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Radio detection of Cosmic-Ray Air Showers and High-Energy Neutrinos

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Abstract

In the last fifteen years radio detection made it back to the list of promising techniques for extensive air showers, firstly, due to the installation and successful operation of digital radio experiments and, secondly, due to the quantitative understanding of the radio emission from atmospheric particle cascades. The radio technique has an energy threshold of about 100 PeV, which coincides with the energy at which a transition from the highest-energy galactic sources to the even more energetic extragalactic cosmic rays is assumed. Thus, radio detectors are particularly useful to study the highest-energy galactic particles and ultra-high-energy extragalactic particles of all types. Recent measurements by various antenna arrays like LOPES, CODALEMA, AERA, LOFAR, Tunka-Rex, and others have shown that radio measurements can compete in precision with other established techniques, in particular for the arrival direction, the energy, and the position of the shower maximum, which is one of the best estimators for the composition of the primary cosmic rays. The scientific potential of the radio technique seems to be maximum in combination with particle detectors, because this combination of complementary detectors can significantly increase the total accuracy for air-shower measurements. This increase in accuracy is crucial for a better separation of different primary particles, like gamma-ray photons, neutrinos, or different types of nuclei, because showers initiated by these particles differ in average depth of the shower maximum and in the ratio between the amplitude of the radio signal and the number of muons. In addition to air-shower measurements, the radio technique can be used to measure particle cascades in dense media, which is a promising technique for detection of ultra-high-energy neutrinos. Several pioneering experiments like ARA, ARIANNA, and ANITA are currently searching for the radio emission by neutrino-induced particle cascades in ice. In the next years these two sub-fields of radio detection of cascades in air and in dense media will likely merge, because several future projects aim at the simultaneous detection of both, high-energy cosmic-rays and neutrinos. SKA will search for neutrino and cosmic-ray initiated cascades in the lunar regolith and simultaneously provide unprecedented detail for air-shower measurements. Moreover, detectors with huge exposure like GRAND, SWORD or EVA are being considered to study the highest energy cosmic rays and neutrinos. This review provides an introduction to the physics of radio emission by particle cascades, an overview on the various experiments and their instrumental properties, and a summary of methods for reconstructing the most important air-shower properties from radio measurements. Finally, potential applications of the radio technique in high-energy astroparticle physics are discussed.