A JAPANESE PLAN: LARGE RADIO HELIOGRAPH IN THE SOLAR MAX #22

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Abstract

An outline as of February, 1986 is briefly described of a Japanese plan to construct a large radio heliograph in the next solar maximum. The principal performance specifications of the heliograph are 10 arsec by 10 arcsec x SEC(Zenith Distance) spatial resolution, 1 arc degree by 1 arc degree field of view, 1-sec temporal resolution, and six hour coverage of observing time. It will be operated at 17 GHz with possible other frequency of 35GHz.

1. Motivation

In the solar activity cycle #22 as many as ten examples or so are obtained of simultaneous high-resolution observations by X-ray telescopes on board SMM or HINOTORI and large radio telescopes such as VLA or WSRT. Results obtained from these examples are diverse, and they are unfortunately not associated with an intense flare. It is evidently premature to draw any definite conclusion from these poor samples on the physics in solar flares.

One of fundamental objectives in observations of high energy phenomena in solar flares will be to obtain quite good number of samples on simultaneous observations in X-rays and microwaves with high spatial and temporal resolutions enough for studies on such critical issues as thermal/non-themal, foot-point/loop-top arguments and conduction front problems etc. It is also important to observe preflare activities, which will give us clues to locate such points as of energy build-up, of particle acceleration and/or of energy release. For these and other purposes we have a plan to construct a large radio heliograph in Japan in the next solar maximum, which will be expected around 1991, which, if realized, hopefully operated simultaeously with X-ray telescopes on board a Japanese satellite Solar-A currently scheduled to be launched in August, 1991.

2. Performance Goals

During post several years we had now and then oppotunities among radio astronomers in Japan to discuss the feasibilities to have a large radio heliograph in the solar maximum #22 and its general performance such as what are the most important necessary conditions it has to satisfy. It turned out that the heliograph requires to have full Sun images and to be dedicated to solar observations. These requirements emerged from considerations of the facts that either VLA or WSRT was limited in observation time alocated for the Sun, and restricted in the filed of view they can map in a single observation, which both believed directly related to poor sample of solar flares. The following goals agreed a few years ago after critical discussions based on both aspects of technical feasibility studies and scientific output considerations.

Field of View As mentioned earlier, the field to be mapped is as large as 1 arc degree times 1 arc degree or larger according to hour angle and declination to cover full Sun image. This allows us to observe any bursts which give rise to during the antennas are pointed to the Sun. It also gives us rather uniform sample of solar flare events with respect to time, and we will be free from laborious but sometime fruitless work of flare prediction. The size of element antenna is automatically determined by this parameter, if the operating frequency is given.

Spatial Resolution It is clearly evident that greater resolution is always desirable, but at the same time the resolution is limited by the area of the site available to the radio astronomers. The latter point is very severe particularly in Japan. There is one and only way to relax this severe constraint, which is to choose a higher frequency of observations. This, however, brings us other aspects of physics involved, which will be discussed later in Polarization and Frequency. The resolution chosen is 10 arcsec times 10 arcsec in the favorable condition and 5 arcsec in one dimension (E-W), taking the above and other restrictions into consideration.

Temporal Resolution It is evidenced in this cycle that high energy phenomena showed very rapid fluctuations as fast as tens msec in hard X-rays and 1 sec or possibly less in gamma-rays. Our choice is 1 sec for normal mode, in which the heliograph is operated as long as 6 hours of observations, and 50 msec for fast mode or burst mode for some limited time of observations, which will be bounded by the fast recording device available. A possible physical resasoning of the desirable temporal resolution will be given by the ratio of the spatial resolution over the velocity of electrons relevant to microwave emissions, which will be given by 7000 km / 100,000 km/sec (20 keV), and it is equal to 70 msec.

Polarization and Frequency It is rather easily acceptable that the heliograph is capable to measure both right- and left-handed circular polarizations, since the circular polarization observations are key parameters to estimate magnetic fields of solar flares in acceleration and/or energy release regions. The choice of frequency, on the other hand, requires some considerations on what physical quantities are to be obtained. Microwave spectra of bursts usually show a peak at some frequency around 10 GHz. This spectral peak, which sometimes shifts to a higher or lower frequency, is believed to be due to saturation of radiation in lower frequency side, whereas upper side is due to optically thin gyro-synchrotron emission. The spectral peak frequency is primary function of magnetic field vector and electron energy distribution. It is, therefore, necessary in ideal situation to determine spectral peak value across each burst source, and/or spectral index in optically thin part. The primary frequency of the heliograph is chosen to be 17 GHz, where most of burst source will be optically thin, but for very energetic flares sources will be possibly optically thick. The secondary frequency, if possible, will be either higher or lower than this. Our choice, based on the above consideration, is 35 GHz for the secondary frequency, since our emphasis is put on high energy phenomena in solar flares. It is, however, still difficult to estimate its feasibility, as the cost of 35-GHz amplifiers strongly depends on state-of-the-art.

Time Coverage With conventional equatorial mounting or micro-computer-controlled altitude-azimuth mounting system, antennas will usually cover observation time of 6 hours a day or 3 hours before and after CMP around 0^{o} declination.

Sensitivity The sensitivity of the heliograph is limited by several factors, among which major contributions will be radiometer system noise, confusion due to side lobes and to atmospheric effects. The goal for the overall sensitivity or dynamic range of image is 1/100 or 100:1. Each factor should be, therefore, much smaller than the total value in the sense of the sensitivity. As far as the contribution from the radiometers is concerned the requirement is overcome either for intense bursts in snapshots or weak active regions in synthesis maps as will be explained later. For other contributions they will also be discussed in the later sections.

3. Conceptual Design

Array Configuration and Number of Antennas A tee array configuration is chosen for the heliograph, since the simple application of Fast Fourier Transform is possible to obtain images from complex correlations or visibility functions or, in other words, there is no step to perform time-consuming gridding procedure, which will give us much less burden in computer time in the flood of data to process such as an image in a sec even in normal mode. Further discussion on array configuration will be given later in Image Formation and in Aperture Synthesis. Basic idea to determine number of antennas is given by the number of independent pixels in the field of view. If we take the fundamental grating lobe interval as 35 arcmin or 98 lambda with 10 arcsec angular resolution, the number of pixels will be 44,000. This means that more than 400 by 200 element element antenna tee array will be necessary to form a complete map of independent pixels. When there is some symmetry in source structure or when structure is simple, entire pixels are not independent, and we will not need so many number of antennas. This is expressed in other way as a simple image can be recovered from incomplete samples in UV plane, where a sort of interpolation in done in UV plane or in image plane. One straight-forward way to solve incomplete sampling problem in UV plane is as follows: a tee array is formed of double tees. One is a dense array of 64 x 32 antennas with a fundamental base line interval of 90 lambda or so, and the other is a sparse array of 64 x 32 with a larger fundamental interval of 6 times that of dense array or 540 lambda. Total number of element antennas will be 174 instead of 192, if a single antenna represents each role for the sparse and the dense array at duplicated positions. The fundamental grating lobe interval of the sparse array is about 6 arcmin, which well covers the size of most of intense active regions. With the dense array we can have a complete map of quiet Sun with 1 arcmin resolution, from which we can estimate accurate beam positions both for dense and sparse arrays, taking into account of redundancy of antenna configuration. If we have a single burst source whose brightness at maximum is much higher than that of the quiet Sun, the image obtained with the sparse array represents a high-resolution image of the burst source, and its position is shown in the low-resolution image from the dense array.

Image Formation and Phase Calibration Most popular method is CLEAN to restore an image from a so-called dirty map, which is Fourier transform of incomplete UV plane data. It is, therefore, a kind of interpolation performed in image plane. This procedure will be a powerful tool in the case of the heliograph to recover images from dirty maps of double tee array configuration, which will be snapshots. If this configuration is adopted, there will be ample redundancy in antenna configuration, which may be used for calibration of complex gain, or amplitude and phase, of each antenna, where the Sun is employed as an only calibrator source because of the small antenna size. This method has been extensively used in the 17-GHz interferometer at Nobeyama Solar Radio Observatory. With the calibrated complex antenna gain, we can correct distorted maps to obtain high-quality images with a high-dynamic range.

Atmospheric Effects Successful operations of 5-Element 10-Meter Diameter mm-Wave Synthesis Radio Telescope at Nobeyama have revealed that atmospheric scintillation is serious even at 22 GHz at arcsec resolution. It is operated with 10 sec integration time, therefore, there are no data available on atmospheric scintillation spectra in the range faster than 10 sec, in which the heliograph will be operated. When atmospheric scintillation effects are serious, very frequent calibrations of complex antenna gain have to be conducted using the redundancy antenna configuration.

Aperture Synthesis In normal mode of observations snapshots of the Sun are obtained, which are as mentioned earlier synthesized from incomplete UV plane samples. As the dynamic range of image is not expected to be high for these snap-shots, we can not well see small or weak active regions or other fine structures in or above quiet area. In order to observe those low-brightness structures with intense background radiation of quiet Sun, rather complete coverage of UV plane will be necessary. Appreciable improvement of UV coverage is expected for 15 to 30 minutes accumulation of UV data in favorable conditions as simulated in preliminary analyses.

Alternative Choice: Array Configuration, Self-Calibration So far we have described image formation in the heliograph system based on the double tee array configuration. There is, however, an alternative to handle this problem in a more progressive way, which is to employ the self-calibration developed for VLA and MERLIN and extensively used for both, and also applied recently to radio maps observed by the mm-Wave Synthesis Radio Telescope at Nobeyama. If we adopt this self-calibration method for image formation and antenna calibration, we will not need redundancy in array configuration, which implies there is a possiblity to reduce the number of antennas of the heliograph. In this case array configuration will not be of grating type but for example randomly spaced tee. Risky points associated with the self-calibration method are first, there is no stable general software is developed for extended source structures, which are mostly the case for solar bursts with possible simple or complex sources and the disk of quiet Sun, and it is a time-consuming procedure for a large mass of image data, which means we will need extensive computer time or an ultra-fast super-computer to process these data. The problem to be solved will be, therefore, what is a proper balance between one part of cost and manpower spent for the antenna system and the other part spent for the computer system with an assumption of a limited total cost for the entire heliograph system.

4. Concluding Remarks

An artist impression of the radio heliograph is illustrated in the Figure.

System Design Preliminary studies have been started and are in progress on system design of the heliograph, involving several firms such as specialized in electronics, computer systems, small antenna systems, etc. The system design includes element antennas and mounting, frontend and IF receivers, the local oscillator system, the correlator system, cable systems, control and data-processing computer systems etc. Results of the studies will be reported separately, after certain step and proper reviews are cleared.

Some of cosmic radio astronomers show strong interest in this plan to employ the heliograph as a radio Schmidt camera to find new radio objects or to survey time-varying peculiar radio sources. In that case we will have to install very low-noise receivers with a wide bandwidth.

This plan is promoted by radio astronomers at Tokyo Astronomical Observatory, University of Tokyo, at the Research Institute of Atmospherics, Nagoya University, and the Department of Physics, Nagoya University. Vigorous efforts are undertaken to obtain fund for this plan. In this respect we will welcome supports from scientists in every aspect and comments, suggestions, criticism etc, as well as international supports.

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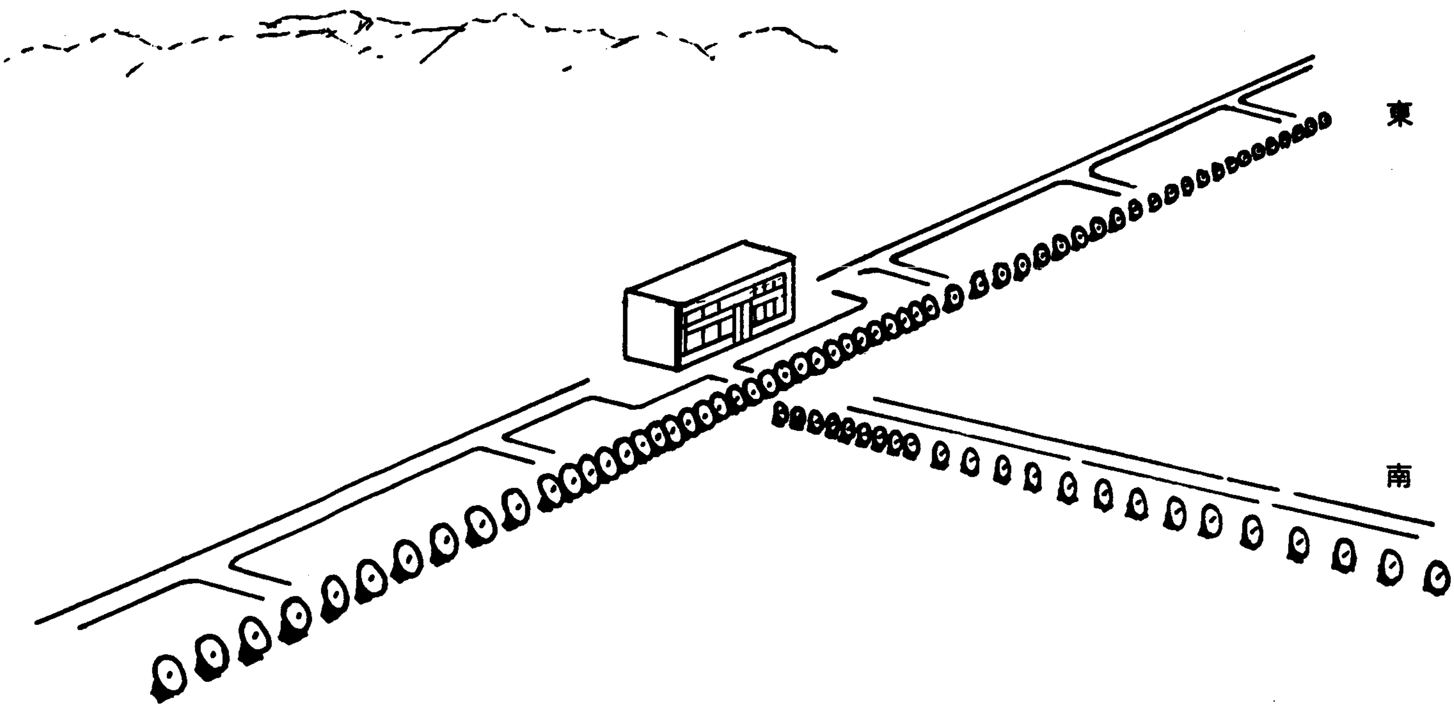
大型太陽電波写真儀



(完成予想図)

装置の概要

全　　　長	600m（東西） 300m（南北）
アンテナ総数	~200基（口径1m赤道儀）
観測波長	短センチ波帯
空間分解能	10秒角×10秒角
	5秒角（東西方向）
時間分解能	1秒
偏　　　波	左右円偏波
前置増幅器総数	~200
相関器総数	~20,000

太陽電波研究者グループ
（昭和57年9月）