Flexible low-band Instrument for RF Measurement and Imaging (FIRMI). M. Knapp[1], F. C. Robey[2], F. D. Lind[3], M. Hecht[3], [1] MIT Dept. of Earth, Atmospheric, and Planetary Science, 77 Massachusetts Ave. Cambridge, MA 02139, [2] MIT Lincoln Laboratory, 244 Wood St., Lexington, MA 02420, [3] MIT Haystack Observatory, 99 Millstone Rd, Westford, MA, 01886.

Introduction: Recent antenna technology has the potential to significantly improve space-based sensing, particularly at the low end of the radio band. The vector antenna, a structure that measures full electric and magnetic field vectors [1], [2], is a novel approach to radio frequency sensing that provides angular resolution, polarization state information, and improves sensitivity in a compact, electrically short structure. As such, vector antennas promise to substantially reduce the mass and volume of spacecraft RF sensor antennas and, in some cases, eliminate the need for spatially distributed arrays of elements. Here we propose to apply this novel technology to RF source characterization, ionospheric sounding, and to surface penetrating radar in support of planetary sciences data collection. **FIRMI will operate from 250 kHz – 30 MHz and will be capable of both active radar sounding and passive imaging.**

Vector Sensor: An electromagnetic vector sensor (EMVS) samples the electric *(E)* and magnetic *(H)* field at a single location in space and with a common phase center. To do this, a vector sensor is composed of three orthogonal dipole elements and three orthogonal loop elements. These six elements allow for a complete measurement of the E-field and H-field amplitude and phase of incoming radiation. The vector sensor is named for its capacity to fully measure the electromagnetic vector field rather than the single scalar measurement associated with a single element antenna. One consequence of sensing the full E and H vectors is that the vector sensor natively measures full polarization information. The advantages of a vector sensor are described as follows.

- Vector sensors are able to determine direction of arrival of sources [1] without resorting to multiple poses as required for a tripole.
- Vector sensors can null or isolate specific sources [2] based on spatial and polarization characteristics of the sources.
- Vector sensors can distinguish between electrostatic and electromagnetic in-situ plasma waves in the sensor frequency range.
- Vector sensors maximize the statistics collected from a single point in space.
- Vector sensor data is invariant to rotation of the spacecraft and omni-directional in coverage.

Instrument Description: FIRMI's compact form factor, low mass, and low power requirements will provide novel capabilities while minimizing resource (mass, power, volume) competition with other mission instruments. The vector sensor antenna provides unique capabilities to achieve angular resolution on a variety of static or transient sources and to perform simultaneous radar measurements when required. The vector sensor is somewhat more complex than a simpler antenna (e.g. dipole) but enables performance which easily justifies the increased complexity. **The proposed instrument is lightweight and compact, fitting in a stowed volume of 1.5 L (10 x 10 x 15 cm), weighing less than 2.5 kg, and consuming less than 10 W.**

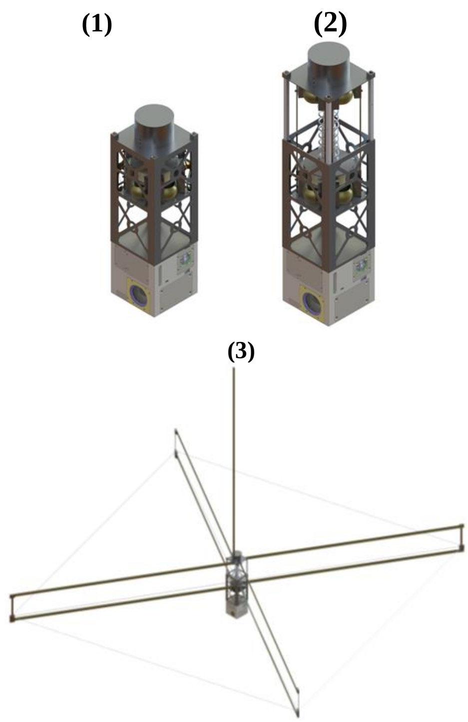

Figure 1. FIRMI antenna fully stowed (1), telescoped but not deployed (2), and fully deployed (3). The vertical monopole is stowed in the cylinder on the top of the 3U CubeSat frame and the remaining five elements (two rectangular loop/dipoles and square perimeter loop) are stowed in the top 1U.

The vector sensor that will be implemented will utilize two crossed elements that serve to simultaneously provide both loop and dipole sensing modes [3,4]. A perimeter loop provides mechanical stability to the crossed loop/dipole elements, and a final monopole provides the sixth element to create the full complement of sensing modes. The stowed and deployed instrument is shown in Figure 1 on a 3U CubeSat body for reference.

Applications to Planetary Science:

Active sensing (sounder/radar). FIRMI's active sensing capabilities are well suited to a variety of subsurface imaging and ionospheric sounding tasks on various solar system bodies. For example, surface-penetrating radar offers the potential for detection of ice / water interfaces on Europa [5], the study of subsurface geyser structures on Enceladus [6], and searching for lava tubes and basaltic caves which have significant potential as astrobiological habitats [7] among many other potential targets. **FIRMI's small mass, volume, and power requirements compare favorably to previously flown radar payloads that address similar science needs.**

FIRMI's sounding capability also offers significant potential for the study of planetary ionospheres in the solar system using radio sounding and radar techniques. Targets include the Martian ionosphere as well as planets such as Venus, Jupiter, and Saturn that have have significant and complex ionospheres. Several moons in the solar system also have relatively dense atmospheres, ionospheres, and complex interactions with the planets that they orbit (e.g. Io, Titan, Enceladus, etc.). These bodies offer the opportunity to examine atmosphere/solar wind interactions, neutral atmosphere to ionosphere coupling, the transport of plasma in planetary ionospheres, and the occurrence of plasma turbulence and non-linear plasma phenomena which can also exhibit large radar cross-sections.

Passive Imaging. Imaging of transient phenomena with even modest angular resolution has been difficult or impossible with past single-spacecraft instruments that operate in the low frequency regime. FIRMI will allow resolved imaging of planetary electrostatic discharge (ESD) phenomena, such as lighting and impact flashes. Planetary lightning is a probe for atmospheric dynamics, including cloud layering and composition, storm evolution, neutral atmosphere-ionosphere coupling, volcanic plumes, and disequilibrium chemistry.

Passive imaging at low frequencies also offers access to plamsa wave and driven emission from auroras, moon-influenced plasma emission, and solar wind-magnerospheric interactions. FIRMI offers remote sensing capability in the frequency range where cyclotron magnetospheric emission is brightest, enabling monitoring of planetary rotation and magnetosphere/ionosphere/atmosphere coupling via time variability of auroral emission. FIRMI will be able to localize the emission region(s) and measure polarization in a single snapshot observation, enhancing the study of the fundamental plasma processes that give rise to the auroral radio emission and related phenomena.

FIRMI's remote sensing capabilities provide useful overlap with in-situ plasma instruments and complement IR/Vis/UV imagers and spectrometers. FIRMI's small size is well suited to micro/nanosat applications as well.

Applications Beyond Planetary Science:

Spatially and spectrally resolved HF measurements from space have numerous applications in disciplines beyond planetary science.

Heliophysics. Observations of the polarization, refraction field and angular broadening properties of the cosmic radio sky carry information on the plasma within the heliosphere. A small interferometric array of spacecraft equipped with FIRMI would provide images of solar burst radio emission source regions. FIRMI's frequency range would enable spatially resolved tracking of Type II radio bursts farther from the solar corona than is currently possible.

Earth Observation. Of radio emissions from the Earth, auroral kilometric radiation (AKR) is the strongest distributed source. The FIRMI instrument in an appropriate orbit would observe and locate AKR and provide polarimetric measurements. FIRMI will also be capable of top-side sounding the terrestrial ionosphere as well as detection and localization of some terrestrial plasma wave phenomena.

Astrophysics. FIRMI would provide a capability that for the first time could enable cost-effective long baseline astronomical radio interferometry in the < 10 MHz window, which is inaccessible from the ground due to the ionospheric cut-off frequency. These observations can be especially useful for studies of the interstellar medium where propagation effects are large, allowing observations of dispersion measure, interstellar turbulence, and interstellar free-free absorption. A moderate resolution map of the low frequency sky (better than 60° angular resolution achieved by RAE-2) would be a significant step forward.

References:

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