Radio observations of the Sun at Nançay

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Abstract. At the Nançay Radio Observatory, in central France, observations of the Sun have always been performed since its foundation in 1952. At present, two main instruments, the Radioheliograph and the Decametric Array, are used for monitoring solar activity, as well as a few smaller monitoring antennas. The Radioheliograph is a unique 43-element interferometer dedicated to solar imaging in the metre wavelength range (0.6-2 m). Its powerful new correlator allows the imaging of the solar corona at a rate of 20 images per second in 5 frequency bands. Its rapid, multi-frequency capability enables the study of events in the corona between heights of about 0.1 to 0.5 solar radius. The Decametric Array is a unique 144-element interferometer dedicated to observations at very long wavelengths (3-30 m). At this instrument the upper solar corona is monitored at high time and spectral resolution.

Keywords: solar activity, flare, CME

1. Introduction

At the Nançay Radio Observatory, located 200 km due South of Paris, observations of the Sun have always been a constant activity from its foundation in 1952 (see also our Website http://www.obs-nancay.fr), as the Sun was the first celestial object to be studied at radio wavelengths by French physicists and astronomers, and a series of solar radio telescopes has since its beginning been erected on the Nançay site (see Figure 1). At present, two main instruments (the Radioheliograph and the Decametric Array) are used for monitoring solar activity, as well as a few smaller monitoring antennas.

Figure 1: Nançay – the early years (1955). Left: elements of the solar interferometer in use at the time, these dishes are still printed on the packages of the famous Nançay *sablé* shortbread cookies; to the right: one of the converted 8-meter German Wurzburg radar antennas buot in 1943, part of a large interferometer used to study Galactic structure.

2. The Radioheliograph

The radioheliograph (see Figure 2) is a unique 43-element radio interferometer dedicated entirely to solar imaging in the metre wavelength range (0.6-2 m). For more detailed descriptions of the instrument, see Kerdraon & Delouis (1997) and Radioheliograph Group (1993).

As a result of a long evolution initiated in 1982, it now consists of a cross-shaped multi-antenna array, comprising an East-West branch with 19 antennas along a 3.2 kilometer long baseline and a North-South branch of 24 antennas over a total length of 3 kilometer, with minimum baselines of about 50 meters. This configuration allows the two-dimensional imaging of the Sun with a beamsize of about 0.4 to 1.8 arcmin (at 0.6, resp. 2 m. wavelength) during summer months; during winter months the beam is more elongated in the North-South direction.

The rapid structural variations in the (radio) corona require fast imaging capabilities. It has recently been equiped with a digital correlator, which permits the true two-dimensional imaging of the solar corona, using all possible baselines of the T-shaped array, at a maximum rate of 20 images per second in each of 5 fixed wavelengths between 60 cm and 2 meter wavelength. Observations at different wavelengths probe different heights in the corona, in the case of the Nançay radioheliograph regions between 0.1 and 0.5 solar radius above the visible surface.

It is an instrument dedicated to solar observations, and presently the only instrument to provide the astronomical community with radio observations of the solar corona at metric wavelengths during 8 hours each day, all year round; the other dedicated solar radio telescope, at Nobeyama Radio Observatory in Japan, observes at much shorter, centrimetric, wavelengths which probe the solar atmosphere much closer to the visible surface, and other radio telescopes, like the Very Large Array (VLA) in the U.S.A. or the Giant Metre wave Telescope (GMT) in India, observe the Sun only infrequently, and have not been designed for such specialized observations of a highly variable, very intense radio source.

A series of radio images taken during the total solar eclipse of August 11, 1999, is shown in Figure 3. These images were made at the longest of the 5 wavelengths observed, 1.8 meter. These images clearly show the extension of the radio corona with respect to that of the optical disk (plotted as a white circle). The eclipse was about 95% in the optical at Nançay; the image taken at the maximum occultation (10:23 UT) shows the offset of the lunar shadow against the radio corona from the outline of optical disk. Clearly, any solar eclipse which is total in the optical will always remain annular at these radio wavelengths. Note the CME occuring around 09:43 UT.

Figure 2: Antennas of the North-South branch of the Nançay Radioheliograph, an interferometer dedicated to observations of the middle solar corona at metric wavelengths. The 5-meter diameter antennas operate between λ 0.6 and 2 meter.

Radioheliograph images are stored on CD-ROMS and made available on a daily basis to the astronomical research community through the BASS 2000 solar database (see Website http://mesola.obspm.fr/nancay2d.html).

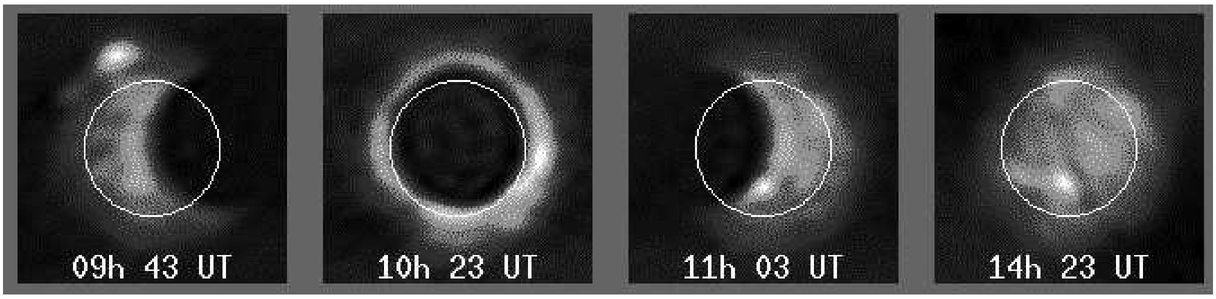

Figure 3: Radio images of the total solar eclipse of August 11, 1999, obtained with the Radioheliograph at 1.8 meter wavelength. The white circle denotes the size of the optical solar disk. Note that the lunar disk will never cover the entire solar radio image during any eclipse, as the middle solar corona (at a height of about 0.5 $R_\odot$ above the visible surface) is detected at this metric radio wavelength. The maximum occured at 10:23 UT; note the Coronal Mass Ejection (CME) occuring around 09:43 UT.

The Radioheliograph imaging data provide a complementary, radio view of events like flares and coronal mass ejections (CMEs – see Figure 3); e.g., Maia (1999) and Pick et al. (1999). Comparison with observations made in other wavelength domains, from the ground as well as with spacecrafts (like ULYSSES, SOHO, YOHKOH and TRACE), combined with modelisation of the underlying magnetic field structures and their evolution allow a fuller understanding of solar physics (e.g., Manoharan et al. 1997).

3. The Decametric Array

The Decametric Array (see Figure 4) is a unique 144-element interferometer dedicated to radio observations at the longest wavelengths (3-30 m) which can still penetrate the Earth's ionosphere (even longer wavelengths are reflected back into Space by the ionosphere). With this instrument the upper solar corona is monitored when there are no ongoing observations of the radio activity of Jupiter. At these long wavelengths the solar corona cannot be resolved by it, which is compensated by high time-resolution over a broad frequency range.

The Decametric Array is dedicated to the study of the magnetic and ionized environment of the Sun and planets (mainly Jupiter). In these plasmas not only the low-frequency emission (decametric radio waves) detected with the Decametric Array are produced, but also very low frequency emission (at kilometric wavelengths, observable by spacecraft only; e.g., Barrow et al. 1996) and ultraviolet radiation (planetary aurorae, observed with the HST; e.g., Prange et al. 1998). The radio observations show a variety of phenomena (down to time scales of less then a second: the so-called millisecond bursts of Jupiter, and solar and stellar eruptions) which allow the study of the dynamics of these ionized plasma environments.

Figure 4: The Decametric Array consisting of 144 antennas. The 144 "teepee" type antennas are fixed and pointed towards the South, where the Sun and Jupiter can be observed. Their field of view is very large (about 60°, pointing and tracking is done completely electronically.

The Decametric Array, developped in the years 1975-1978, is an interferometer consisting of 144 antennas of 9 meter high and 5 meter in diameter at their base, distributed over an area of 10,000 square meter. The 8 conducting wires on each antenna have been wound in a spiral pattern on a conical surface - giving them the nickname of teepee antennas, after the American-indian conical tents. The wires on the antennas are wound in either a left- or a right-handed winding spiral pattern, making them sensitive to either left- or right-hand circularly polarized radio waves. Thus, the Decametric Array exists in fact of two sub-arrays of 72 antennas each, and is capable of measuring circular polarisation, which is very important since the radiation from Jupiter is highly polarized. The broad-band spectroscopy of the emissions, often very variable, requires specialized, very fast receivers which can take several thousand measurements per second.

The principal beam, i.e. the spatial resolution, has a size of 7 by 14 degrees - large compared to the actual size of a few degrees for the solar corona or only a fraction of a degree for Jupiter's magnetosphere, as seen from the Earth. This "nearsightedness" remains the weak point of observations at such long wavelengths (except for very-long baseline interferometry, VLBI). It does not permit detailed imaging and prevents therefore the localization of the radio emission in or near the observed radio source. Fortunately, this lack of spatial resolution is compensated by the high frequency and time resolution of the observations made with the Decametric Array.

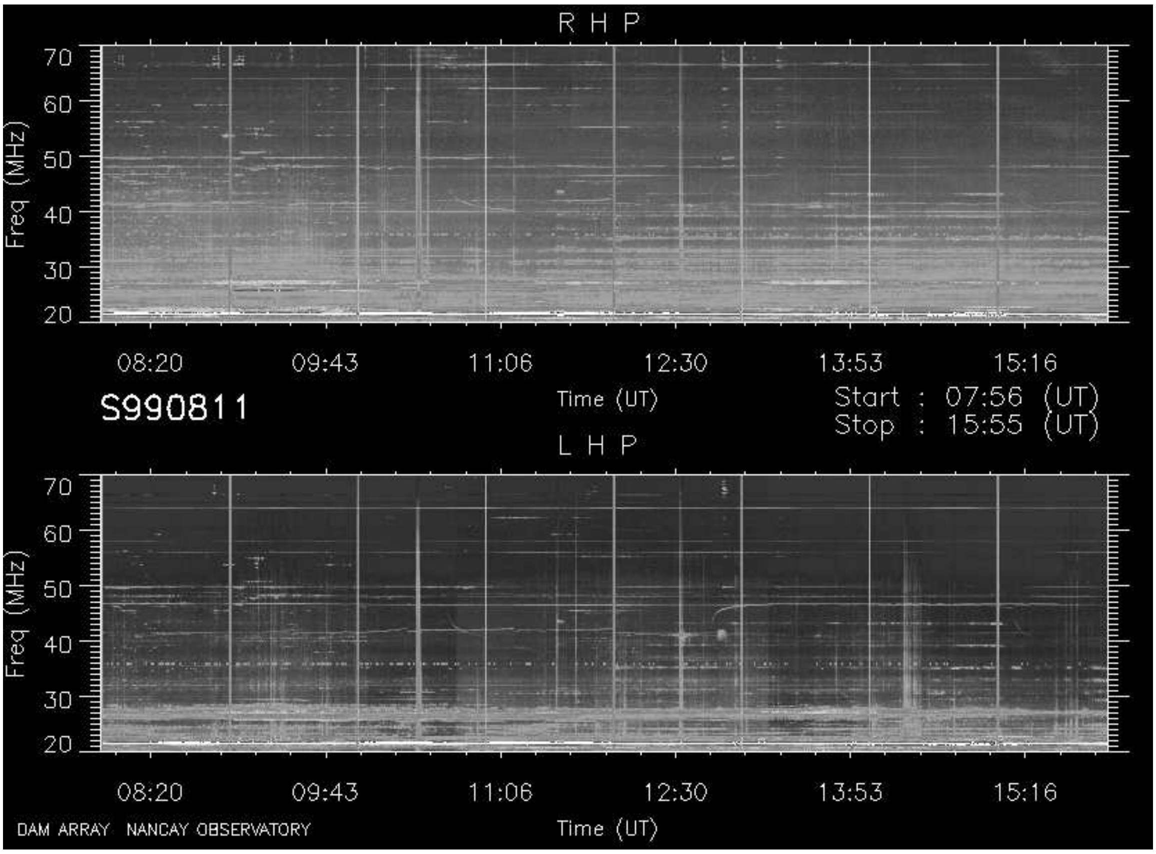

Figure 5: Dynamic spectra of the Sun made with the Decametric Array during the day of the total solar eclipse of August 11, 1999. The vertical axis shows frequency, the horizontal axis time and the greyscale indicates the intensity of the emission. Observations were made in two polarisations: left-hand (LHP) and right-hand (RHP). The lunar disk occults only a small fraction of the upper solar corona detected at these very long radio wavelengths, hence the effect of the eclipse at these wavelengths is much less clear than in the images obtained with the Radioheliograph. The maximum occured at 10:23 UT.

Far prior to any other wavelength domains, decameter wave radioastronomy became a challenging task because of man-made radio interference due to the increasing needs in telecommunications. However, most of the astrophysical studies in this frequency band – particularly those of non-thermal radiations from magnetized objects – require high gain, multi-polarisation antennas and the use of high sensitivity, high dynamic range spectroscopy techniques. Actually, the observations are essentially digital, and made with four complementary receivers, including:

A frequency-sweeping spectral analyzer (ASB): this provides us with systematical broad-band observations of the Sun and Jupiter, with a time resolution of about 1 second, during about 6 to 8 hours per day around the meridian passage of each object. It records both left- and right-hand polarized radiation. The observed data (1 to 3 Mbyte per hour) are stored on CD-ROMs and made available to the scientific community (see the Website http://www.obs-nancay.fr/quest/index_se.htm). As an example, the routine observational solar data are shown here (Figure 5) for August 11, 1999, the day of the total solar eclipse.

Digital receiver: a new generation of wide band spectrum analyzers, well suited to overcome the interference constraints, are presently being developed. They are based on the utilization of newly available, high performance, programmable digital circuits for signal processing, arranged in an architecture which can directly compute the power spectrum of the input signal (e.g., Lecacheux et al. 1998). The possibility of processing the telescope signal in real time appears a key to maintaining acceptable sensitivity in an increasingly 'hostile' radio electric environment. The bandwidth of the prototype receiver will be increased and more sophisticated algorithms will be developed for the recognition and elimination of interference, both in real time and for further off-line data reduction.

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