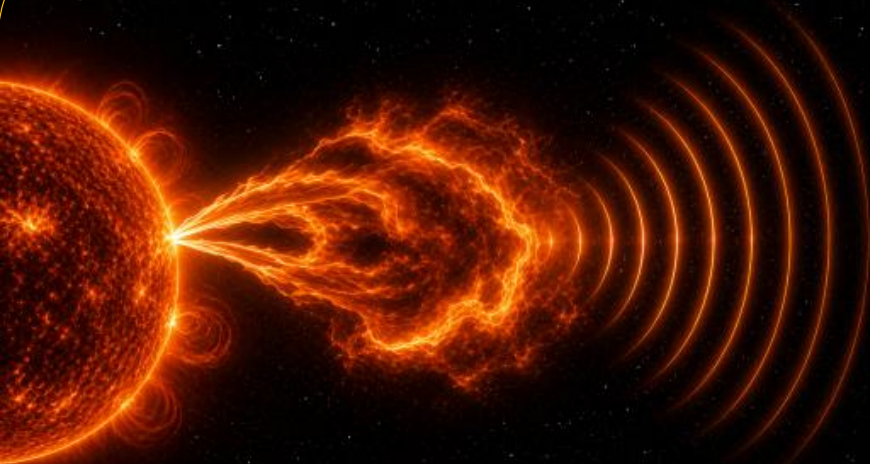


MEGAWAVE RADIO SURVEYOR

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

STELLAR EXOSPACE WEATHER



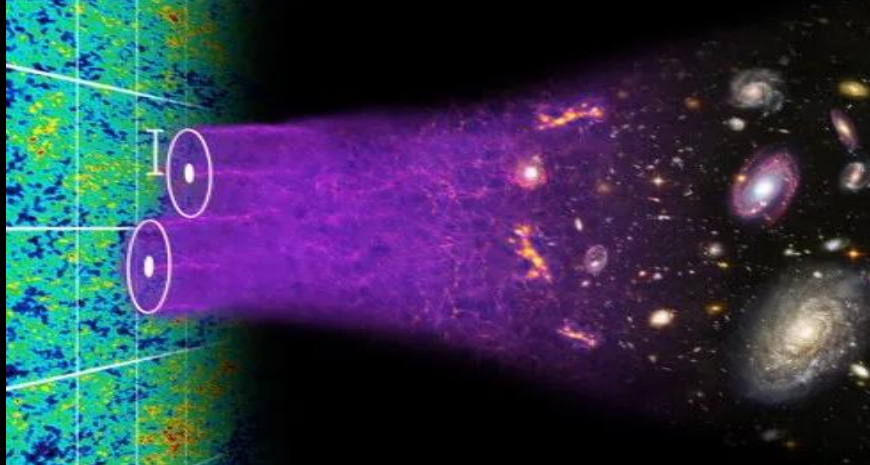
Monitor stellar eruptions and radio bursts to investigate stellar activity and its impact on planets and habitability.

EXOPLANET MAGNETIC FIELDS



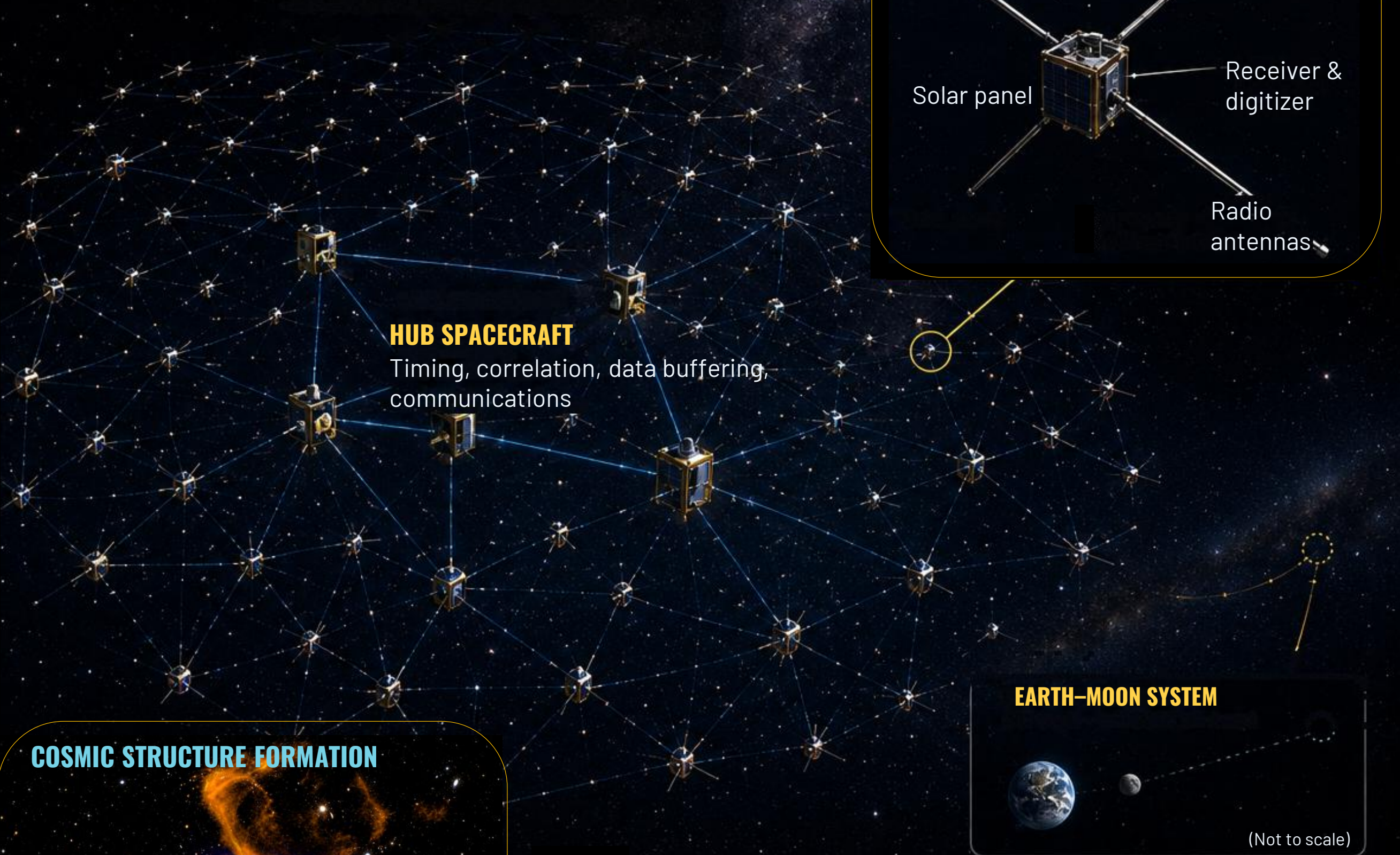
Probe exoplanetary interiors and atmospheric retention with radio emission from exoplanetary magnetic fields.

DARK AGES COSMOLOGY



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

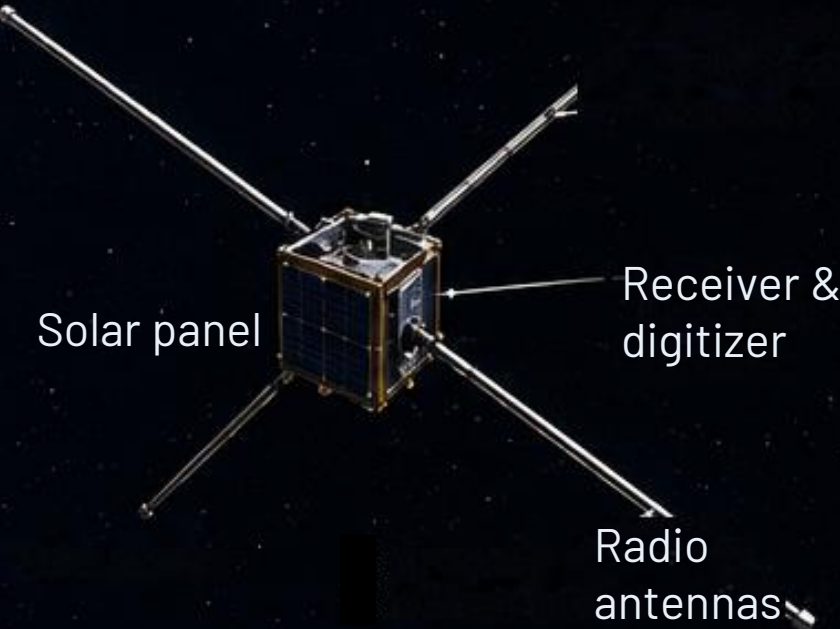
DISTRIBUTED INTERFEROMETER ARRAY



HUB SPACECRAFT

Timing, correlation, data buffering, communications

ONE SMALLSAT ELEMENT



EARTH-MOON SYSTEM



FREQUENCY RANGE

0.1 – 45 MHz
Above the ionosphere

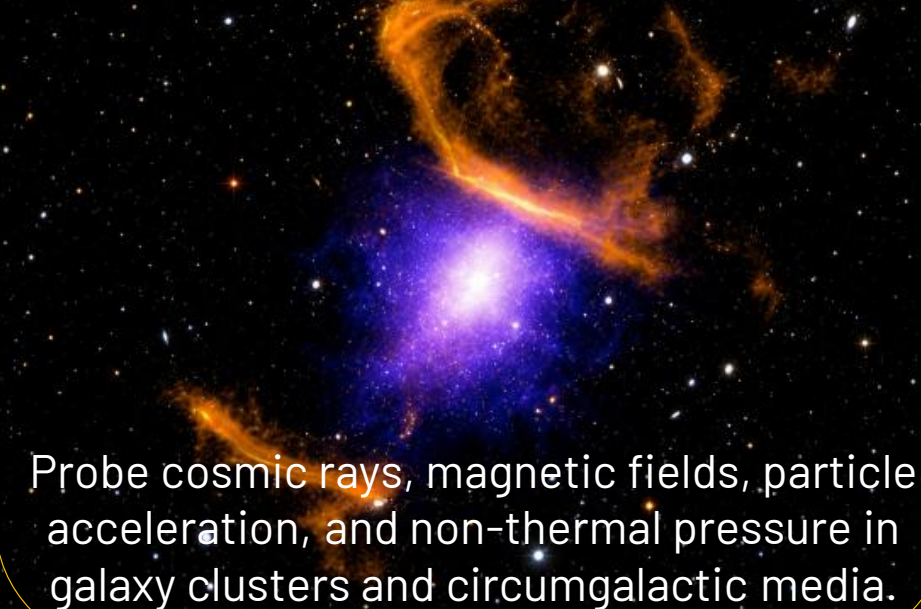
PARALLEL OBSERVATIONS

Multiple science goals simultaneously

SCALABLE & RESILIENT

Distributed architecture for robustness and staged growth

COSMIC STRUCTURE FORMATION



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

MegaWave Radio Surveyor

Joseph Lazio (University of Michigan)

James Aguirre (University of Pennsylvania)

Stuart Bale (University of California, Berkeley)

Judd Bowman (Arizona State University)

Ruby Bryne (California Institute of Technology)

Joseph Callingham (ASTRON, The Netherlands)

Tracy E. Clarke (Naval Research Laboratory)

Ivey Davis (ASTRON, The Netherlands)

Tim Dolch (University of New Mexico)

Peter Driscoll (Carnegie Institute of Washington)

Anastasia Fialkov (Cambridge University, UK)

Steven Furlanetto (University of California, Los Angeles)

Simona Giacintucci (Naval Research Laboratory)

Ravit Helled (University of Zurich, Switzerland)

Jacqueline Hewitt (Massachusetts Institute of Technology)

Phil Hopkins (California Institute of Technology)

Andrea Isella (Rice University)

Daniel Jacobs (Arizona State University)

Eloy de Lera Acedo (University of Cambridge, UK)

Melodie M. Kao (Lowell Observatory)

Mary Knapp (MIT/Haystack Observatory)

Evgenya Shkolnik (Arizona State University)

Nicholas Kern (University of Michigan)

L.V.E. Koopmans (Kapteyn Astronomical Institute, The Netherlands)

Jasmina Lazendic-Galloway (Eindhoven University of Technology)

Susan Lepri (University of Michigan)

R. O. Parke Loyd (Eureka Scientific)

James P. Lux (Jet Propulsion Laboratory, California Institute of Technology)

James P. Mason (APL/JHU)

Raul Monsalve (Universidad Andrés Bello)

Miguel Morales (University of Washington)

Julian B. Muñoz (University of Texas~Austin)

Rachel Osten (Space Telescope Science Institute)

Sebastian Pineda (University of Colorado, Boulder)

Jonathan Pober (Brown University)

Sam B. Ponnada (Chalmers University)

Leslie A. Rogers (University of Chicago)

Saurabh Singh (Raman Research Institute, India)

Jackie Villadsen (Bucknell University)

Jake D. Turner (Cornell University)

Philippe Zarka (LIRA, Observatoire de Paris, France)

John ZuHorne (Harvard-Smithsonian CfA)

Ellen Zweibel (University of Wisconsin, Madison)

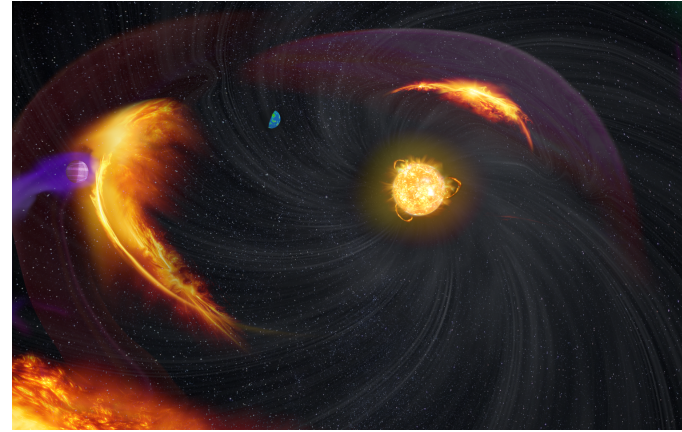
Science Investigation

MegaWave Radio Surveyor



Science Objective

Presentations



Exospace Weather

To determine the extent to which stars generate powerful transient stellar space weather events that eject material into their stellar winds and to determine properties of their winds

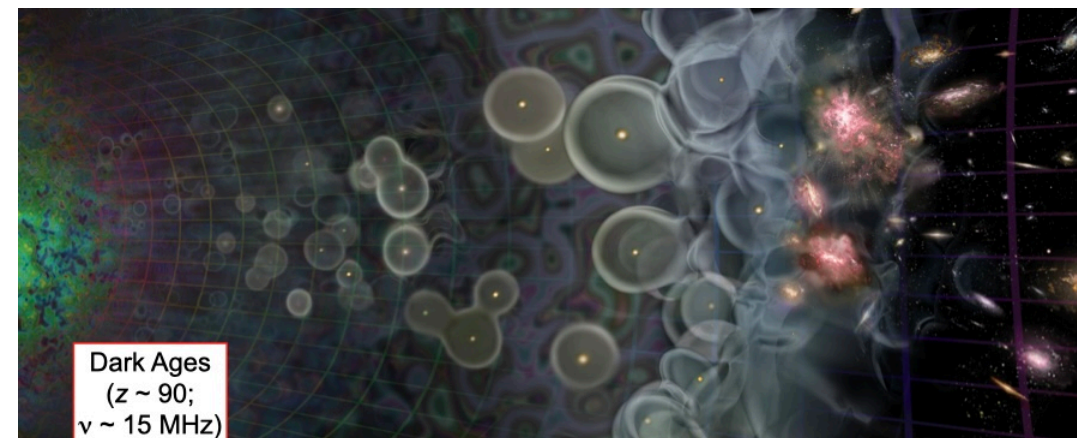
Davis



Magnetic Planets

1. To determine if exoplanet interiors support a more diverse range of magnetic fields than Solar System planets;
2. To determine if magnetic fields provide effective shielding for secondary atmospheres

**Hallinan
Turner**



Dark Ages

1. To test novel physics beyond the standard cosmological model through its effects on the thermal history of the intergalactic medium in the Dark Ages;
2. To test concordance of structure formation in the Dark Ages with inflationary-era predictions.

**Kern/Furlanetto
Burns**



Low-Energy Cosmic Rays

To determine significance of cosmic rays and magnetic fields, including their non-thermal pressure contributions, in intracluster and circumgalactic media

**Oei
Plant
(Park?)**

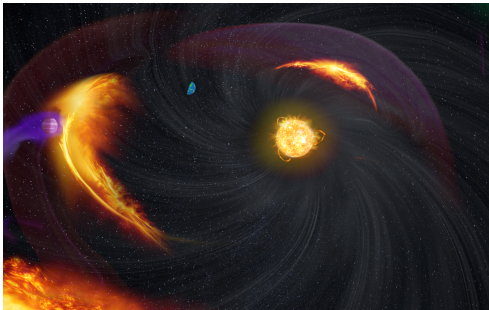
Opening new window in electromagnetic spectrum

Science Implementation

MegaWave Radio Surveyor



Science Objective



Exospace Weather

To determine the extent to which stars generate powerful transient stellar space weather events that eject material into their stellar winds and to determine properties of their winds

Magnetic Planets

1. To determine if exoplanet interiors support a more diverse range of magnetic fields than Solar System planets;
2. To determine if magnetic fields provide effective shielding for secondary atmospheres

Dark Ages

1. To test novel physics beyond the standard cosmological model through its effects on the thermal history of the intergalactic medium in the Dark Ages;
2. To test concordance of structure formation in the Dark Ages with inflationary-era predictions.

Low-Energy Cosmic Rays

To determine significance of cosmic rays and magnetic fields, including their non-thermal pressure contributions, in intracluster and circumgalactic media

Instrumental/Telescope Requirements

Comments/Rationale

Frequency range:
0.1 MHz—45 MHz

Requires observations beyond Earth's ionosphere, plasmasphere

Angular resolution:
< 5° for Dark Ages
1' for other science cases

Dark Ages: foreground characterization
Other science cases: mitigate source confusion, ensure source identification

Temporal resolution:
≤ 1 min.

Exospace Weather: Type III bursts

Polarization: Full Stokes

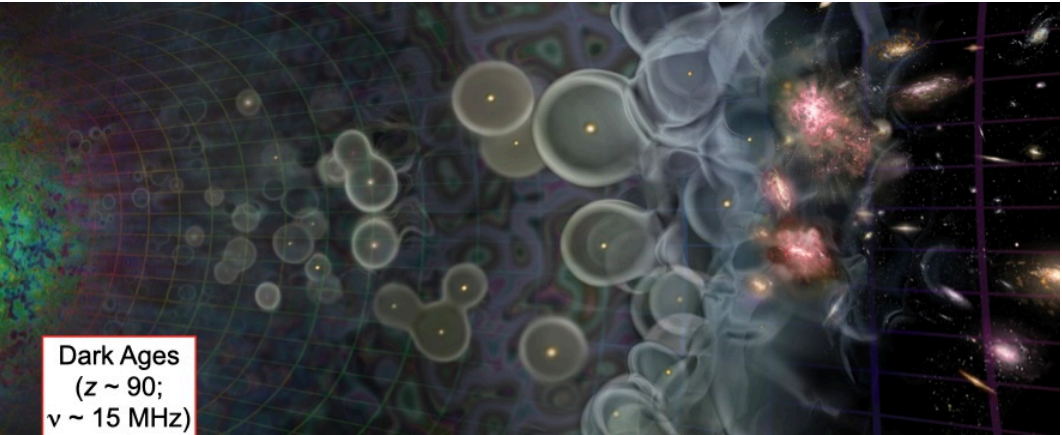
Magnetic Planets: electron cyclotron maser emission

Sensitivity: sub-mJy

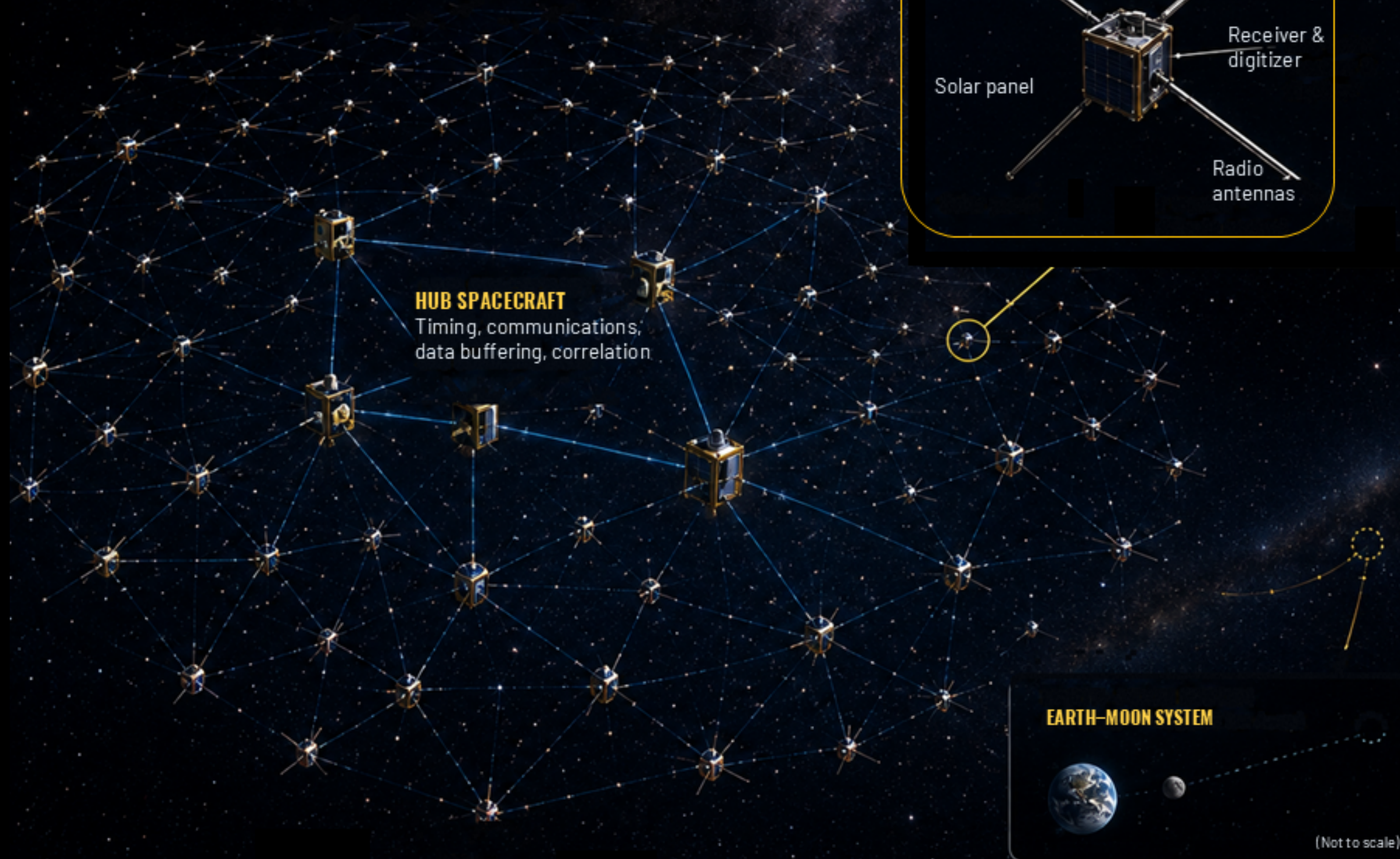
Exospace Weather, Magnetic Planets

Calibration:
1 part in 10⁷ or better

Dark Ages H I signal amplitude; requires instrumental stability



DISTRIBUTED INTERFEROMETER ARRAY

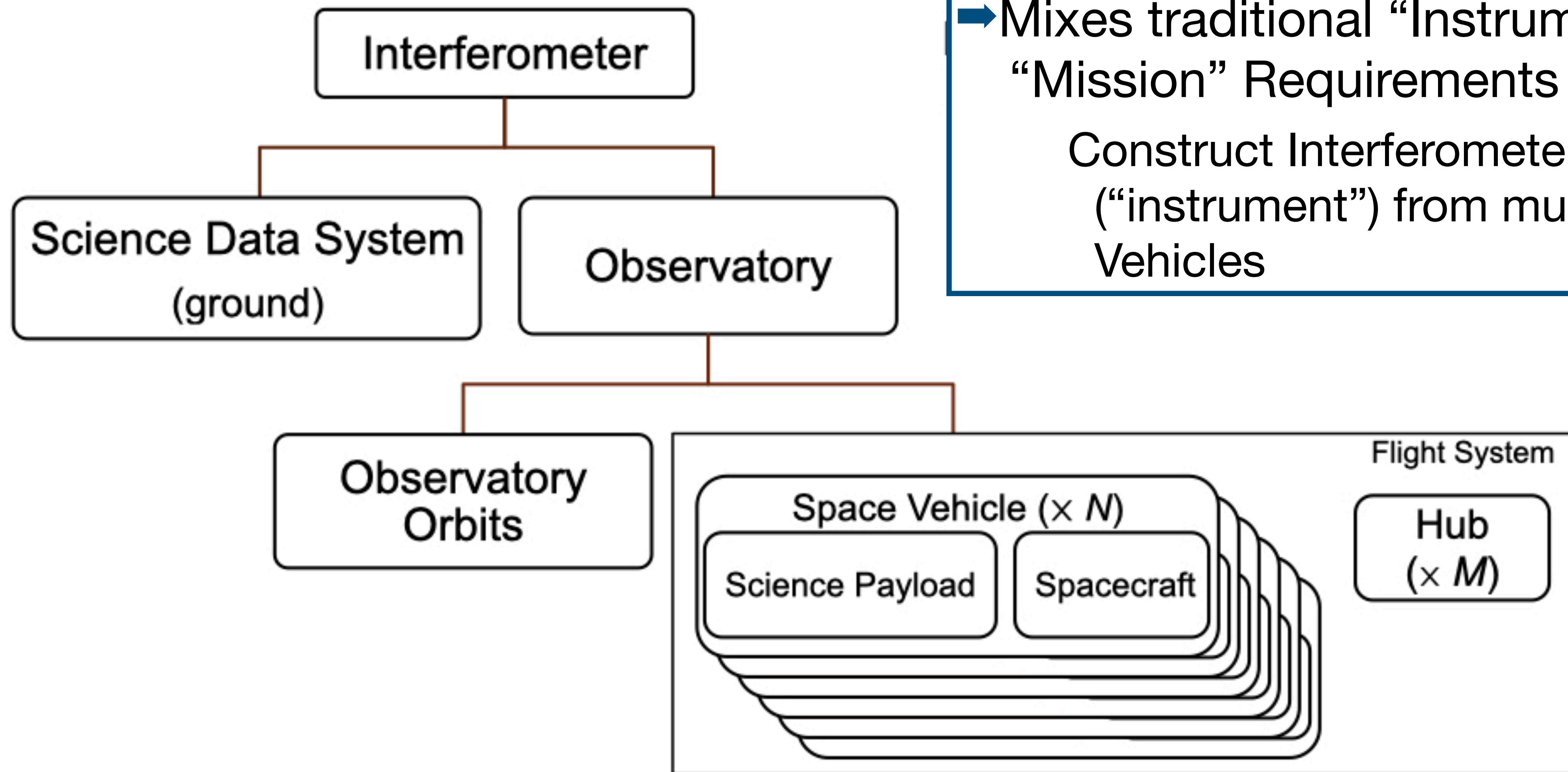


FREQUENCY RANGE
0.1 – 45 MHz
Above the ionosphere

PARALLEL OBSERVATIONS
Multiple science goals simultaneously

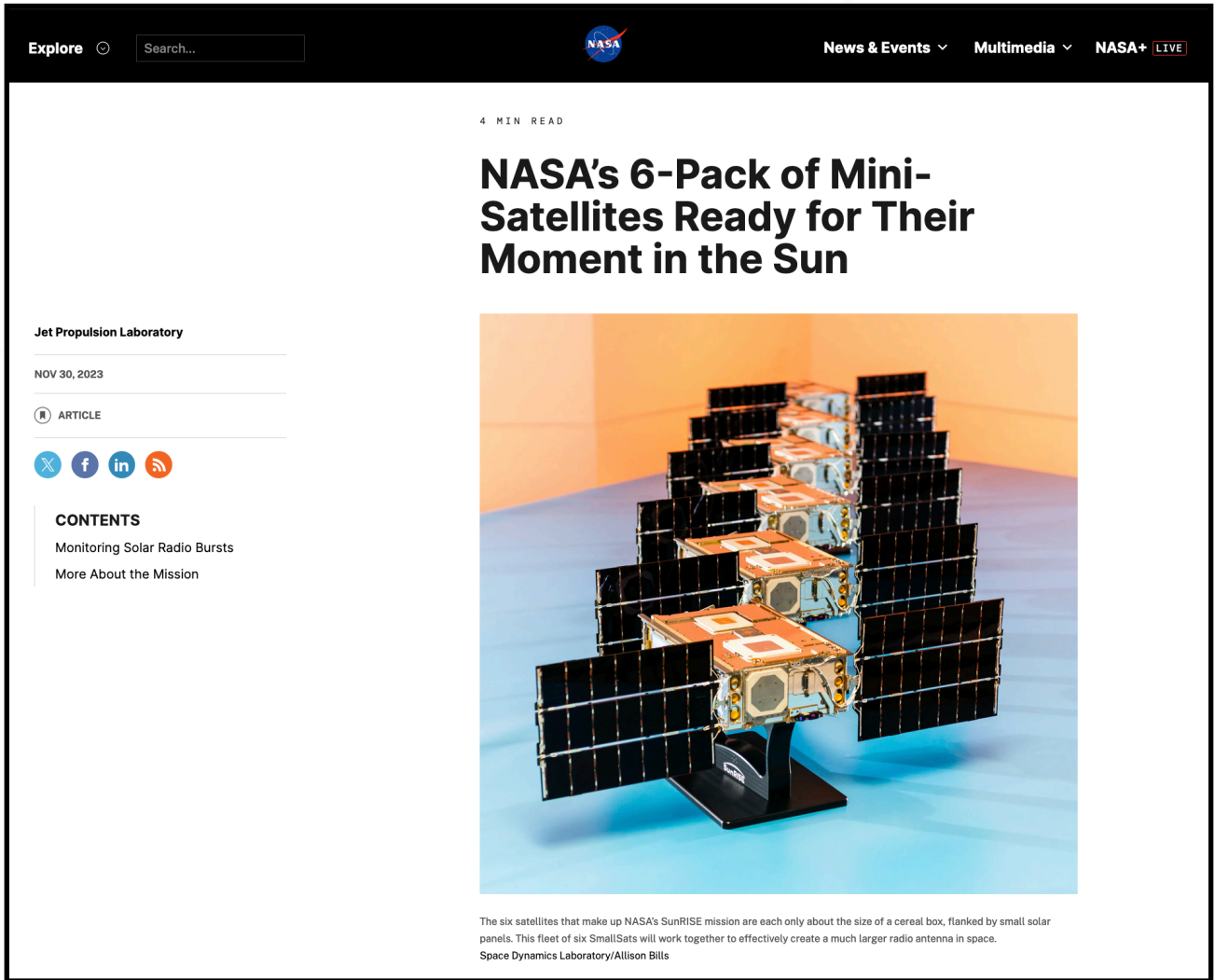
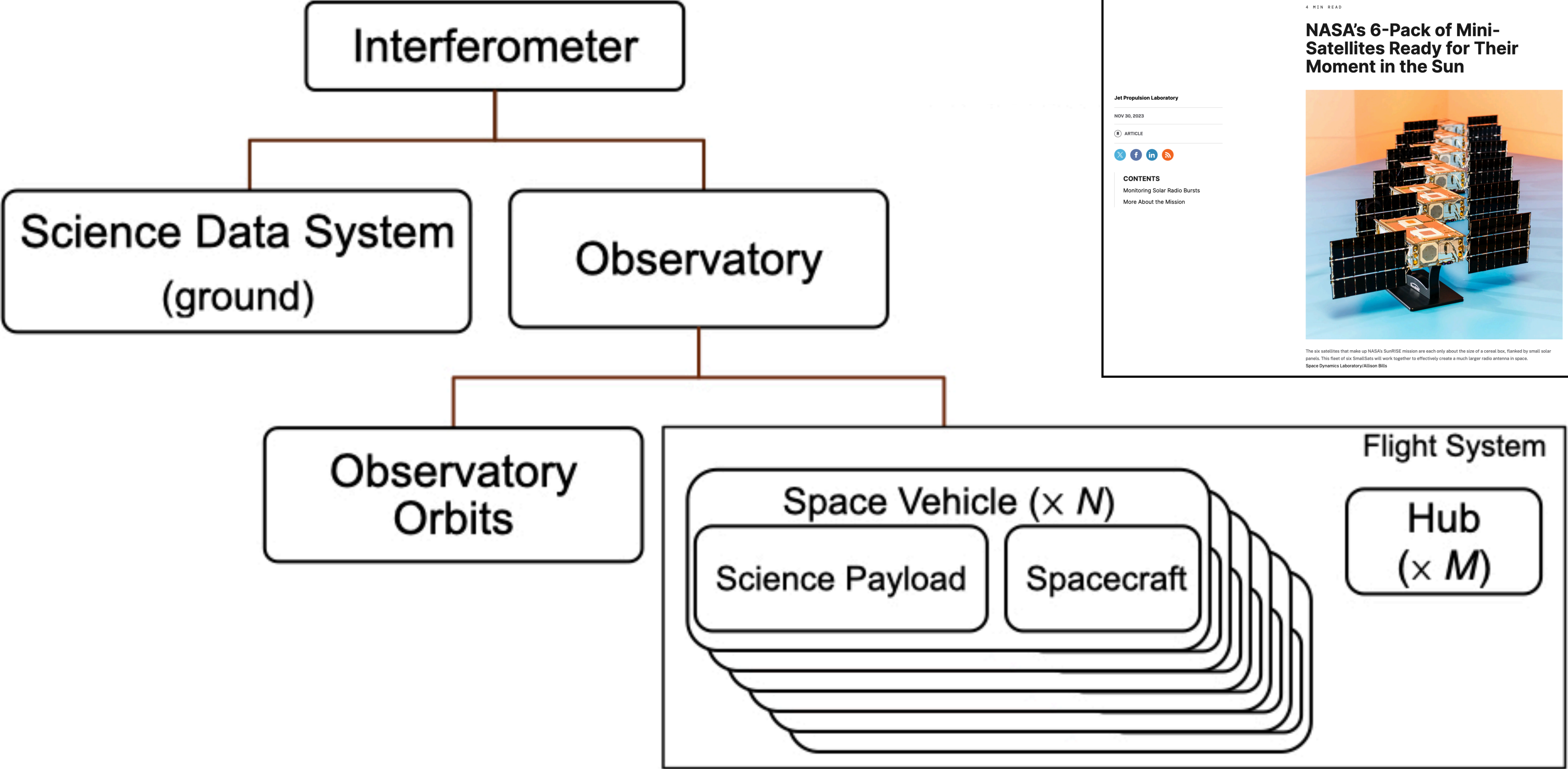
SCALABLE & RESILIENT
Distributed architecture for robustness and staged growth

MegaWave Radio Surveyor Architecture



→ Mixes traditional “Instrumental” and “Mission” Requirements
Construct Interferometer (“instrument”) from multiple Space Vehicles

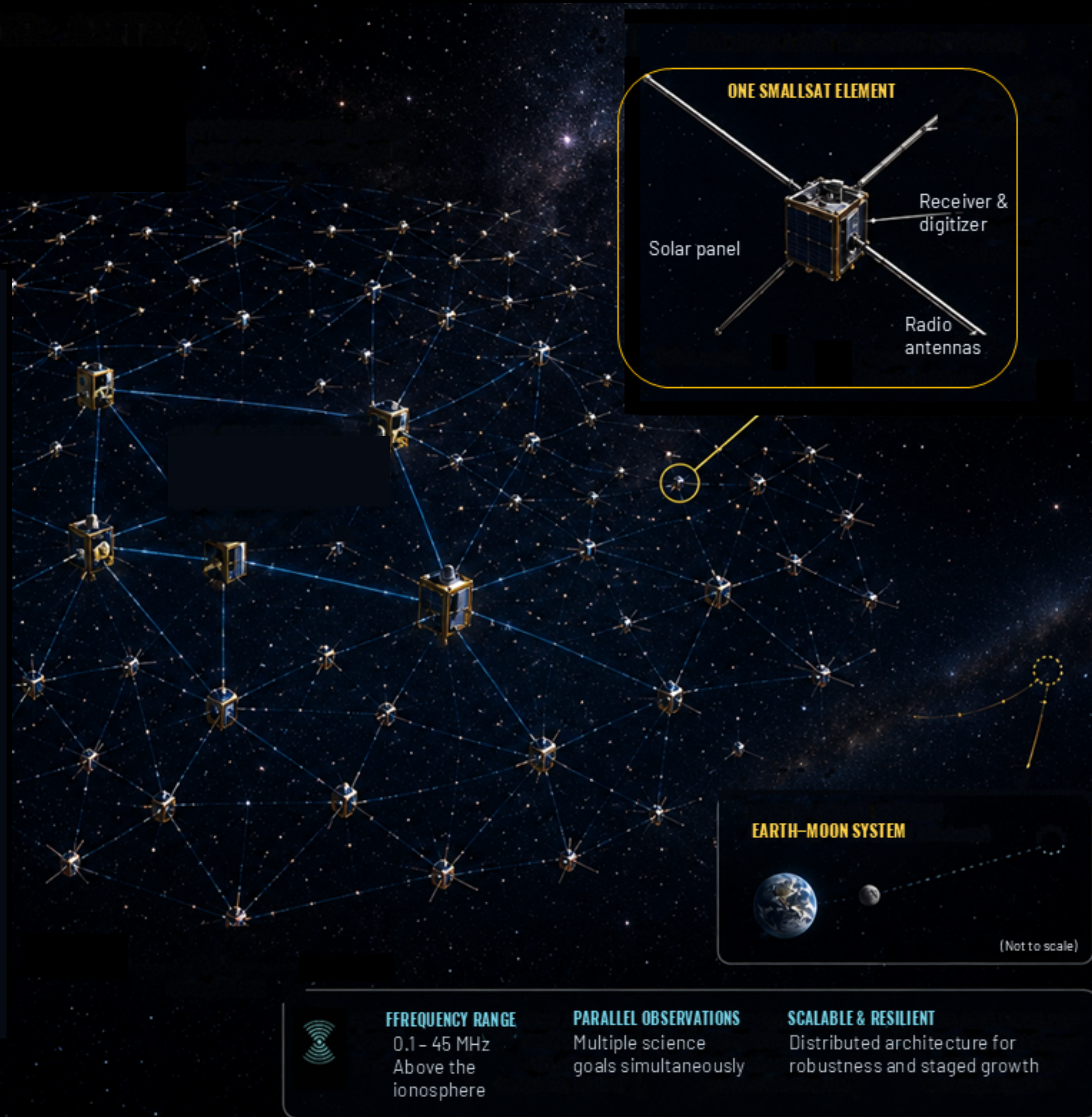
System Engineering Heritage



Builds upon
system
engineering
from Sun
Radio
Interferometer
Space
Experiment
(SunRISE)

Requested Content

- Most critical or key enabling technology [or capability]?
- Based on mission destination and observing program, what are most demanding design drivers [...]
- How does implementation strategy leverage external capabilities—specifically commercial industry advancements, the Artemis infrastructure, or strategic partnerships?
- High-level technology development plan?



MegaWave Radio Surveyor Technologies



Technology Talks

Science Data System

Bryne: post-processing calibration

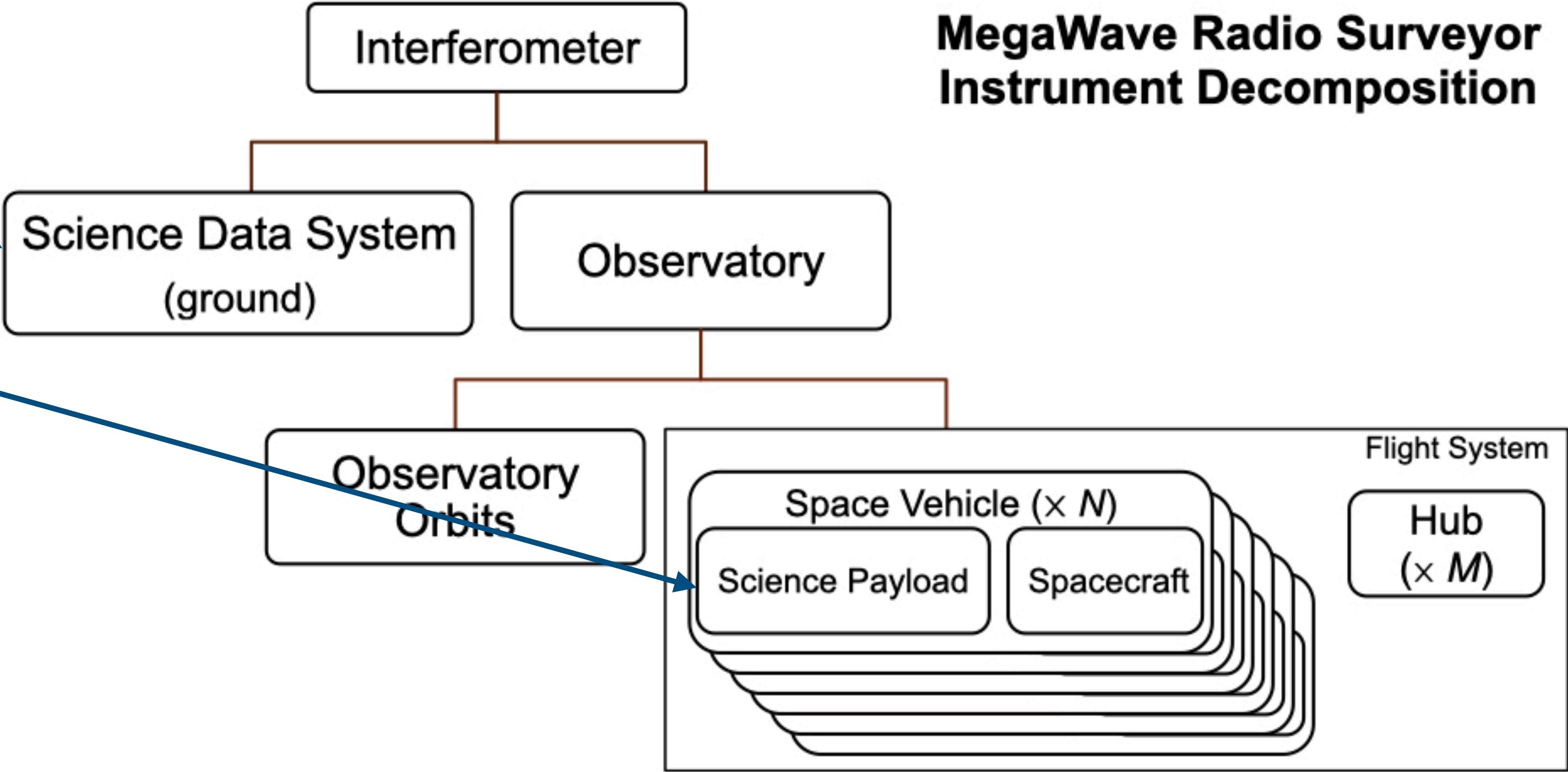
Science Payload

Knapp:
Antennas

Jacobs:
Receiver

Plant: Signal Processing

MegaWave Radio Surveyor Instrument Decomposition

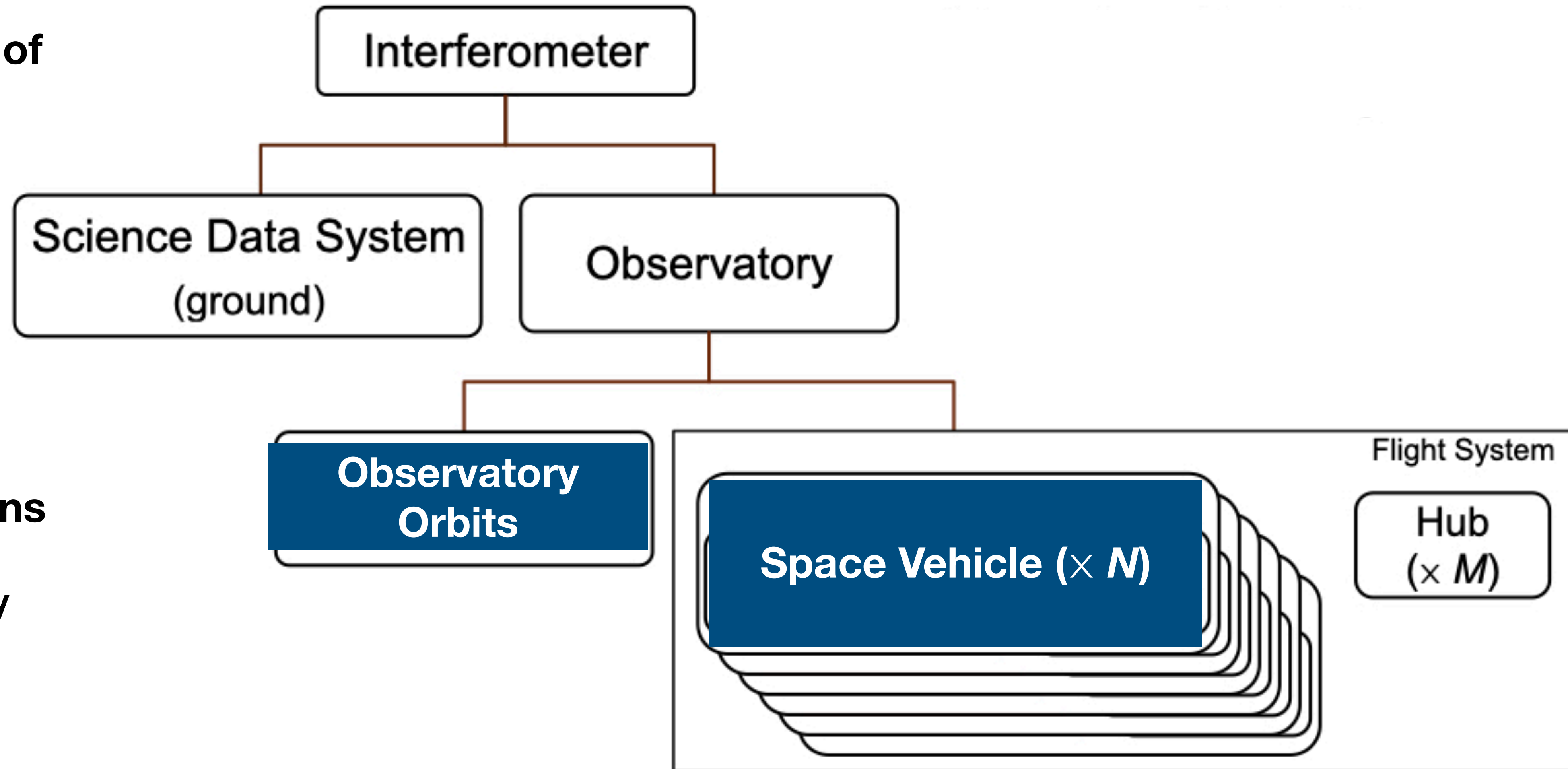


Key Enabling Capabilities and Opportunities



Large number N of
Space Vehicles
required to meet
sensitivity
requirement,
critical for
implementation

Observatory
orbits/destinations
options exist to
meet calibration/
stability
requirement



Industrial Partnerships

Key Enabling Capability

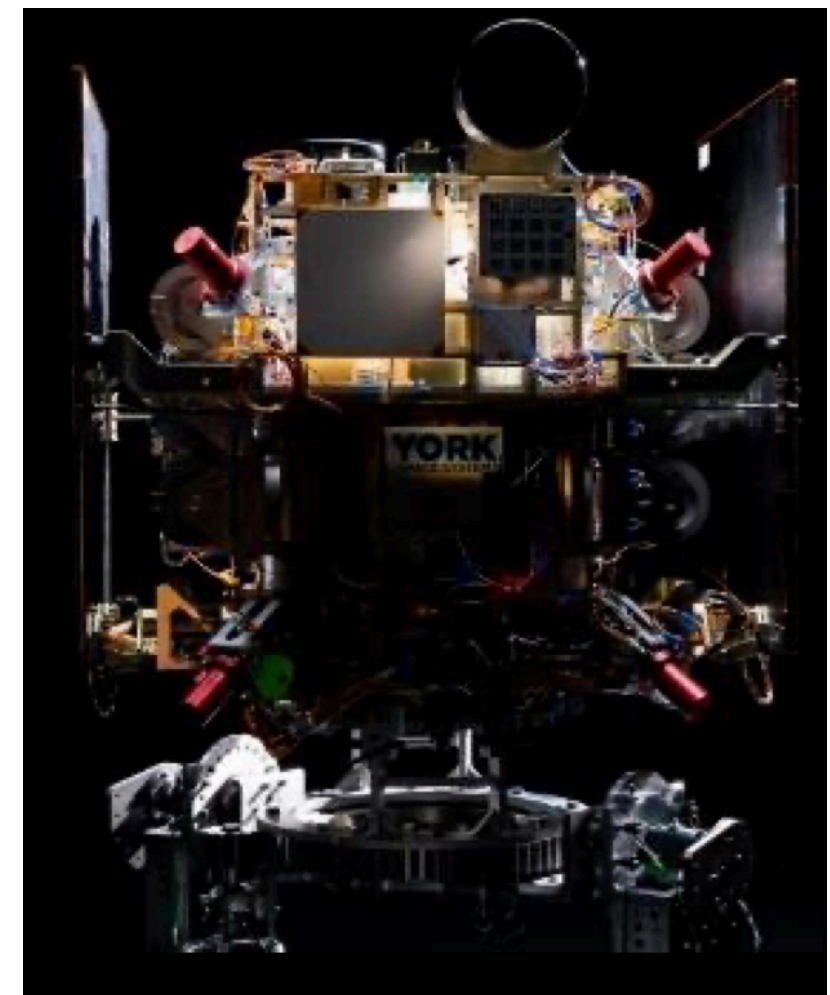
Not “Technology” problem per se

- Leverage U.S. space industry capabilities to deliver *many* spacecraft (*absolutely required*)

Multiple firms advertising production of hundreds of spacecraft per year

- New approaches to assembly, integration, and testing (AI&T)

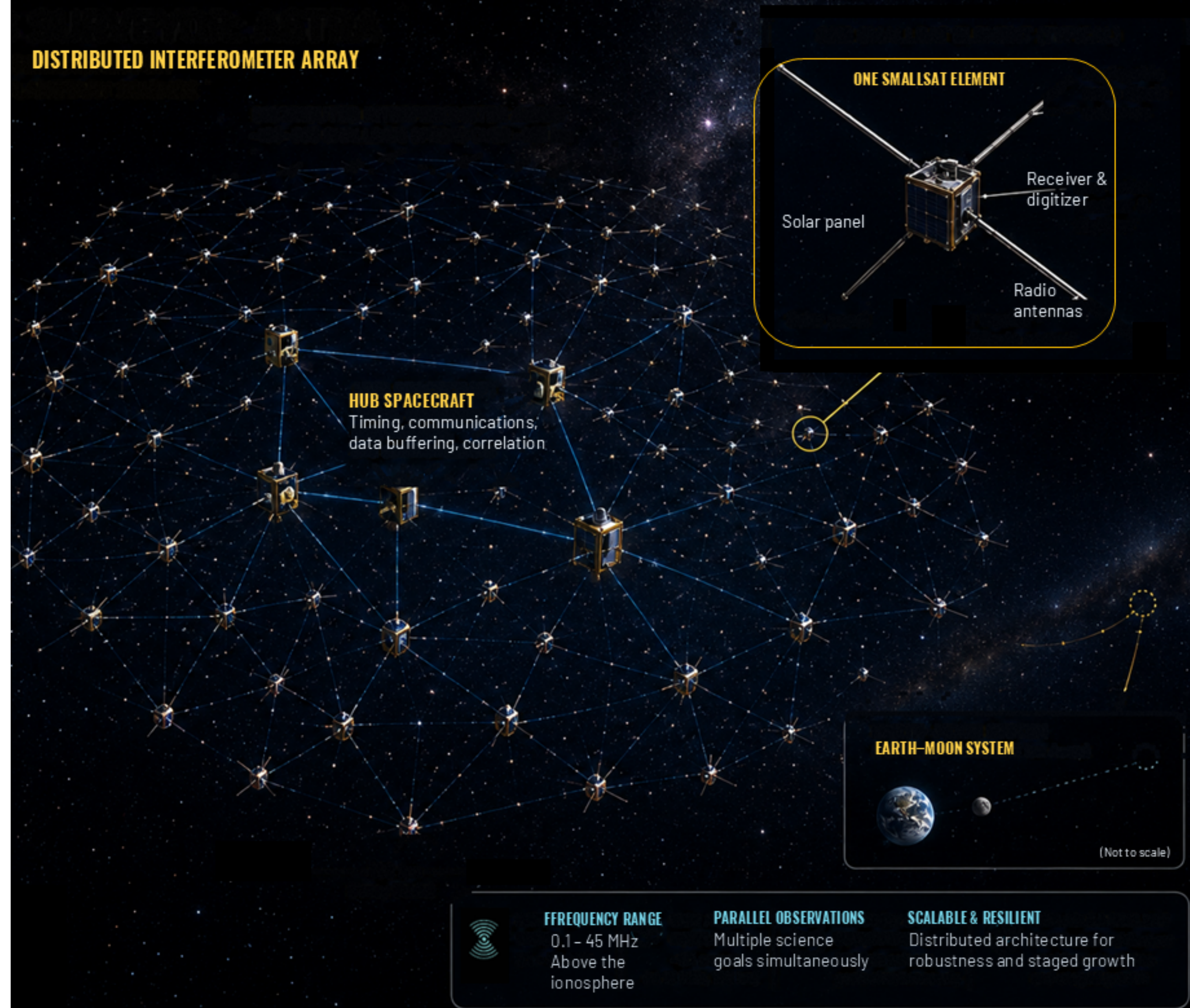
Buy in “batches,” test one, jettison batch if test item fails? Buy many, many units, test each unit in order to obtain N good units? ...?



Opportunities

Interferometers
naturally scalable and
resilient

Loss of 1 element
decreases
performance by only
 $\approx 1 - 2/N \ll 1$ for
large N



Opportunities

**New approaches to
operations ...**

**e.g., increase
capabilities/science
return with time, service
by replenishing, ...**



Opportunities

**New approaches to
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**e.g., increase
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return with time, service
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Opportunities

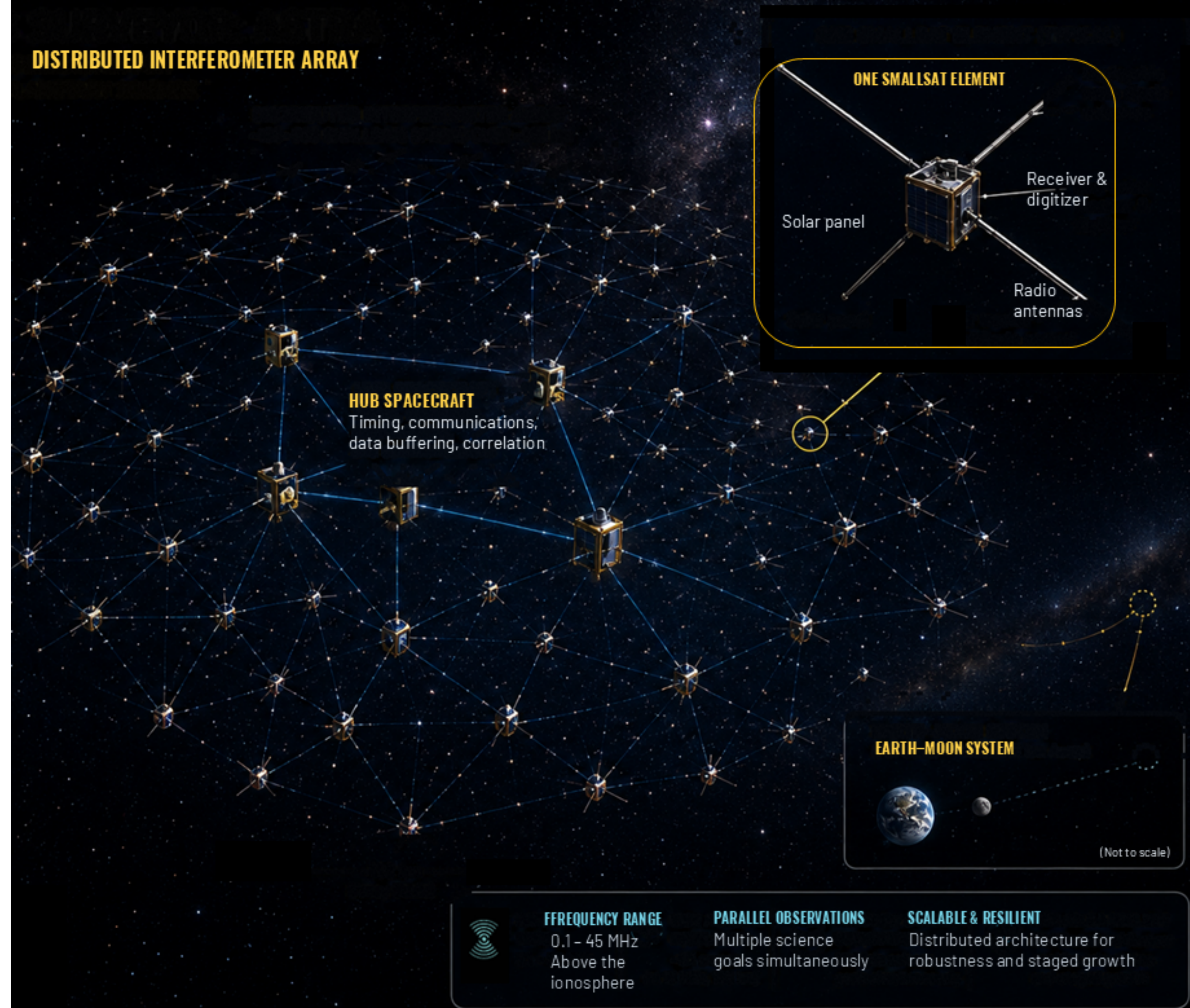
**New approaches to
operations ...**

**e.g., increase
capabilities/science
return with time, service
by replenishing, ...**



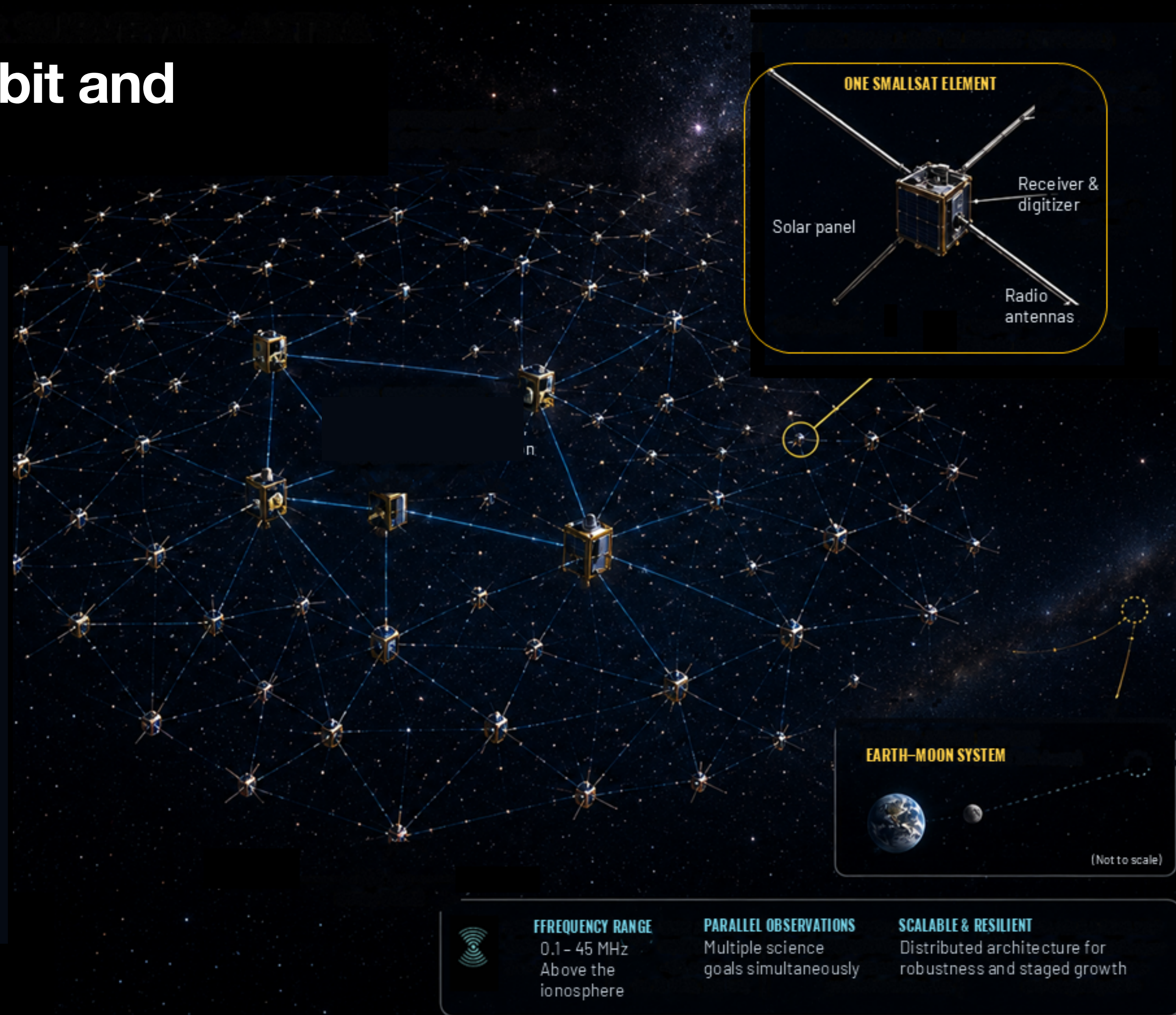
Opportunities

- **Interferometers naturally scalable and resilient**
Loss of 1 element decreases performance by only $\approx 1 - 2/N \ll 1$ for large N
- **New approaches to operations ...**
e.g., increase capabilities with time, service by replenishing, ...



Mission Destination/Orbit and Observing Program

- Observatory destination/orbit options exist to meet calibration/stability requirement
 - Thermal stability
 - Enable continuous (and simultaneous) observing
- Opportunity to leverage Artemis/Moon-to-Mars program infrastructure



Artemis/Moon-to-Mars Infrastructure I

Destinations/Orbits and Access to Space

Potential locations for the MegaWave Radio Surveyor

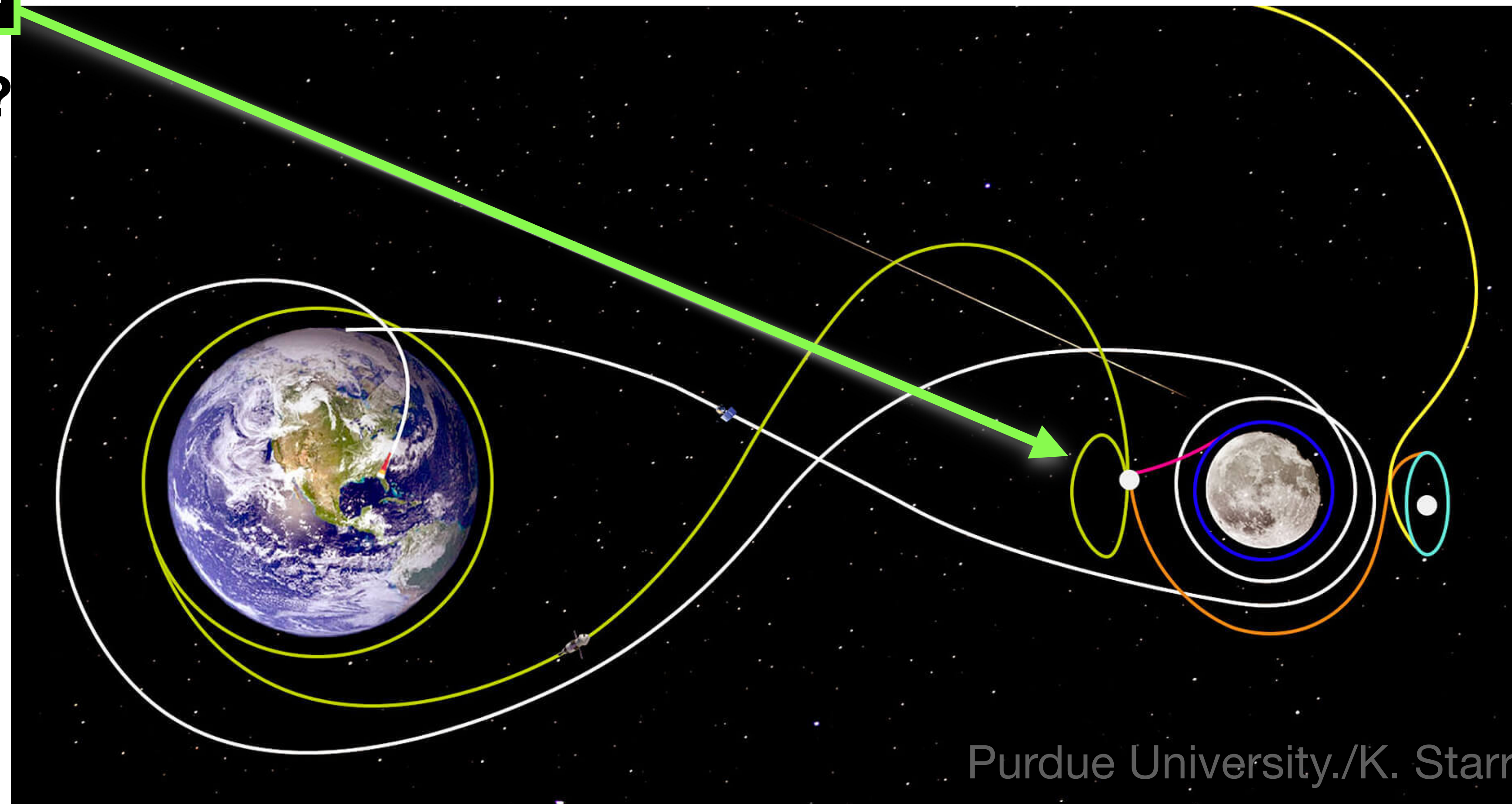
Earth-Moon L1 point?

Earth-Moon L2 point?

Earth-Moon L4 or L5 point?

Sun-Earth L2 point?

Sun-Earth L4 or L5 point?



Artemis/Moon-to-Mars Infrastructure I

Destinations/Orbits and Access to Space

Potential locations for the MegaWave Radio Surveyor

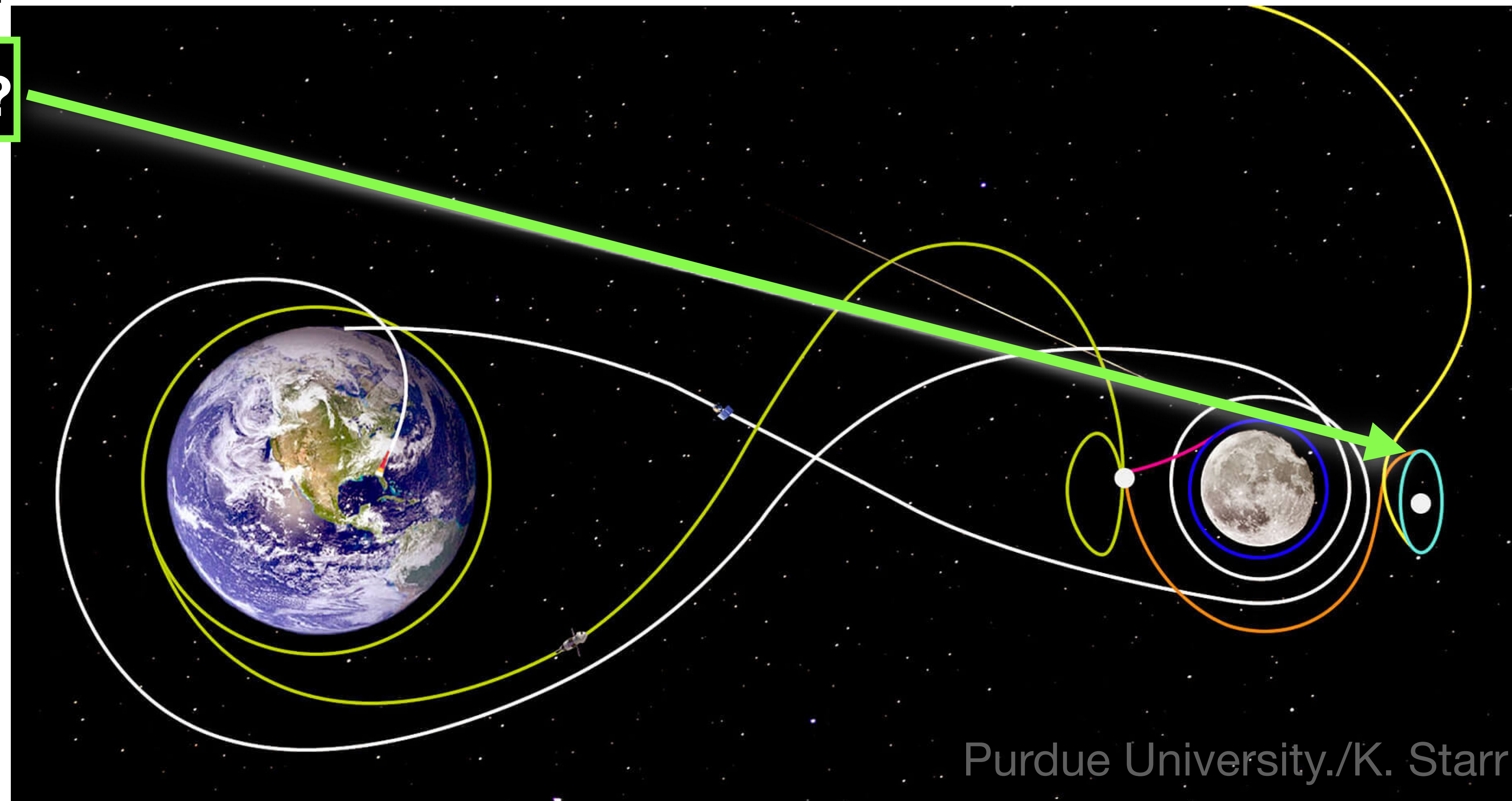
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Destinations/Orbits and Access to Space

Potential locations for the MegaWave Radio Surveyor

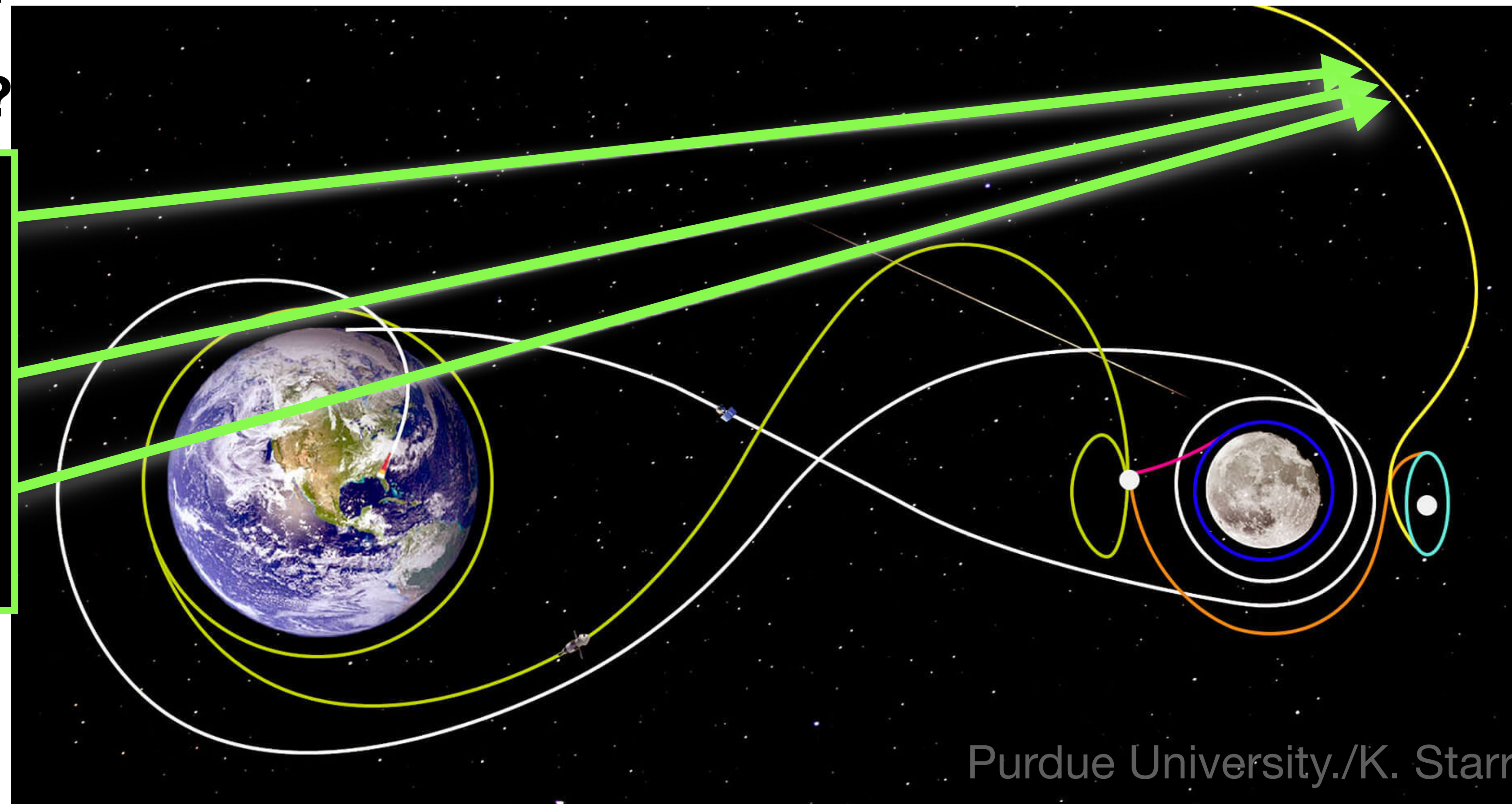
Earth-Moon L1 point?

Earth-Moon L2 point?

Earth-Moon L4 or L5 point?

Sun-Earth L2 point?

Sun-Earth L4 or L5 point?

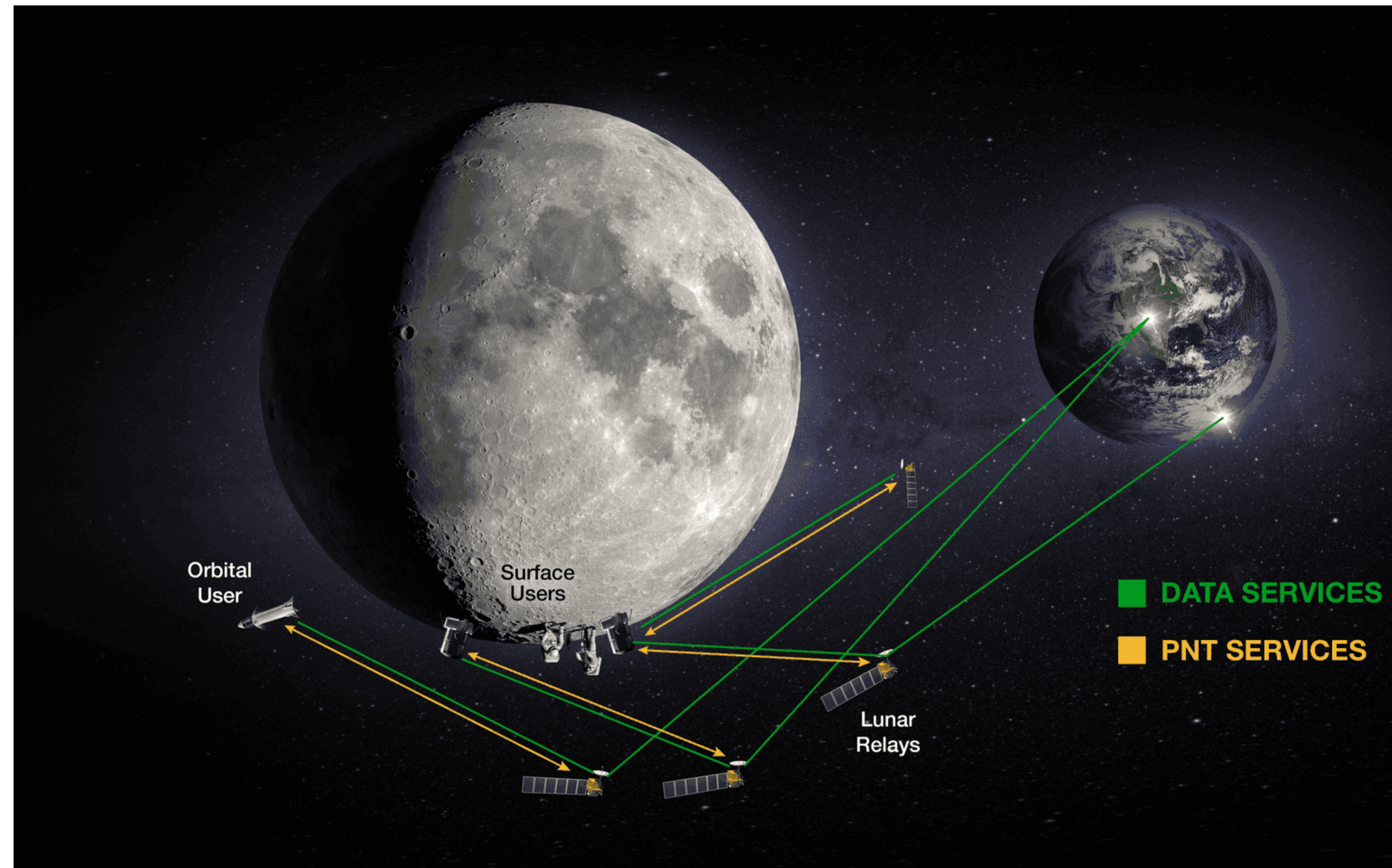


Artemis/Moon-to-Mars Infrastructure II

Lunar Communications Relay & Navigation Services (LCRNS)

Contracts already let for initial capabilities!

- **Prices and availability?**
\$1000+/-hr [TBC]
- **Coverage? (viz. Orbits)**
Lunar South Pole [TBC]
- **Capability?**
10 m position determination [TBC]



Technology/Capability Development Plan

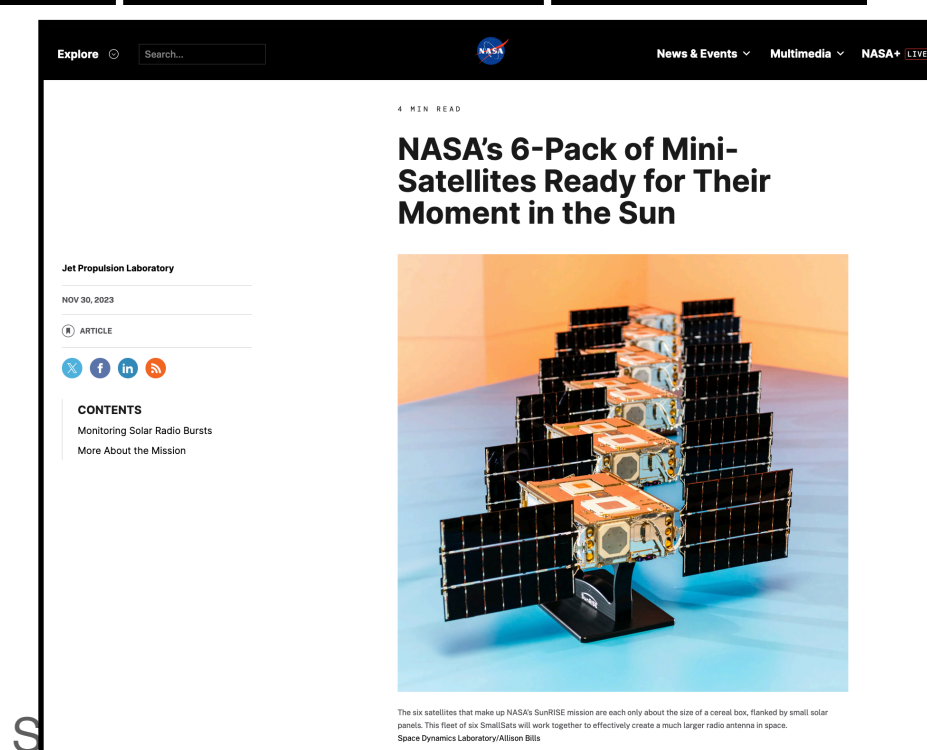
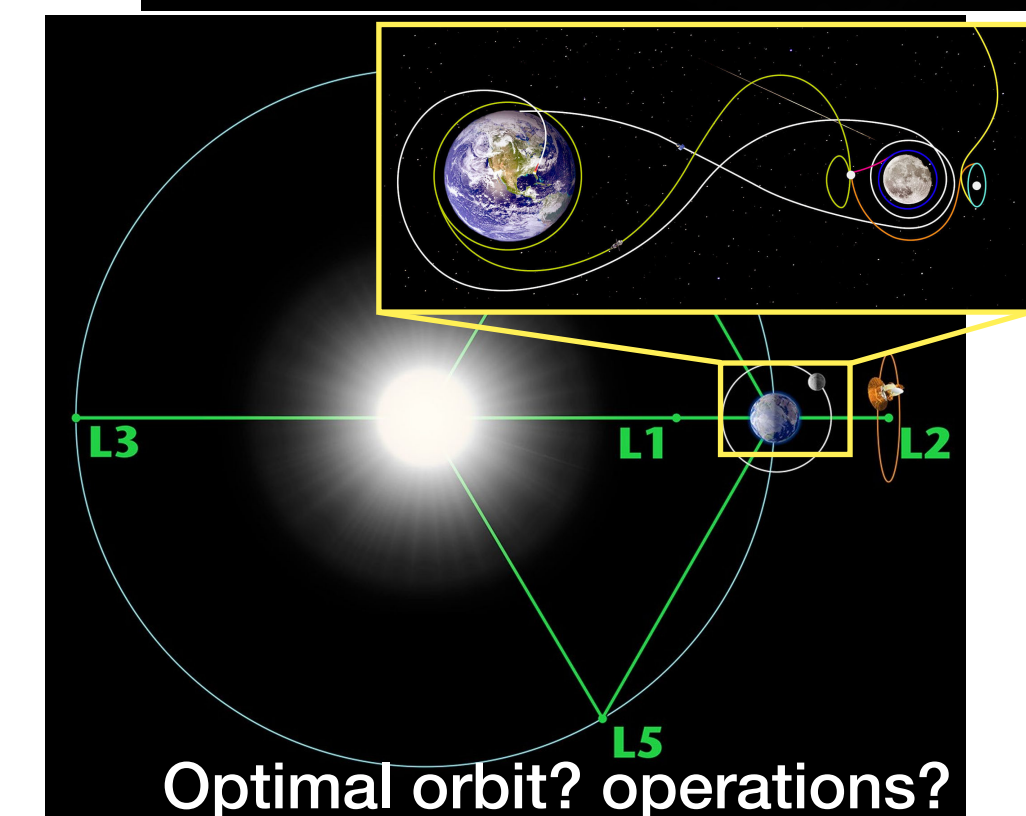
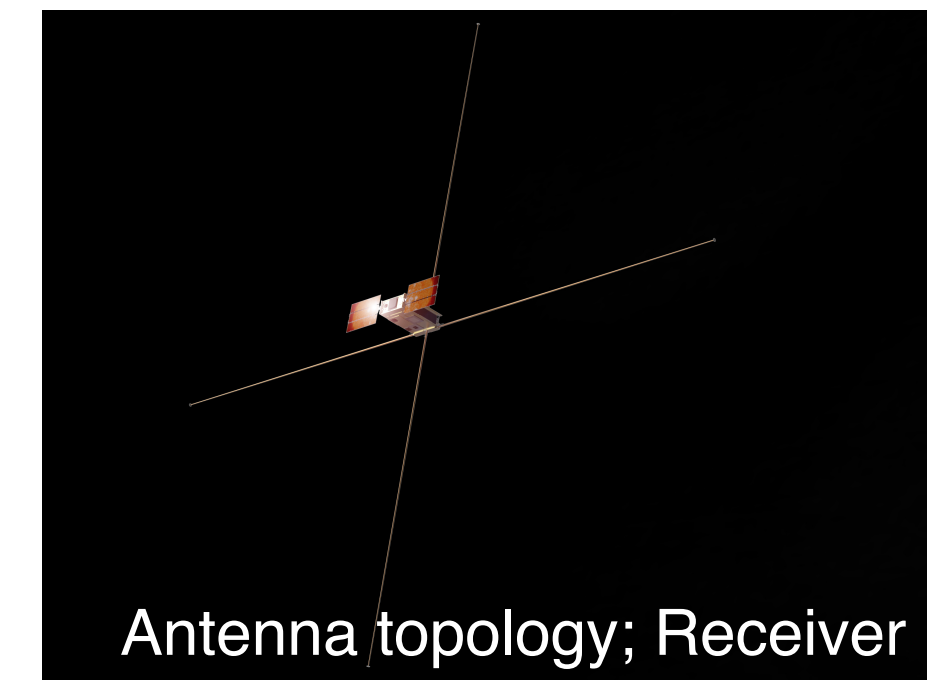
MegaWave Radio Surveyor

Trade Studies

- **Antenna topology**
 - **Dipoles often assumed, but other topologies relevant: vector sensor vs. helical vs. ...**
 - **Affects sensitivity, observing plan, operations, ...**
- **Orbit vs. Communication-Navigation vs. Operations**
 - Balance between on-board autonomy and infusion of AI/ML vs. downlink capabilities**

Demonstrations/Prototype/Pathfinder

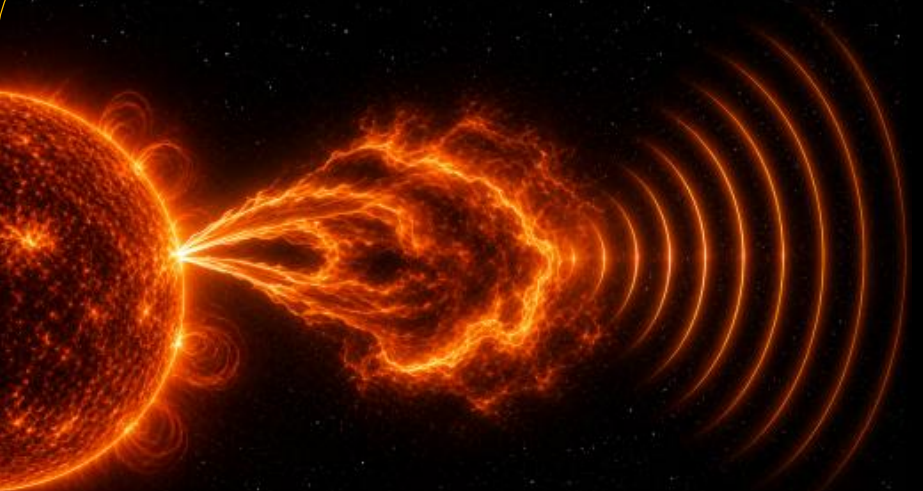
- **Pathfinder: SunRISE space radio interferometer**
- **Demonstrate, prototype: TRL 6 Science Payload**



MEGAWAVE RADIO SURVEYOR

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STELLAR EXOSPACE WEATHER



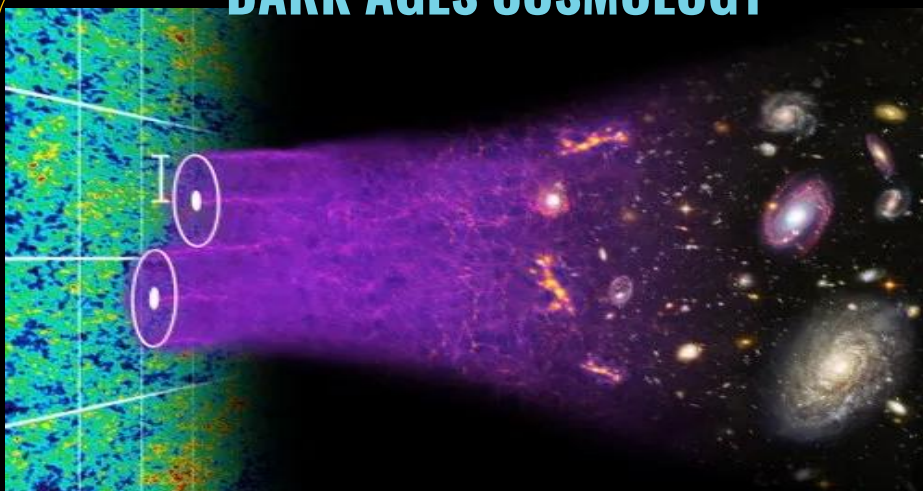
Monitor stellar eruptions and radio bursts to investigate stellar activity and its impact on planets and habitability.

EXOPLANET MAGNETIC FIELDS



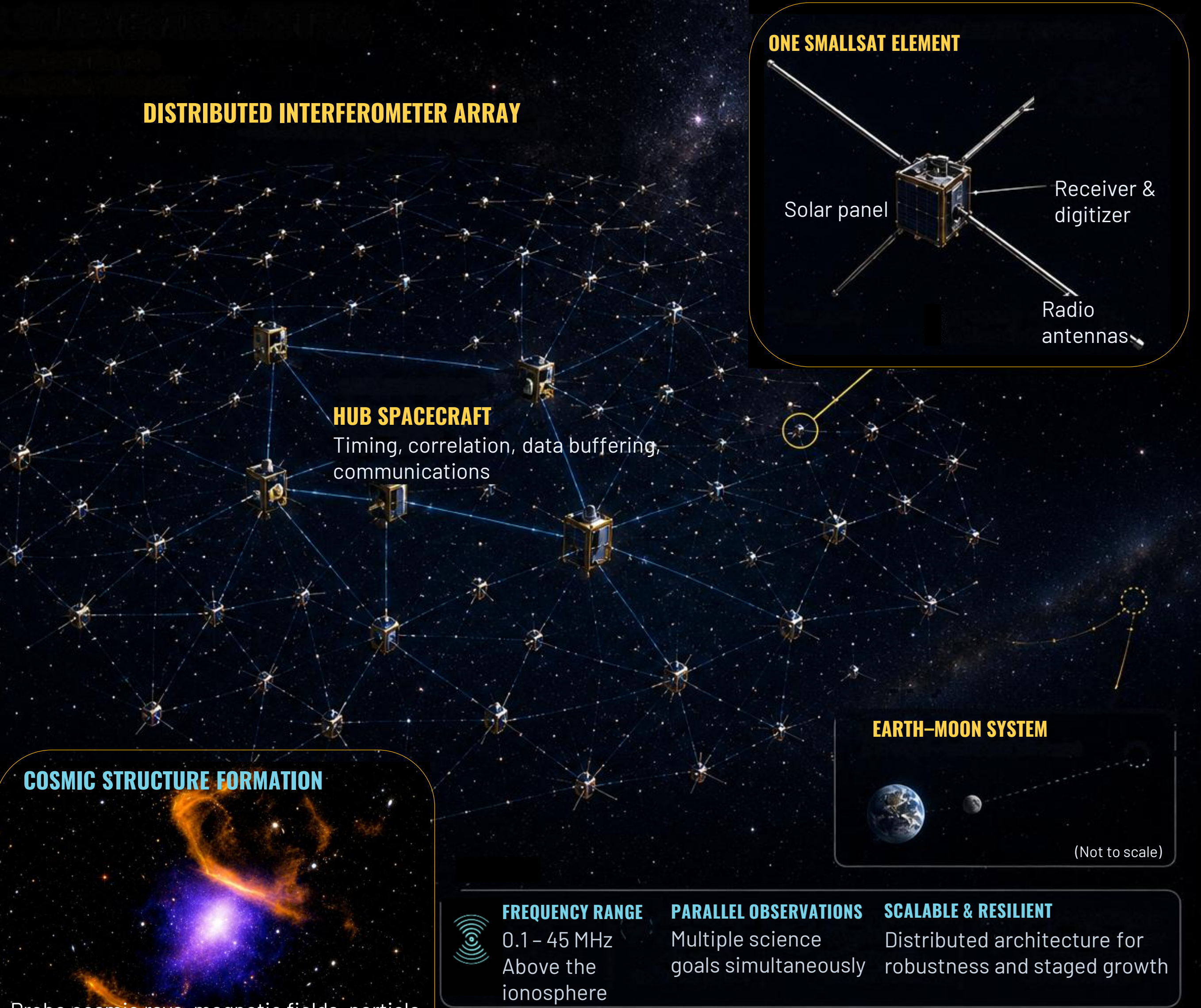
Probe exoplanetary interiors and atmospheric retention with radio emission from exoplanetary magnetic fields.

DARK AGES COSMOLOGY

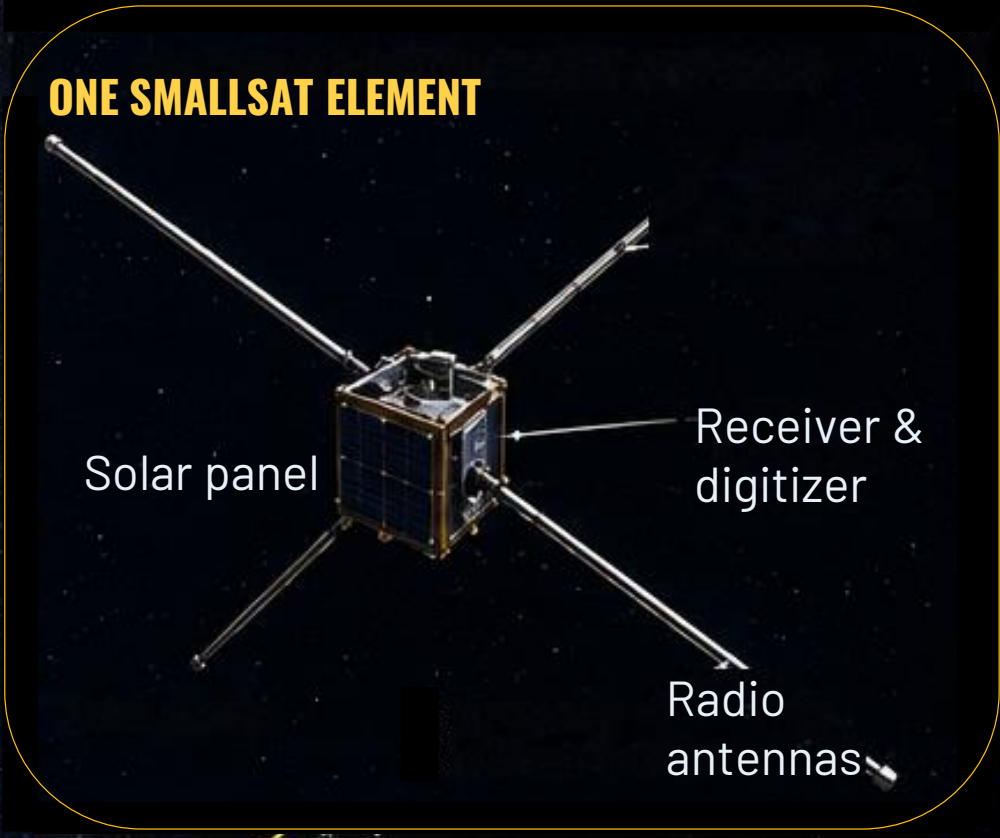


Track the Universe's evolution before first stars and galaxies emerged using hyperfine spectral line from H I

DISTRIBUTED INTERFEROMETER ARRAY



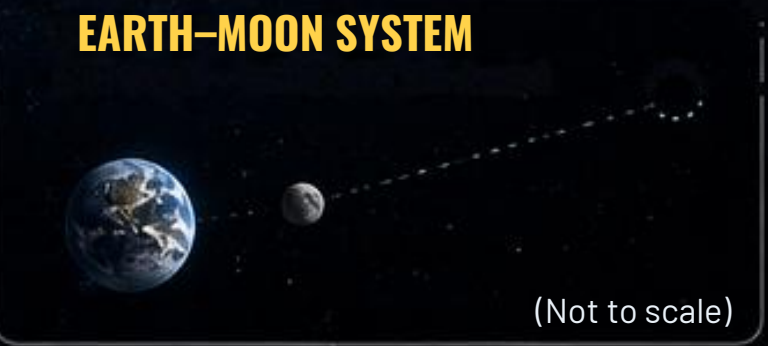
ONE SMALLSAT ELEMENT



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Timing, correlation, data buffering, communications

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(Not to scale)

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Multiple science goals simultaneously

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arXiv: 2608.26322

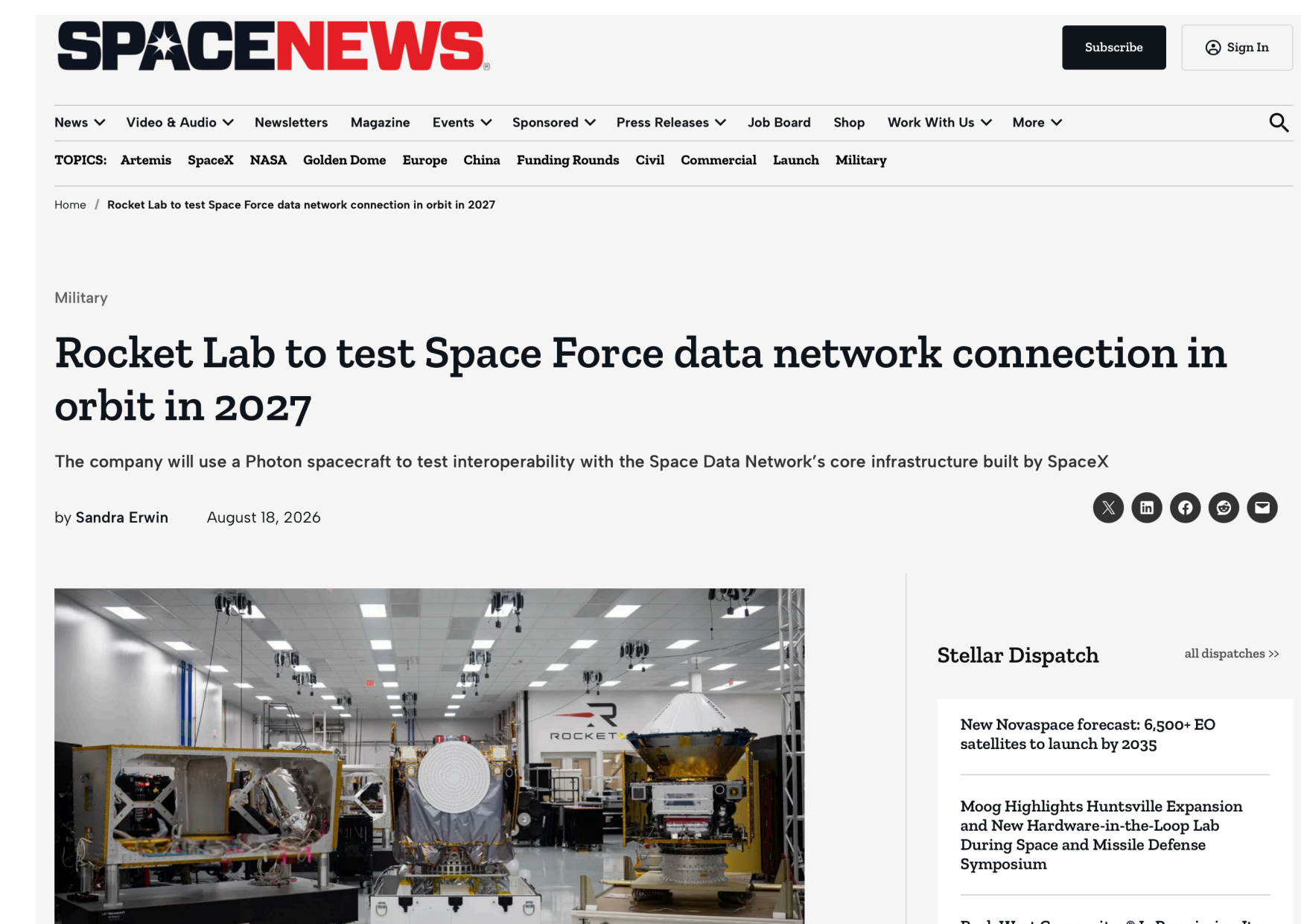
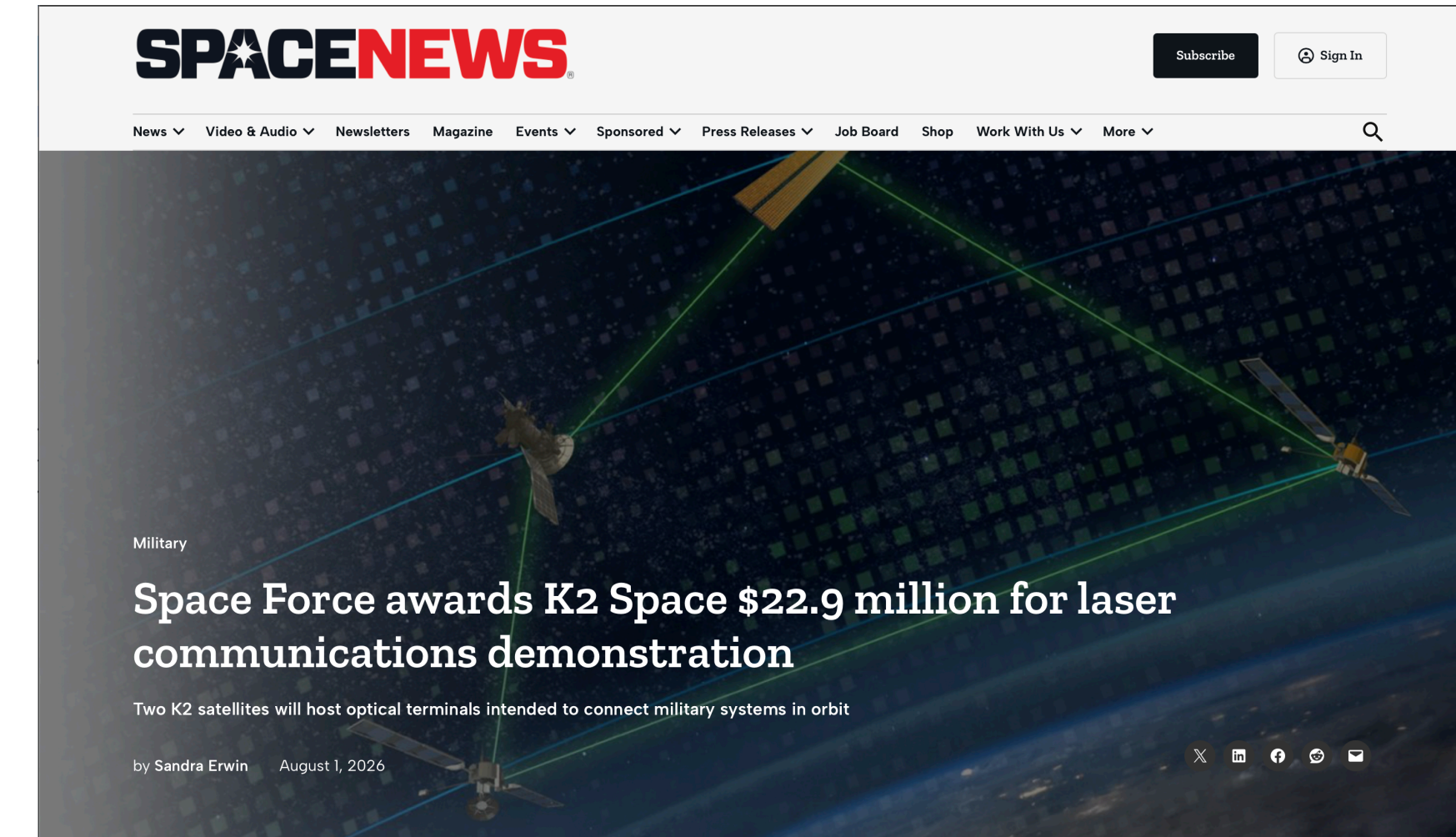
Laser Communications

Enabling Technology

Laser communications would enable large enough data volumes to transmit complete baseband radio spectrum between Space Vehicles and Hubs or from Hubs to ground stations

➡ NASA investment likely **not necessary**

Sufficient investments from other entities likely will mature technology (well) before required for MegaWave Radio Surveyor



International Partnerships

MegaWave Radio Surveyor



Europe

Scientific interests; Contributions could include flight hardware and/or ground-based post-processing, in part based on operations of the Low Frequency Array (LOFAR) and post-processing of its data

United Kingdom

Scientific interests; Contributions could include flight hardware

India

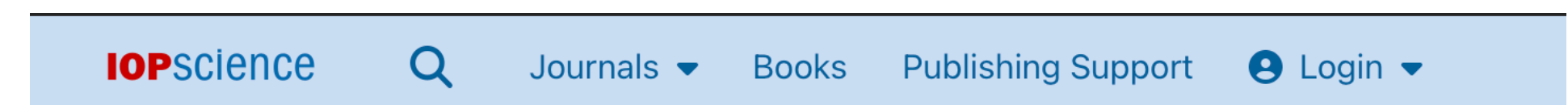
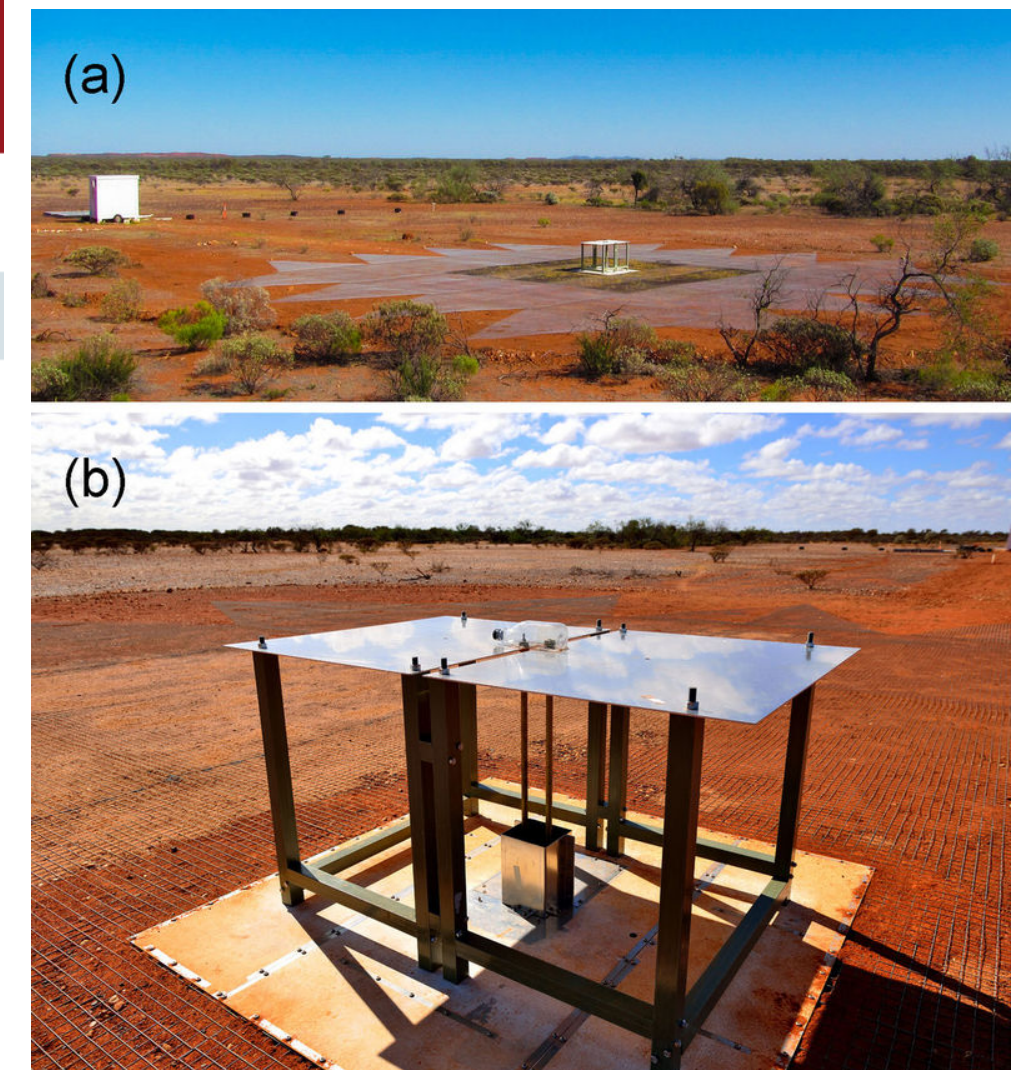
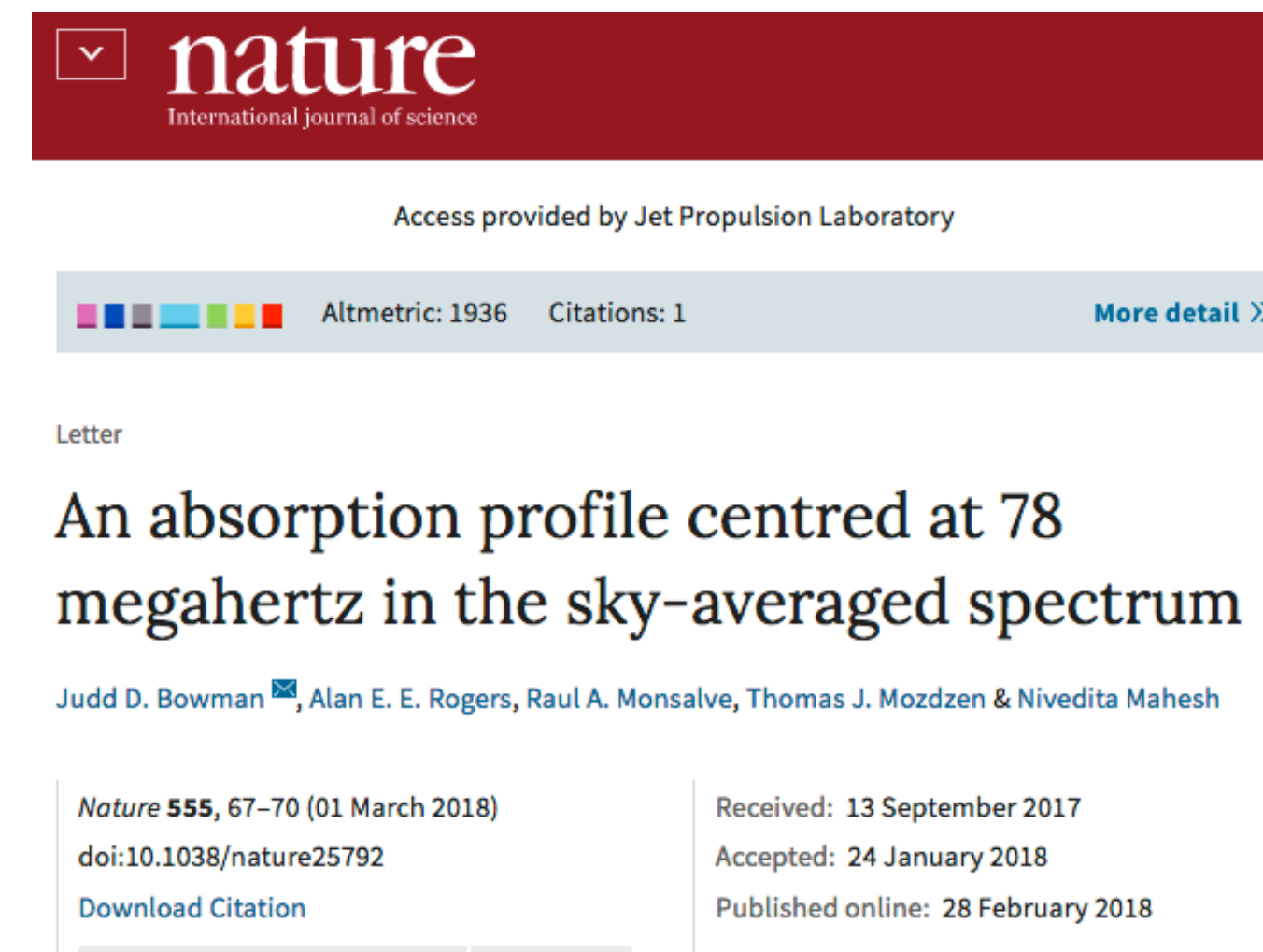
Scientific interests; Contributions could include flight hardware and/or ground-based post-processing, in part based on operations of the Giant Metrewave Radio Telescope (GMRT) and post-processing of its data

Radio Frequency Interference

MegaWave Radio Surveyor

Radio frequency interference (RFI) potentially tractable

- Both experimental and modeling efforts indicate feasible to mitigate
- Significant ground-based efforts (SKA1-Low, \$500+M) devoted to observations at relevant frequencies
- Always will be spacecraft/instrument emissions



THE ASTRONOMICAL JOURNAL

OPEN ACCESS

STARFIRE-2: Can We Detect the Global Redshifted 21 cm Signal from the Cosmic Dawn in Earth Orbit?

Yogen Pranesh, Mayuri Sathyanarayana Rao, and Saurabh Singh

Published 2026 June 24 • © 2026. The Author(s). Published by the American Astronomical Society.

[The Astronomical Journal](#), Volume 172, Number 1

Citation Yogen Pranesh et al 2026 AJ 172 46

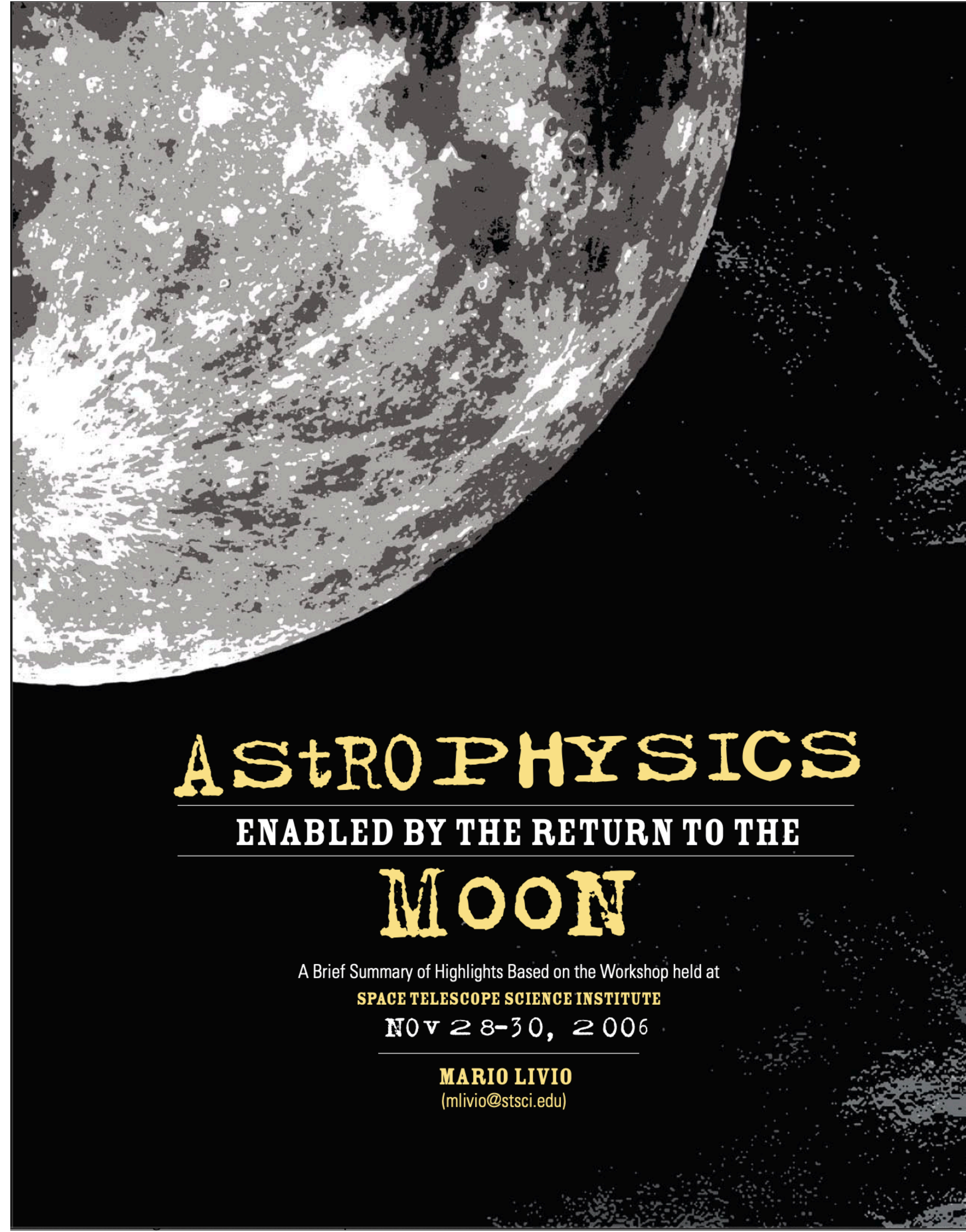
DOI 10.3847/1538-3881/ae70fb

The MegaWave Radio Surveyor

The workshop “identified a few important astrophysical observations that can potentially be carried out from the lunar surface. [...]

(i) Low-frequency radio observations from the lunar far side, to probe structures in the high-redshift (...) Universe”

“At the same time, the Workshop highlighted the fact that observations from free space (and in particular from Lagrange points) offer the most promise for significant progress in broad areas of astrophysics. Given the impressive capabilities of the proposed Vision for Space Exploration (VSE) infrastructure, every possible effort should be made for the VSE not to preclude—but rather to enable—future observations from free space.



ASTROPHYSICS ENABLED BY THE RETURN TO THE MOON

A Brief Summary of Highlights Based on the Workshop held at
SPACE TELESCOPE SCIENCE INSTITUTE
NOV 28-30, 2006

MARIO LIVIO
(mlivio@stsci.edu)