The Nançay Radioheliograph

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Abstract. The Nançay Radioheliograph has been upgraded in order to provide high time resolution 2D images of the soler corona. This is due to its new digital correlator (Stokes I and V, 576 channels). Calibration has also been improved. The multifrequency operation remains almost unchanged. It allows simultaneous observations of up to 10 frequencies in the range 150-450 MHz. Integrated data will be available on the internet, and special observing modes may be decided on request.

Résumé.
Le Radiohéliographe de Nançay a maintenant la possibilité de faire à grande vitesse des images à 2 dimensions de la couronne solaire. Un nouveau corrélateur digital (576 canaux, Stokes I et V) a été construit à cet effet. Le mode multi-fréquence n'a pratiquement pas été modifié. Il permet l'observation quasi simultannée de 10 fréquences dans la bande 150-450 MHz. Des observations intégrées seront disponibles sur internet, et des modes d'observation speciaux pourront être mis en place à la demande

1 Introduction

The Nançay Radioheliograph (NRH) has been recently upgraded by switching from an analog to a digital correlator. The new digital correlator has 576 channels, and allows fast 2D imaging. Up to now the NRH provided only fast 1D projections of the solar corona along two axis (The Radioheliograph Group(1993)). An aperture synthesis mode was also operating (Alissandrakis and Lantos(1985)). The old analog correlator provided only 55 channels, and was at the origin of the 1D imaging limitation. It will be described in more details hereafter. Daily observations began in July 1996.In the following we briefly describe the antennas, the broadband receiver, the new correlator and the data acquisition system. Some examples of new observations will be shown.

2 Technical description

The NRH was designed for fast imaging of solar radio emissions. Almost simultaneous observations at different frequencies are achieved by a fast time sharing (The Radioheliograph Group(1993)). According to scientific and technical constraints, the observing frequencies and the speed may be chosen in

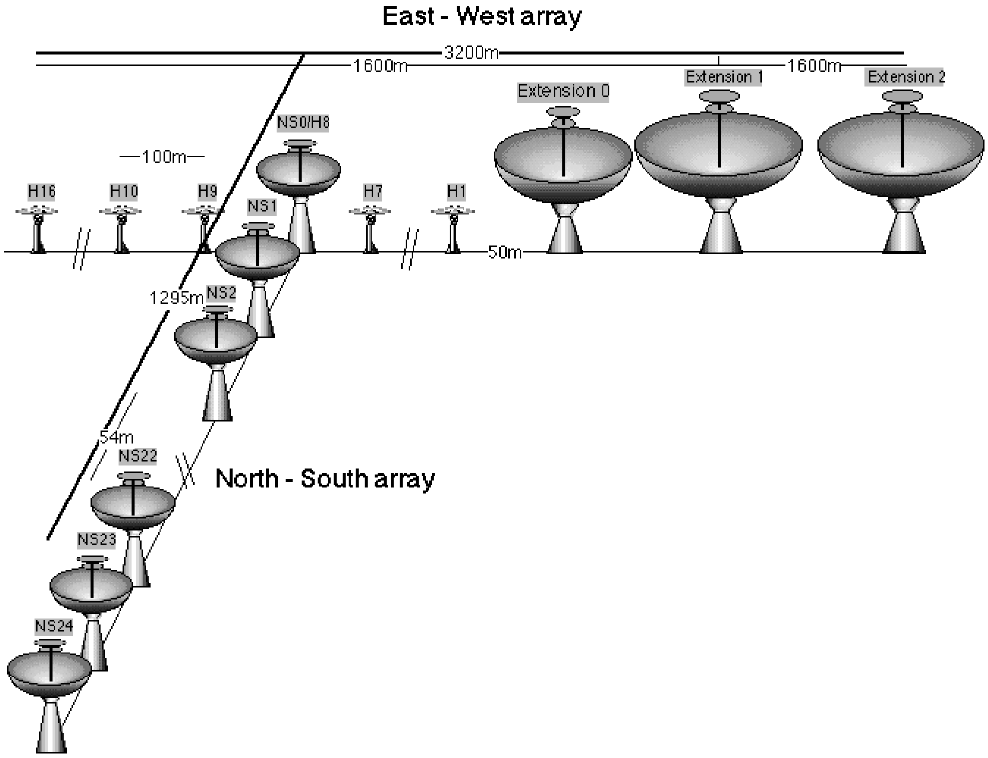

Fig. 1. The Nancay Radioheliograph antennas

the limits 150 - 450 MHz and a maximum number of 200 images per second. Four basic parts will be described: the antennas, the broadband receiver, the correlator, and the data acquisition system.

2.1 The antennas

The antennas are organized in two perpendicular arrays (fig 1). The east west array consists of 19 antennas, and provides baselines ranging from 50m to 3200m. Four antennas have parabolic collectors (two 10m dishes, one 7m dish and one 5m dish at the array crossing point). These antennas are equipped with the wide band feeds which have been described in The Radioheliograph Group(1989). These feeds consist in four thick dipoles, and receive two orthogonal linear polarization in the 150 - 450 MHz frequency band. The remaining 15 antennas are based on a variation of thick dipoles and have no collector. They have only one linear polarization, and their gain ranges from 10 to 14 dB.

The north-south array consists of 5m parabolic collectors, with the wide band feeds described in The Radioheliograph Group(1989). Baselines range from 54.3 to 1248m.

In order to measure circular polarization, correlations are made between signals coming from antennas with parallel dipoles(Stokes I correlations) and with perpendicular dipoles (Stokes V correlations). These measurements provide the parameter V only if the received emissions have no linear polarization. This is a very reasonnable assumption, because the Faraday rotation in the solar corona is high enough to wash away any linear polarization in the 700 kHz receiving bandwith. Very low crosstalk between perpendicular dipoles located on a same antenna has been achieved(The Radioheliograph Group(1989)) and the tracking accuracy of the antennas is 1 °. This allows the measurement of polarization rates as low as a few percent.

In order to make fast 2D images with a Fourier transform, only the 17 antennas of the western part of the east - west array are used. They form, together with the north - south antennas, a T shaped array which gives a regular coverage of the u-v plane. A two dimensional Fourier transform therefore gives images which have a spatial resolution fourfold lower in the east - west direction than in 1D east -west scans. Another consequence of the arrays configuration is that the minimum east - west baseline used for 2D images is 100m. That length leads to an image size of the order of 30 arcmin at the highest frequencies, and to a strong aliasing on images. In most cases, these limitations can be by-passed by looking at 1D east - west scans.

2.2 The broadband receiver

Each antenna has broadband amplifiers and filters. Because of strong terrestrial interferences, a filter removes the band 200 - 210 MHz, and pass band filters reject the FM band (88 - 108 MHz) and TV emitters located very near the top edge of the receiver band (above 450 MHz). This set of filters is necessary in order to avoid intermodulation lines and saturation. A first mixer changes the observing frequency to a fixed 113 MHz frequency, which is transmitted to the laboratory through buried coaxial cables. The variable local oscillator is transmitted to the antennas also through buried coaxial cables. It is multiplied by 80 before entering the mixer, and the upper or lower image bands are used in order to reduce the frequency range of the local oscillator. The receiver of the north-south antennas is located in the antenna pedestals. Temperature variations induce a gain variation which will be corrected during the data processing (typical variations are of the order of 10% during an observing day). The receivers of the east - west antennas are buried, and do not have this drawback. For both north - south and east - west receivers, the phase is stable. Phase variations occur only in the transmission coaxial cables (signal and local oscillator). Because these cables are buried at a depth of 1m, the temperature variations are very slow, and phase calibrations remain valid for weeks.

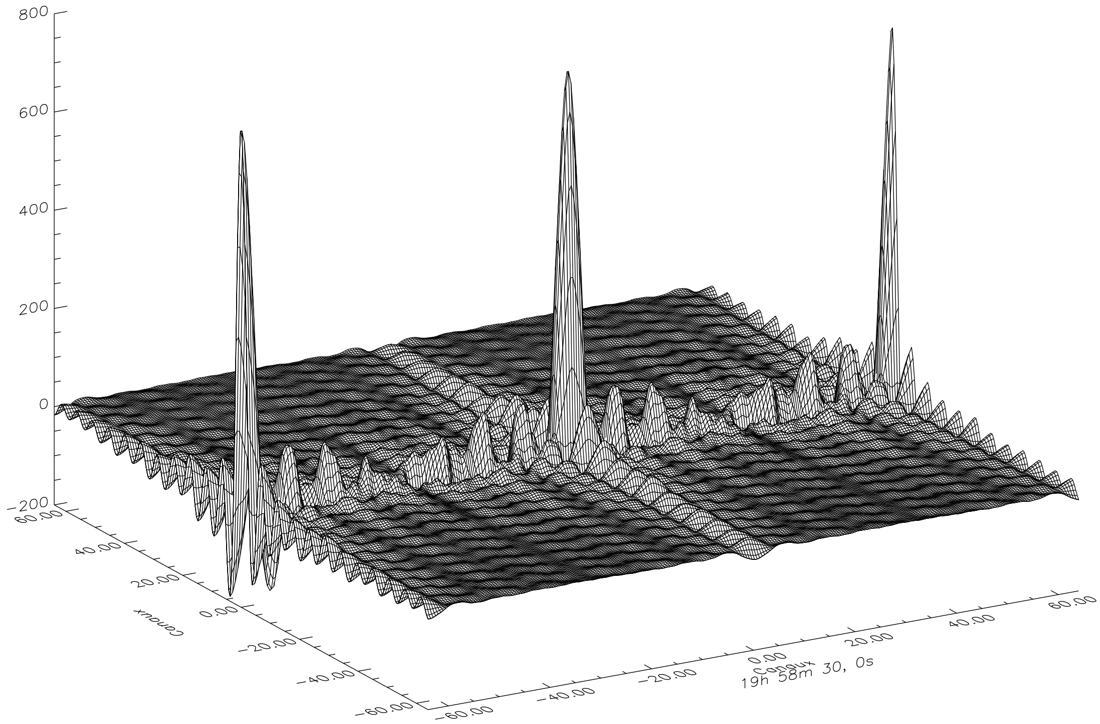

Fig. 2. Cynus A image at 164 MHz. The two horizontal axis are instrumental spatial coordinates. The vertical axis is brightness, in arbitrary units. Two periods of the image are plotted along the east-west direction.

The multifrequency operation is achieved by time sharing: a basic 5 ms integration time is used, and the observing frequency may be changed between two integrations. That change, and the needed dipoles and filters commutations are achieved during a 100 microsecond reset time. The electronic gives no limit to the number of frequencies which can be successively observed. Frequencies are chosen with a 100 kHz step,which is much smaller than the 700 kHz observing bandwith. That feature is useful because terrestrial interferences are mostly line emissions.

2.3 The correlator

The old analog correlator provided only 55 correlations and, because of that, it was not used for fast 2D imaging. It has been replaced by a new digital correlator which is able to make all the possible correlations between the antennas. The total number of correlations is 861. Because this total includes a large number of redundant correlations, mainly in the directions of the two arrays, the correlator has been limited to 576 correlations. It makes all the products of north - south by east - west antennas, and some redundant products, mainly on short baselines in the direction of the two arrays. We used programmable logic arrays, which leads to a very compact receiver.

Before entering the digital correlator, the 113 MHz signals coming from the antennas are shifted to 10.7 MHz by a second local oscillator. Two main analog components remain unchanged: a 700 kHz passband filter determines the observing bandwidth, and an attenuation subsystem keeps the power level within a 3dB range. Attenuators range from 0 to 45 dB, with a 3dB step. They are controlled by an ancillary total power receiver. During each 5 ms period, that receiver observes at the frequency which will be used by the correlator during the next 5 ms cycle. It uses an antenna which has two independent wide band receivers, and requires the transmission of a second local oscillator to that antenna. This subsystem is needed because the solar emissions present variations, which are too strong for both the analog 10.7 MHz receiver and the analog to digital converters. Because the signals are still varying with time, a 1 bit digitization has been chosen. A separate measure of the power in the intermediate frequency is therefore needed in order to compute visibilities from the correlations. It is made by detectors whose output is integrated during 5 ms and converted to 16 bit numbers. The intermediate frequency is converted to 1 bit numbers before entering the correlator. The sampling rate has been chosen very high given the Nyquist frequency corresponding to the 700 kHz bandwidth. The sampling frequency is 42.8 MHz. That allows a very simple method to make the 90°phase shift used for sine correlation (a 1 sample shift), and the delay line time resolution (4 samples). The sampling rate is decreased before the correlation by dropping unused samples. It is divided by 13, because that leads to an over sampling close to 2 which gives, in the case of 1 bit correlations, a significant increase of the signal to noise ratio.

Table 1. Main caracteristics and observing mode

Time resolution	5ms
Spatial resolution	from 0.3 to 6 arcmin, depending on the frequency and direction
Observing frequencies	up to 10 (150 - 450 MHz)
Polarization	Stokes I and V
Observing time	7.5 h centered around 12 UT

A basic correlator cell is made of two complex correlators. As mentioned

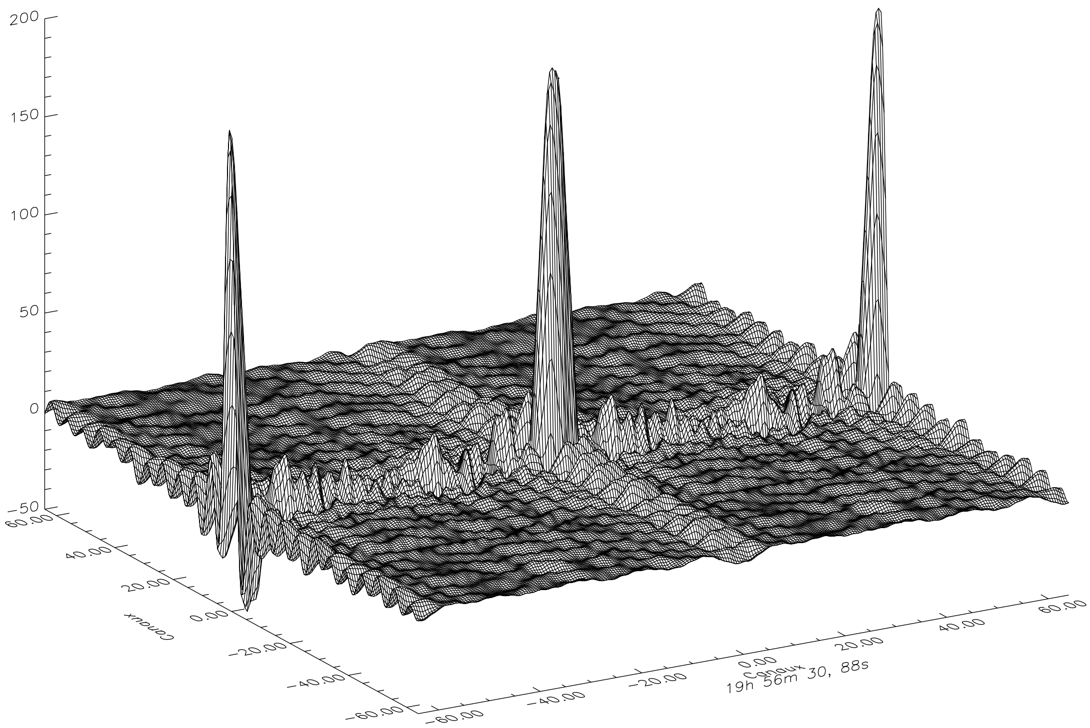

Fig. 3. Cynus A image at 432 MHz. The two horizontal axis are instrumental spatial coordinates. The vertical axis is brightness, in arbitrary units. Two periods of the image are plotted along the east-west direction.

above, it computes for each pair of antennas, the correlations of parallel and perpendicular dipoles. In order to transmit the signals from two dipoles in one coaxial cable and IF electronic, a phase modulation by a set of Walsh functions is used. The phase modulation is made at the antennas, and the demodulation in the correlator. Because the NRH has many antennas and the integration time is small, the frequency of these functions is higher than usual, and an accurate knowledge of the propagation time of modulation commands and of the modulated signals is needed. This modulation scheme also reduces the effects of crosstalk on the correlations.

2.4 The data acquisition system and calibration

The receiver outputs (correlations and power measurement) are fed into a real time computer (a Concurrent Computer Maxion biprocessor). This computer has two main functions: the receiver control - mainly the multifrequency

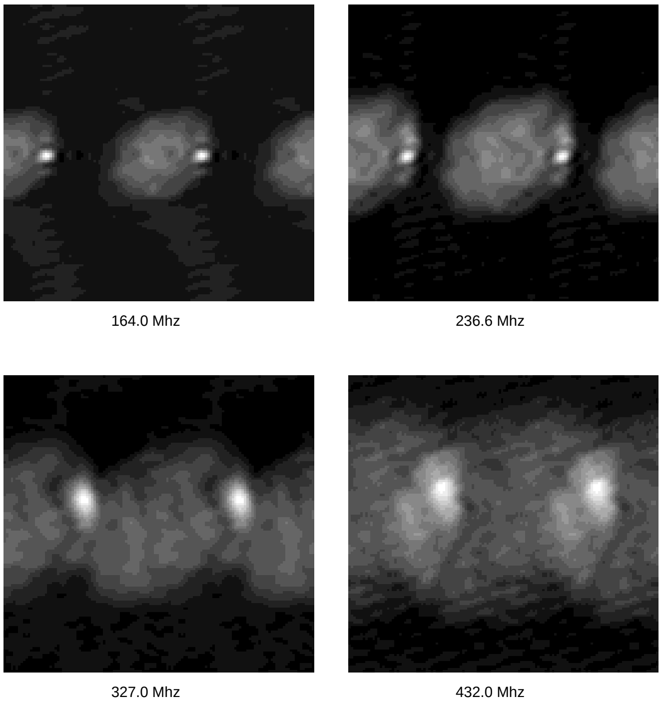

Fig. 4. The sun on 1996,July 12 at 13 32 44 UT. From top left to bottom right, four images at four frequencies are plotted (164, 236.6, 327 and 410.5 MHz). Images are computed on two periods, in order to show the aliasing phenomena at the highest frequencies.

operation- and the data acquisition, including real time computations. These computations include fringe stopping, computation and calibration of the visibilities, integration and data recording on disk. 1D and 2D raw images are also computed and displayed in real time at a low speed in order to control the proper operation of the whole system, and to allow real time scientific interaction.

The system is calibrated by observations of known intense radio sources, usually the radiogalaxy Cygnus A. Since the most intense sources are extended, a source model is fitted to the observations. Gain and phase errors are computed for each antenna and are used to compute visibilities in real time. In order to calibrate the polarization measurement, relative gain and phase of perpendicular dipoles are measured for the antennas equipped with such feeds. Because there are no polarized calibrators, the antenna at the crossing point of the arrays and two small antennas of the east - west array

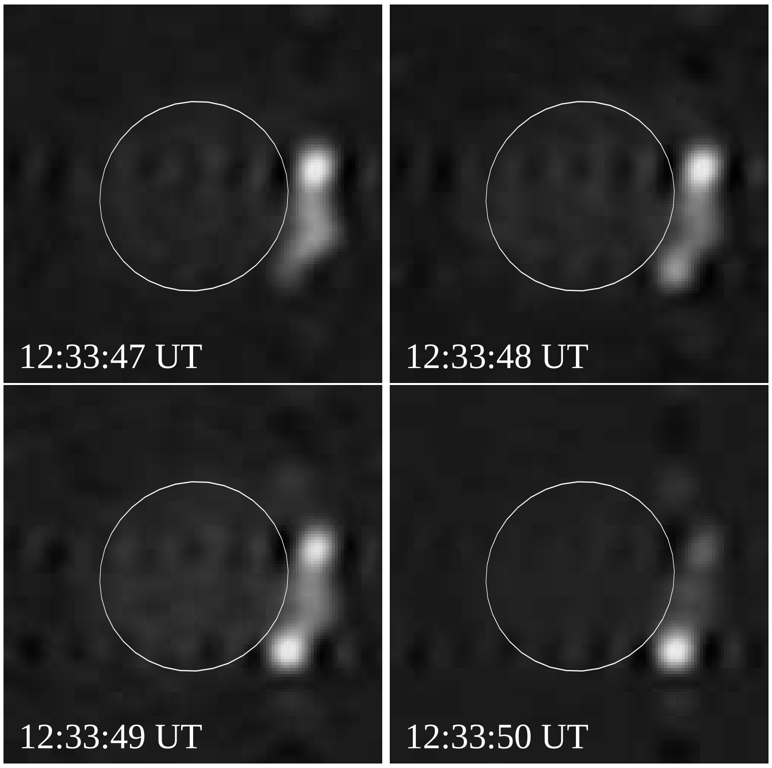

Fig. 5. The sun on 1996,July 1 at 13 33 47 UT. From top left to bottom right, four successives times are plotted, showing fast spatial evolution of type III/type V radio burst.

are rotated by 45°. Unpolarized sources therefore produce non-zero Stokes V correlations, which allow the determination of phase errors and gain. These parameters are likely to be stable because they are determined by few electronics components and small coaxial cables located close to the dipoles. The main cause of phase error -the long buried coaxial cables- are common to both dipoles.

Figures 2 and 3 show 2D observations of Cygnus A at two frequencies. The images are very close to a theoretical image of a point source. 1D images have almost the same quality.

A standard observing mode has been defined. The major constraint is the amount of data. A limited set of visibilities (east - west and north south) are stored at 10 sets per second. Each set comprises 5 observing frequencies and Stokes parameters I and V. This set is used to compute 1D images. The total set of visibilities is stored twice per second. It is used to compute 2D images.

The total amount of data is of the order of 2 Gbyte per day, for an observing time of 7,5 hours.

The frequencies are chosen in order to cover almost all the 150-450 MHz spectrum. Moreover, frequencies 164 and 327 MHz are almost mandatory because they are used for systematic observations leading to a list of radio emissions in Solar Geophysical data, and to images stored in the BASS2000 solar data base located in Paris Observatory (http://mesola.obspm.fr)

Furthermore, special observing modes will be possible on request. The main limits of such modes will be the huge amount of data generated at the maximum speed (more than 3 Gbyte/hour) and the interferences which can severely limit the choice of the observing frequencies.

3 Some typical observations

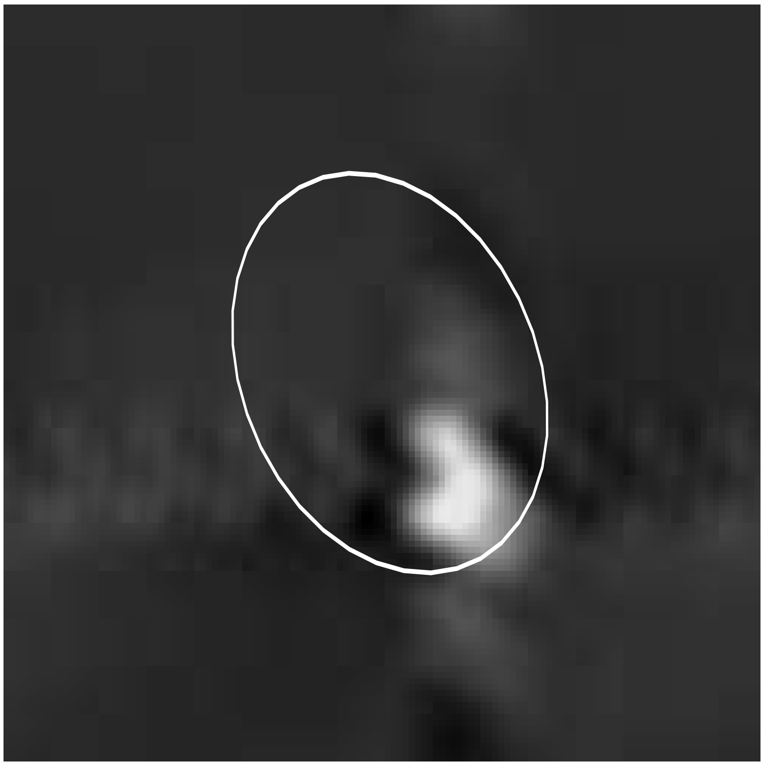

Fig. 6. The sun on 1996,July 09 at 092054 UT at 164 MHz. The white ellipsis is the optical sun limb, plotted with the geometrical distorsions which affect the raw radio map.

We will present here some observations which clearly specify the new capabilities of the NRH. Figure 4 shows an observation of a weak noise storm activity superimposed on the quiet sun. Such an emission is difficult to see on 1D projections, because the brightness contrast between the noise storm and the quiet sun is very low on such images. The non thermal source appears in figure 4 at the four plotted frequencies. These are raw images without any geometrical corrections. Two periods of the FFT image are plotted, in order to show clearly the aliasing which occurs at the highest frequencies It should be noted that the ambiguities between sources at east or west limbs can be removed by a look at 1D images, which are not affected by aliasing.

Figure 5 shows a type III/type V radio burst on 1996, July 1. Although the four successive images are displayed whith a time resolution of only 1 sec., they show that the emission consist in succesive brightenings at different positions in a loop structure. This emission is associated with a CME event.

Figure 6 shows a loop shaped continuum emission which occurred on 1996 July 9. The 2 dimensional shape of the radio source is clearly visible, although it is observed close to the lowest available frequency, which leads to the lowest spatial resolution.

4 Conclusion

The Nançay Radioheliograph has been greatly improved by its new digital correlator. The main new capability is fast 2 dimensional imaging: it is now possible to observe the 2 dimensionnal shape of radio sources which present very fast time variations. Almost simultaneous observations are available at up to ten frequencies in the 150-450 MHz frequency range. This range corresponds roughly to a 0.1- 0.5 solar radius altitude range above the photosphere. The instrument is also able to measure the circular polarization rate.

Systematic daily observations with the new receiver began on July 1996. They show that the 2 dimensionnal structure of radio bursts is well observed. A standard observing programm is used for these daily observations. It includes 1D and 2D images at 5 frequencies, respectively at 10 and 2 images per second. Integrated daily observations will be available on line, and non standard observing modes can be studied on request.

References

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