The AERO/VISTA Twin Small Satellite Project

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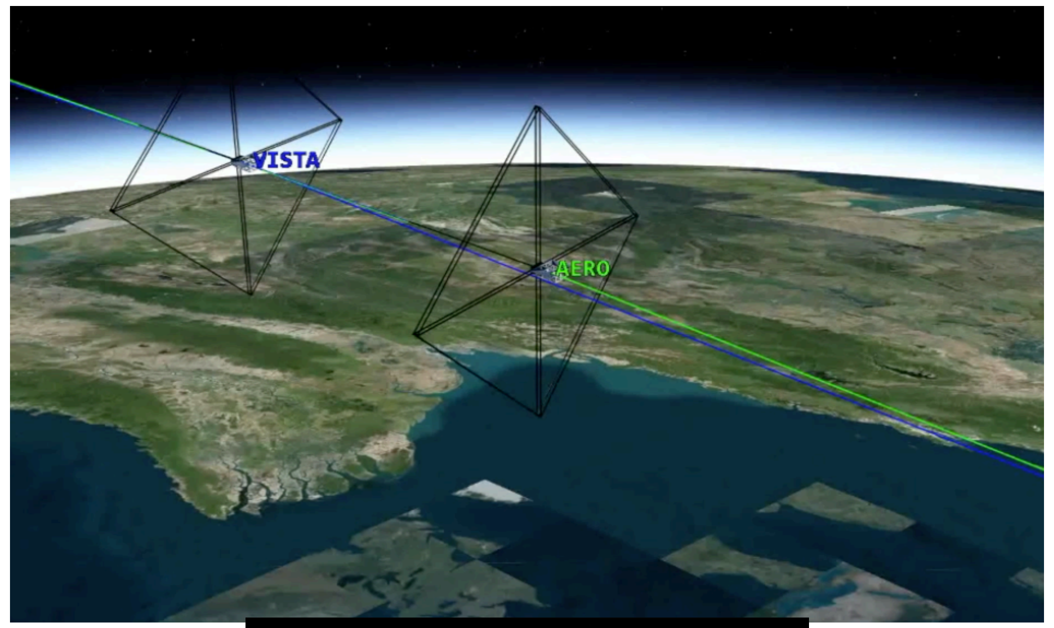
7Merrimack College



Outline:
- Mission Overview
- Science and Technical Targets at HF Frequencies
- Electromagnetic Vector Sensor: High Dimensional Interferometry
- Collaborative Science, including the Amateur Community

TAPR Digital Communications Conference 2020
11-12 Sep 2020

AERO and VISTA Mission Overview

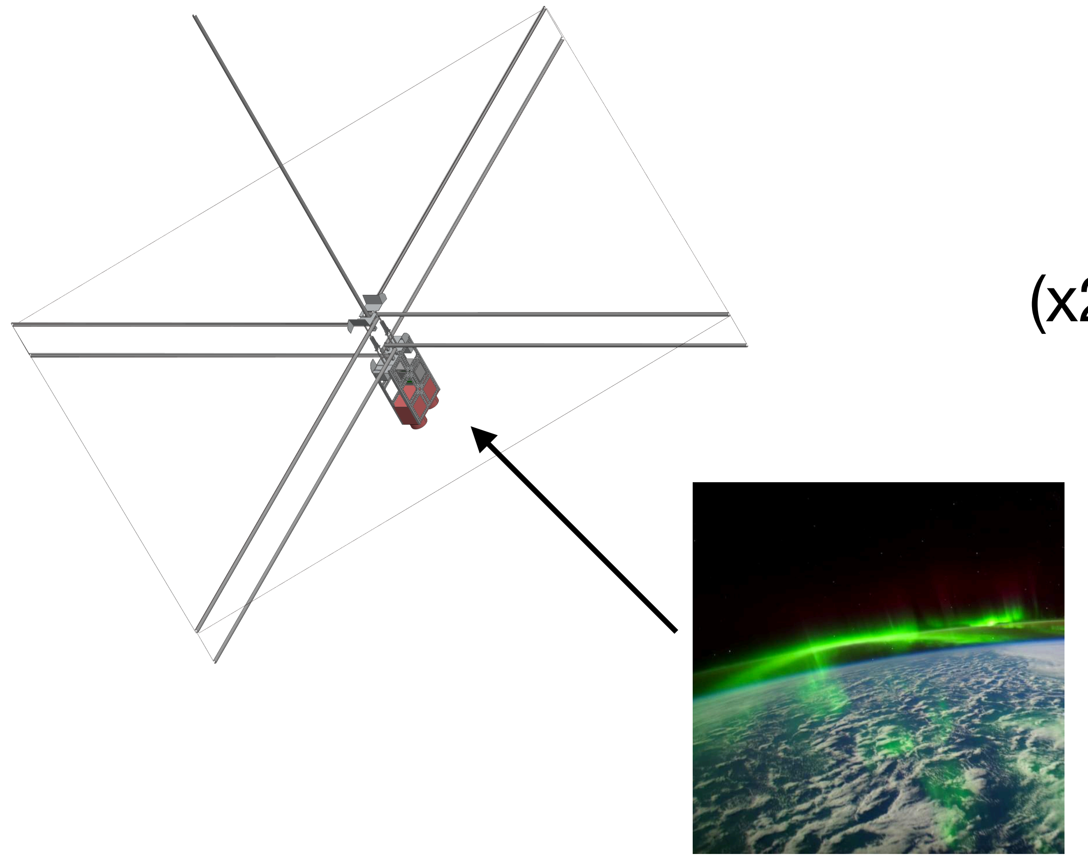
Auroral Emissions Radio Observer (AERO)

- $4.2M over 4 years
- NASA Heliophysics Technology and Instrument Development for Science (H-TiDES) 2017
- HF radio capture (0.1 - 5 MHz)
- Primarily **SCIENCE** focused: radio aurora

Vector Interferometry Space Technology using AERO (VISTA)

- $3.5M over 3 years
- NASA H-TiDES 2018
- HF radio capture (0.1 - 15 MHz)
- Build-to-print copy of AERO
- Primarily **TECHNOLOGY** focused: high-dimension interferometry

https://www.haystack.mit.edu/geospace/geospace-projects/aero-vista-cubesat-mission/



- ❖ 6U cubesat (20 cm x 30 cm x 10 cm)
- ❖ Noon-midnight sun sync orbit (450+ km altitude)
- ❖ Deployable antenna (100 kHz – 15 MHz)
- ❖ Auroral science targets: 100 kHz – 5 MHz
- ❖ Interferometry targets: up to 15 MHz
- ❖ Auxiliary Sensor Package (ASP) including magnetometer and optical aurora sensor
- ❖ AERO and VISTA: 2x auroral science platforms

Mission duration: 90 days
Nominal launch: 2022

AERO PI: P. J. Erickson
VISTA PI: F. D. Lind

MIT Haystack Observatory · MIT Lincoln Laboratory, Massachusetts Institute of Technology · Dartmouth · Morehead State University · EAPS Earth, Atmospheric and Planetary Sciences · Merrimack College · MIT AeroAstro · University of Tromsø · NASA

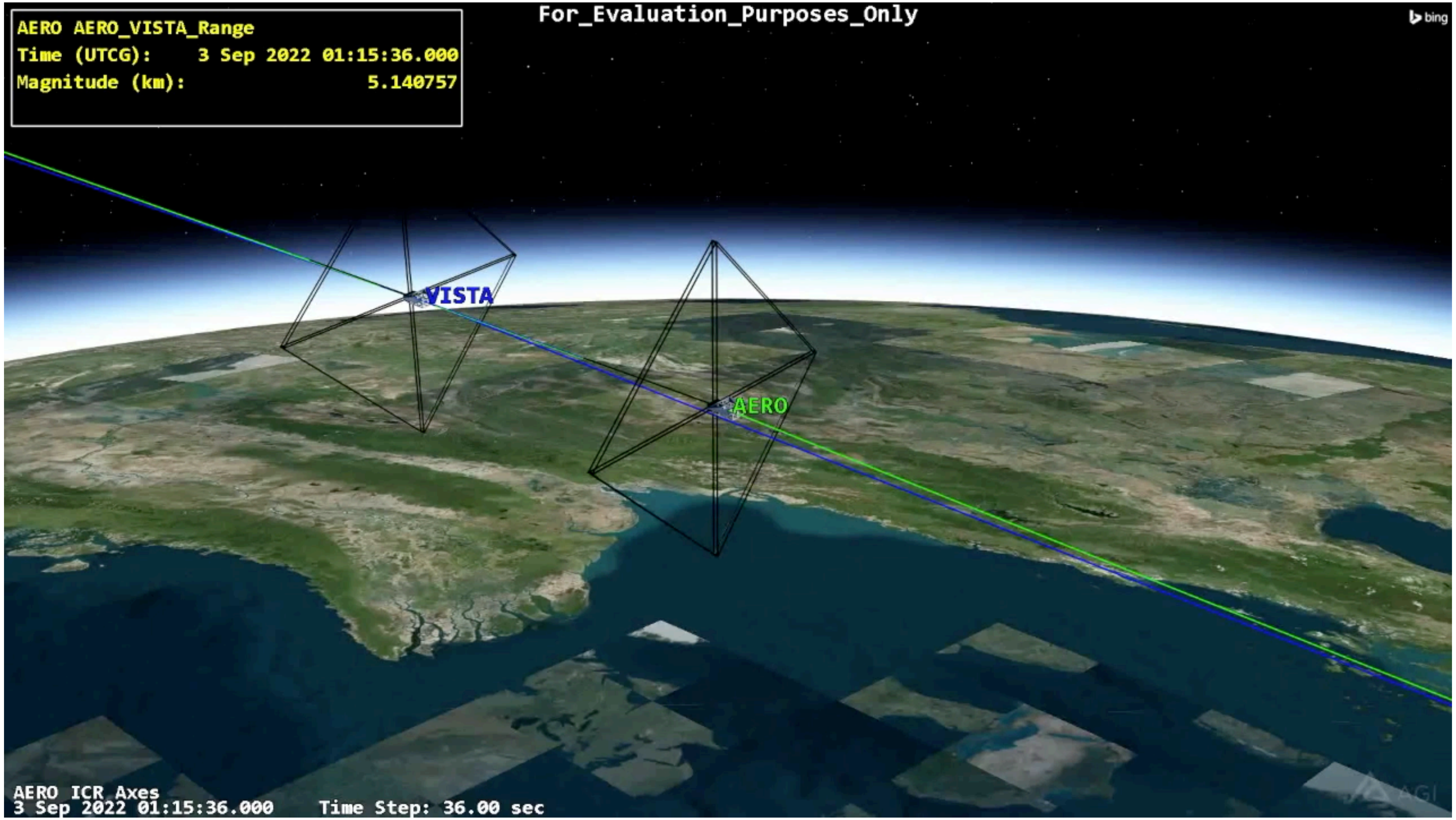
Mission Science Target: The Radio Aurora

High-latitude optical aurora viewed from the ISS (~350 km altitude)
September, 2011 (NASA ISS Crew Earth Observations experiment)

- Optical aurora has structures and dynamics on vast number of scales
  - Temporal: < msec to hours
  - Spatial: < m to >10s km
- Radio aurora also exists
  - Far less studied
  - > 1 GW EIRP radiated
  - Coherent plasma waves
  - Magnetic field direction plays a large role (electron gyromotion)
- Many radio auroral emissions in LF/HF and only observable from orbit: ionosphere blocks them from ground view

AERO VISTA

AERO + VISTA   Nominal Orbit Simulation



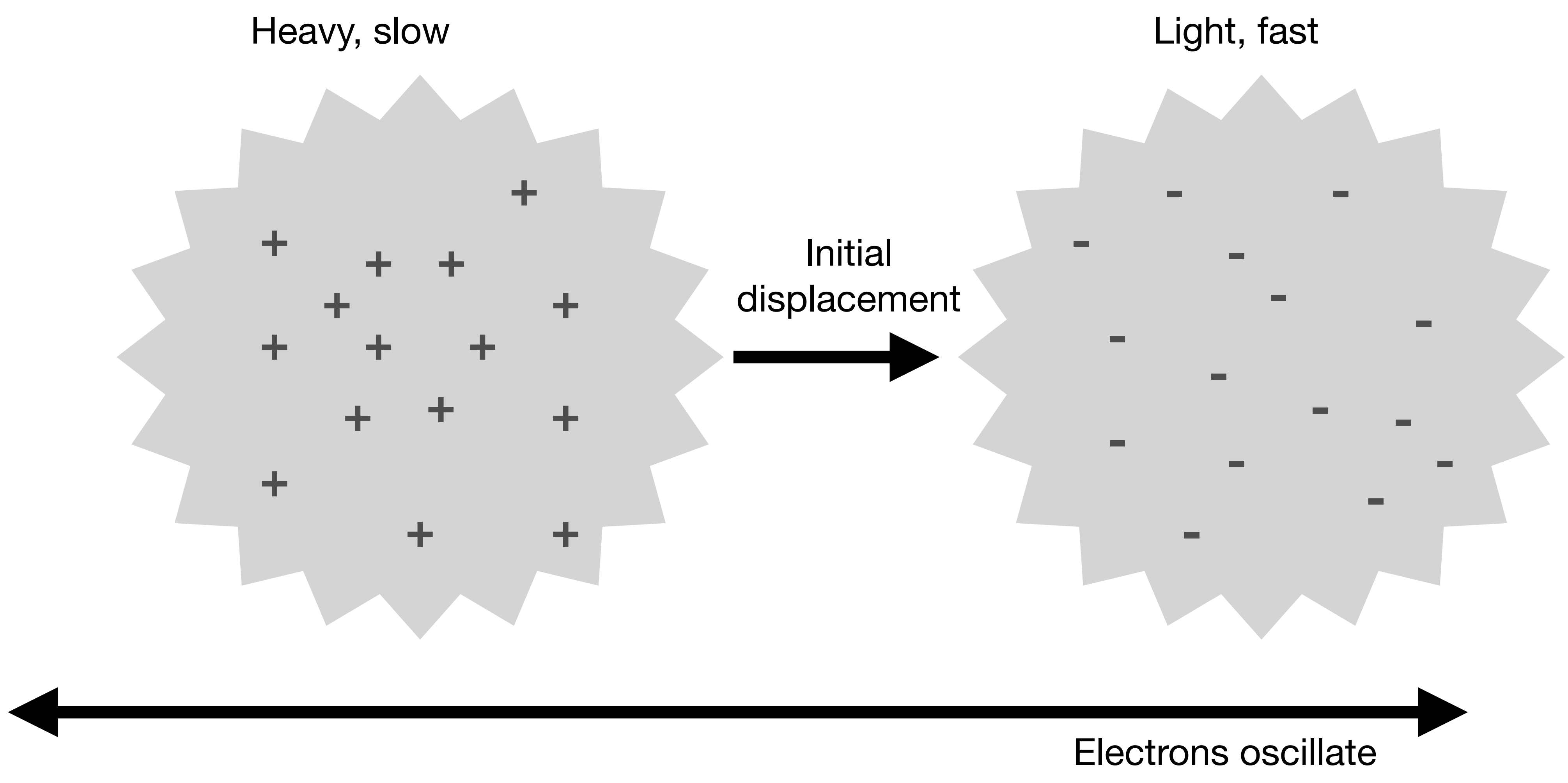
- Low Earth orbit: nominal 450 - 600 km
- Sun-synchronous orbit to intercept nighttime auroral regions: between [2100, 0200] local time
- Launch provided through NASA CubeSat Launch Initiative (CSLI):

  Ride-share launches to space via existing launch services of government payloads, or dedicated launches from VCLS contracts

(simulation: Vince Skelton, Merrimack College)

Ionospheric Cutoff: Langmuir Resonance

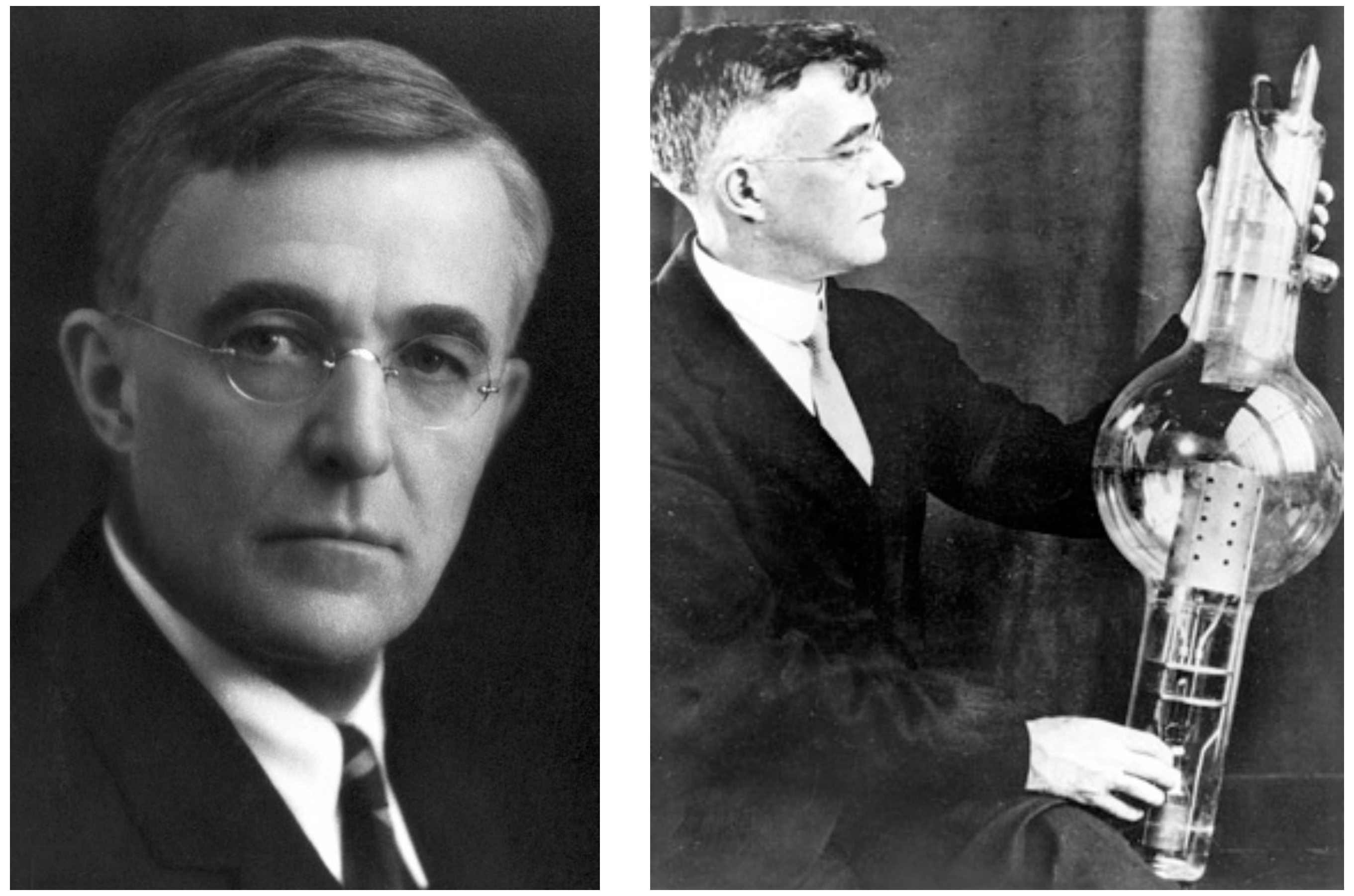
- Fundamental resonance property of any plasma
- Interaction provides hard reflection at HF
- Principle behind ionosondes



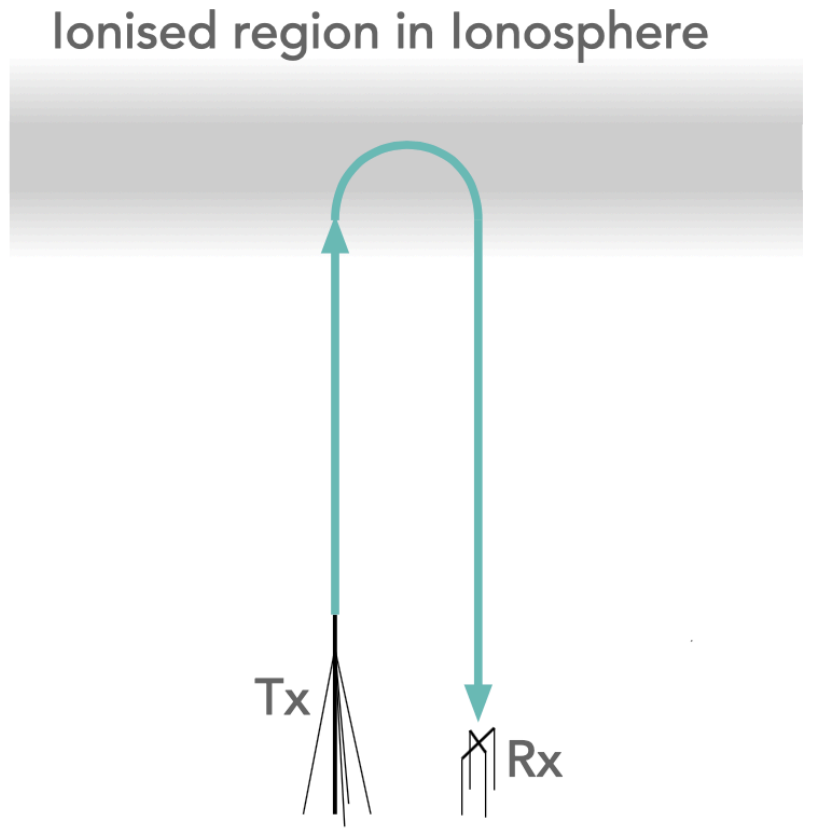
$$\omega_{pe}^2 = \frac{N_e \, e^2}{m_e \, \epsilon_0}$$

Langmuir frequency

Typical 1-12+ MHz: reflects incoming waves above F region



Irving Langmuir
1881 - 1957
Nobel Prize, chemistry 1932



Basic concept of the operation of an ionosonde

https://www.electronics-notes.com/articles/antennas-propagation/ionospheric/ionosonde-ionogram.php

Radio Auroral Emission Types (1)

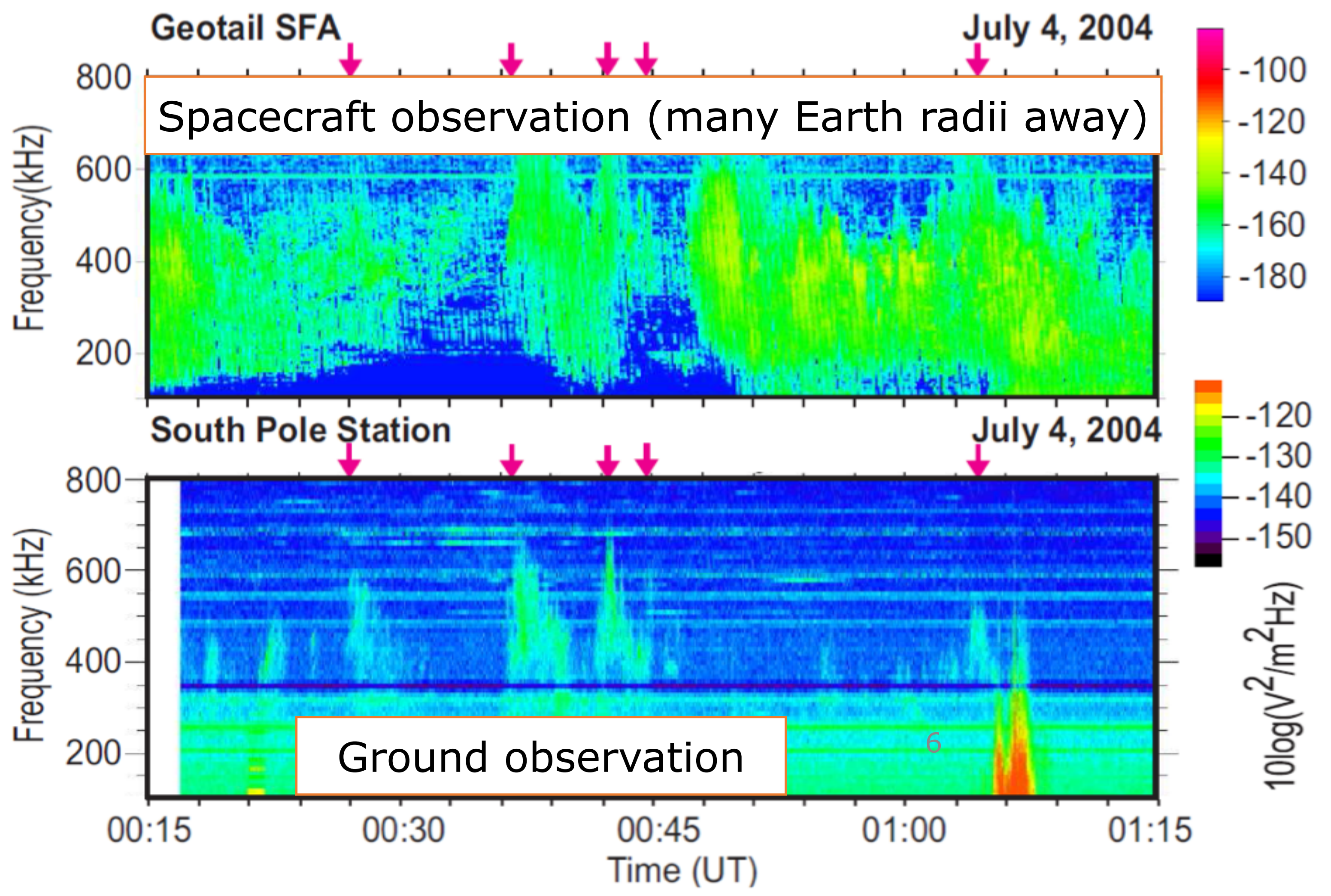
Type	frequency	polariz'n	outstanding problems
Auroral Hiss	<1 MHz (below f_{ce})	Right (W-mode)	**Structure: hisslers, LF cutoff etc.** **Dayside/nightside** **Source altitudes**
Auroral Kilometric Radiation AKR	50-750 kHz (below f_{ce})	Right	**Confirm connection** **How W-mode generated?** **Ducted? Area illuminated?** **Remote sensing application?**
Auroral Roar	$2f_{ce}$, $3f_{ce}$, $4f_{ce}$, $5f_{ce}$	Left (sometimes Right?)	**Nonlinear mode conversion?**
Medium Freq Burst	1.5-4.5 MHz (above f_{ce})	Left (L-mode)	**Generation mechanism?** **Use for substorm onset timing?** **Connected to Langmuir cavitation?**

f_{ce} = electron gyrofrequency
~ 0.8-1.2 MHz in LEO

Example:
Auroral Kilometric Radiation

- LF, HF frequencies
- Some broadband, others narrow band
- Electromagnetic propagating modes -> both E and B
- Polarized!
- Source regions probably far above LEO orbits
- Many, many unanswered generation and HF propagation questions

??? I should not see this from the ground!



Radio Auroral Emission Types (2)

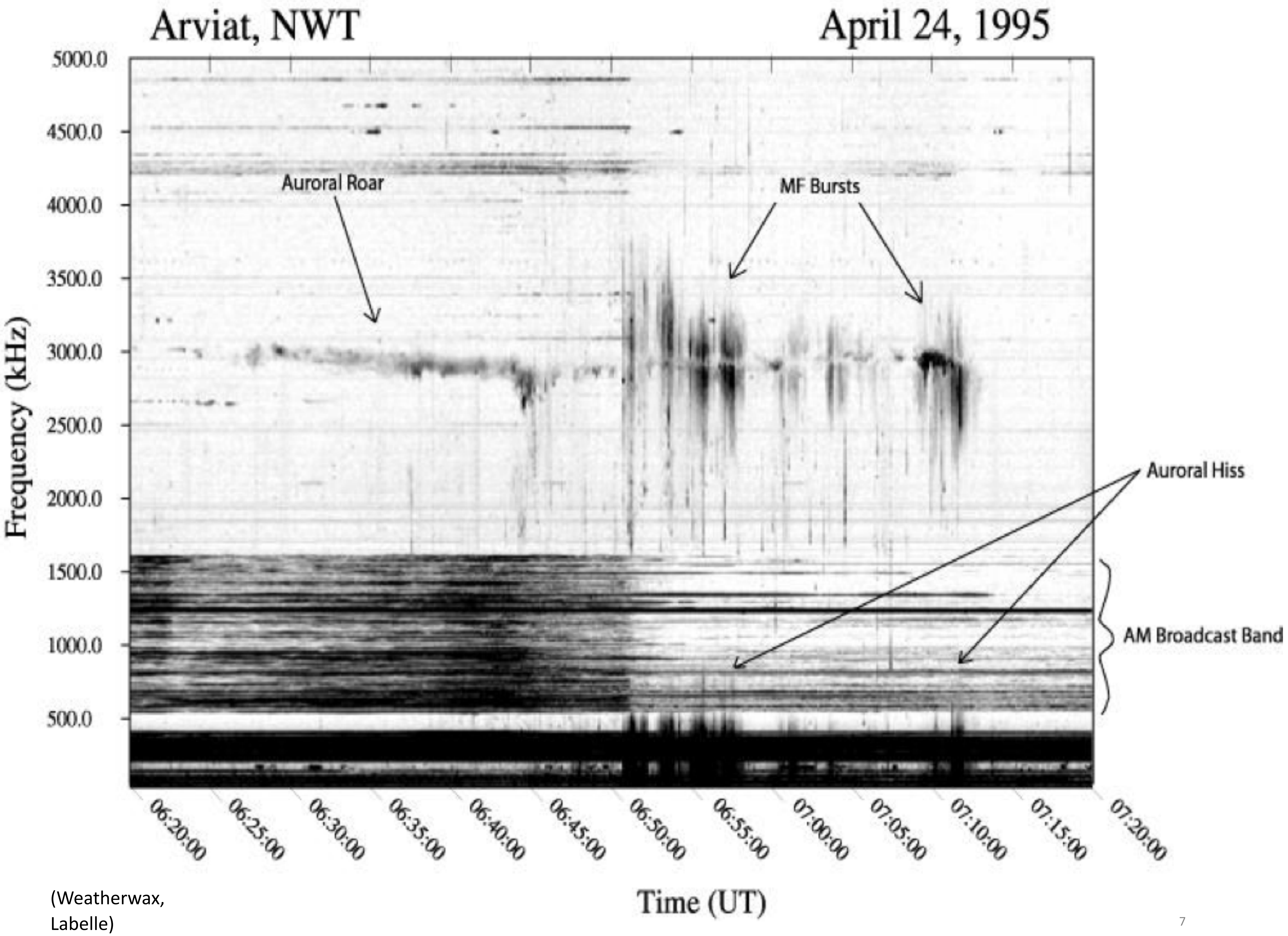
Observed both from the ground and in space…

Intensity:

Roar:
<10^{-18} - 10^{-15} W/m^2/Hz

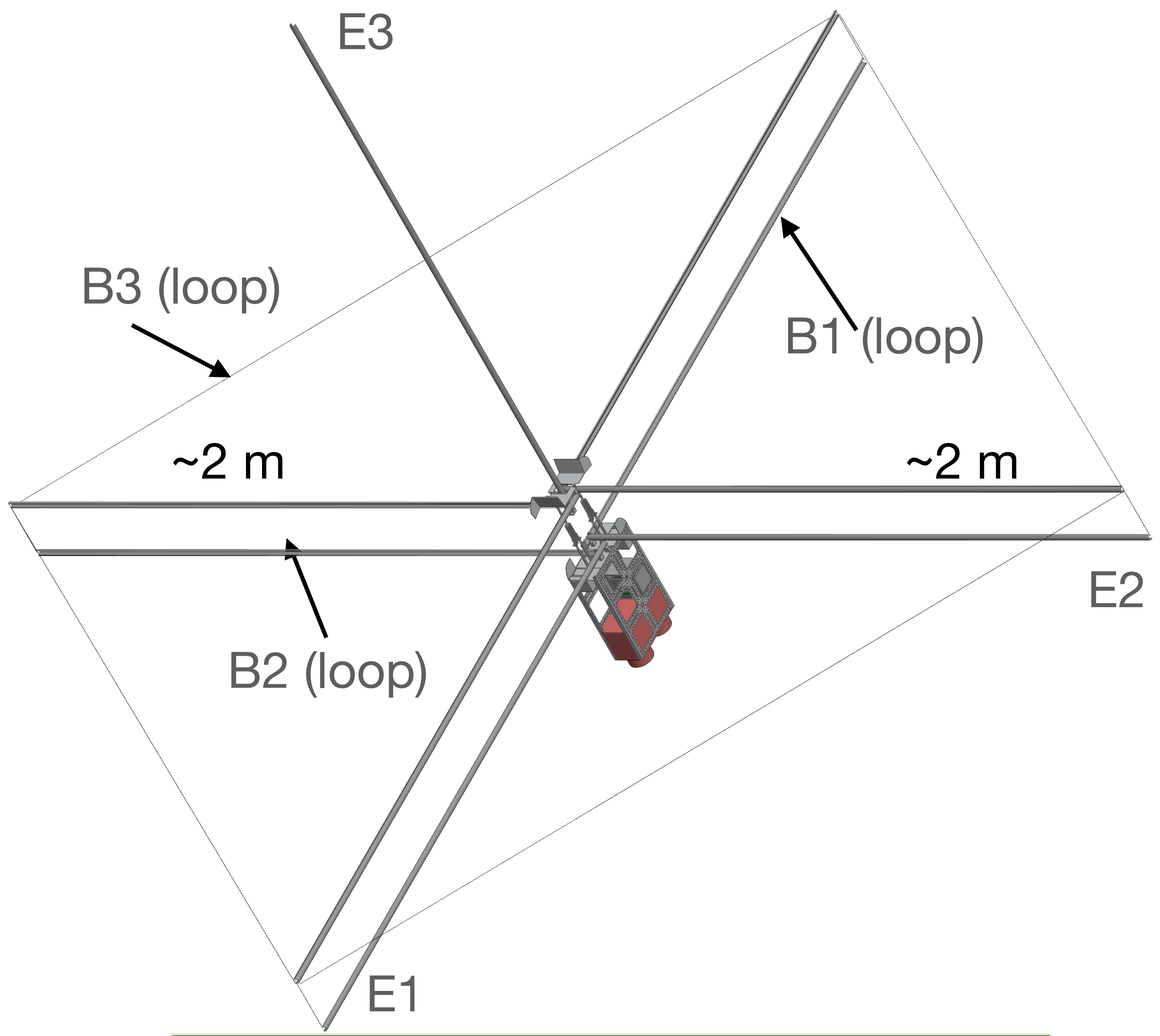
MF Burst:
~10^{-19} - 10^{-16} W/m^2/Hz

Hiss:
<10^{-18} - 10^{-16} W/m^2/Hz



(Weatherwax, Labelle)

Electromagnetic Vector Sensors



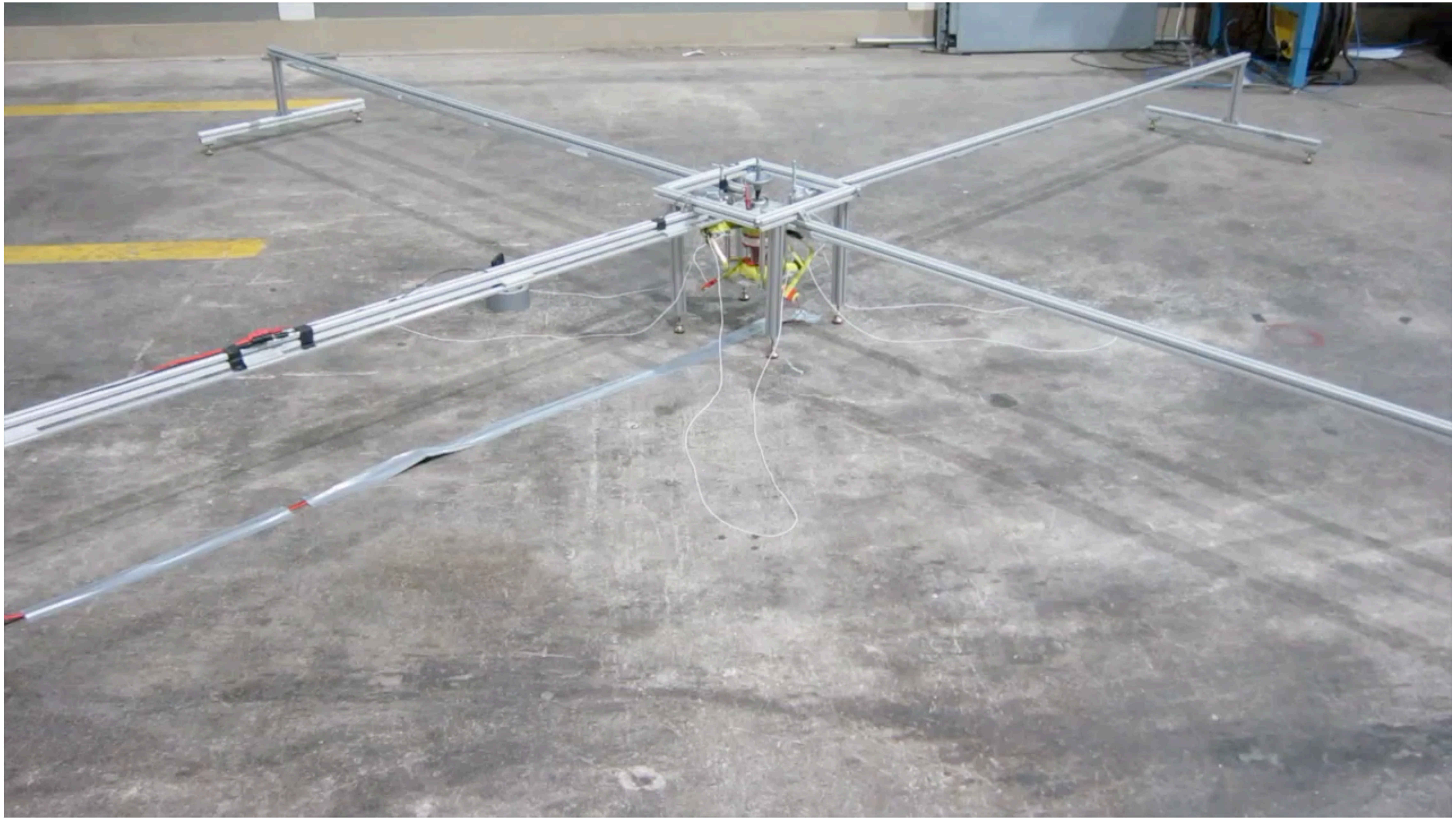
Spatially resolved imaging with a single electrically small sensor

Separation of multiple sources, beam-forming, nulling

(RFI tolerant)

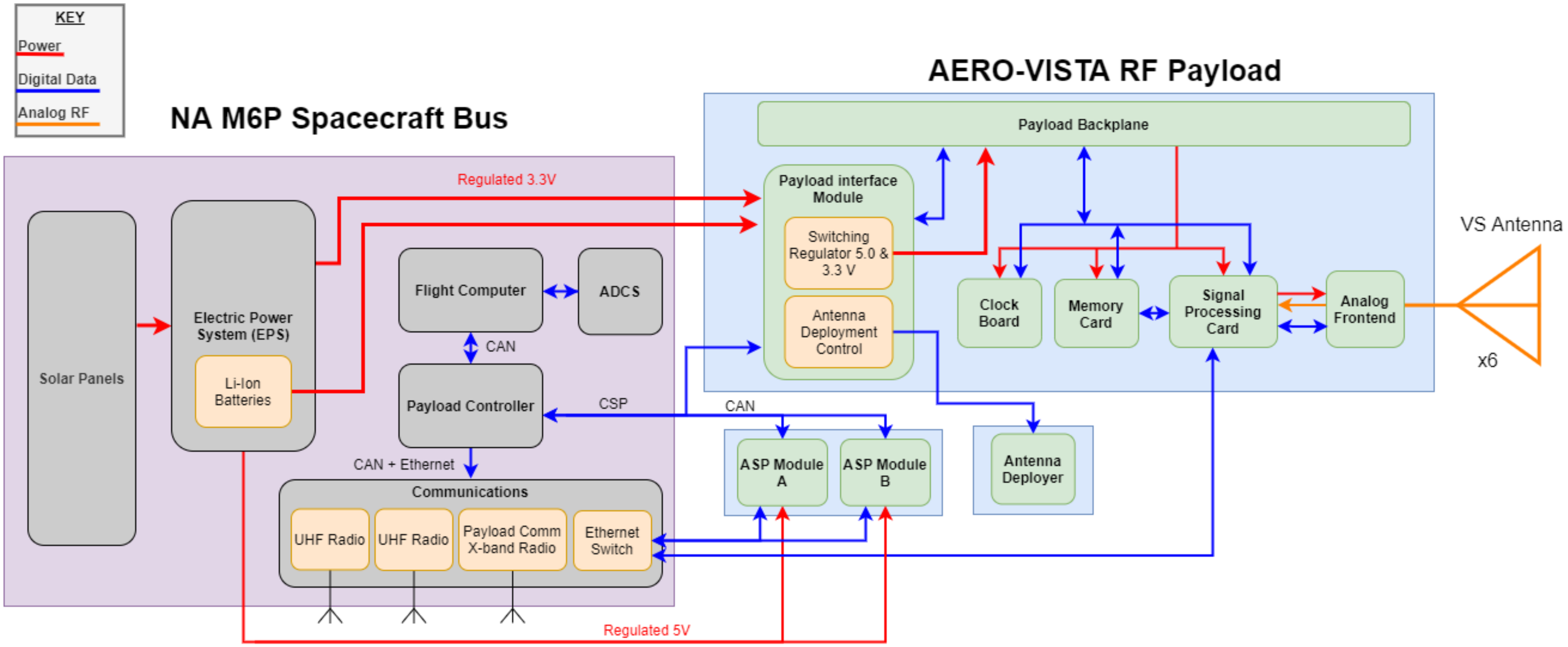
- 3 dipoles + 3 loops (electrically small)
- Measures full E and B field vectors, ExB = S (Poynting vector)
- Determines sources' intensity, direction and polarization in single snapshot
- Typically used for finding direction of strong sources, can also perform spatially resolved imaging
- Can localize human signals (beacons) or natural signals (radio aurora)

Electromagnetic Vector Sensor Mechanical Deployment

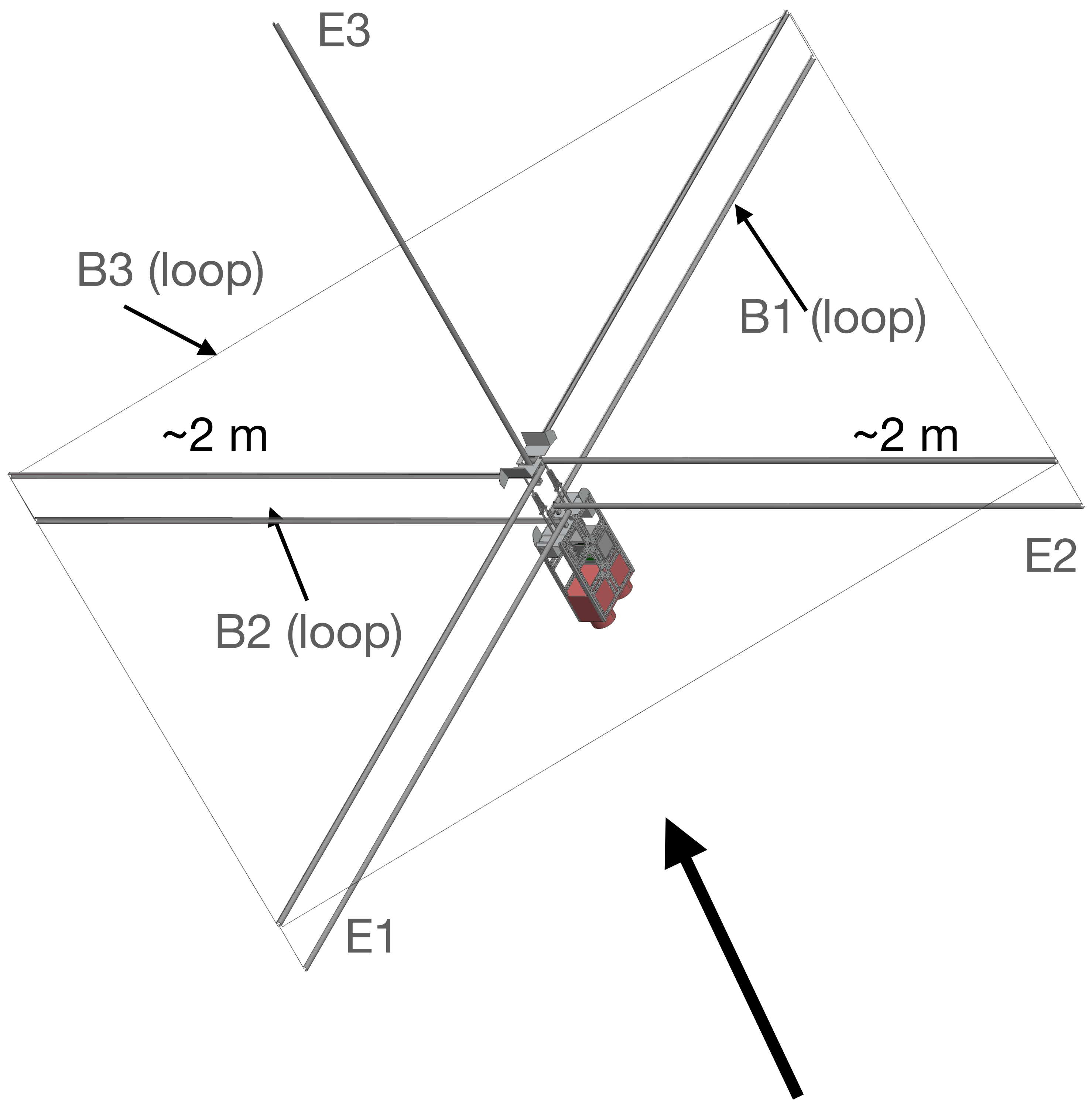


(M. Silver, MIT Lincoln)

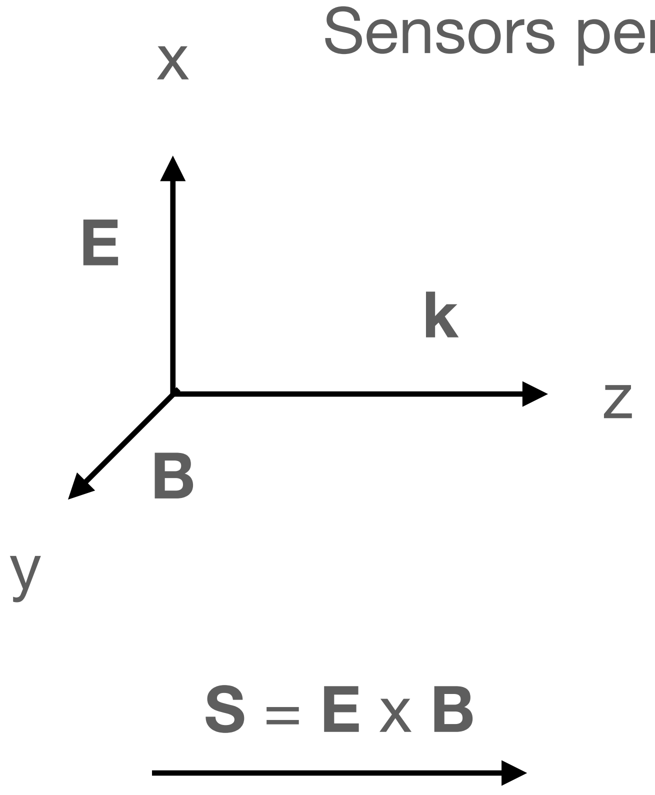
AERO/VISTA Spacecraft Hardware



Electromagnetic Vector Sensor Direction-Finding Example (1)



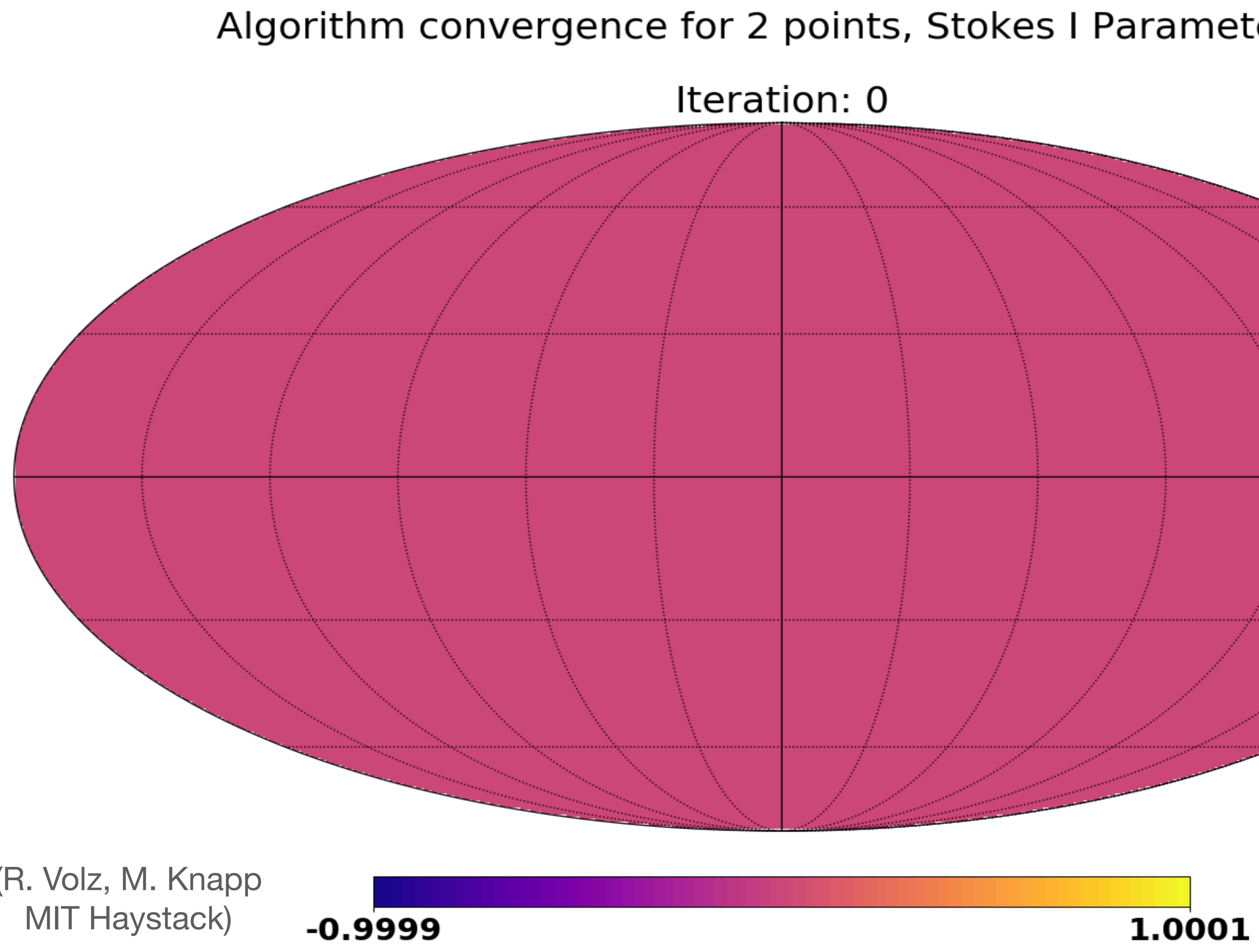
Simple case: EM wave propagating in Z direction
Sensors perfectly aligned with wave coordinates



$$\mathbf{E} \times \mathbf{B} \rightarrow \begin{bmatrix} 0 & 0 & 0 \\ & 0 & 0 \\ & & ExB \end{bmatrix}$$

- Onboard processor cross-correlates every element with every other element (E1, E2, E3, B1, B2, B3)
- Upper triangular matrix
- Sources can be Gaussian random as long as mean/ variance properties are wide-sense stationary
- Covariance analysis allows a sensor with broad response pattern to achieve source direction finding (interferometry)
- Relatively insensitive to platform orientation

Electromagnetic Vector Sensor Direction-Finding Example (2)

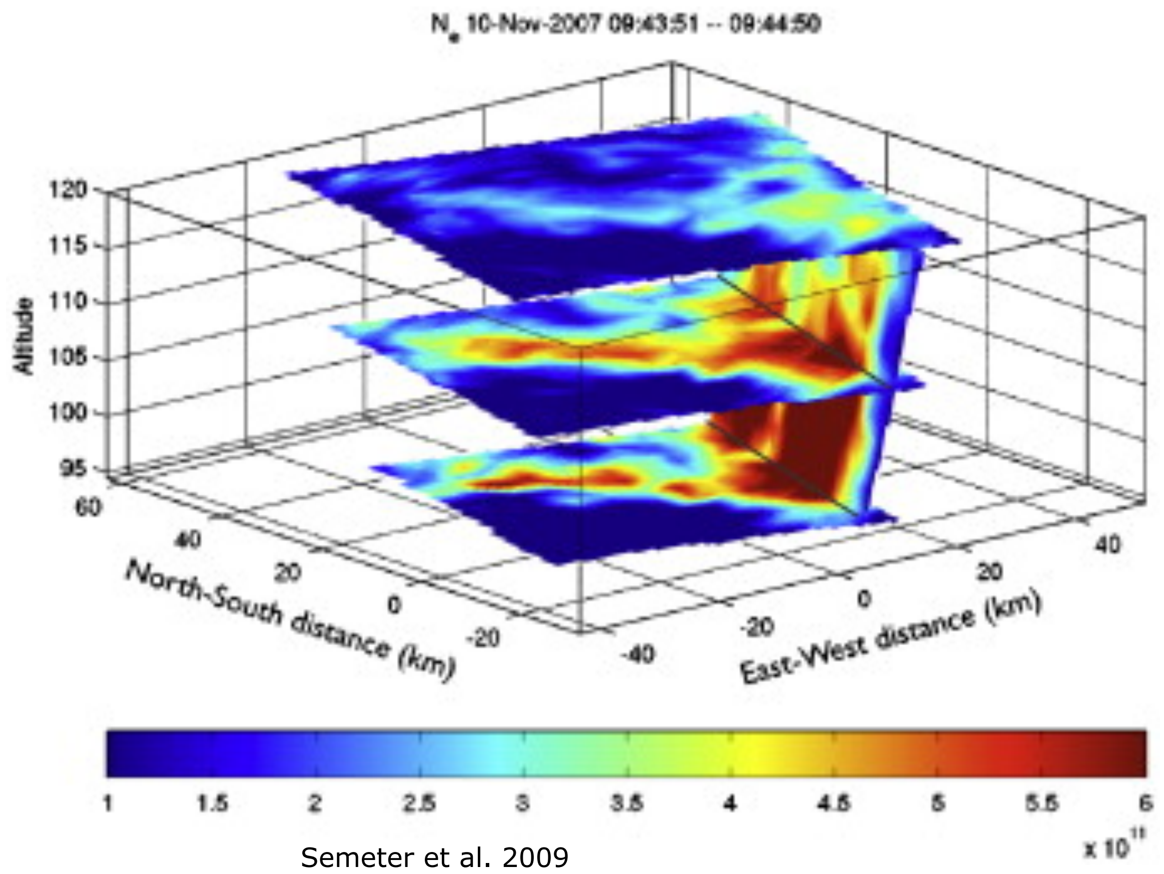


(R. Volz, M. Knapp
MIT Haystack)

- Iterative processing provides angle of arrival of compact sources
- Not completely unambiguous in all situations
- Auroral sources should be reasonably bright and compact, which helps

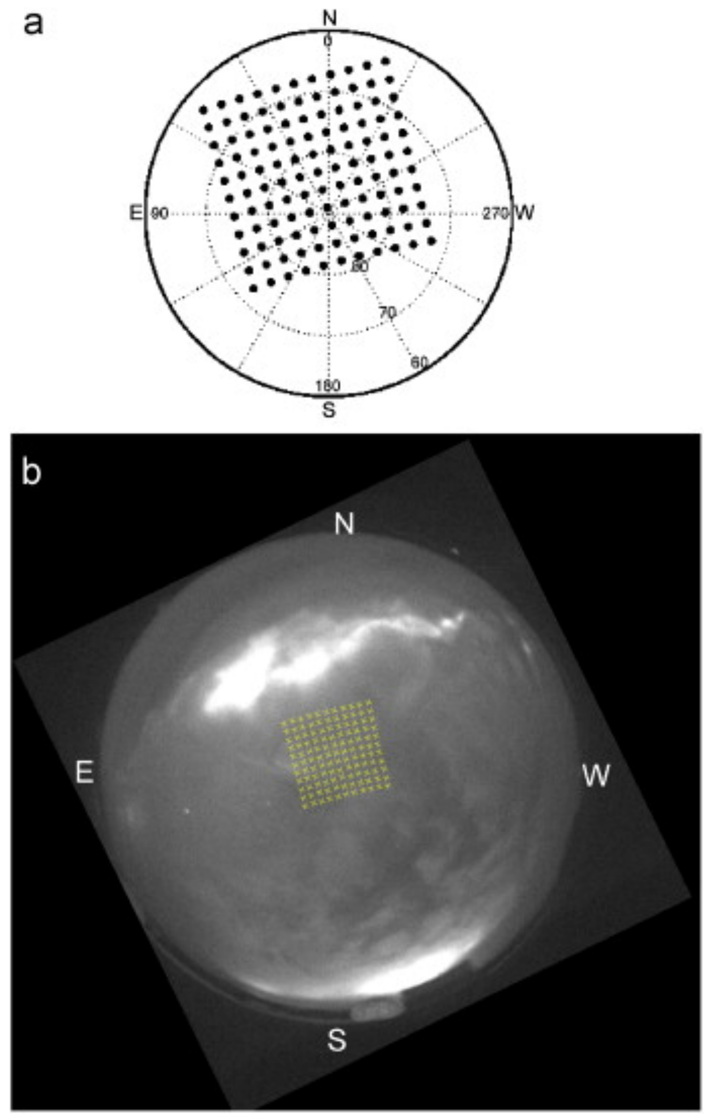
cf.
R. Volz, M. Knapp, F. D. Lind and F. C. Robey, "Covariance estimation in terms of Stokes parameters with application to vector sensor imaging," 2016 50th Asilomar Conference on Signals, Systems and Computers, Pacific Grove, CA, 2016, pp. 1339-1343, doi: 10.1109/ACSSC.2016.7869593.

Coordinated Science Observations: Maximizing a Cube Sat



Semeter et al. 2009

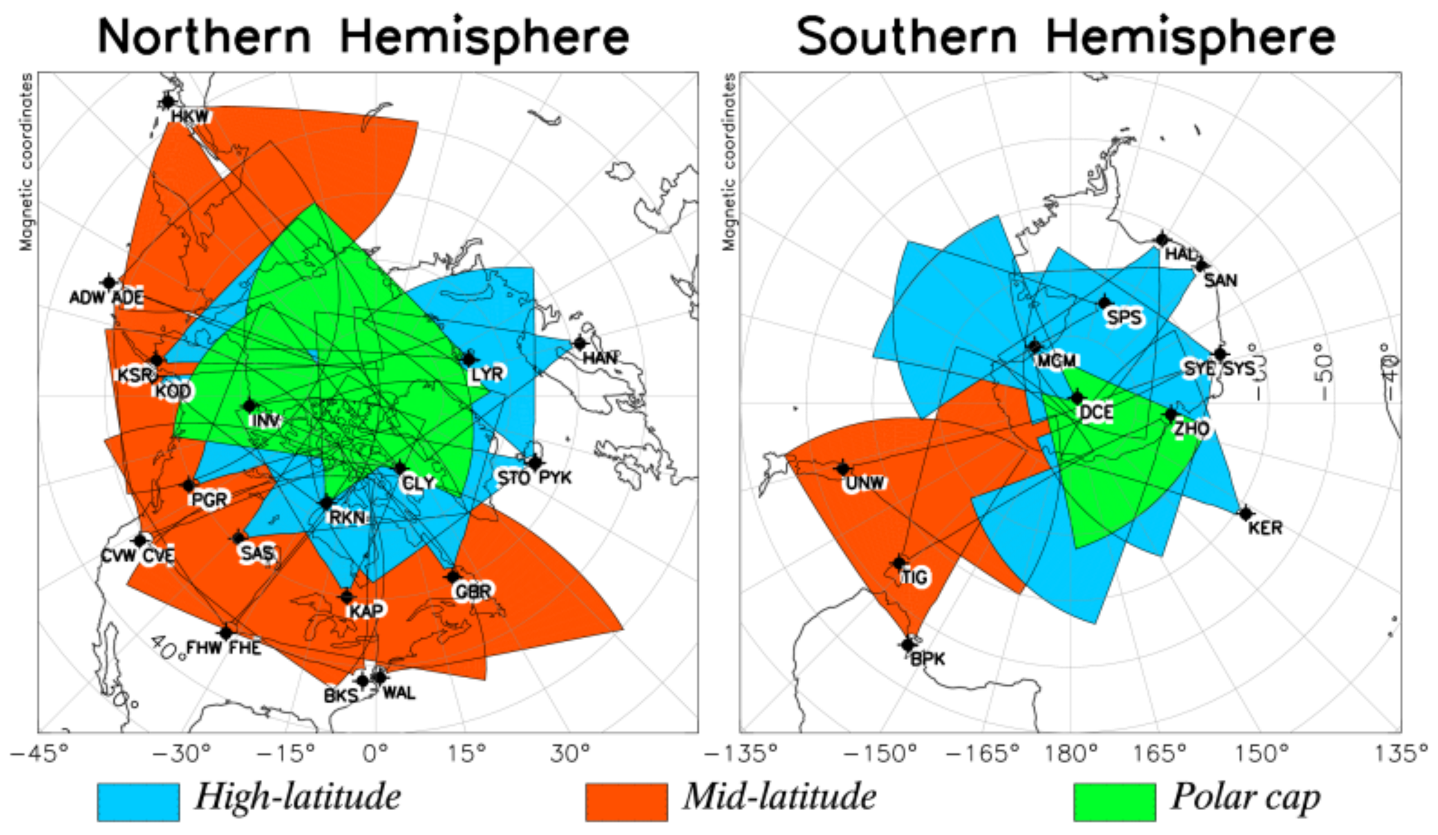
AMISR / EISCAT 3D Incoherent Scatter Radar Auroral Diagnostics

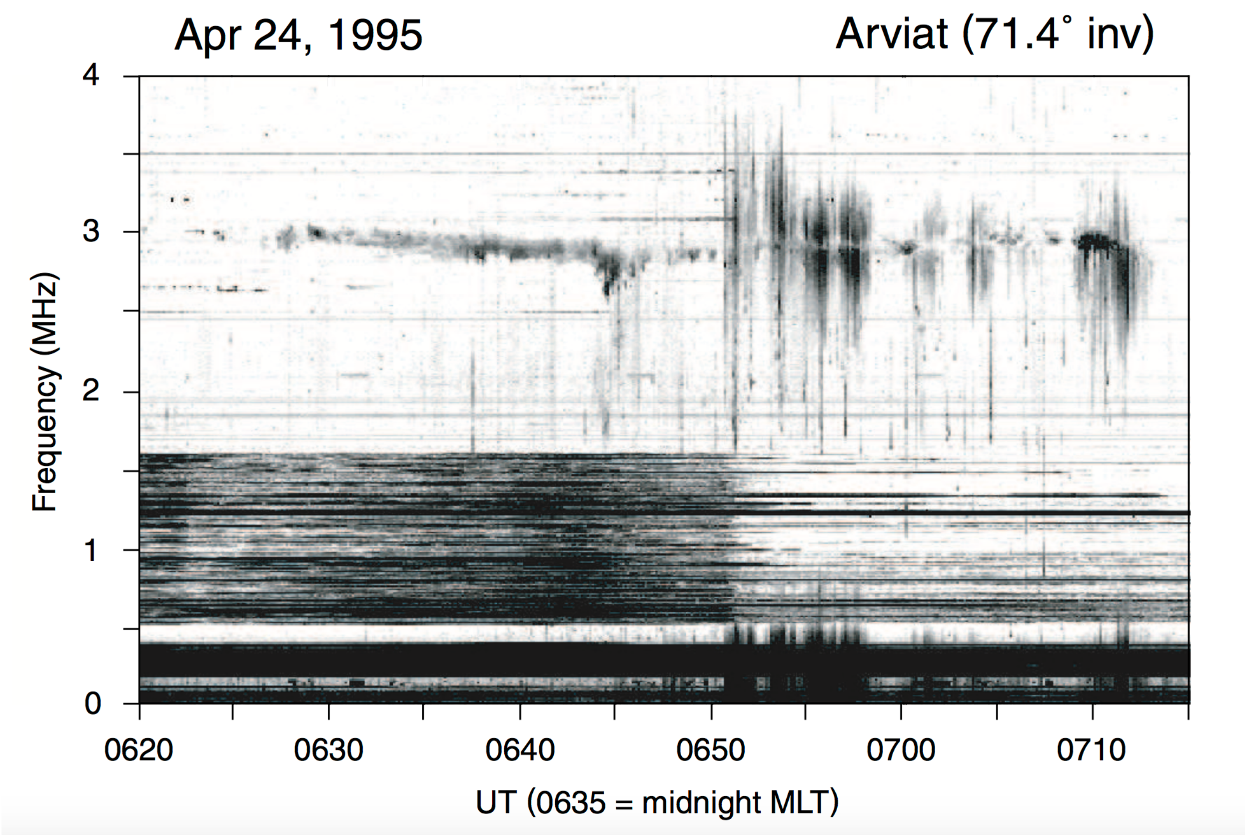


Optical Auroral Diagnostics

Semeter et al. 2009

HF Radar Auroral Diagnostics (SuperDARN)

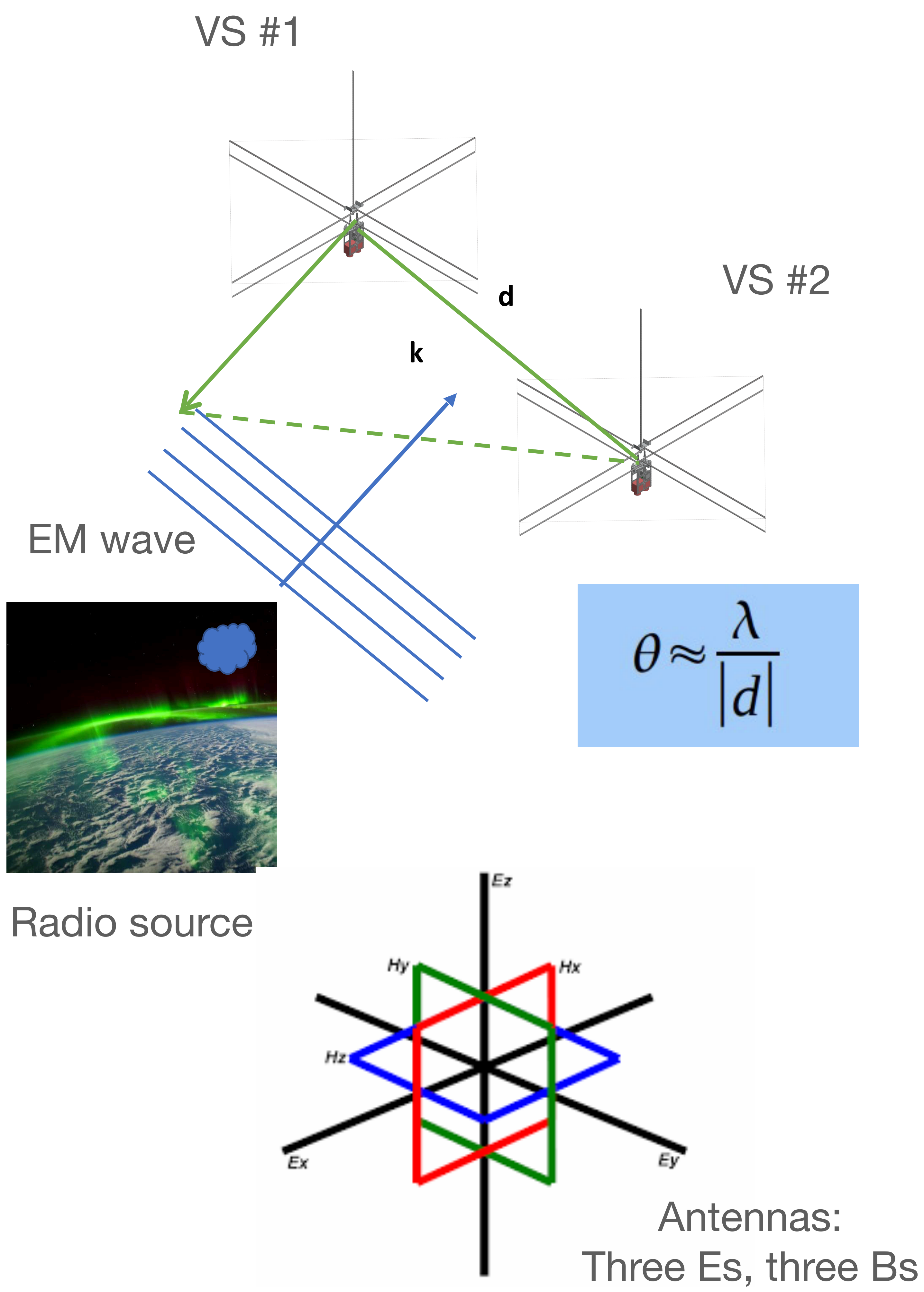




Ground Based Radio Receivers

Labelle 2006

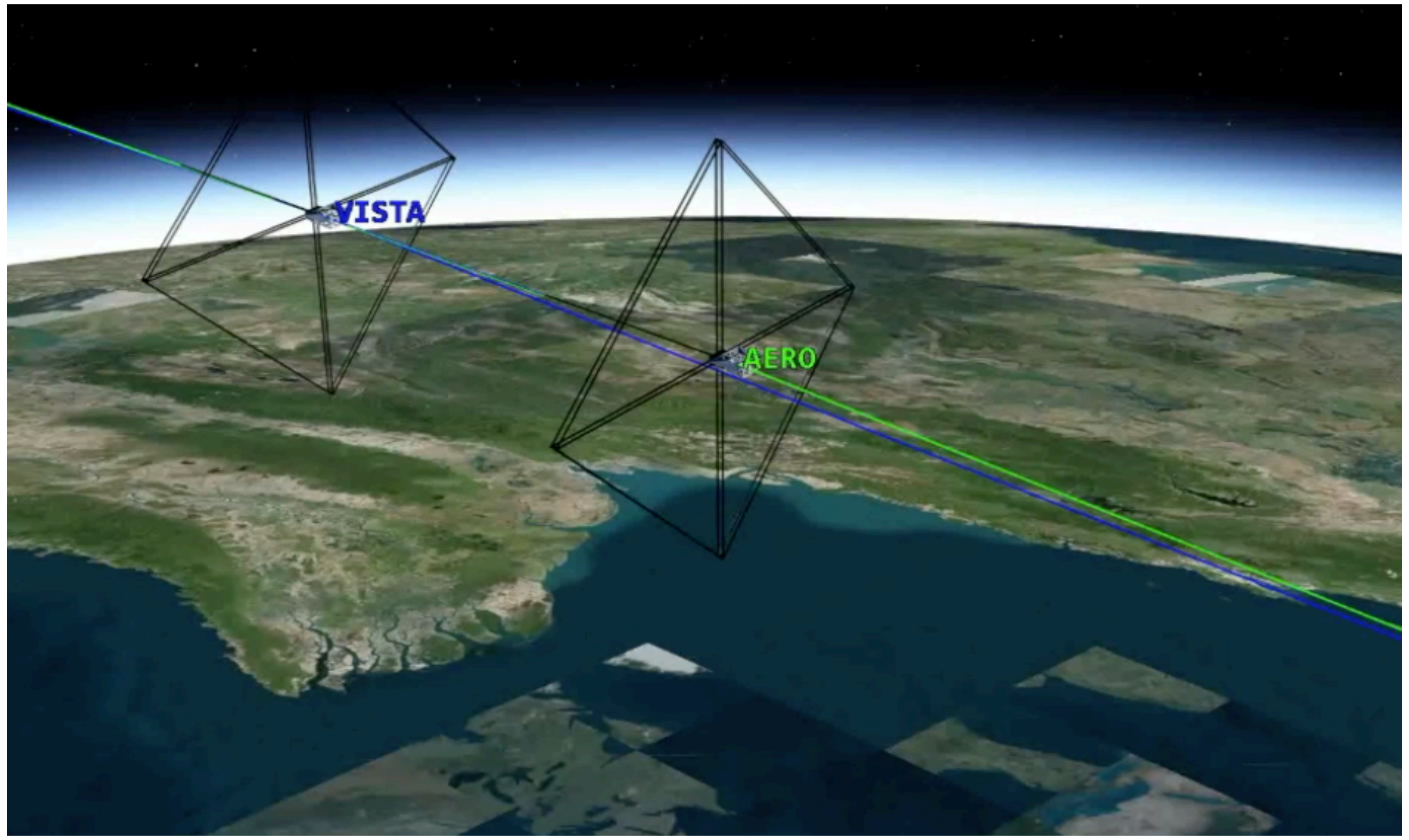
Mission Technical Target: Radio Interferometry From Orbit



- Interferometry
  - Combine signals from two antennas
  - Phase measurement
  - Yields in the end good angular resolution
  - But.. ambiguities exist for spaced antenna set: results in “fringes”, especially when your antennas are in motion
- Vector Sensor (VS) Interferometry
  - **Each** VS provides an angle of arrival estimate
  - This acts like a set of short interferometer baselines!
  - Additional degrees of freedom available
    - Estimate additional quantities (e.g. polarization)
    - Improve variance of estimates
    - Scales rapidly with number of satellites
- Mathematical development for this is complex and is ongoing
- Special considerations in a plasma environment
  - Sensor is immersed in a non-symmetric dielectric medium
  - Response is different depending on the angle you view with respect to B!
  - Frontier topic for space based radio remote sensing

AERO/VISTA and the Amateur Radio Community

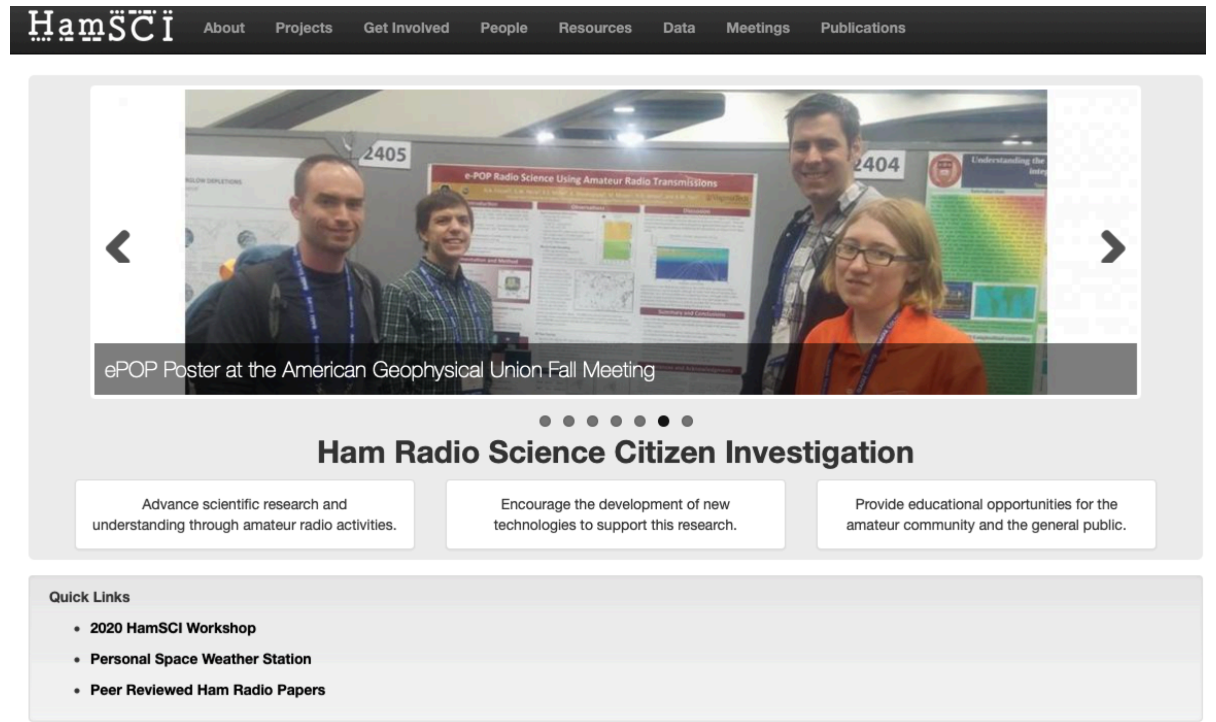
AERO VISTA



- Coherent beacons useful for VS interferometry "signals of opportunity"
  - Where do they leak out of the ionosphere?
  - Does interferometric processing agree with known locations?
  - Small antennas with wide patterns beneficial: no steering needed of beacon TX
- Potential wide area capture of UHF AX.25 downlinks / heartbeats (discussion ongoing in A/V telemetry team), coordinated with e.g. SatNOGS efforts
- General ionospheric HF propagation science, in coordination with HamSCI, TAPR, ARRL Frequency Measurement Tests, etc.

HamSCI

https://www.hamsci.org



Collaborative Ground-Satellite, Amateur-Professional Science

Radio Science

RESEARCH ARTICLE
10.1029/2017RS006496

Key Points:
- Amateur radio transmissions are used to detect plasma cutoff and single-mode fading
- Fundamental ionospheric characteristics and magnetoionic phenomena can be studied with amateur radio transmissions
- New and compelling radio science experiments are possible with the participation of citizen radio scientists

Citizen Radio Science: An Analysis of Amateur Radio Transmissions With e-POP RRI

G. W. Perry[1], N. A. Frissell[2,3], E. S. Miller[4], M. Moses[2], A. Shovkoplyas[5], A. D. Howarth[1], and A. W. Yau[1]

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Abstract We report the results of a radio science experiment involving citizen scientists conducted on 28

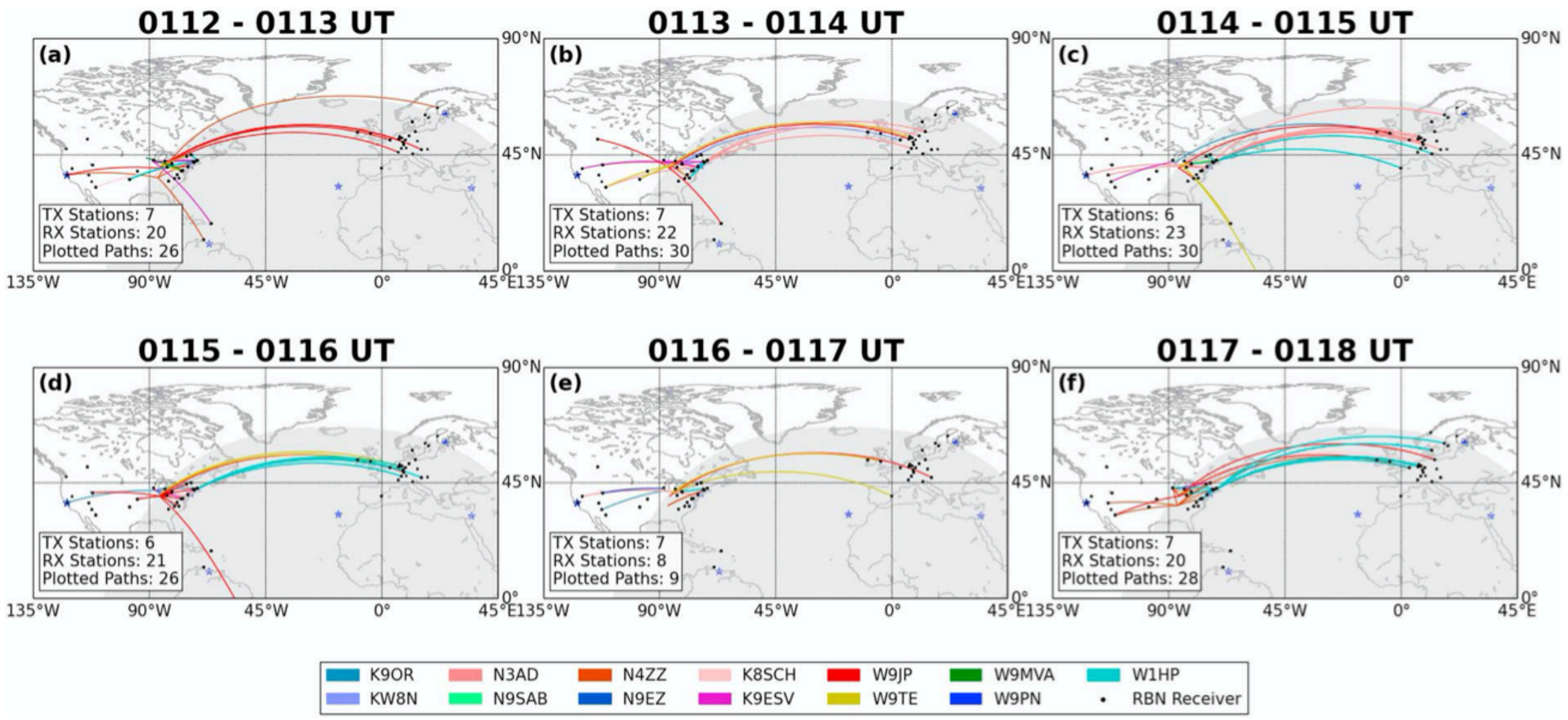


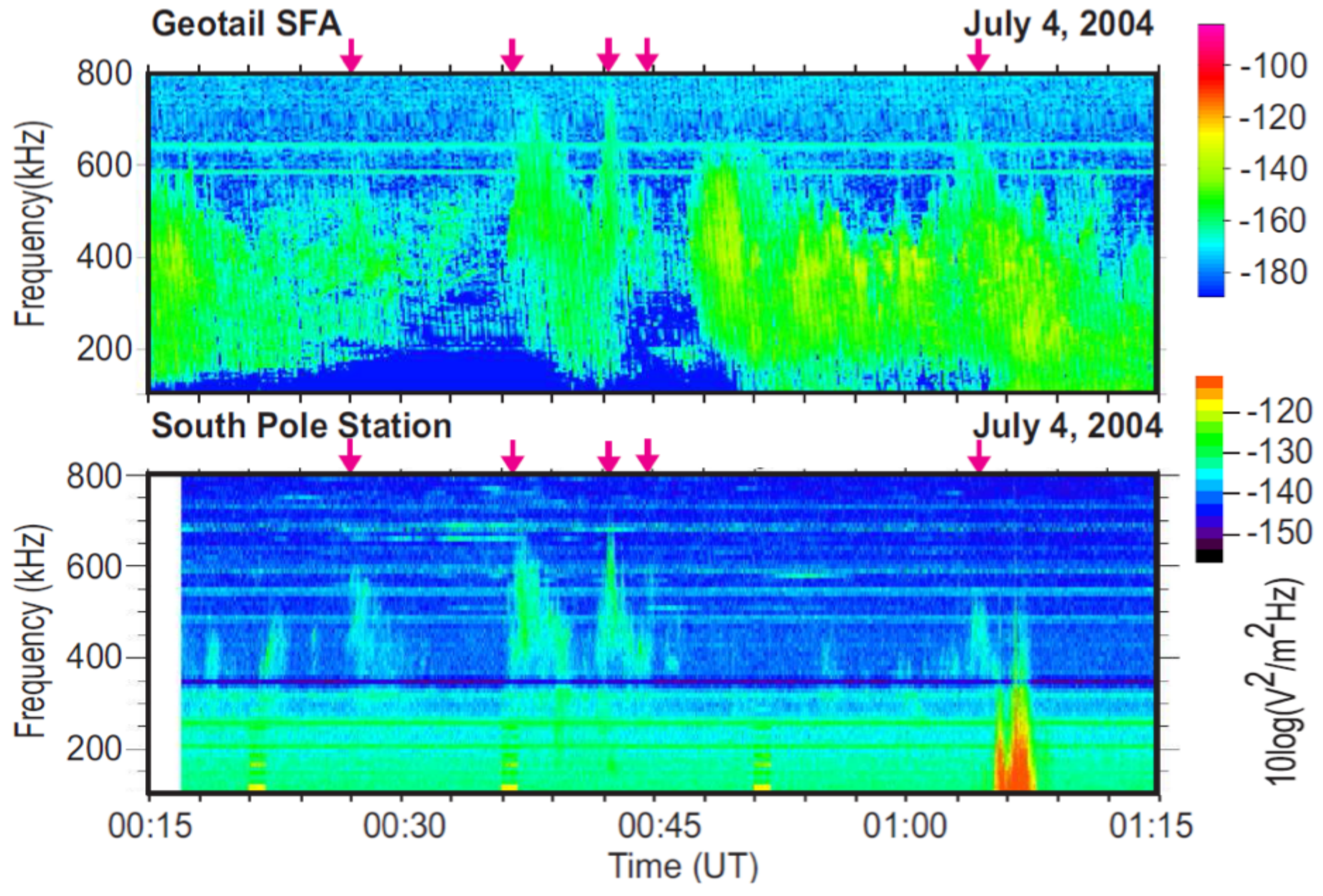
Figure 5. A visualization of the estimated propagation paths of ham radio links established on the CW portion of the 40 m band during the Field Day experiment according to RBN records. The identified hams are marked by color. It is evident that hams were continuously transmitting during the entirety of the Field Day experiment. (a) 0112–0113 UT; (b) 0113–0114 UT; (c) 0114–0115 UT; (d) 0115–0116 UT; (e) 0116–0117 UT; (f) 0117–0118 UT.

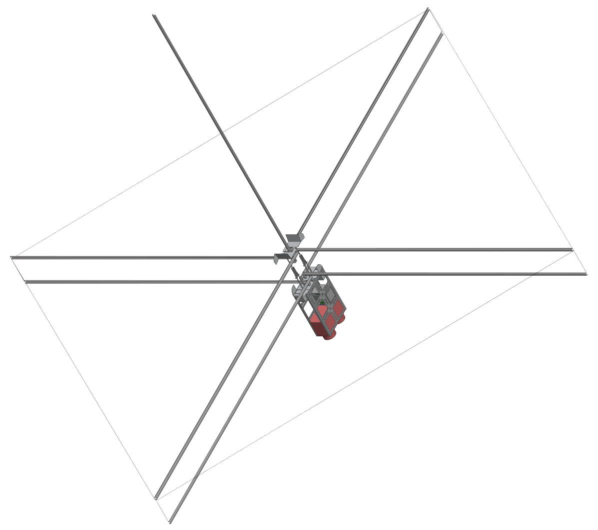
- Canadian ePOP HF radio receiver
- Propagation dependence provided dynamic reception for ground-to-satellite links, depending on conditions
- Amateur TX used as sources

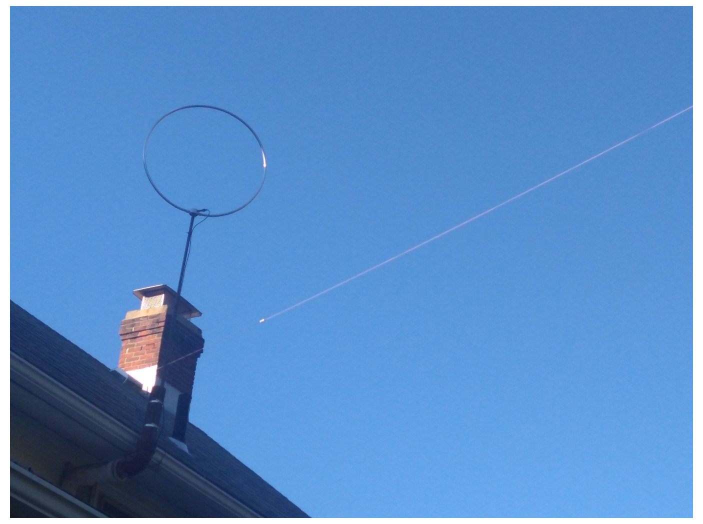
AERO/VISTA: Add interferometry!

Summary

- AERO + VISTA will address radio science of the aurora at HF frequencies
- Novel EM vector sensor in low Earth orbit allows direction finding of natural, human HF sources
- HF propagation science with amateur radio collaborations







https://www.haystack.mit.edu/geospace/geospace-projects/aero-vista-cubesat-mission/

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