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NEW OBSERVATION

Lambda 8-CM Solar Maps Observed with the RSIP, A Real-Time Multi-Channel Digital Correlator Backend Installed to the Radioheliograph at Toyokawa

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and
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Abstract

The lambda 8-cm radioheliograph at Toyokawa has been improved with respect to sensitivity and time resolution by the introduction of a new real-time digital correlator backend, which is called RSIP (Real-Time Solar Image Processor). Observations were started in late February, 1986. Radio maps of the daily observations are shown in part, and synoptic charts of total period of observations are illustrated for solar rotations between Carrington rotation number 1773, which started March 10, 1986, and 1783. Active regions are clearly seen on these synoptic charts, some of which are at high latitude of the new solar cycle and also absorption features are definitely recognized corresponding to dark filaments. Quality of the images is estimated to be 30 to 1 or 15 dB. Applied data processings are described briefly to obtain present images from observed antenna output correlations.

Explanations

Introduction

The lambda 8-cm radioheliograph at Toyokawa was constructed in 1975 (Ishiguro et al., 1975). It was of swept-lobe type interferometer. It took about 20 minutes to obtain a two dimensional map. Examples of observations in those days have been presented (Shibasaki et al., 1976), and the results of the analyses have been published (Shibasaki et al., 1978, Ishiguro et al., 1980). Limitations or disadvantages were soon realized associated with an interferometer of beam-forming type. With general developments of digital techniques widely used for commercial products, it became feasible within our budgets to design and fabricate a digital correlator of 512 or so complex visibility functions for the lambda 8 cm radioheliograph (Nishio et al., 1982), with preliminary arrangements for a phase-stable multi-channel receiver system for it (Ishiguro et al., Nishio et al., 1985).

The project to construct a real-time digital correlator system, RSIP was financed for the fiscal year 1984 and 1985 (Nishio et al, 1987). After tuning the performance of the RSIP, regular observations have started in late February, 1986. A farther improvement of the RSIP to enhance the performance and to reduce the maintenance burden is under consideration. The design of a new correlator unit has been completed using Australia Telescope correlator chips, or AT chips of VLSI (Kobayashi, 1987). Assembly of the new correlator unit will be finished in a few months.

Instrument

The beam width is 2.3 arcmin X 2.3SEC(ZD) arcmin. This and other parameters of the radioheliograph system have not been changed from those given in the previous paper on data (Shibasaki et al., 1976), except for the operational mode, which was a skip scanning mode in the previous case. It is now of Fourier type or a correlator mode. Details of the present status of the radioheliograph system are given elsewhere, featuring the RSIP (Nishio et al., 1987).

Data Processings

1) The correlator outputs are fit with sinusoidal curves of the virtual Sun to estimate both amplitude and phase of each Fourier component, or complex visibility functions.

2) Correlator outputs from 31 and 15 pairs of interferometers of fundamental base-line length on EW and NS arms ,respectively, are used to calibrate the phase of each antenna, where redundancy of the antenna pairs is essential.

3) Phase errors obtained in the process 2) are applied to correct the

512 complex Fourier components.

4) Corrected Fourier components are then Fourier transformed to synthesize an image.

5) The phase error between the EW and NS arms is estimated and corrected from projected one-dimensional NS image. Estimation of the center of the Sun is also done simultaneously from a virtual quiet Sun obtained by clipping the observed image at the quiet Sun brightness.

6) Images obtained in the process 4) are then CLEANed with an ideal beam.

7) Correction of the foreshortening effect and rotation of images are done to bring the north pole to the top.

8) Calibration of brightness is done using the total flux observations by a radiometer measured simultaneously.

Display of Images

Images are displayed with 64 X 64 pixels on a color monitor with pseudo color of 32 levels from 15000 K to 37400 K in 700 K step as shown in Fig. 1, or on print-out of a laser printer with one of standard plot utilities such as ruled surface mapping and contour mapping.

Superposition of daily maps is done to obtain a synoptic chart of the Sun for each Carrington rotation. These synoptic charts are displayed on a color monitor by one of a few available projection methods. Fig. 2 shows the synoptic charts in Mollweide projection for solar rotations between Carrington rotation number 1773 and 1783. Pseudo color levels range from 15000 K to 31000 K in 500 K steps. The most remarkable feature is active regions in these maps. We can easily identify active regions of the new solar cycle by their location at high latitudes in the synoptic chart of #1777 in Fig. 2e. We can also see very clearly darker areas in almost every chart at a high latitude of about 40° south, which correspond to dark filaments. It should be noted that dark features close to intense active regions will be spurious or side lobes as seen in Fig. 2a and 2b. The extreme example of this kind is seen in Fig. 2i. The active region at longitude 225° is most intense during the period covered, which deteriorates image quality as bright as quiet Sun level over the entire hemisphere with the active region at the center. Analyses of these synoptic and daily maps, and comparisons with other data are in progress and will be treated elsewhere as well as reliability check of image quality, which will be discussed later.

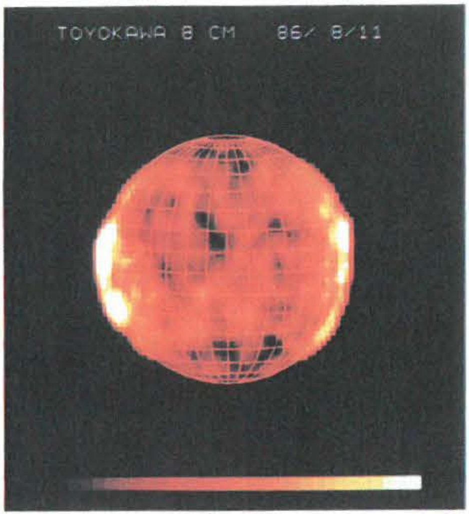

Fig.1a

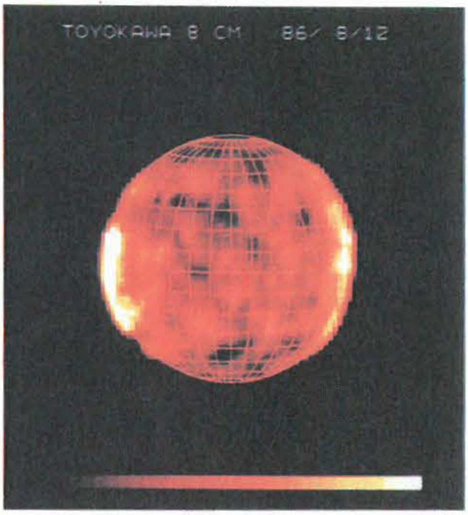

Fig.1b

Fig.1c

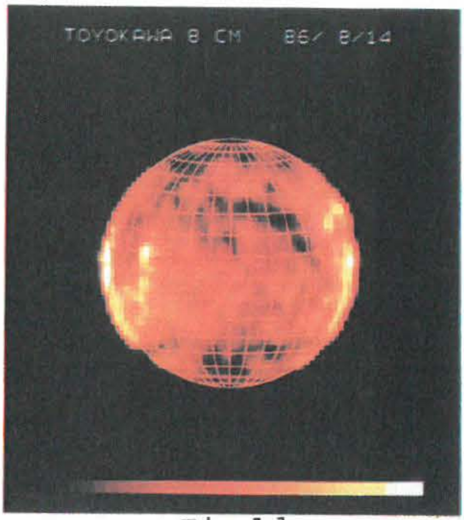

Fig.1d

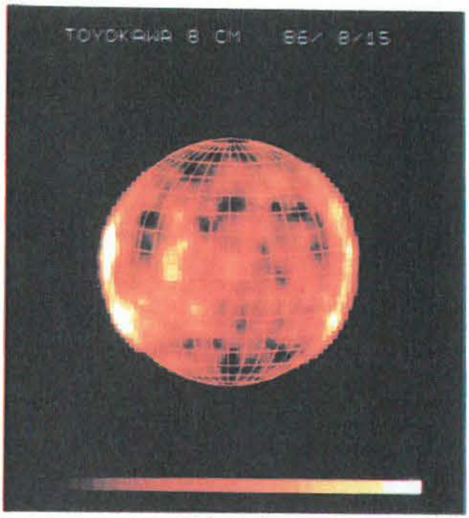

Fig.1e

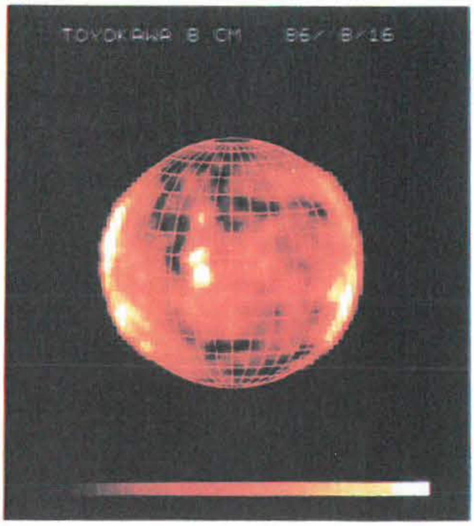

Fig.1f

Fig. 1a - 1f:Radio maps of the Sun at 8 cm between August 11 and 16, 1986. Pseudo color code levels are 32 steps from 15000 to 37400° K in 700° interval. Deconvolution by CLEAN is done for Figs. 1a -

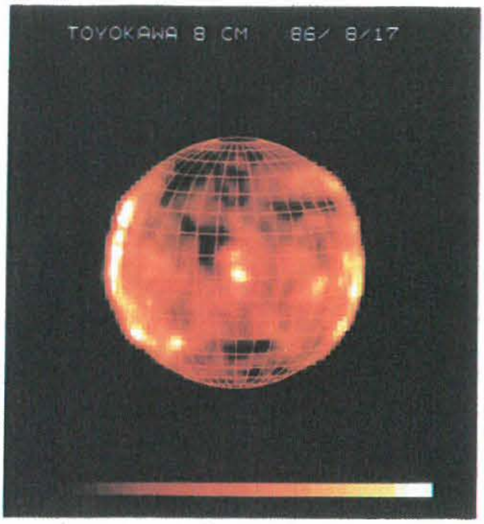

Fig.1g

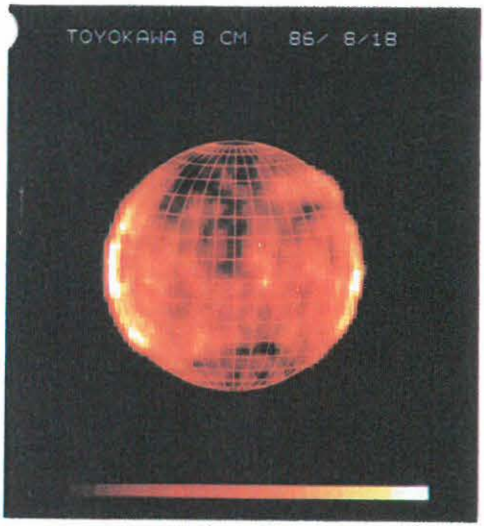

Fig.1h

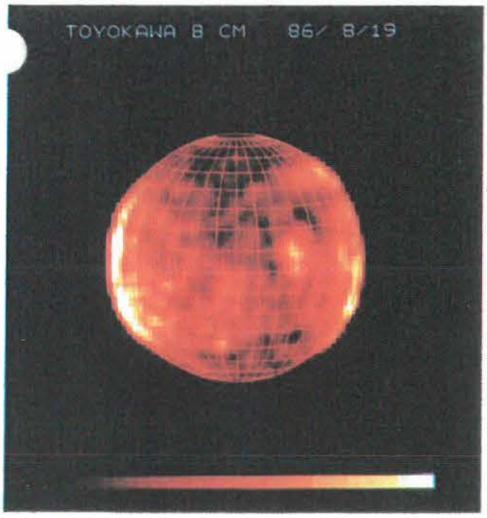

Fig.1i

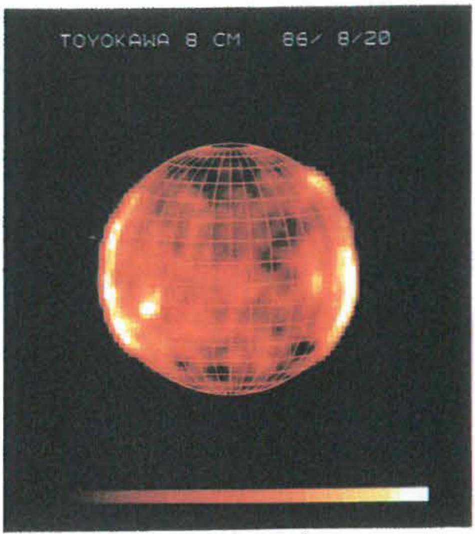

Fig.1j

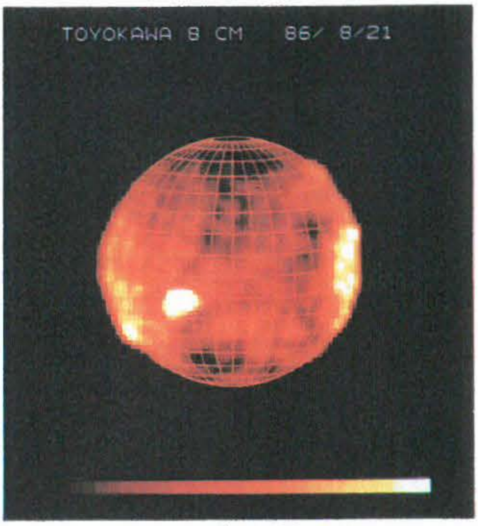

Fig.1k

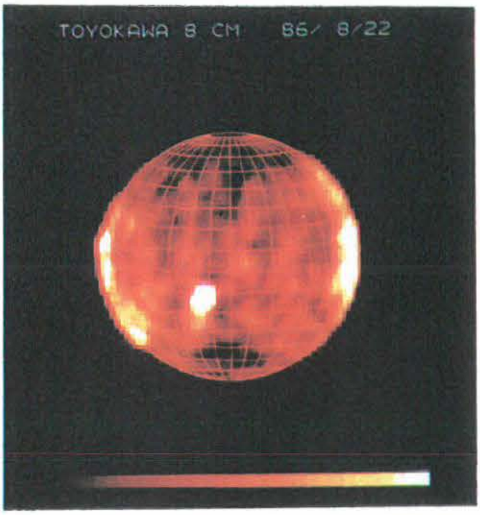

Fig.1l

Fig. 1g - 1l:Radio maps of the Sun at 8 cm between August 17 and 22, 1986. Pseudo color code is same as that in the previous Figure.

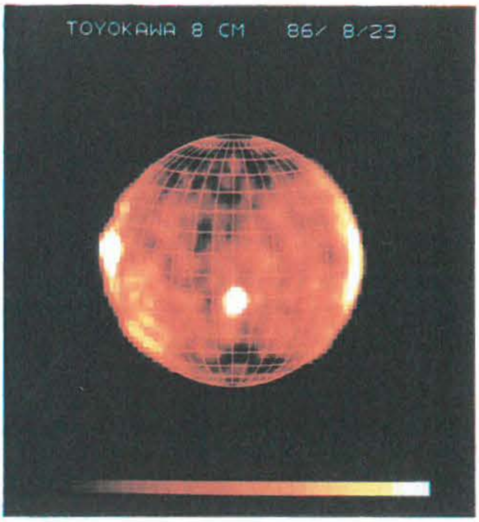

Fig.1m

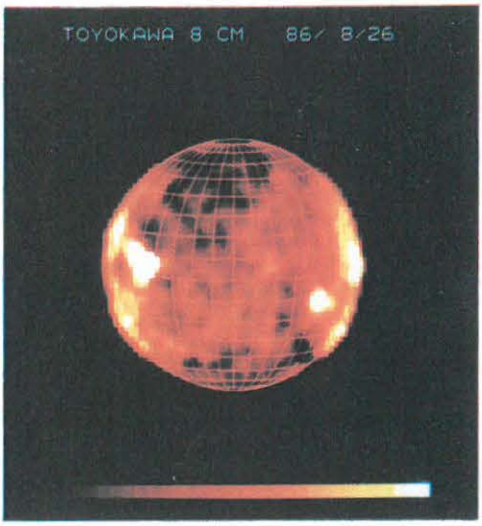

Fig.1p

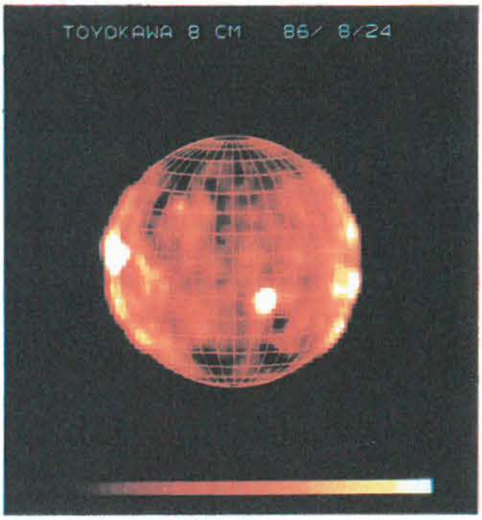

Fig.1n

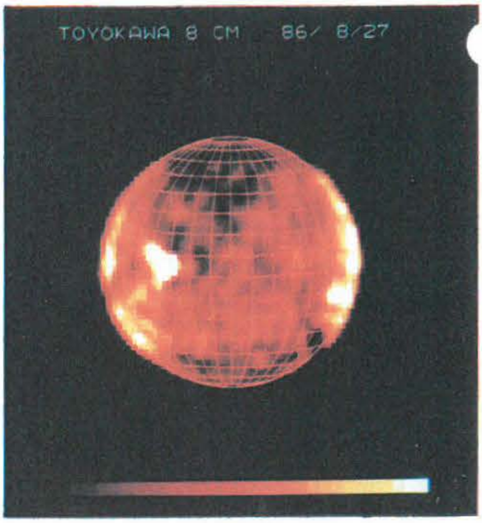

Fig.1q

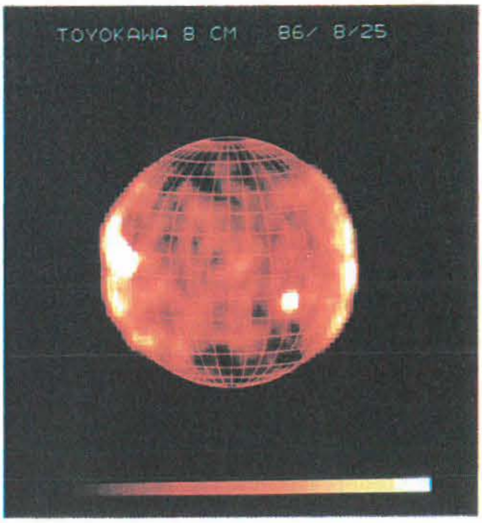

Fig.1o

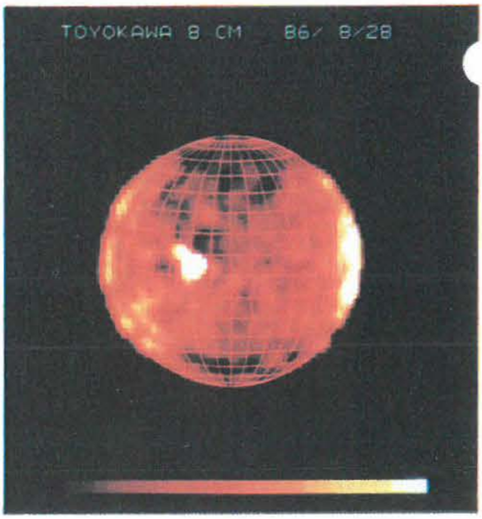

Fig.1r

Fig. 1m - 1r:Radio maps of the Sun at 8 cm between August 23 and 28, 1986. Pseudo color code is same as before.

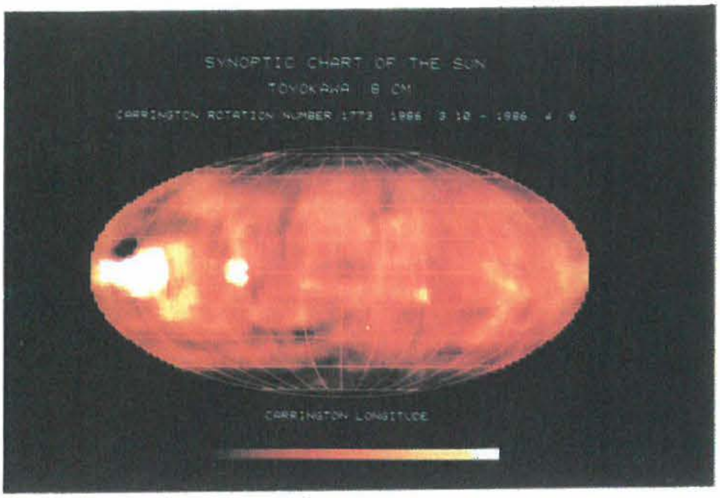

Fig.2a

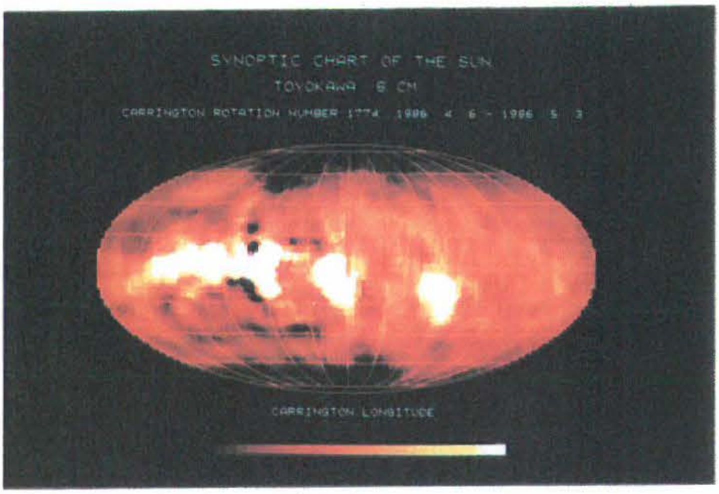

Fig.2b

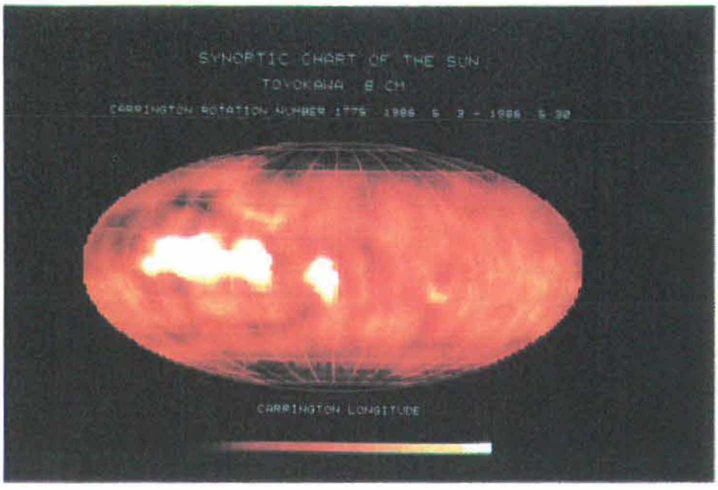

Fig.2c

Fig. 2a - 2c:Synoptic chart of the Sun at 8 cm between Carrington rotation number 1773 and 1775. Pseudo color code levels are 32 steps from 15000° to 31000° K in 500° K interval.

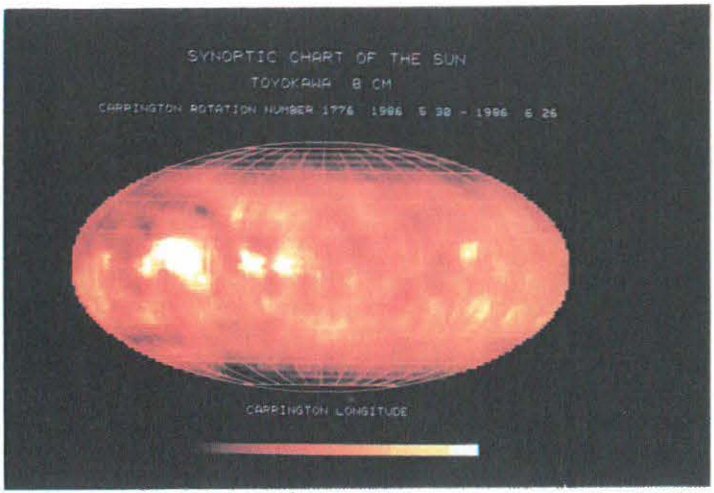

Fig.2d

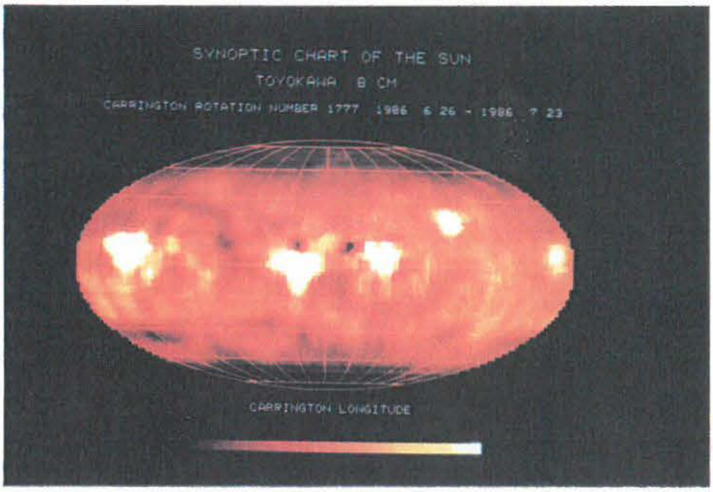

Fig.2e

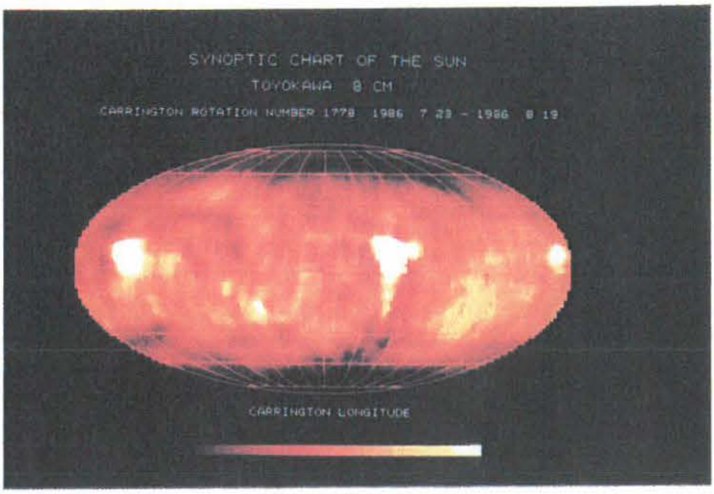

Fig.2f

Fig. 2d - 2f:Synoptic chart of the Sun at 8 cm between Carrington rotation number 1776 and 1778. Pseudo color code is same as that in the Figs. 2a - 2c.

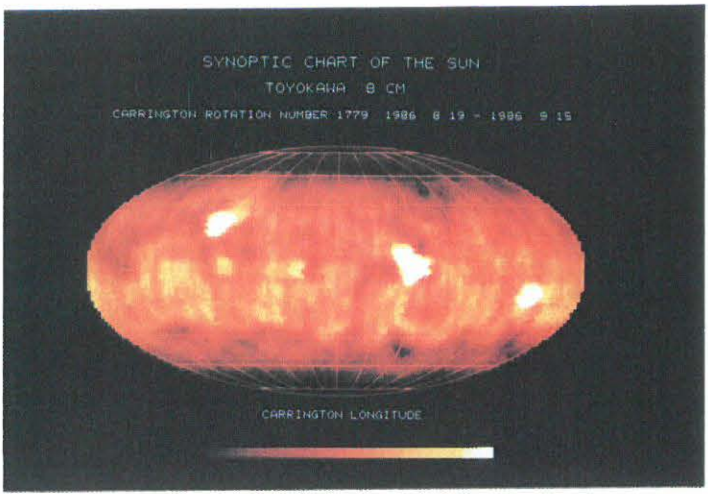

Fig.2g

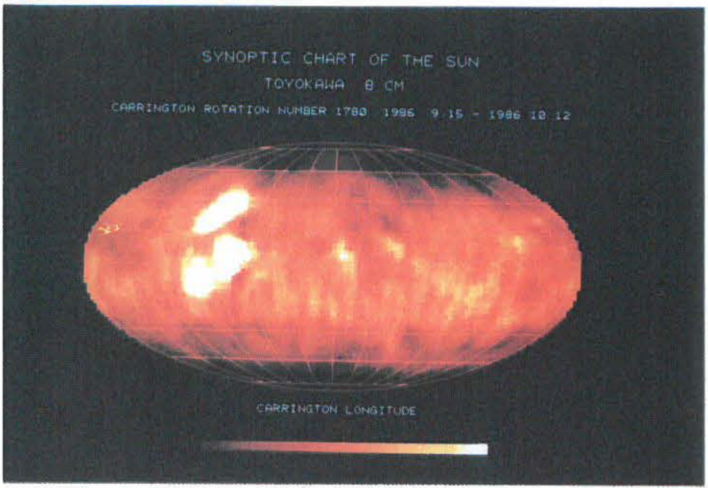

Fig.2h

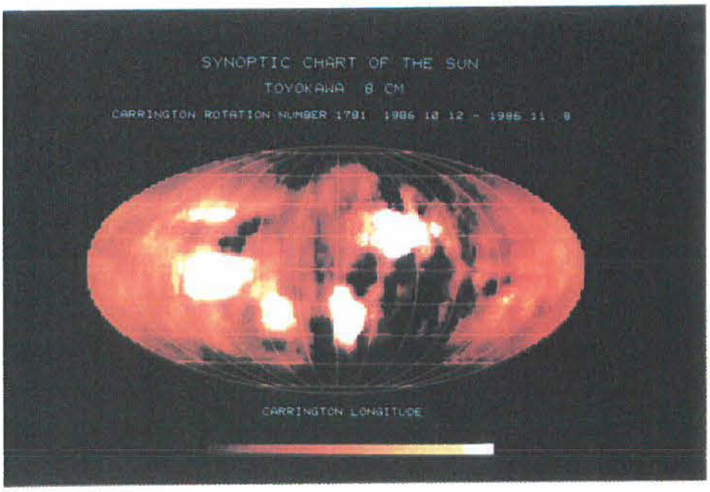

Fig.2i

Fig. 2g - 2i:Synoptic chart of the Sun at 8 cm between Carrington rotation number 1779 and 1781. Pseudo color code is same as before.

Fig.2j

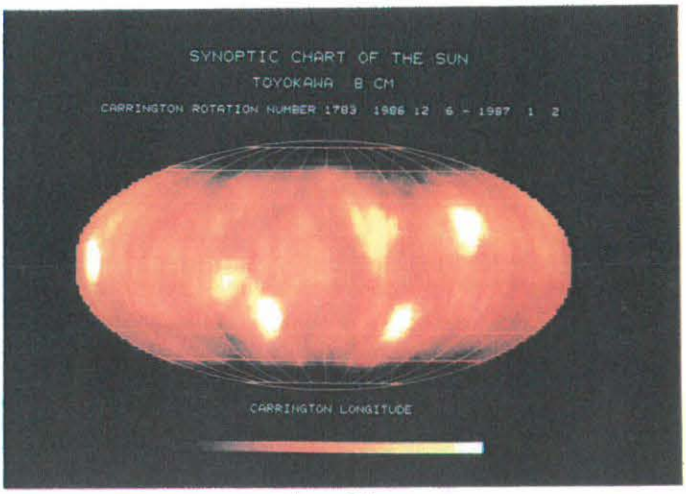

Fig.2k

Fig. 2j - 2k:Synoptic chart of the Sun at 8 cm for Carrington rotation numbers 1782 and 1783.

Effect of CLEANing

It is well known that CLEAN (Hogbom, 1974) algorithm is one of the most commonly used deconvolution method in radio astronomy as described in standard text books (e.g. A. R. Thompson et al., 1986). It is regarded as a kind of interpolation done in the image plane for incomplete set of complex visibility data or u-v samples based on an assumption that the true image consists of an assemblage of point-like sources. It is, therefore, not very effective for sources with extended patches or with overwhelming lower spatial Fourier components. A number of modifications of CLEAN method is proposed to overcome this difficulty by introduction of a priori information of the source available from earlier low resolution maps (Hogbom, 1984). The radio maps of the Sun have a circular disk of 32 arcmin in diameter and of $2.2X10^4$ K in brightness with active regions with size much smaller than that of the quiet Sun but with brightness ranging from as low as quiet Sun or lower to hundred times for strong S-components or 10^7 times for burst sources. This feature of image characteristics is easily understood not suitable for application of original CLEAN method. As a variation of modifications described above, we have assumed a circular disk of the quiet Sun of $2.0x10^4$ K and subtracted it from the synthesized images before CLEANing. If we go into the detail of the CLEAN algorithm that we applied to our visibility data observed with the RSIP, the loop gain is 0.3, iteration is stopped when the peak of the residual map is one tenth of the assumed quiet Sun or $2x10^3$ K, and the restored beam is a Gaussian with the half-power beam width of 2.3 arcmin, which is equal to that of the theoretical beam pattern of the 32x16 tee array. Examples of synthesized maps before and after CLEANing are shown in Fig. 3, which clearly demonstrate improvement of the images in the reduction of side-lobe pattern for compact sources from active regions, discrimination of secondary or weak sources from side-lobe patterns, and absorption or reduced brightness regions darker than the quiet Sun from side-lobe patches.

An estimate of the image quality of current radio maps is 30:1 or 15 dB (Nishio et al., 1987). For farther improvement of the quality, estimation of amplitude error is indispensable, which will be obtained either from observed data or from redundant antenna pairs. Development of software corresponding to the VLA selfcalibration method is considered for the former case and a new correlator backend is developed with redundant antenna pairs up to sixth harmonics (Kobayashi, 1987).

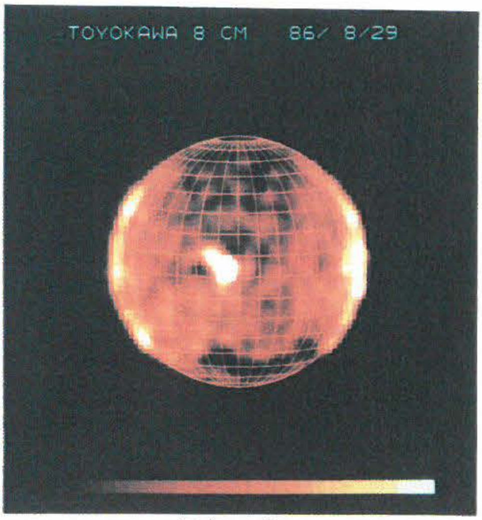

Fig.3a

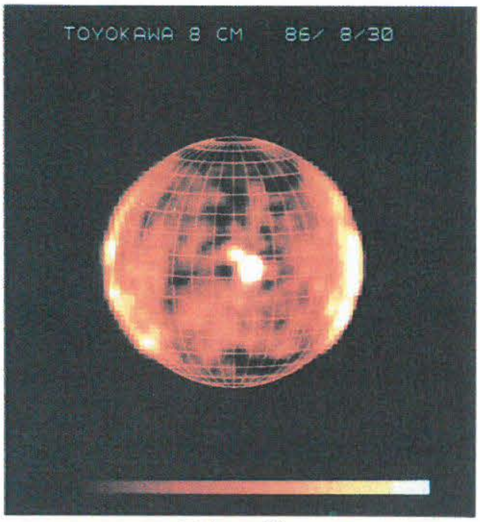

Fig.3b

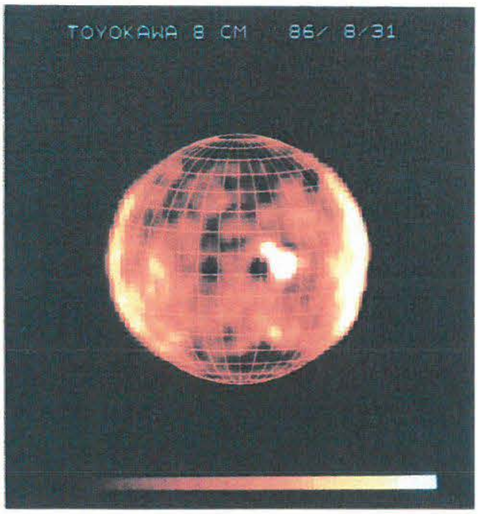

Fig.3c

Fig. 3a - 3c:Radio maps of the Sun for August 29 - 31, 1986. Deconvolution by CLEAN is done for these.

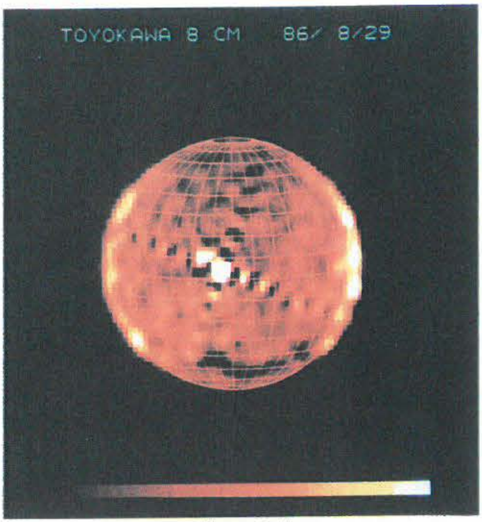

Fig.3d

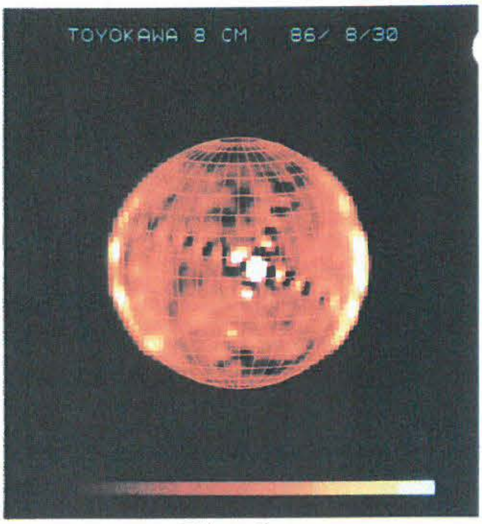

Fig.3e

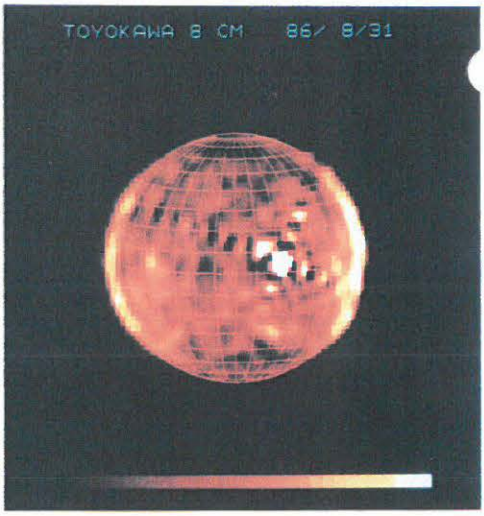

Fig.3f

Fig. 3d - 3f:Radio maps of the Sun for the same period as Fig.3a - 3c. These are synthesized maps before CLEAN.

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