frequency (Mc/s)	Aerial	Type of observation	Start of regular observation: flux density	Start of regular observation: polarization	Observing time (U. T.)
9400 ($\pm 60 \pm 5$)	1.2 m dish	$R+L$, $R-L$	May '56	July '57	23–08 (July) 00–06 (Dec.)
3750 ($\pm 60 \pm 5$)	1.5 m dish	$R+L$, $R-L$	Nov. '51	July '57	
2000 (± 5)	2.2 m dish	$R+L$, $\frac{R-L}{R+L}$	June '57	June '57	
1000 (± 5)	3 m dish	$R+L$, $\frac{R-L}{R+L}$	March '57	March '57	
4000 (± 5) Interferometer	8×1.5 m dishes	E–W, drift, R or L	March '53 (5 dishes)	June '54	23–07 (July) 00–06 (Dec.)

Note: R and L denote right- and left-handed circularly polarized component.

III. Equipment.

1. Aerials.

All the paraboloids are made in similar figures having aparture angle of 160 degrees. Circular waveguide feeds of H_{11} mode are used except for 4000-Mc/s interferometer. The half-power width of directive pattern is shown in Table 2 together with the aerial gain.

Table 2 Half-power width and directive gain of the aerials.

Frequency (Mc/s)	9400	3750	2000	1000	4000 Interferometer
Diameter of paraboloid	1.2 m	1.5 m	2.2 m	3 m	1.5 m
Half-power width (degrees)	2.0	4.0	5.14	7.54	EW 3.25 NS 4.00
Gain	8544	1982	1397	607	1920

2. Switches for measuring circular polarization.

Turnstile junctions with polarization selector which had been in operation till June 1957 for 9400 and 3750 Mc/s were replaced by high speed switches as shown in Fig. 1 (a). Right- and left-handed circularly polarized components (hereafter to be called R and L) are converted at the quarter-wave plate into two linear components crossed at right angles. They alternately enter a rectangular waveguide by passing a gyrator of $\pm 45°$. At the output of the receiver, the switching frequency is detected by a synchronous rectifier and the DC output which is proportional to $R-L$ is amplified and recorded.

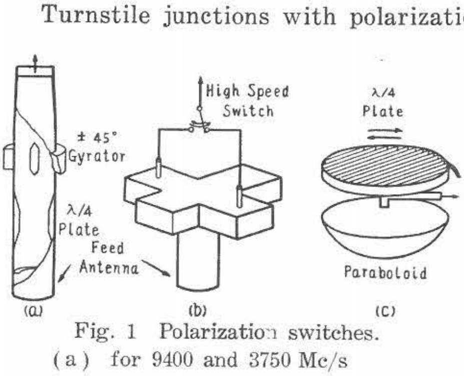

Fig. 1 Polarization switches.
(a) for 9400 and 3750 Mc/s
(b) for 2000 and 1000 Mc/s
(c) for 4000-Mc/s interferometer

For 2000 and 1000 Mc/s, R and L are separately conducted to a receiver and switched mechanically by a rotating disk as shown in Fig. 1 (b). Fig. 1 (c) is a hand-operated quarter-wave plate used for 4000-Mc/s interferometer.

Switching frequencies are summarized in Table 3.

3. Radiometers.

Each radiometer has a Dicke-type modulator. A gyrator using ferrite is also used here for 9400 and 3750 Mc/s while a mechanical switch of the same type as is used for polarization measurement is employed for 2000 and 1000 Mc/s. For 4000-Mc/s interferometer Dicke's original modulator of rotating-disk type is used.

All the intermediate-frequency amplifiers have a center frequency of 60 Mc/s with a band width of 10 Mc/s. Square-law detectors, non-selective audio-frequency amplifiers and gate-type synchronous rectifiers are used, which are followed by linear recording apparatus with a time constant of 0.5 second.

The switching frequencies are summarized in Table 3 together with noise figures of the receivers measured at each aerial feed.

Table 3 Switching frequencies and noise figures.

Frequency (Mc/s)	9400	3750	2000	1000	4000 interferometer	7350 experiment
Polarization switch (c/s)	125F	35F	70M	40M	once for each drift	circ. 40M lin. 80M
Dicke-type switch (c/s)	500F	140F	280M	160M	30M	95F
Noise figure (db)	13.5	11.5	11	14	14	14

Note: F and M denote ferrite and mechanical switch respectively.

4. 4000-Mc/s interferometer.[2)]

Aerial spacing of the 8-element interferometer is 86λ (6.45 m). Beam spacing and half-power width are 40' and 4.5' respectively around local noon. The sun is scanned stripwise in one direction about 20 times an hour. As the scanning velocity changes day after day, the recorder speed is changed by a stable variable-frequency oscillator so as to keep the drift-speed constant. The drift-curves thus obtained around local noon can be superimposed directly without adjusting time scale.

Drift-curves are taken as many as 120 times a day even in December, though the resolving power decreases as the beam number increases. Precise observation is made for 10 drift-curves around local noon, five curves for R and five for L. For the other period, R is received by a reduced recorder-speed sufficient to locate outstanding occurrences.

IV. Tabulation.

Tabulation is made on standard forms supplied by C. S. I. R. O. Radiophysics Laboratory, Sydney.

1. Single frequency observations.

a) Flux density—The value of flux density is the sum of two polarizations, i. e. $R+L$, in MKS unit. At 9400 Mc/s, the absorption by the rain or rain-cloud is very large and occasionally the estimation of the flux density becomes impossible owing to the fluctuation of the record. But in most cases, no serious error can be perceived provided the receiver gain is adjusted so, by directing the antenna towards the zenith, as if there were no absorption. It means that the temperature of the absorber is broadly the same as the room temperature. When the value of flux density is referred to as a quantity of solar radiation, a correction should be made for the variation of distance between the sun and the earth. The maximum correction coefficient is 1 ± 0.035.

b) Sense and degree of polarization—The following symbols are used to express sense and degree of polarization.

R=Right-handed circularly polarized more than 50%.
r= 〃 less than 50%.
O=Polarized less than 0.5% (No directions in the Instruction Manual).
l=Left-handed circularly polarized less than 50%.
L= 〃 more than 50%

It must be mentioned here that the polarization of steady flux at 1000 Mc/s is less accurate than at the other frequencies, because the value is usually less than 2% and moreover the instrumental accuracy is rather poor owing to long transmission lines between the aerial and the switch.

2. Outstanding occurrences.

Outstanding occurrences observed simultaneously at four frequencies are summarized in one table. Weak occurrences which have a value less than 20 units at 9400 Mc/s and less than 10 units at the other frequencies are not tabulated.

a) Starting time and duration—Until June 1957, starting time was taken as a time of 20% rise of the first peak and duration was taken as a period between 20% rise and fall of the first and last peaks. Since the beginning of IGY, starting time of a sharp-rising burst is taken as a time of sudden commencement. In the case of an indeterminate beginning, a time of 20% rise is taken and is indicated by 'x' following the time. Unless the end of the disturbance is very clear cut, duration is taken to a time of 20% fall of fhe last peak.

b) Type—The following symbols are used here.

S=Simple rise and fall of intensity.
C=Complex variation of intensity.
D=Distinct from (i. e. apparently superimposed upon) the general background.
A=Appears to be part of general activity.
E=Sudden commencement or rise of activity.

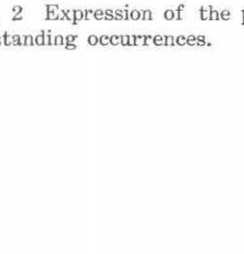

Fig. 2 Expression of the position of outstanding occurrences.

c) Position—Position is measured by the 8-element interferometer at 4000 Mc/s. Position angle and distance is chosen as shown in Fig. 2. It is to be noted, however, that 'position' listed here is the position of a peak on the drift-curve taken around local noon which increases its height at a corresponding time. The read-off accuracy is $\pm 0.05\, R_\odot$ ($R_\odot = 16'$). As the resolving power decreases in the morning and evening and, in addition, the scanning direction changes gradually, the position of some bursts occurred at such a time is uncertain.

V. Observed properties of steady flux.

1. Correlation among daily values.

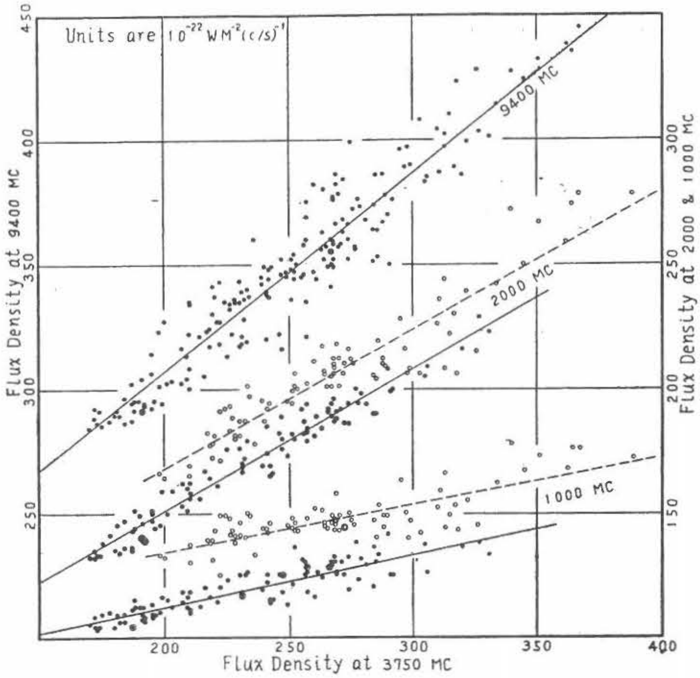

Fig. 3 Scatter diagrams of daily values at 9400, 2000 and 1000 Mc/s versus 3750 Mc/s. July-Dec., 1957.

Scatter diagrams of daily values for the period of July to December 1957 are shown in Fig. 3; the flux density at 3750 Mc/s is taken as a standard. Two different lines are fitted for 2000 and 1000 Mc/s because clear enhancement can be perceived after the beginning of October. Fig. 4 is also a scatter diagram of flux density at 2800 Mc/s observed at Ottawa station versus flux density at 3750 Mc/s. The correlation coefficients are shown in Table 4.

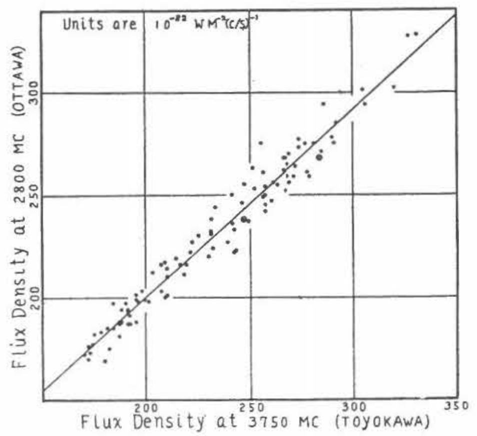

Fig. 4 Scatter diagram of daily values → at 2800 Mc/s (Ottawa) versus 3750 Mc/s (Toyokawa). July 1-Oct. 11, 1957.

Table 4. Correlation coefficients among daily values.

Frequency (Mc/s)	3750—1000		3750—2000		3750—9400	3750—2400
Period (1957)	July 1—Oct. 11	Oct. 12—Dec. 31	July 1—Oct. 11	Oct. 12—Dec. 31	July 1—Dec. 31	July 1—Oct. 11
Correlation coefficient	0.887	0.794	0.976	0.933	0.955	0.980

2. Correlation with sunspot data.

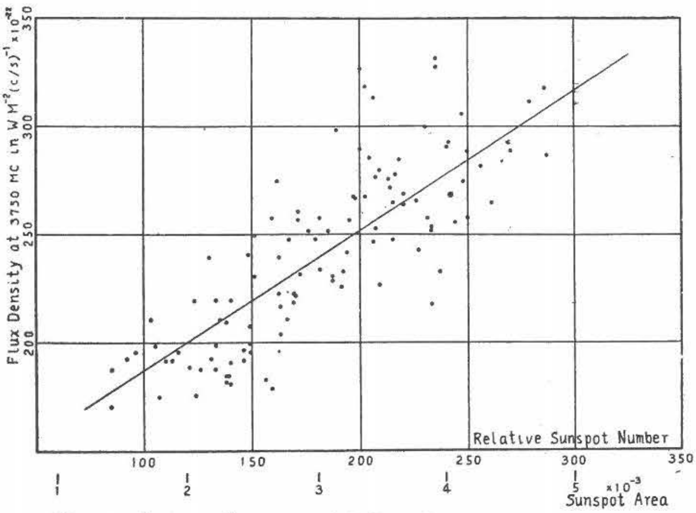

Fig. 5 Scatter diagram of daily values at 3750 Mc/s versus sunspot number (Tokyo). July–Nov., 1957.

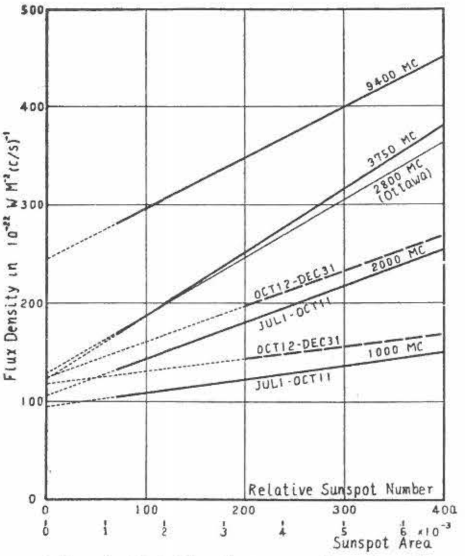

Fig. 6 Relation between flux density and sunspot number.

Fig. 5 is a scatter diagram of daily values at 3750 Mc/s versus relative sunspot number 'N' published at the Tokyo Astronomical Observatory. The correlation coefficient is 0.70. As the data of sunspot area are not available, the scale on the abscissa is calculated from the relation, $A=16.7N$[3]. By retracing the lines in Figs. 3 and 5, the flux density at different frequencies can be expressed as a function of N. They are shown in Fig. 6.

The flux density corresponding to the null sunspot number is often referred to as the base component or B component, and the excess radiation is called the slowly varying component or S component. The B component corresponds to the lower envelope of superimposed daily drift-curves taken by a multiple-element interferometer. The value of B component thus obtained from the 8-element interferometer for the first half-year period of 1957 corresponds to the flux density of 120 units at 3750 Mc/s, which closely coincides with the value obtained from Fig. 6.

3. Frequency spectrum of steady flux.

The value of B component as well as the value of S component corresponding to the sunspot number of 300 (approximately 5×10^{-3} in sunspot area) are plotted against frequency in Fig. 7. The S component has a maximum near 5000 Mc/s while the B component increases rapidly between 3750 and 9400 Mc/s. Fig. 8 shows the frequency spectrum of the percentage increase of flux density, i. e. $S/B\times100$. The data of Ottawa station is also plotted to make the curve more determinate. We can see that the percentage variation of the S component had a maximum near 4000 Mc/s for the latter half-year period of 1957. The curve has a different shape compared with that of Christiansen and Hindman[4].

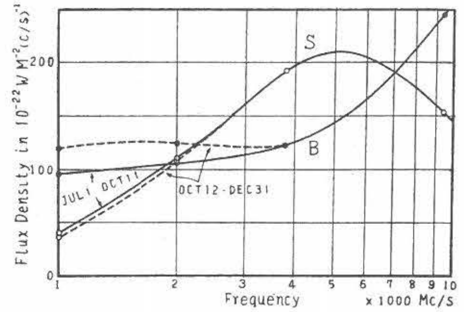

Fig. 7 Spectrum of S and B component. July-Dec., 1957.

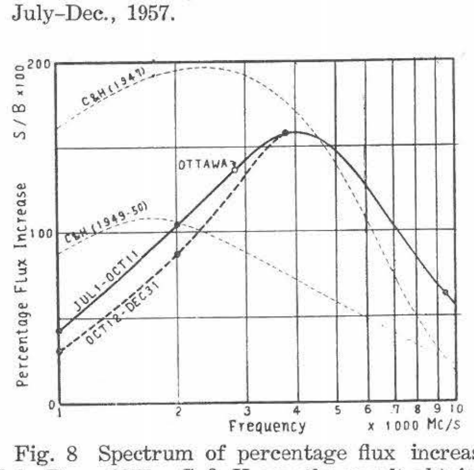

Fig. 8 Spectrum of percentage flux increase. July-Dec., 1957. C & H are the result obtained by Christiansen and Hindman.

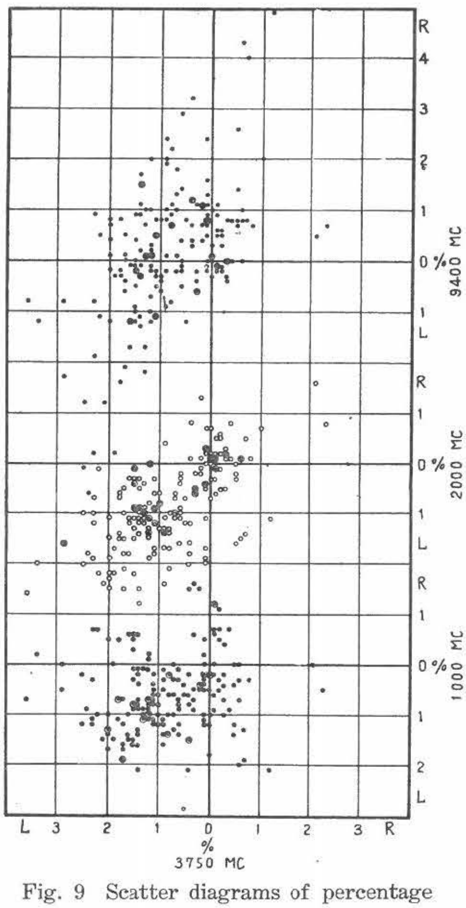

Fig. 9 Scatter diagrams of percentage polarization at 9400, 2000 and 1000 Mc/s versus 3750 Mc/s.

4. Polarization of steady flux.

Scatter diagrams of percentage polarization of steady flux at 9400, 2000 and 1000 Mc/s versus that at 3750 Mc/s are shown in Fig. 9. From this figure, the following properties can be reduced.

a) Percentage polarization of steady flux at 2000 and 1000 Mc/s has a comparatively good correlation with that at 3750 Mc/s; the sense of L is predominant at frequencies below 3750 Mc/s for this period.

According to the observations by 4000-Mc/s interferometer, the sense of several strong radio spots appeared in this period did not reverse near the meridian passage but reversed from R to L near the eastern limb in the northern hemisphere and from L to R near the western limb in the southern hemisphere. Moreover, a few strong radio spots are left-handed polarized in their full courses. Indeed, many radio spots still followed the ordinary rule of reversing their polarizations near the meridian passage but the degree of polarization L was usually larger than R. These are the causes of predominating L for this period.

b) No distinct correlation can be seen between 9400 and 3750 Mc/s; there are many cases of opposite polarization.

For this result, two different causes can be considered. The one is that the individual radio spot may have a different sense of polarization and the other is that the degree of polarization may be quite different at these two frequencies and that more than two radio spots of opposite polarization may exist.

According to the theory by Piddington and Minnett[5], the sense of polarization of S component will not reverse between these two frequencies. Whether the sense reverses or not is a very serious problem in presuming a mechanism of enhanced radiation and it may be solved by an interferometric observation at 9400 Mc/s.

VI. Experiment of detecting linear polarization at 3750 Mc/s.

T. Hatanaka and others found the existence of linearly polarized component for polarized burst at 200 Mc/s[6]. Suggested by the fact that the sence of polarization of outbursts reverses near 3750 or 2000 Mc/s, the authors have tried an experiment of detecting linear polarization at 3750 Mc/s since October 1957. The result was negative for a band width of 10 Mc/s and no linearly polarized components could be detected till the end of 1957.

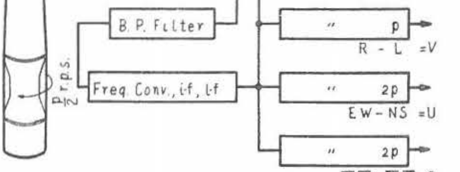

Fig. 10 A block diagram of polarimeter at 3750 Mc/s.

A block diagram is shown in Fig. 10. This type of polarimeter was devised by K. Akabane at the Tokyo Astronomical Observatory. He partly admits the existence of linear polarization at 9500 Mc/s. When a polarized wave enters the rotating quarter-wave plate, the output has a waveform as shown in Fig. 11. These waveforms are all sinusoidal and so we can get Stokes' parameters easily from the output of synchronous rectifiers. Fig. 12 is a photograph of the aerial. A defect of this system is that the sensitivity is poor especially for linear polarizations.

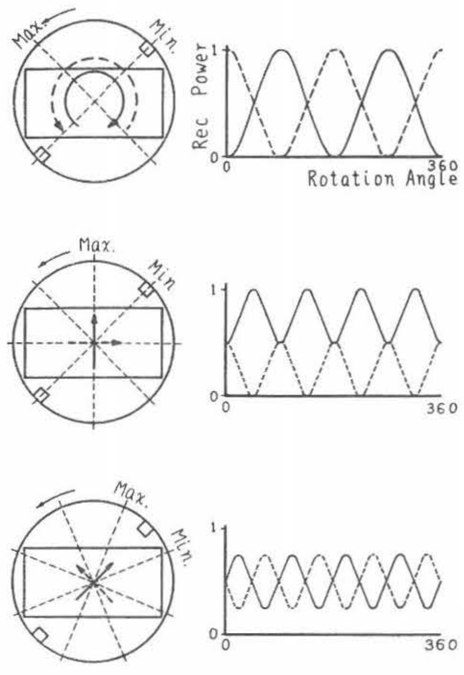

Fig. 11 Principles of polarimeter.

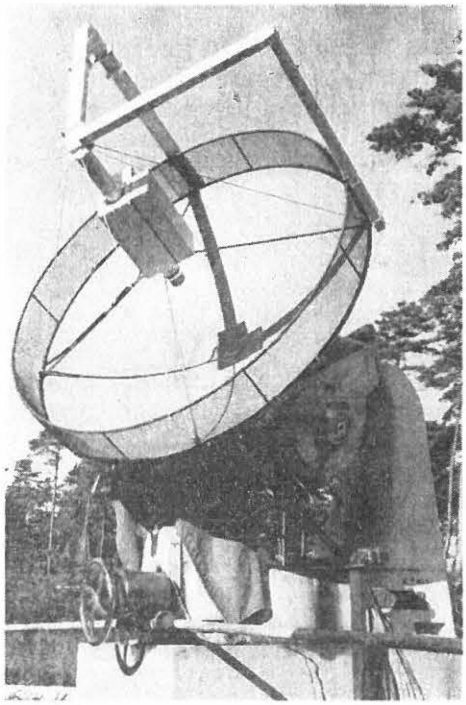

Fig. 12 Aerial of the polarimeter at 3750 Mc/s.

VII. Acknowledgement.

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