The Nançay radioheliograph : recent results and future developments

Alain Kerdraon [(1)], **Philippe Picard**[(2)]

(1) LESIA Observatoire de Paris, 5 place Janssen 92190 Meudon France, Email : alain.kerdraon@obspm.fr
(2) Station de radioastronomie 18330 Nançay France, Email : philippe.picard@obs-nancay.fr

INTRODUCTION

Radioheliography brings valuable data important for the understanding of the solar magnetic activity. Radio emissions are mostly produced by non thermal electrons or by the hot coronal plasma. According to the frequency of the radio waves, the emission comes from deep layers of the solar atmosphere, the chromosphere, at frequencies greater than 30 GHz, of from the corona at metric wavelength. The typical altitude range of the emissions observed by the Nançay radioheliograph (NRH) is 0.1 to 0.5 solar radii above the photosphere.

In the past few years, observations of solar emissions at metric wavelength have brought new insights at solar activity phenomena like Coronal mass Ejections (CMEs), particle acceleration and propagation toward the interplanetary medium, and flares . We will show here some of these new results, and will first present the technical evolution of the NRH and technical developments in progress in Nançay for future instrumentation.

INSTRUMENT EVOLUTION

NRH [1] has a main T shaped array of 42 antennas, 1600m in the east-west direction and 1250m in the north south direction. Two distant antennas, respectively 2400m east and 2350m south of the center of the main array, have been added in order to increase the performance when doing aperture synthesis. Observations are done in a small frequency band (1 MHz) which can be choosen between 150 and 450 MHz. Fast switching of the observing frequency allows almost simultaneous observation of 5 to 10 frequencies. Wide band parts of the receivers, located close to the antennas, are protected from radio frequency interferences (RFI) by high performance filters, and the narrow frequency band help a lot for RFI suppression in most part of the receiver. Attenuators are inserted automatically in order to keep solar signals in a limited dynamic.

A major upgrade was done in 2003, with the addition of 4 new small log peridic antennas. Each is correlated with 18 antennas selected in the north-south arm of the array. This allow to build a denser central core in the u-v plan, with minimum baselines compatible with the size of the sun at the highest frequency. Fig. 1 shows the result :before the upgrade, it was impossible to make good snapshots of the sun at frequencies greater than 250 MHz. A strong aliasing destroyed the image of the thermal corona (a broad 40 arcmin source), and introduced ambiguities on small size sources. With the new antennas, the images of the thermal corona are good, and aliases of small size sources are reduced to ~30% of the principal source brightness, and can be therefore easily removed by CLEAN.

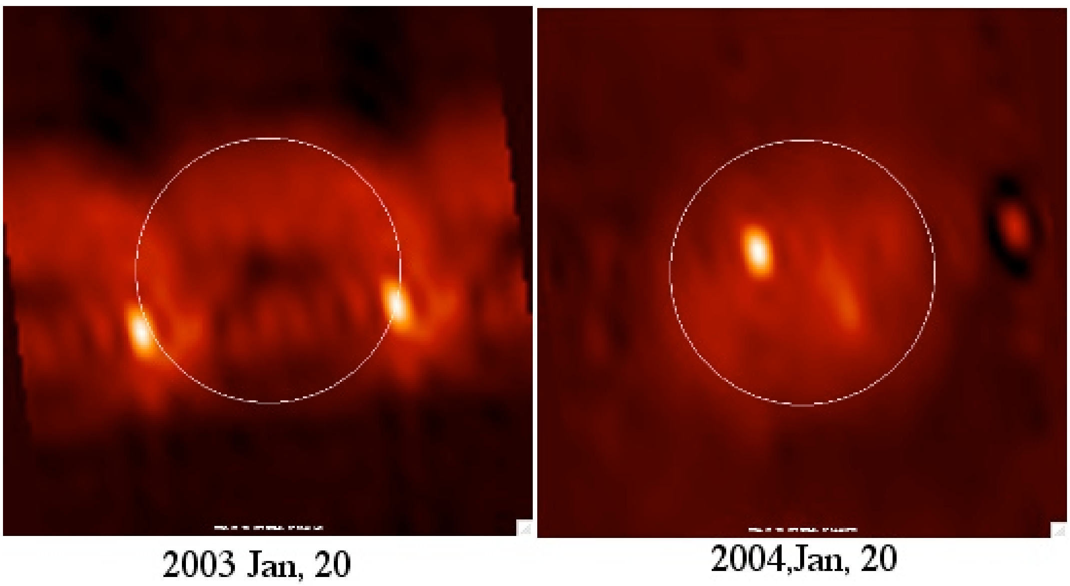

Fig.1 : Images of the sun (broad thermal corona emission and one small size non thermal source), in the same geometrical conditions (same day and time), before and after the addition of 4 new antennas..

For the future, we are studying digital high dynamic receivers for radio interferometry. The goal is to observe a wide frequency band in the typical meter – decimeter wavelengths radio interferences (RFI) landscape. Another paper [2] presents ongoing RFI mitigation studies in Nançay. Solar observations have at least two typical characteristics : (i)the integration time is small, and there is therefore no need to deal with low level RFI, (ii) solar signals have a hign variability, and should be distinguished from typical RFI. We are working on high dynamic filter banks receivers in two cases : 14 bits dynamic and 50 MHz bandwidth, 8 bits dynamic and 300 MHz bandwidth. These studies, including test observations with NRH antennas, will give conclusions for the FASR project [3], and may also be useful for the new chinese radioheliograph project. They may give an economic solution to improve the efficiency of the NRH, which can use presently only 50% of its nominal observing frequency band because of RFI.

A promising new technique, consisting in imaging with a combination of the visibilities from the NRH and the Giant Meterwave radiotelescope (GMRT) was tested [4]. It produces full sun high dynamic images, with a spatial resolution greatly improved by the long baselines of the GMRT.

SCIENTIFIC RESULTS

Radio observations, combined with X rays, UV, visible light and particles observations, led to many new results in the last years. We will give here only some examples of new results for which NRH observations were important. They concern flares, coronal mass ejections (CMEs), particle acceleration, and solar particles injection in the interplanetary space.

FLARES AND PARTICLE ACCELERATION

Paper [5] presents the first study combining X-ray (Rhessi experiment) and radio images (NRH) of flares. X-ray and radio light curves are correlated, and the shapes and positions of radio sources change when X-ray sources are evolving (Fig. 2)

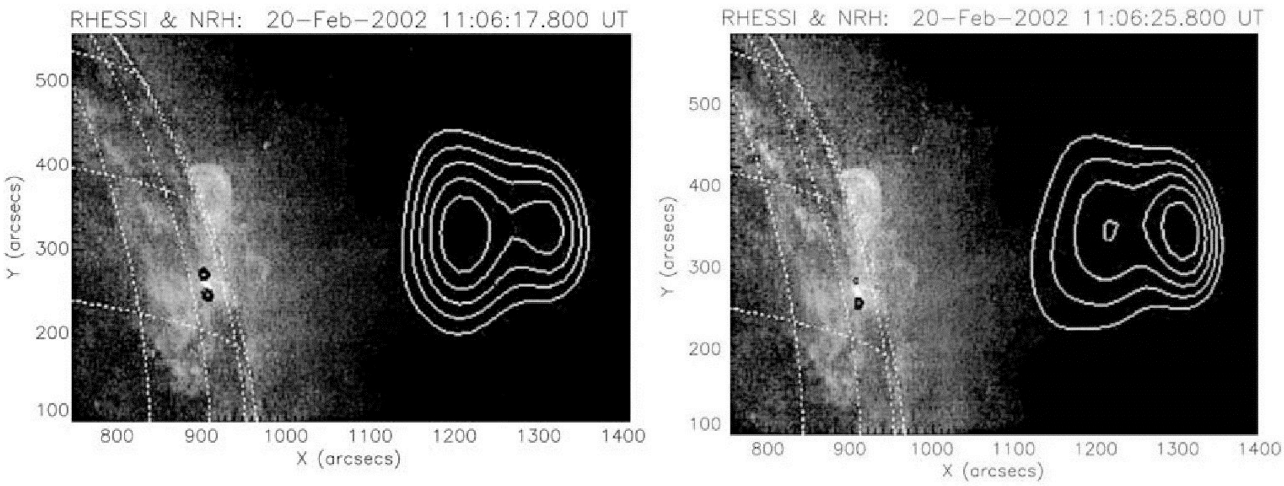

Figure 2 (from [4]) : Rhessi X-ray (25-40 keV) sources contours appears as compact black spots. Radio sources at 410 MHz (NRH) are shown by white contours. The background is the closest EIT image.

In paper [6], the study is extended to a very broad band continuas which occur just after the impulsive phase of a flare. X-ray and radio fluxes have the same modulation (see fig. 3). The radio emission is due to gyro-synchrotron mechanism, and the the authors argue that the modulation of both emissions is likely to be due to the acceleration mechanism, because modulations due to coronal structures (MHD oscillations, betatron acceleration) cannot give the same modulation in a very broad band.

CORONAL MASS EJECTIONS

Radio imaging observations of fast, flare related CMEs near the limb [7] show that the activity spreads from the flare vicinity to the large angular extent of the CMEs in less than 10-15 minutes. Radio observations of CMEs on the solar disk show a similar angular extension. The large scale magnetic restructuring could be interpreted as the result of the interaction of a coronal disturbance with the ambient magnetic field. Recently [8], it was shown that the position of a broad band radio emission was consistent with the observed geometry of a well formed Moreton wave (see Fig. 4).

In that case, radio imaging of a fast halo CME provides the speed and the angular extension of the on disk CME. This is important for solar-terrestrial physics.

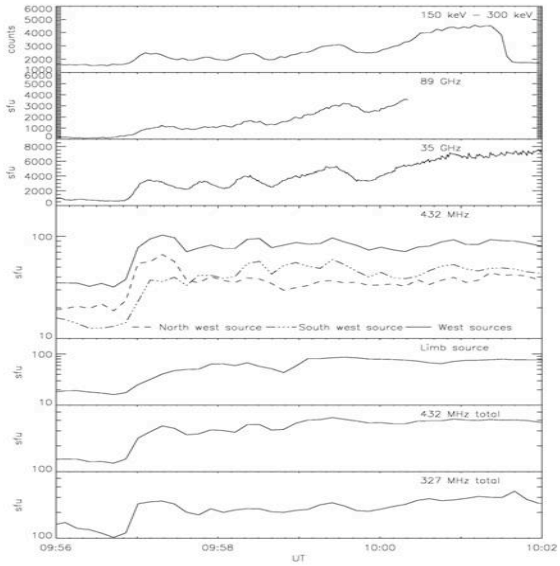

Figure 3 : X-ray and radio modulation, from paper [6]

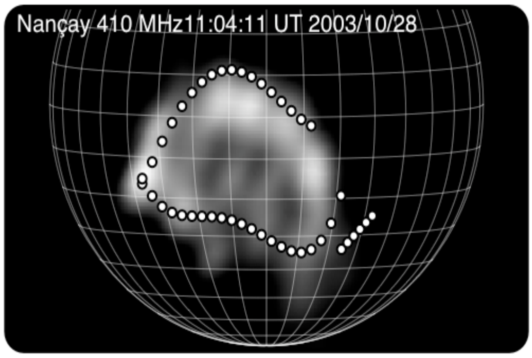

Figure 4 : Coincidence of a Moreton wave (white dots) and of a radio continuum at 410 MHz.(from paper [8])

In paper [9], a complex event, including a fast moving type 4 burst was analyzed in detail. The observationnal constraints allowed to select a CME model based on an eruptive flux rope. (shown on Fig. 5). The conclusion is that moving radio sources, often described as isolated magnetic structures, are in fact not detached from the sun. This is coherent with in-situ observations at 1 AU and beyond.

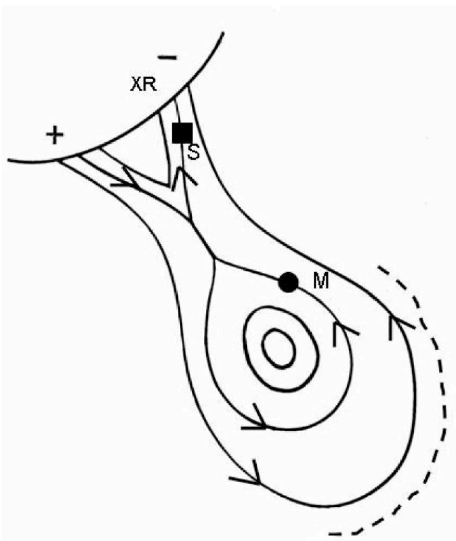

Figure 5 : 2D model for X-ray (XR), stationnary (S) and moving radio continuas (M) emissions. From paper [9]

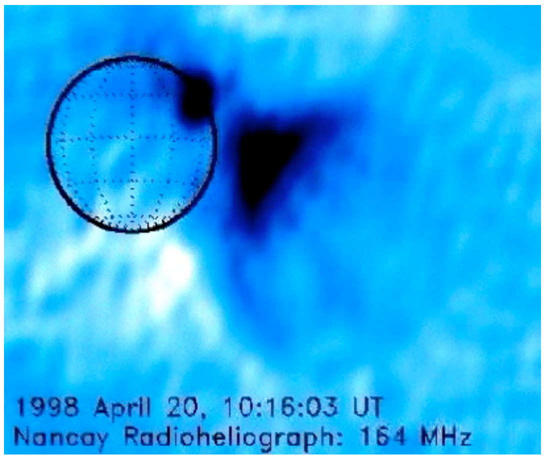

Figure 6 : radio loops in a CME. From paper [10]

An original observation of a a CME was made by Bastian et al. [10] : expanding loops inside a CME were observed because they were illuminated by the gyro-synchrotron emission of Mev accelerated electrons. They were observed at large distances from the sun (Fig. 6). This observation provided informations on the electronic density and the magnetic field stength inside the CME. Such events are very difficult to observe because of their low brightness, but they are more common closer to the sun, at higher frequencies.

The large angular extension of the radio emission associated to the CMEs may give an explanation to the observation of particles at the earth for flares which are not magnetically connected, for example flares located in the eastern hemisphere.. In such cases, radio emissions show that accelerated electrons are present in the corona at connected longitudes, far from the flare site. In paper [11], authors studied solar energetic particle events, They found that protons are probably not accelerated in the shock driven by CMEs, but closer to the sun. They suggest that the plausible site of acceleration is in the corona, where the magnetic field disturbed by the CME reconnects. That gives an image of flare/CME events in which particles may be accelerated and injected in interplanetary space far from the flare site.

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