A Low-Frequency Distributed Aperture Array for Radio Astronomy in Space

A.J. Boonstra\textsuperscript{1}, N. Saks\textsuperscript{2}, H. Falcke\textsuperscript{3}, M. Klein-Wolt\textsuperscript{4}, M.J. Bentum\textsuperscript{1,6} R.T. Rajan\textsuperscript{1}, S.J. Wijnholds\textsuperscript{1}, M. Arts\textsuperscript{1}, K. van 't Klooster\textsuperscript{5}, F. Beliën\textsuperscript{2,7}

\textsuperscript{1}ASTRON, \textsuperscript{2}ASTRIUM, \textsuperscript{3}Radboud University, \textsuperscript{4}ALTRAN, \textsuperscript{5}ESA/ESTEC, \textsuperscript{6}University of Twente, \textsuperscript{7}Delft University of Technology

Abstract

The frequency band below 30 MHz is one of the last unexplored bands in radio astronomy. This band is well suited for studying the early cosmos at high hydrogen redshifts, the so-called dark ages, extragalactic surveys, (extra) solar planetary bursts, and high energy particle physics. In addition, space research such as space weather tomography, are also areas of scientific interest.

Due to ionospheric scintillation (below 30MHz) and its opaqueness (below 15MHz), earth-bound radio astronomy observations in these bands are either severely limited in sensitivity and spatial resolution or entirely impossible. A radio telescope in space obviously would not be hampered by the Earth’s ionosphere. In the past, several (limited) studies have been conducted to explore possibilities for such an array in space. These studies considered aperture synthesis arrays in space, at the back-side of the Moon, or a satellite constellation operating in a coherent mode.

In 2009 an ESA project, Distributed Aperture Array for Radio Astronomy in Space (DARIS), set out to investigate the space-based radio telescope concept. The focus of this feasibility study is on a moderate size three-dimensional satellite constellation operating as a coherent large aperture synthesis array. This aperture synthesis array would consist of 5 to 50 antennas (satellites) having a maximum separation of 100 km. This study considers the main aspects of such a distributed system in more detail than previous studies. This conference contribution aims at presenting an overview of the DARIS project and at discussing the main results.

The project selected extra-galactic surveys and the search for transient radio sources as the best suited science cases within the DARIS concept, and it investigated the scientific and technical requirements for such an array. Several antenna concepts were considered and simulated. An active antenna dipole array concept would be well suited, and a moderate 5 m tip-tip antenna system would lead to a sky noise limited system. Multiple digital signal processing scenarios were considered. Ultimately, although a distributed signal processing approach would be favorable in terms of reliability and scalability, for complexity reasons the project has chosen to have several (5 to 50) identical receiving nodes, and one centralized processing node i.e. the correlator. Analysis has shown that with current technologies, one MHz bandwidth can be processed with full duty cycle. The limiting factor is the inter-satellite link bandwidth. Several deployment locations, such as Moon orbit, Earth-Moon L2, and dynamic Solar orbits were investigated. Each of those locations has its pro's and con's such as interference levels from the Earth (which drive the number of sampling bits), relative speed-vectors of the satellite nodes (influencing maximum correlator integration times), and the need for orbit maintenance, and achievable
down-link bandwidth to Earth. Two preferred deployment location were selected: Moon orbit and dynamic Solar orbit. The main advantage of the Moon orbit is that the synthetic aperture is filled more rapidly, making it more suitable for transient science than the dynamic Solar orbit.

The project also studied the relation between the three-dimensional satellite configuration, the deployment location and the quality of the sky maps. The conclusion is that for the science cases under consideration, sufficient independent aperture sampling points can be obtained in a 1 MHz limited band (with 1 kHz channels) by using bandwidth synthesis. It is expected that, as a result, up to about one million astronomical sources can be detected in a five year duration mission.