LF/HF Interferometry in Low Earth Orbit Using Electromagnetic Vector Sensors: The AERO-VISTA Mission

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***Abstract*—We describe AERO-VISTA, a NASA Heliophysics twin cubesat mission targeting the LF to HF frequency range with instrumentation implementing data collection, interference nulling, and direction finding capability on in-situ space platforms. The Auroral Emission Radio Observer (AERO), along with a second identical spacecraft, the Vector Interferometry Space Technology using AERO (VISTA), are upcoming 6U size CubeSats which will be launched concurrently into a common polar orbit. AERO-VISTA will observe 100 kHz - 15 MHz radio emissions of auroral origin such as Auroral Kilometric Radiation (AKR), auroral hiss, auroral roar, and Medium Frequency Burst (MFB). We will give an overview of the AERO-VISTA mission, describe its technical approach, present milestones achieved, and discuss the greater potential of EMVS high dimensional approaches for astrophysical applications.**

I. Introduction

The low frequency portion of the electromagnetic spectrum below 15 MHz is populated by naturally generated radio emissions. These signals are rich in content and include wave modes generated by the terrestrial aurora. Low frequency spectral ranges are poorly explored from ground based radio remote sensors due to opacity of the Earth's ionosphere. Some scientific studies also require large interferometric baselines to achieve useful angular resolution and sensitivity which presents a large logistical difficulty. Achieving thermal noise limited measurements is particularly challenging at low frequencies using conventional approaches in low Earth orbit, due to terrestrial signals and interference from satellites.

A measurement approach achieving sensitive and high angular resolution measurements in these bands would open a wide range of science topics across heliophysics, radio astronomy, and geospace applications [1]. In particular, magnetospheric planetary dynamics, exoplanet searches targeting bodies with a magnetosphere, solar radio bursts and coronal mass ejection dynamics, heliospheric and interstellar medium mapping, radio absorption measurements, and studies of highly red-shifted signals from the early universe would be enabled by sensitive RF measurements from low Earth or geostationary orbits.

II. Low Frequency Interferometry: AERO-VISTA

A. Mission Overview

Accessing a LF to HF frequency range for scientific study requires instrumentation with data collection, interference nulling, and direction finding capability on in-situ space platforms. AERO-VISTA, a NASA Heliophysics twin cubesat mission, targets these goals. The Auroral Emission Radio Observer (AERO) [2], along with a second identical spacecraft, the Vector Interferometry Space Technology using AERO (VISTA) [3], are upcoming 6U size CubeSats which will be launched concurrently into a common polar orbit. AERO-VISTA will observe 100 kHz - 15 MHz radio emissions of auroral origin such as Auroral Kilometric Radiation (AKR) [4], auroral hiss [5], auroral roar, and Medium Frequency Burst (MFB) [6]. The primary mission payload involves a deployable tape spring and perimeter loop Electromagnetic Vector Sensor (EMVS) antenna with multiple elements. The six elements of the antenna, comprising dipole, monopole, and loop configurations, enable complete measurement of the electric and magnetic vector field of incoming radiation at a single point in space using a common phase center. Another instrument, the Auxiliary Sensor Payload (ASP), will provide background magnetic field direction determination and cameras for antenna deployment verification.

B. High Dimensional Low Frequency Interferometry

Together, the two AERO/VISTA platforms will enable a novel form of space-based interferometric measurements with high dimensionality. The approach enables coarse direction of arrival estimation for multiple sources, nulling of interference, and interferometric measurements with resolution an order of magnitude better than possible with a single spacecraft. The mission will also demonstrate the technologies necessary for low frequency EMVS interferometry in space. Constellations of such satellites could potentially operate closer to Earth orbit using a smaller number of platforms than other equivalent mission concepts for space based low frequency radio arrays.

C. Frequency Coverage

The electromagnetic sensor portion of AERO-VISTA is optimized for science emissions in a 400 kHz - 5 MHz frequency range. However, the sensor has been designed to provide measurements over an expanded range from 100 kHz to 15 MHz to enable detection of AKR harmonics and enable demonstrations of interferometric measurement using controlled ground based beacons. Such beacons can be used as localized coherent signal sources and may prove interesting for ground to space LF and HF propagation studies.

D. Advantages of the Vector Sensor Approach

The complexity of a vector sensor for RF signal acquisition is justified by an increase in effective sensitivity compared to a dipole or tripole, and by increased measurement degrees of freedom. These capabilities allow mitigation of interfering RF signals and also enable operation in lower-cost orbits. Joint analysis of two EMVS platforms as planned for AERO-VISTA offers a greatly expanded dimensional space that effectively mitigates the need for closely spaced baselines in an interferometric constellation. Achieving the needed sensitivity and processing performance in a small stowed volume is challenging, but the AERO-VISTA satellites will provide an on-orbit technology implementation and demonstration of not just the EMVS electronics but an advanced LF/HF deployable antenna system.

E. Covariance Analysis

Analysis of EMVS data for direction finding and imaging presents a challenging problem in covariance estimation. However, prior work [7] has successfully demonstrated that a Stokes parameter representation of the source covariance matrix is both qualitatively and computationally convenient [8]. The necessary covariance estimation processing and Cholesky factorization can be accomplished onboard a small satellite platform. Earth's radio aurora presents a particularly useful target for this approach, as sources such as AKR are bright and are thought to be reasonably compact.

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