

Electromagnetic Vector Sensors: Better Antennas for Space-based Low Frequency Radio Interferometry



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MEGAWAVE RADIO SURVEYOR

LARGE SATELLITE CONSTELLATION FORMING A SPACE INTERFEROMETER FOR STELLAR AND EXTRAGALACTIC ASTROPHYSICS, EXOPLANETARY SCIENCE, AND COSMOLOGY

STELLAR EXOSPACE WEATHER



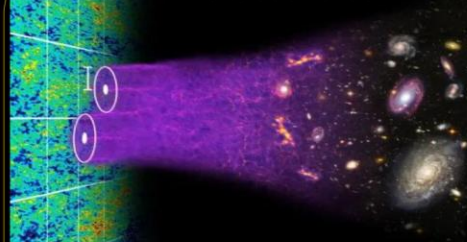
Monitor stellar eruptions and radio bursts to investigate stellar activity and its impact on planets and habitability.

EXOPLANET MAGNETIC FIELDS



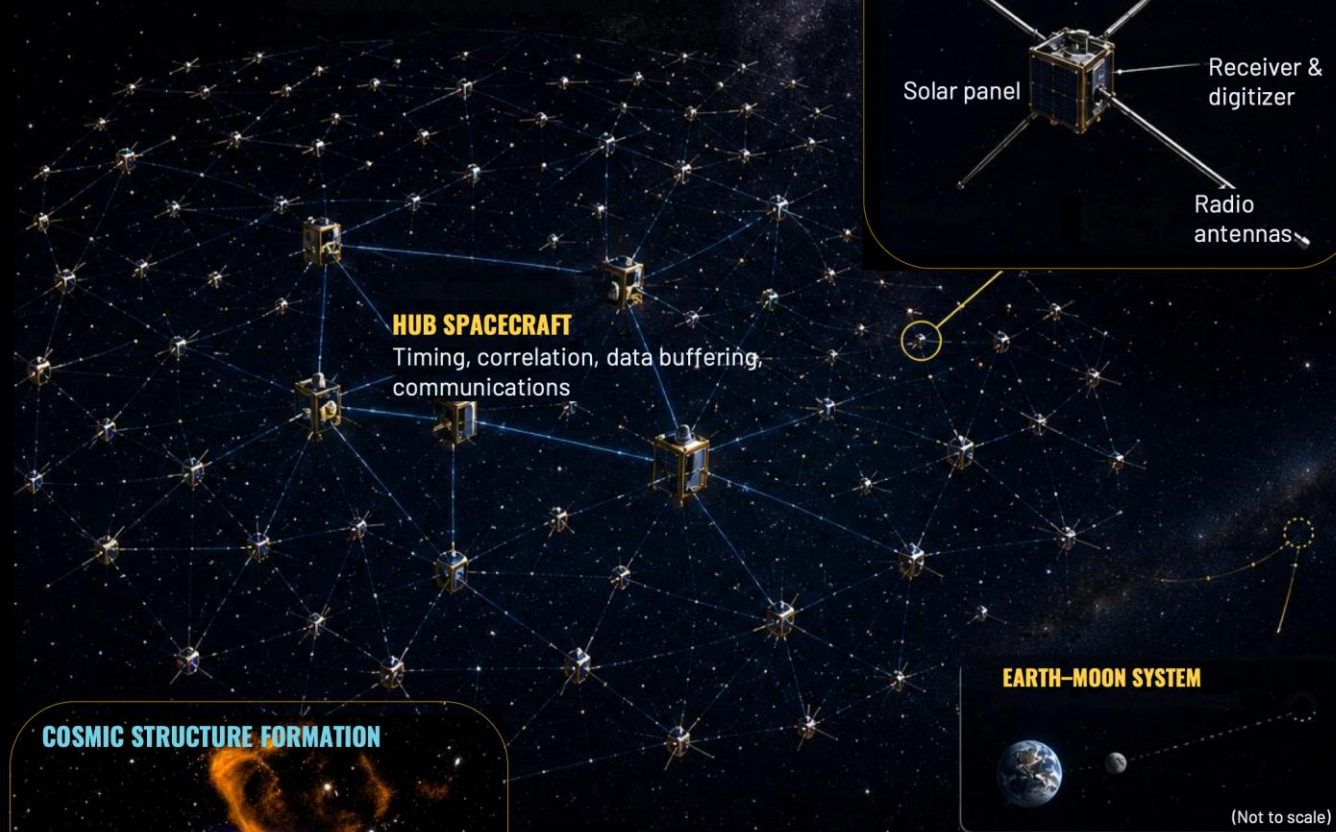
Probe exoplanetary interiors and atmospheric retention with radio emission from exoplanetary magnetic fields.

DARK AGES COSMOLOGY



Track the Universe's evolution before first stars and galaxies emerged using hyperfine spectral line from H I

DISTRIBUTED INTERFEROMETER ARRAY



COSMIC STRUCTURE FORMATION



Probe cosmic rays, magnetic fields, particle acceleration, and non-thermal pressure in galaxy clusters and circumgalactic media.



FREQUENCY RANGE
0.1 – 45 MHz
Above the ionosphere

PARALLEL OBSERVATIONS
Multiple science goals simultaneously

SCALABLE & RESILIENT
Distributed architecture for robustness and staged growth

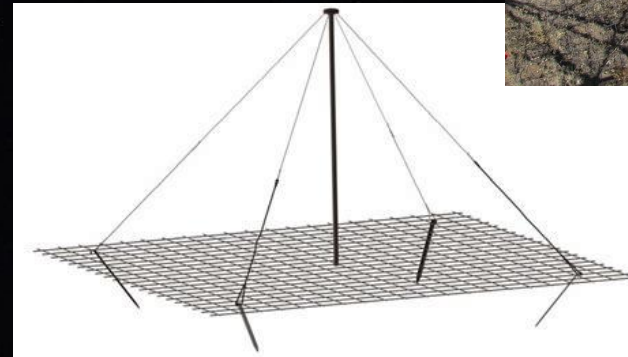


arXiv:
2608.26322

Antenna choice for space-based interferometry is critical

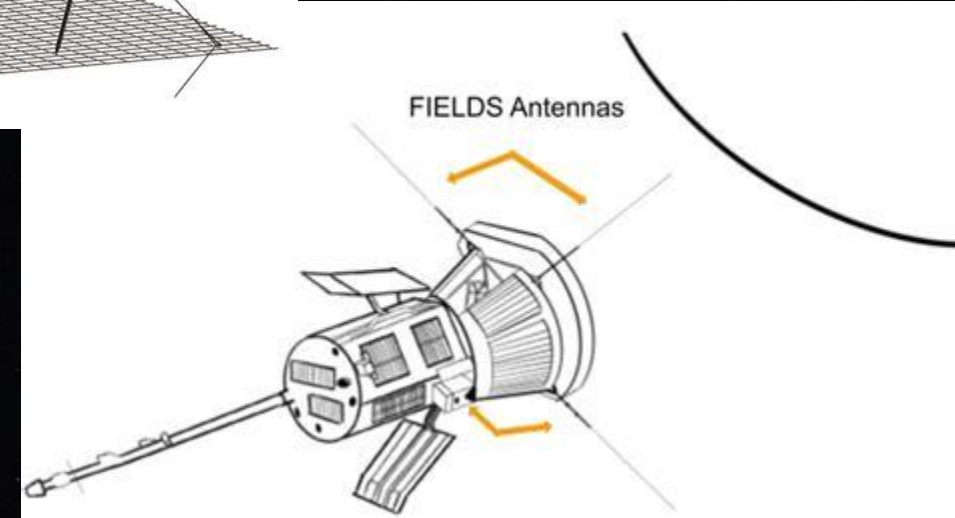
- ◆ Standard for ground-based low frequency arrays: crossed dipoles
- ◆ Standard for single spacecraft or small constellation low frequency instruments: dipoles or monopoles
- ◆ Advantages:
 - Mechanically, electrically simple
 - Broad beam pattern
 - High heritage deployable stacer antennas for space
 - Electrically small – good for SWaP
- Disadvantages:
 - Limited beamforming capability
 - Susceptible to quasi-thermal noise

LOFAR LBA



LWA

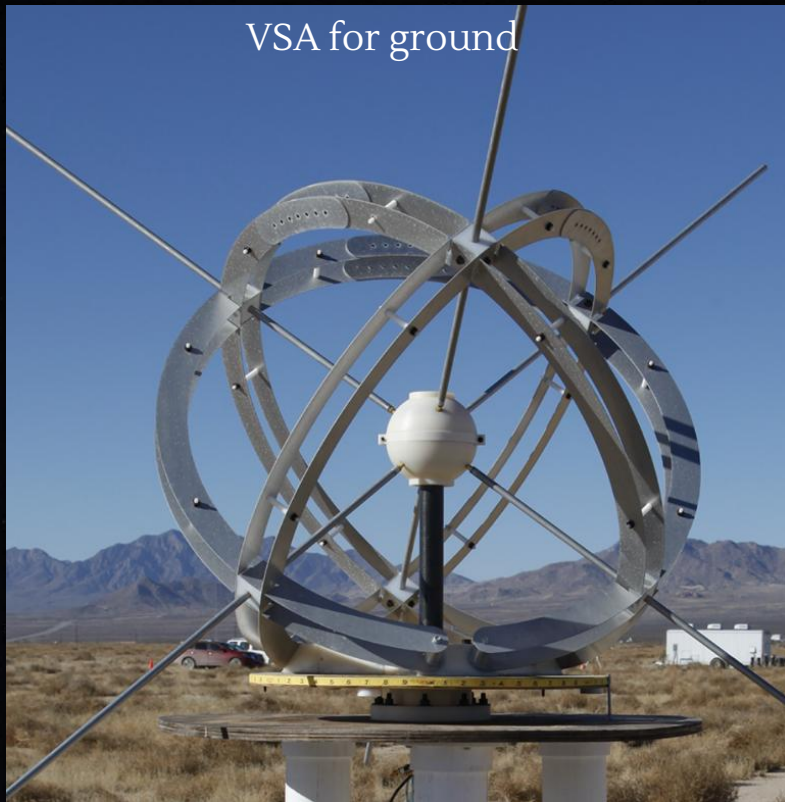
Parker Solar Probe



Vector sensor: a better broadband low frequency antenna



Learn more
about AERO-
VISTA antenna,
vector sensors
for imaging

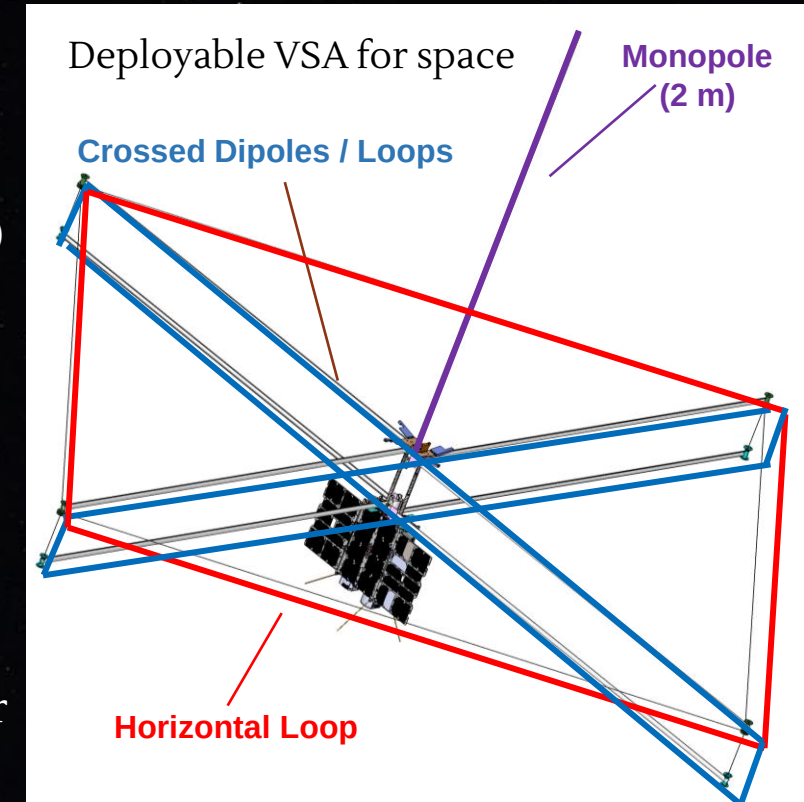


VSA for ground

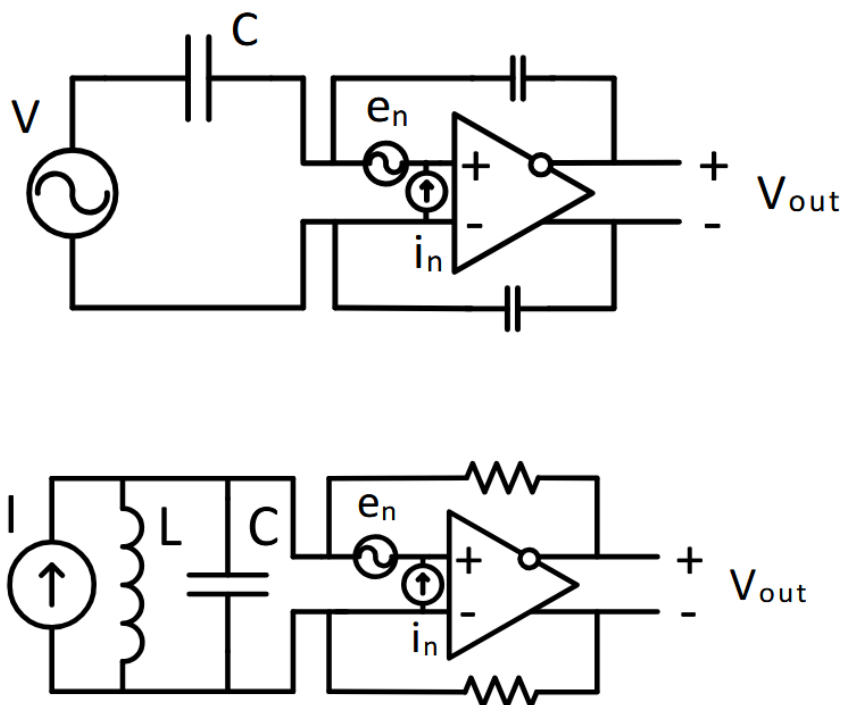
NRL/IARPA HFGeo vector sensor at
White Sands, NM (Brown, 2019).

Vector sensor antenna: 3 orthogonal
dipoles, 3 orthogonal loops

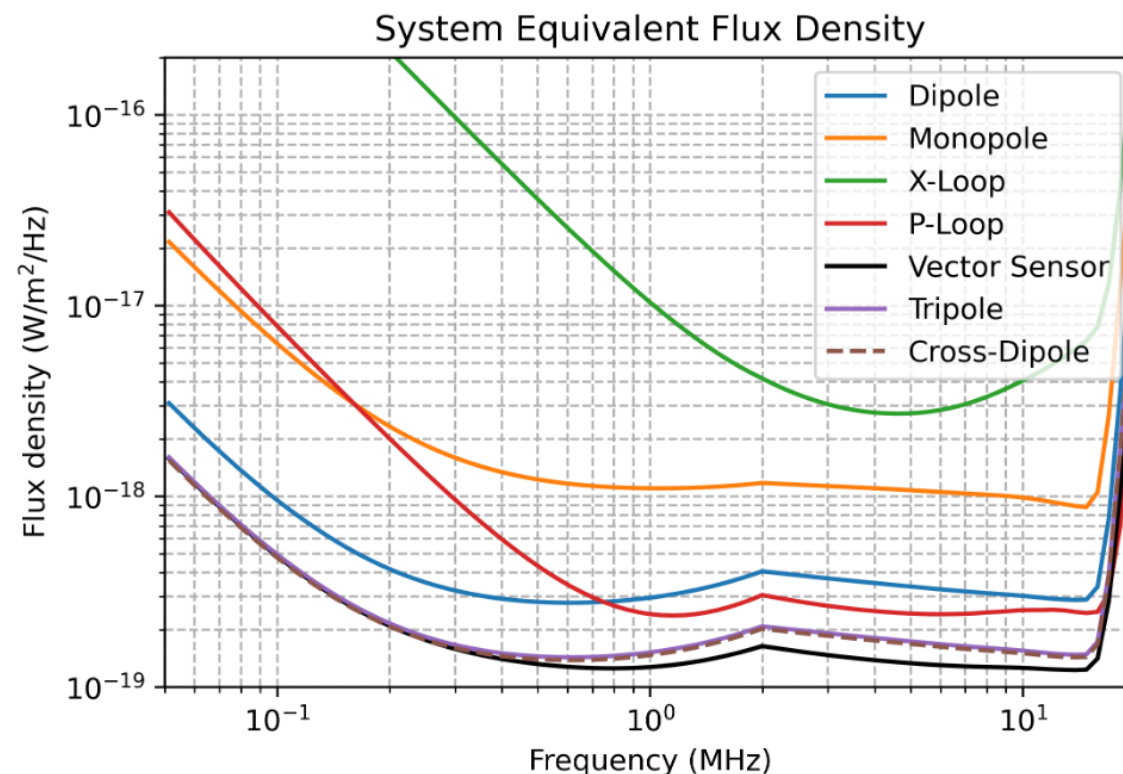
- Senses all 6 components of incident electromagnetic wave (Nehorai, 1994)
- Developed for ground- or air-based direction finding of terrestrial signals
- Single VS capable of recovering direction of arrival and polarization of multiple sources (Volz, 2016; Knapp 2016a)
- Omni-directional beam pattern
- Electrically small → broadband, lower SWaP
- Beamforming/nulling possible



LNAs and Element Sensitivity



Dipole component charge amplifier design (top) and loop antenna transimpedance amplifier (bottom). The left side of each diagram is an equivalent analog circuit representing the dipole and loop antennas.



Instantaneous sensitivity of individual elements and combined sensor. Only the dipole/monopole components are combined into a tripole sensor for comparison

Deployable VSA, CubeSat form factor

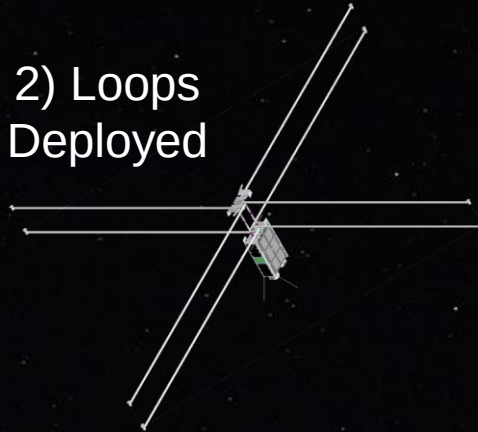
0) Stowed



1) Extended



2) Loops Deployed



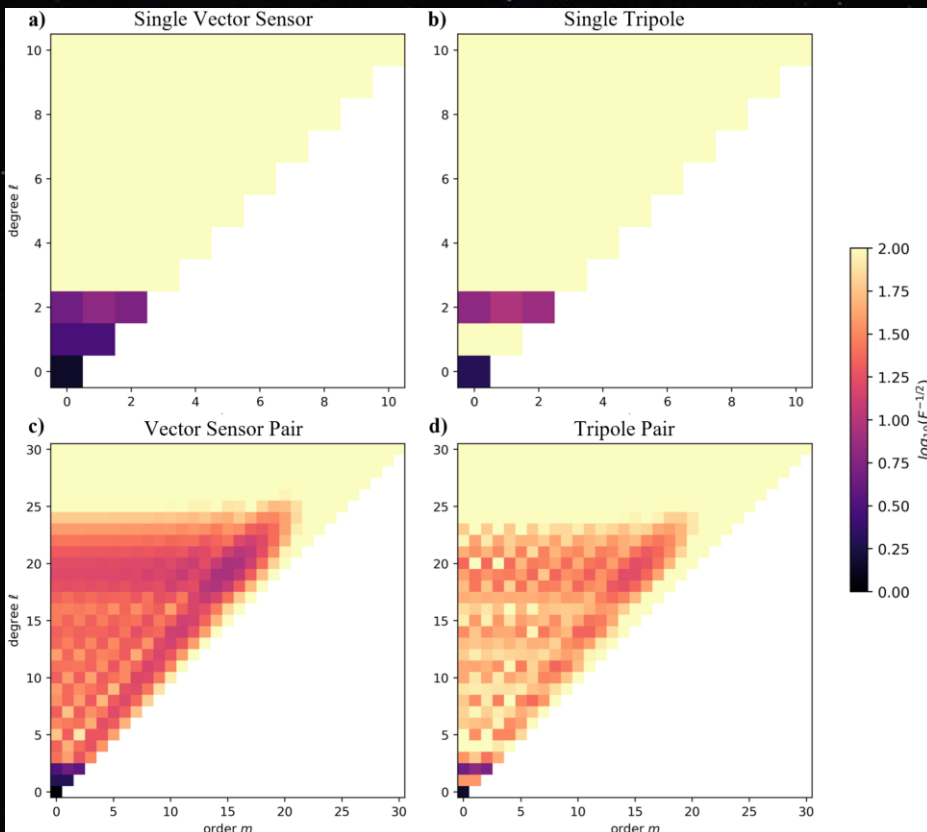
3) Fully Deployed



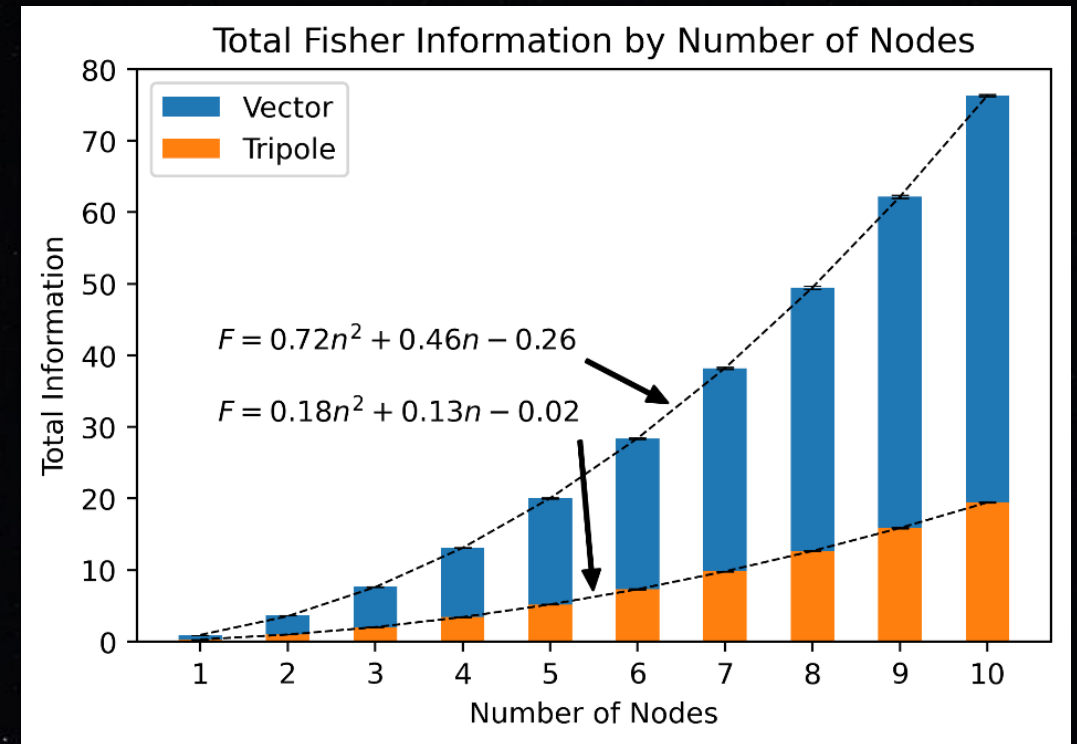
Deployable VSA design by Lincoln Laboratory
See Silver et al. (2024), DOI:
10.1109/AERO58975.2024.10521397

Vector sensor: a better interferometric broadband low frequency antenna

Fisher information for single VSA vs. tripole (top),
baseline pair (bottom)



Vector sensors deliver more information per
number of nodes than tripoles; are up to 2x more
sensitive



Additional benefits of vector sensors

Beamforming/nulling

- Managing interference from the Earth and Sun is a major challenge for a space-based array
- Vector sensors are a special case of phased array and can be beamformed; cardioid beam has a sharp null
- Vector sensors in a cluster/station offer more degrees of freedom for beamforming

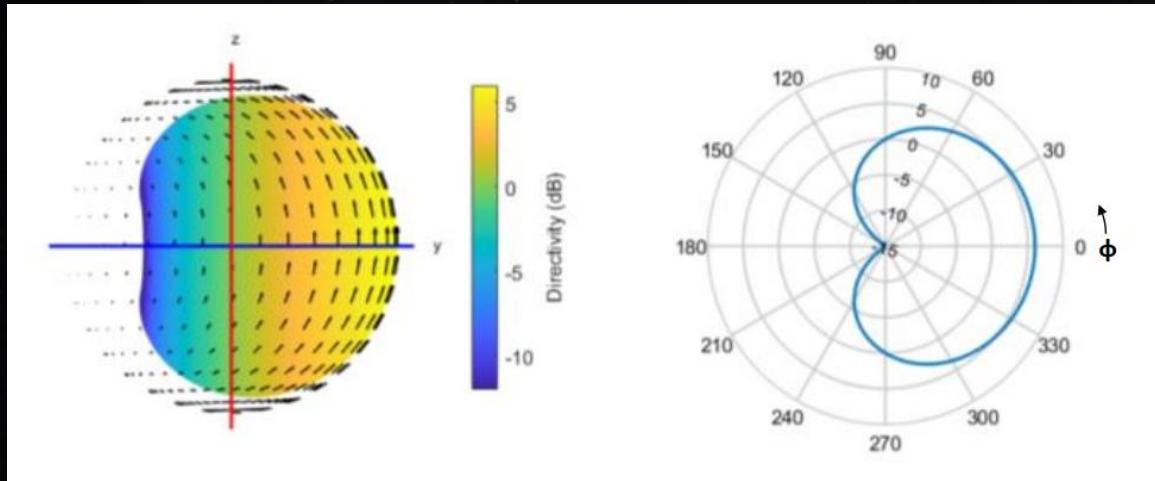


Figure from Morris et al. (2022), DOI: 10.1109/PAST49659.2022.9975075

Quasi-thermal noise (QTN)

- Low frequency (<500 kHz) observations in the solar wind are affected by voltage fluctuations caused by plasma motion
- Loop antennas may not be as affected by this electrostatic noise source

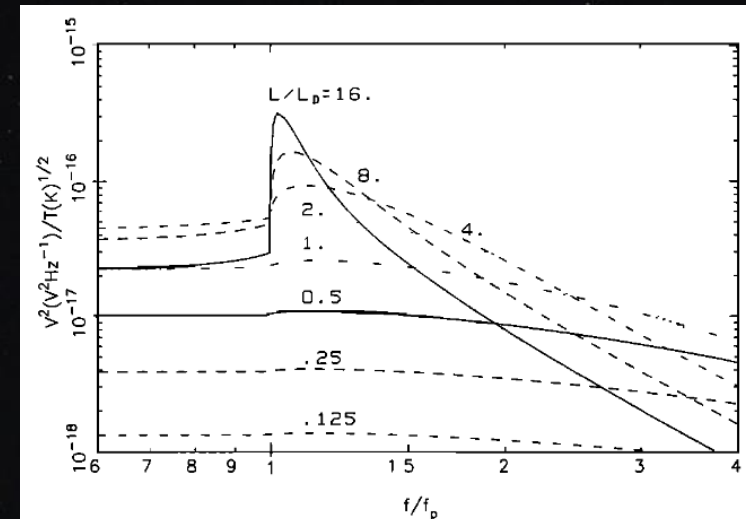


Fig. 2. Normalized thermal noise spectra $V^2(V^2 \text{ Hz}^{-1})/T^{1/2}$ (K) as a function of f/f_p , for a wire dipole antenna with different values of L/L_D . For $L/L_D \gg 1$, the high-frequency spectra vary as f^{-3} . For $L/L_D < 1$, the spectra are nearly flat.

Fig. 2 in Meyer-Vernet & Perche (1989)

Let's talk!

- ◆ I have not yet found a treatment of QTN for anything other than dipole antennas – if you know of a paper, please let me know!
- ◆ Ideas for other vector sensor geometries? Let's chat!
- ◆ Intrigued by vector sensors and want to hear more? Happy to share and make connections with the rest of the team.
- ◆ Ideas for tests (ground or flight) to further investigate the capabilities of vector sensors for constellations? I'm all ears!

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Acknowledgements

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GO-LoW Phase I final report

Backup

VSA element antenna patterns

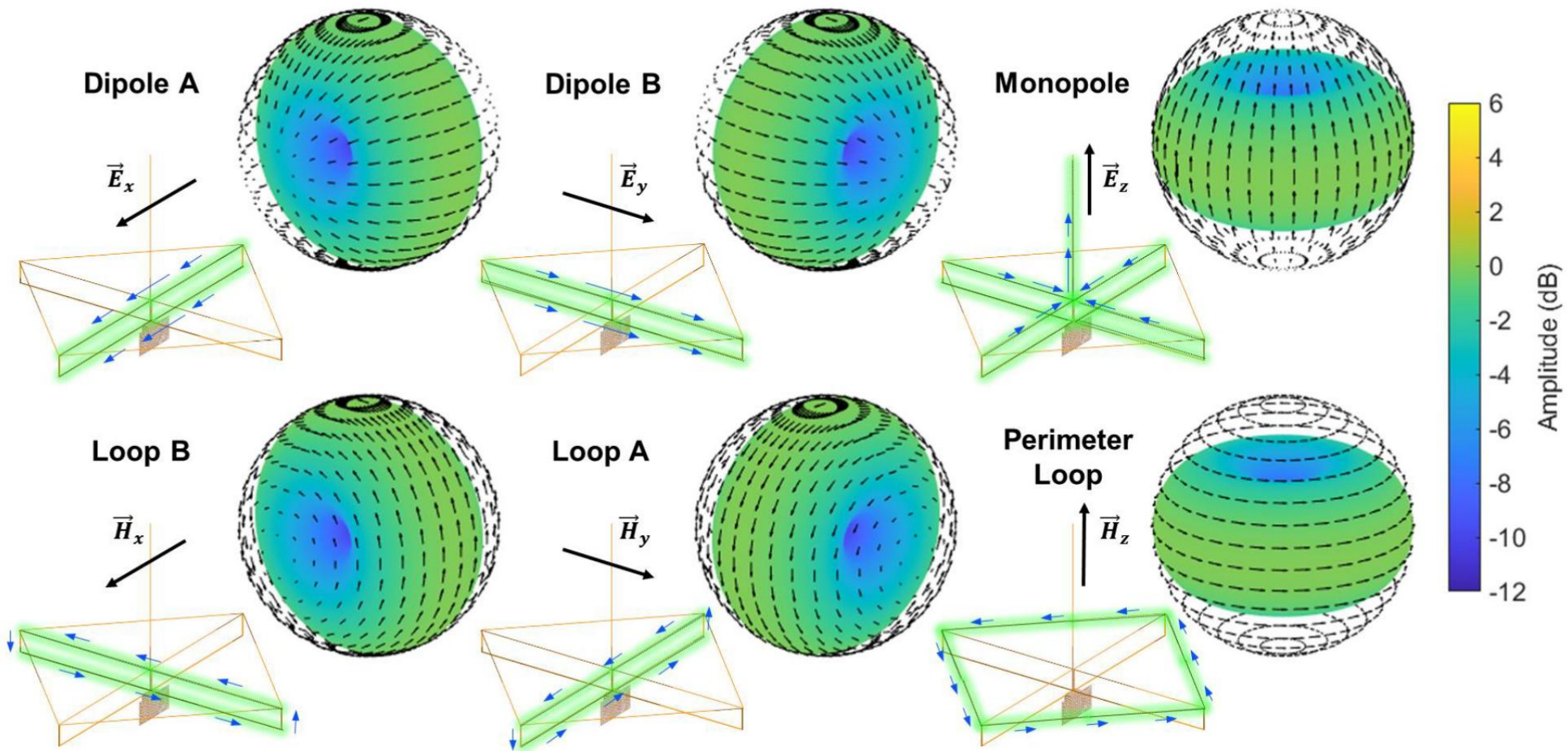


Figure from Morris et al. (2022), DOI: 10.1109/PAST49659.2022.9975075

Mode former

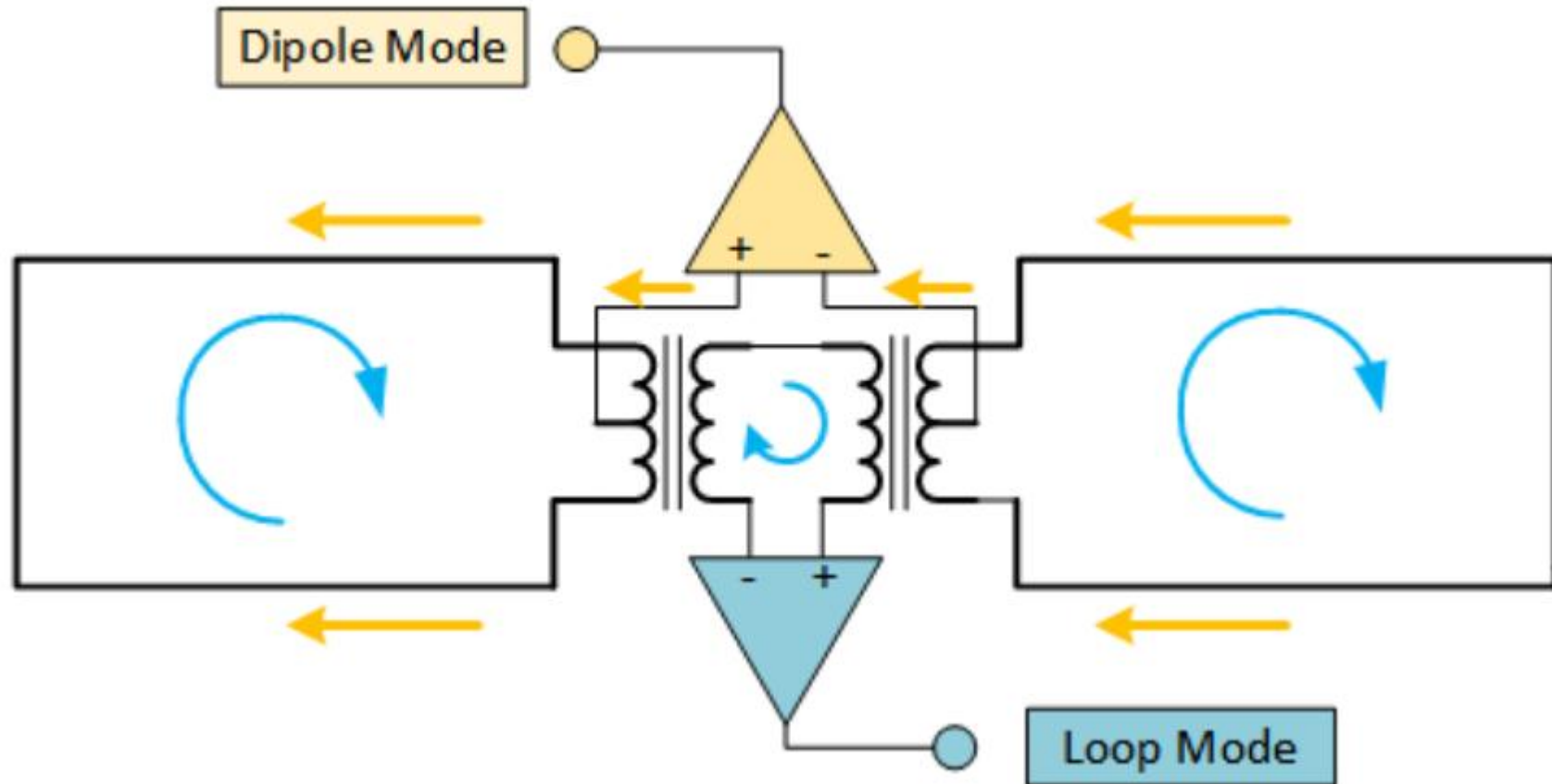


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