Detecting astrophysical ultra-fast radio transients: the RadioGAGa trigger board on the NenuFAR radio telescope

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and the NenuFAR builder list

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Abstract

Today a proven detection technique, the radio detection of ultra-fast transients (few tens of ns) emitted by ultra-high energy cosmic ray atmospheric showers has been successfully used on several experiments such as LOPES, CODALEMA, LOFAR, AERA, the firsts among many others. However, at the present time, all these antenna arrays are not suitable for the detection of air showers below an energy of ~$10^{16.5}$ eV, thus burdening the detection of the most energetic gamma ray air showers, expected at most at a few PeV "only". The current air shower detection arrays are composed of individual antennas, and regardless their number the overall sensitivity is limited by the single antenna sensitivity. The central idea of RadioGAGa is to build an efficient trigger for lower energies by phasing the signals of several antennas before the trigger decision is taken. We take advantage of the special configuration of NenuFAR and its numerous 19 antennas mini-arrays, each one having a sensitivity of about 4.3 times higher than a single antenna. By digitally combining the analog phased signals of several mini-arrays (*i.e*. 8), the expected sensitivity in the pointing direction could reach more than 30 times the one of a single antenna, lowering the shower energy threshold down to the PeV or even below and thus opening the door to the radio-detection of PeVatron gamma air showers. This addresses energies beyond the usual limits reached by current and future Cerenkov telescopes (H.E.S.S., CTA), with the possibility of reaching a duty cycle close to 100 %, since the day/night alternation and the weather have no influence on the detection itself. Tested on several well-known gamma ray sources since late 2021, it has unfortunately not given any positive result yet concerning gamma showers detection, due to the lack of statistics at the expected energies. However, during test phases and set-up of the board parameters, several test sources (Sun, Cas_A, Cyg_A) were observed and we have surprisingly detected fast radio transients at the tens of ns scale. These unexpected signals deserve further analysis and observations. For CasA and CygA, if the astrophysical origin of those transients is confirmed, there will be still to explain the processes leading to the production of such pulses visible in the time domain over a large frequency band in sources experiencing a consequent DM, and to possibly correlate them with other emissions in X or even radio. For the Sun, the solar origin leaves few doubts and can be correlated to specific emissions observed in the time-frequency domain, but the short temporal structure is still to be explained. More generally, RadioGAGa could be of huge interest in the detection of any fast radio transient, such as pulsar's giant pulses or FRBs. The board can be UDP-triggered externally by any other telescope. We specially think about the NRT, whose FRB observation program on known sources gave interesting results, allowing us to expect triggering NenuFAR via RadioGAGa as soon as an FRB transient is observed at higher frequencies. Taking into account the latency due to the dispersion measure between high and low frequencies, the idea is to program the triggering of RadioGAGa at specific times and rates covering the complete dispersed bandwidth, and to examine the potential nanosecond structure of an FRB pulse. NenuFAR being also considered as a SKA pathfinder, this could be of paramount importance to develop such an innovative solution in the perspective of SKA.