

ABSTRACT

We present details of our White Paper submitted to the National Academies Solar and Space Physics Decadal Survey proposing the larger idea of not just implementing a space weather monitoring mission but establishing spaceborne communication arrays outside of Earth's orbit usable for Inner Solar System Communications (ISS Comms) and for Deep Space Network Communications (DSN Comms). We put forth the idea of deploying the

Lagrange Communication Advanced Realtime Space-weather Array (LCARS)

located at key positions in the solar system autonomously providing warning back to Earth to protect significant spaceborne assets near and distant from Earth.

This mission concept would firstly place spacecraft into orbit at each of the five Sun-Earth Lagrange points. Each spacecraft would include all necessary instrumentation for in-situ surveillance of the interplanetary medium and remote observation of the Sun and the inner heliosphere. The historical and present use of the L1 Lagrange point (ref ACE, SOHO, WIND, DSCOVR, etc.) as a key location for the deployment of Space Weather monitoring beacon(s) is recognized and built upon by the LCARS Array. Additionally, the Heliospheric community recognizes the major success of the STEREO mission with its dual view of the Sun effectively identifying Solar activity that potentially affects the Earth and provides insight of the solar wind, the Sun, and transport of emergent shocks.

Considering the ongoing National Academies Solar and Space Physics Decadal Survey's purpose to explore the possibilities by the year 2050, improving our deep space communications capabilities will be vital to the success of future missions. Including a Deep Space pointing communications dish on each of the L2-L5 spacecraft, the system as a whole can be used as a fixed set of Deep Space Communication Beacons that enhances the existing NASA Deep Space Network and can provide for more autonomous and nearly continuous levels of monitoring deep space missions as humanity starts stepping farther out into the solar system — either through exploratory spacecraft (such as Interstellar Probe) or via colonization to Mars and the asteroid belt. Future enhancements of this system can include utilizing other Lagrange points from the other planets for the deployment of Earth's first Inter-Planetary Communications Network.

LCARS Science Questions (initial thoughts)

- 1) Coronal Acceleration Physics**
What causes the extreme acceleration taking Photospheric plasma at ~4500 °K to become the ~1000000 °K Coronal plasma within tenths of solar radii? Is this related to the Camp Fires on the surface, magnetic field Switch Backs in transport, development of the current sheets, etc.?
- 2) Structure of the Solar Wind at 1 AU**
Complimentary, what are the processes that reduce the highly structured Coronal plasma as it is transported outward into interplanetary space causing energy dissipation down to the kinetic thermal scales as the highly thermalized Fine Structure of the Solar Wind observed at 1AU?

In considering this problem from the fundamental physics and using models compared to the observations, it becomes clear that there are "chaotic" processes currently not understood nor included in existing solar wind plasma transport models. [see discussion in Zank, 2021]

LCARS Science Methods

- 1) Coronal Acceleration Physics**
Observation of the million degree plasma in the Corona is being done at extremely high spatial and temporal scales using Earth Based telescopes. Complimentary to those observations, each LCARS observation platform would include remote observation sensors capable of seeing the sun in multiple wavelengths with the high spectral and spatial resolutions possible. This would include visible wavelengths through the far X-ray spectra.
- 2) Structure of the Solar Wind at 1 AU**
Observation of the solar wind plasma is also being done at present and the LCARS systems would build upon the present successes. The solar wind instruments would need to be capable of sampling the hot and cold populations of the solar wind transforming them from the Spacecraft reference frame into the Solar Wind rest frame. These instruments would need to observe the coupled electric and magnetic fields driving or following the kinetics of the plasma.

Scientific Benefit from the LCARS Array

Utilization of an array such as the LCARS Array provides the capability of directly coupling the in-situ and remote observations to formulate a larger 3D picture of the physics driving the development of the Solar Wind and transporting energy into interplanetary space along with many other scientific research topics in Solar and Space Physics.

LCARS Fulfills Present and Future Needs

- 1) Space Weather Operations**
 - 1) Multipoint Space Weather Observations including opposite side of the Sun
 - 2) Observations to Modeling (CCMC) improving predictive capabilities needed for Space Weather Prediction for Asset Safety not only for Earth but for those points outward such as Mars
- 2) Interplanetary Communications**
 - 1) Network Communications across a "vacuum" through many AU of interplanetary space
 - 2) Autonomous Communications with Terran Assets from Space Weather Observation

LCARS as a Space Weather Observatory

- 1) The Instruments – In-Situ (list of possible instruments)**

Particles	Instrument Type	Instrument Details		
Plasma	Langmuir Probe	Thermal Plasma Distribution	SC Potential	Solar Wind Speed/Density
Low Energy Particles	Top-Hat / TOF	1 eV to 50 keV	Electrons + Ion Species Resolved (P, He, CNO, ...)	4pi sr resolved + Pitch Angles
Energetic Particles	TOF + Layered Si Wafers	15 keV to 10 MeV	Electrons + Ion Species Resolved (P, He, CNO, ...)	4pi sr resolved + Pitch Angles
Cosmic Rays	Layered Si Wafers	1 MeV to 1 GeV	Electrons + Ions (P, Heavies)	4pi sr resolved + Pitch Angles
EM/Waves				
Magnetic Field	Search Coil + Fluxgate	3 Axis	DC through 50kHz	
Electric Field	3D + Double-probe Sensors	3 Axis	DC through 1kHz	

- 2) The Instruments – Remote Solar Observations (list of possible instruments)**

Target	Instrument Type	Details
Photosphere B-Field Vector	Photospheric Imager	2D-maps of Photospheric B-field vectors
Solar Disk	EUV Imager	Multispectral EUV Imager of solar disk
Corona	Coronagraph	Electron density of corona
Inner Heliosphere	Heliospheric Imager	STEREO based HI like imaging
Composition	Spectrometer	Occulted Spectrometer for composition
Corona	X-Ray Imager	Multispectral X-Ray Imaging of Corona

SM35B-1759

The Lagrange Communication

Advanced Realtime Space-weather (LCARS) Array

Jerry W. Manweiler – Fundamental Technologies, LLC, Lawrence, KS
 J. Douglas Patterson, Fundamental Technologies, LLC Lawrence, KS
 Stephen Ledvina, University of California – Berkley, Berkley, CA
 Andrew Gerrard, New Jersey Institute of Technology, Newark, NJ
 Louis J. Lanzerotti, New Jersey Institute of Technology, Newark, NJ
 Matthew Cooper, New Jersey Institute of Technology, Newark, NJ
 Thomas Y. Chen, Columbia University, New York, NY

LCARS White Paper Purpose

This white paper for the National Academies Solar and Space Physics Decadal Survey is intended to take the value of human imagination and bind it tightly to the possibilities of the expected technologies in order to push the boundaries of humanities progress into exploring and colonizing the Sol system.



Lagrange Communications - Advanced Realtime Space-weather Array (LCARS) The SOL-Network

Primary COMMS:

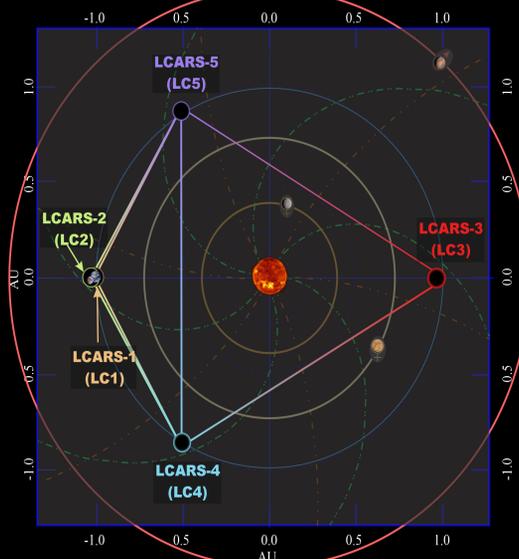
- Earth ↔ LCE1
- Earth ↔ LCE2
- LCE4 ↔ LCE4
- LCE1 ↔ LCE5
- LCE2 ↔ LCE4
- LCE2 ↔ LCE5
- LCE3 ↔ LCE4
- LCE3 ↔ LCE5

Secondary COMMS:

- Earth ↔ LCE4
- Earth ↔ LCE5

Future COMMS:

- Earth ↔ Lunar
- Lunar ↔ LCE1
- Lunar ↔ LCE2
- Lunar ↔ LCE4
- Lunar ↔ LCE5



Lagrange Points for Earth-Sun System with Parker Spiral Ecliptic Plane magnetic field direction for a Solar Wind Speed of 400 km/s and 2000 km/s

LCARS as an Interplanetary Communications Array – The SOL-Network

- 1) Implement continuously operating interplanetary communications network (SOL-Network)**

The SOL-Network implemented through the LCARS array would implement humanities first operational interplanetary network. The distances between each satellite will be on the order of hundreds of kilometers all the way to several astronomical units (AU). The technical complications of attempting to implement an actively and autonomous communicating network when the time delays are as high as 13-16 minutes (~800 to 1000 seconds) present the need for high bandwidth redundant communications protocols. The autonomy of the network will be implemented such that multi-packet communications are handled through the use of AI systems working through predictive algorithms to handle communications with such large transport delays. The network would be used to:

- 1) Transfer the significant amount of data from each of the spacecraft down the network back to Earth.
- 2) Handle all Spacecraft commanding from Earth outward through the LCE1 and LCE2 spacecraft
- 3) Provide for redundancy via data transfer down all paths

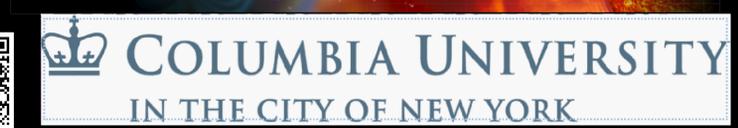
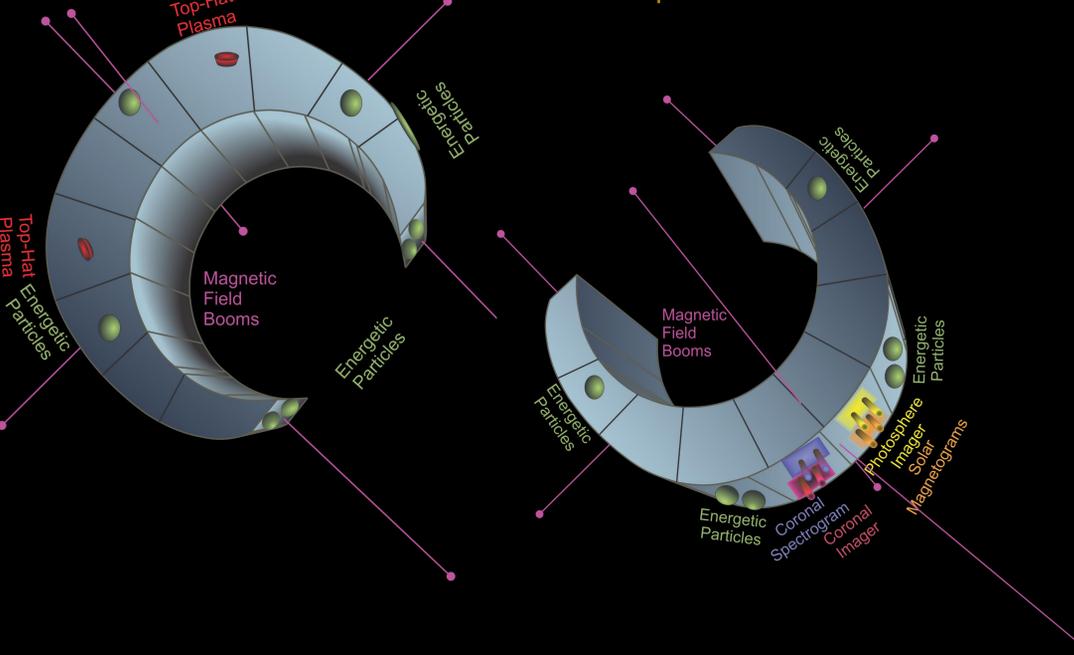
- 2) Implementation of a coupled Laser + Terahertz communication system**

Current communication technologies are pushing the boundaries of Terahertz signal frequencies (0.3 to 10 THz). These high frequency systems have the capability of large data transport upwards of 10 Gb/s in a fully implemented Earth based (small scale) system. Implementation of such an array in a spaceborne system will require technologies capable of maintaining coherent Terahertz signals between satellites, an aspect which has been discussed in other LCARS-related white papers [Cooper, 2022]. Once implemented the LCARS Array will be capable of transporting the significantly large amount of data between satellites and providing for high-bandwidth communications to Lunar stations and Earth orbiting communication arrays. The LCARS envisioned communications would utilize a coupled Terahertz and Laser system to provide for alignment and continuous data transfer between each satellite.

Humanities Benefit from the LCARS Array:

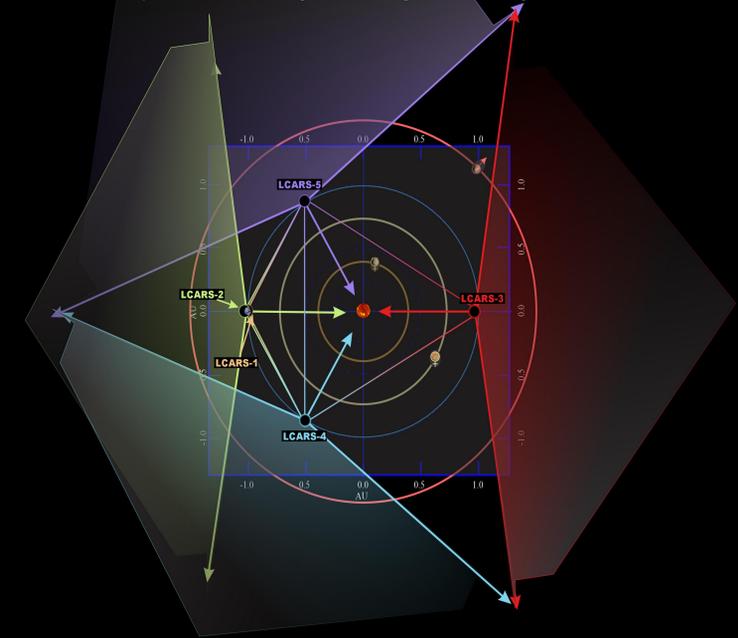
Utilization of an array such as the LCARS Array provides the capability of an autonomous communications network that can be used by future robotic and human exploratory missions and ultimately forms the beginnings of stable communications to support human expansion to Mars and beyond.

LCARS Sensor Platform Concept Instrument Ideas

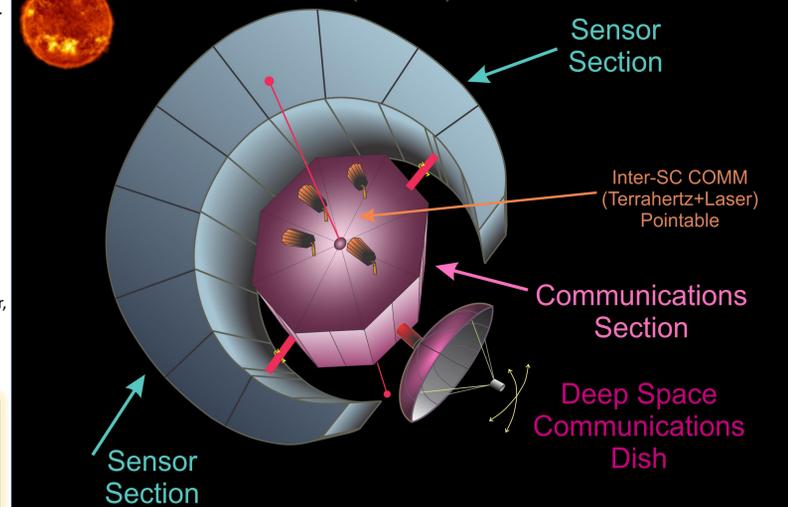


LCARS Deep Space Communications System

Observation views of Deep Space shown for each LCARS Spacecraft with the capability of enhancing the Earth DSN network with continuous monitoring of outer solar system assets. The system would include significant overlap between each Spacecraft



Lagrange Communications - Advanced Realtime Space-weather Array (LCARS)



LCARS into the Future

As Humanity starts expanding into the future the LCARS Array and the SOL-Network also expands to fulfill the communications needs of future colonies on Mars, Europa, Titan, Uranus Space station, etc. As the LCARS and SOL-Network expands then the LCARS satellites become an important component for interplanetary navigation, i.e. an Interplanetary Positioning System (IPS) similar to the Earth bound GPS of today. Additionally, as more LCARS assets are deployed then deep space communications becomes even more continuous as is seen in the figure below with a fully implemented Mars LCARS Array added to the SOL-Network.

