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An Outreach Project for LOFAR and Cosmic Ray Detection

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In the context of the LOFAR project, we started an outreach initiative at the Radboud University Nijmegen. We combined LOFAR prototype electric dipole antennas with a particle detector cluster of the NAHSA (Nijmegen Area High School Array). The purpose of our project is to detect cosmic ray events in radio emission and particles at energies above 10^{15} eV in coincidence. We use two (crossed) dipoles in each of our four antenna stations of LORUN (LOfar @ Radboud University Nijmegen) to study polarization characteristics of coherent radiation pulses from cosmic ray air showers. The LORUN/NAHSA project is also accessible to students, moreover the hard- and software development for the combination of the two experiments was mainly carried out by undergraduate students. We present a description of the instrument and first data.

1. Introduction

ASTRON is building a new radio telescope which is based on an array consisting of simple dipole antennas. This telescope is called LOFAR (Low Frequency ARray). One of the key science projects is the study of Ultra High Energy Cosmic Rays (UHECR). These particles penetrate the Earth atmosphere with energies beyond 10^{15} eV. A so-called shower pancake is created, which is traveling through the atmosphere. The charged particles in the shower evolution - mainly electrons and positrons - get deflected in the Earth magnetic field and emit coherent geosynchrotron radiation [3].
Currently, three test stations for LOFAR exist and two of them are optimized for cosmic ray air shower measurements in the radio regime from 40 to 80 MHz. One of them is LORUN (LOfar @ Radboud University Nijmegen) consisting of four (crossed) dipole antennas (like in Figure 1a) on top of the building of the Radboud University Nijmegen. LORUN is triggered by two particle detectors of the Nijmegen Area High School Array (NAHSA) [5]. NAHSA takes data since June 2002 and is part of the High School Project on Astro-Physics Research with Cosmics (HiSPARC) [6]. In the scope of HiSPARC and NAHSA high school students can perform a six week hands-on training about how to build a particle detector and learn about its scientific applications. In the case of LORUN the experiment was mainly built up by undergraduate students doing their research projects in radio astronomy.
From confirmed detections of cosmic ray air showers with LOPES [4], we learned about basic properties of the antenna response to the radio signal. Based on those experiences, we want to optimize the LORUN experiment in Nijmegen and study polarization of the received radio signal.
In this article we explain the instrument, discuss first results and give an outlook on further activities.

2. Experimental Setup

Each dipole's waveform signal is amplified by a low-noise amplifier (LNA), filtered for a frequency band from 40 to 80 MHz and then digitized. The high performance Analog-Digital Converters (ADC s) with a dynamic range of 12 bit supply a rate of 80 million samples per second, which translates to a time resolution of 12.5 ns

and a data rate of $\sim$ 150 MB per second and dipole. Attributed to the (crossed) and inverted-V-shape design of the antenna dipoles, the whole sky is measured at the same time with a primary beam of 90° centered on the zenith. With off-line beam-forming the array can be pointed at any source in the sky. The antenna prototypes and the data acquisition hardware for LORUN was provided by ASTRON and is very similar to LOPES hardware, which is described in more detail elsewhere [2].
The LORUN antennas are located nearby two scintillator-particle detectors accommodated in ski-boxes, which belong to the NAHSA project (see Figure 1b). NAHSA consists of 8 twin detector stations located all over Nijmegen with distances between 519 and 4679 meters.

(a) **(b)**

Figure 1. (a) LOFAR prototype antenna: two (crossed) inverted-v-shaped dipoles in the legs of the PVC structure connected to two low-noise amplifier (LNA) located in the top box. (b) NAHSA particle detectors: scintillator plates connected to a photo multiplier tube (PMT) accommodated in ski-boxes on top of the building of the Radboud University Nijmegen.

For simultaneous data acquisition, we use a coincidence detection of the two NAHSA scintillators as a trigger for the radio data and store about one millisecond of data around that point in time. By GPS, we get the time information for each event, which is stored with the data of both experiments. To confirm a detection by the radio antennas, we compare the digitized waveform from each dipole and search for coherent peaks. Since the shower emission does not arrive at the antennas at the same time, we search in a time window determined by the light travel time across the maximum distance between two antennas. To reduce the contamination of our waveform by radio frequency interference (RFI), we use FFT and try to select a "clean" part of the spectrum. The data analysis is performed by students with help of a graphical user interface, which provides the tools for basic data reduction like FFT, filtering, beam-forming and displaying.

3. Interference & Timing

Placing the first antenna on top of the building of the Radboud University Nijmegen, we had to realize that the RFI environment is a very sensitive issue. It turns out that we receive 23 times less power (green spectrum, Figure 3a) at the current site of the LORUN compared to the first site (red spectrum, Figure 3a). The very strong RFI at the first location can be attributed to many different transmitters on a nearby building, which went out of view moving to the current position.

Another challenge was accurate timing down to a fraction of a second to match particle and radio data after detection. A GPS synchronized time stamp is stored for each trigger of the particle detectors. Since we use two different computers for data acquisition, we synchronize them via Network Time Protocol (NTP). It turns out that the synchronization works down to a tenth of a second, which is less then the dead time of the NAHSA experiment and this way good enough.

4. First results

To display the response of our dipoles to the unfiltered environment as function of time, a dynamic spectrum is useful. In Figure 2 these spectra are plotted for one hour and two (crossed) dipoles. Figure 2a shows the dynamic spectrum of the dipole pointing NW (330°) and Figure 2b shows the orthogonal dipole facing NE (60°). The plots show the spectra of all the one millisecond event files triggered by NAHSA stacked together. The average time between two successive events is about four seconds. Using this one hour of data to calculate the Stokes parameters and the degree of polarization, it turns out that the signal is 93% polarized. The degree of linear polarization results in 89% and the degree of circular polarization gives 25%. This is not surprising, since the dominating man-made RFI is mostly intrinsically 100% linearly polarized (horizontally or vertically). The latter aspect of RFI opens up the possibility to isolate this kind of man-made interference by correlating spectra of successive events.

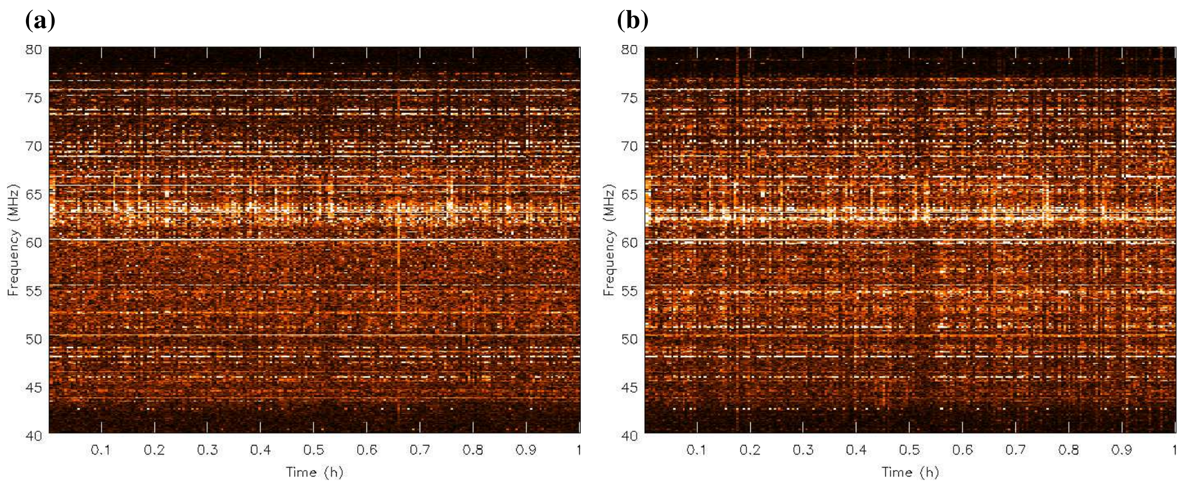

Figure 2. Dynamic spectra of two perpendicular dipoles of one LORUN antenna measured on 24.06.05. (a) as measured by the dipole facing NW and (b) facing NE. The vertical, bright lines indicate strong RFI measured for the related events and the horizontal line at ~ 62 MHz is the carrier signal of a TV broadcasting station.

After we managed to reduce RFI and got correct timing, we started analyzing the data searching for CR peaks in the time window triggered by the particle detectors. In Figure 3b a first candidate is plotted. The squared electric field (power) as function of time for two (crossed) dipoles after filtering in the frequency domain is plotted. We performed filtering by selecting the frequency band from 45 to 60 MHz, which is the least effected by RFI (compare with green spectrum in Figure 3a) and by flagging narrow lines in frequency. Since the antennas are not calibrated yet, the units in the plots are arbitrary.

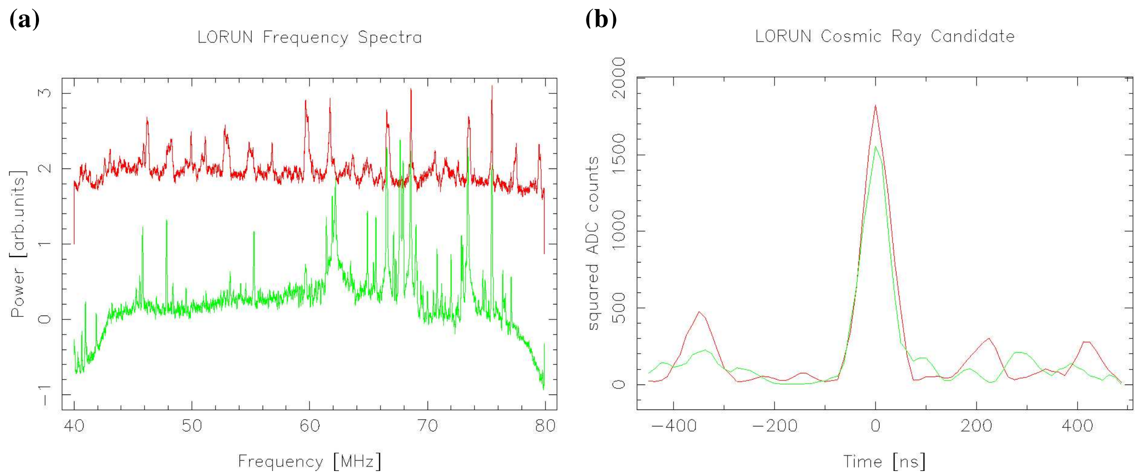

Figure 3. (a) Spectra of two different locations measured with one dipole. The lower spectrum was measured at the current site (green) and shows a TV-station visible at ~ 62 MHz. The upper spectrum taken at the first site (red) shows strong RFI, where even the TV-station is not visible any more. (b) First externally triggered cosmic ray candidate measured with one LORUN antenna consisting of two (crossed) dipoles.

5. Conclusions

Since LOFAR is a digital telescope and entirely computer based, it was easy to combine its prototype antennas with the NAHSA project, which also provides digital data for its detected particles. The high time resolution of LOFAR antennas makes them perfectly suited for simultaneous cosmic ray measurements with NAHSA detectors. A new challenge with dipole antennas is to deal with RFI. These radio antennas receive signals from all directions, unfortunately also strong RFI. This kind of interference can be reduced by forming a beam in direction of a source of interest and choosing a radio ”quite” location. We recorded a first cosmic ray candidate, a short pulse measured with two (crossed) dipoles.

Further, the LORUN experiment is used by undergraduate students to do their research projects. Currently, a team of seven students works on antenna calibration, determination of shower direction, determination of the energy of the primary particle, the study of signal polarization and an extension of the experiment by magnetic loops.

To increase the outreach of LOFAR and CR detection, we also plan to open the opportunity for high school students to extend NAHSA stations with radio antennas.

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