

## ABSTRACT

We present our work on a Space-borne communication array outside of Earth's orbit usable for Inter Solar System Communications (ISS Comms), Deep Space Network Communications (DSN Comms), and instrumented as the most advanced Solar and Space Weather research and monitoring system in the solar system.

We present updates of our ongoing mission concept development for the

### Lagrange Communication Advanced Realtime Space-weather Array (LCARS)

**LCARS** would be placed at key solar system locations, autonomously warning Earth and protecting space assets. The **LCARS** Spacecraft will orbit Earth-Sun Lagrange points, providing:

- **Solar Observations: High Time and Spatial Resolution**
- **Solar Wind: In-situ and Remote Surveillance of Interplanetary Medium**
- **Communications: High Bandwidth, Multichannel Heliospheric communications**

The Lagrange point utility is beheld from existing use as key location for the Space Weather monitoring and observational assets. For example, L1 hosts ACE, SOHO, WIND, DSCOVR, etc.; L2 hosts WIND, Planck, Gaia, JWST, Euclid, etc.; L4 hosted (STEREO A) and L5 hosted (STEREO B).

As a space weather mission, each **LCARS** maintains relative position to Earth, allowing continuous monitoring of the sun and solar wind, the issuance of early warning alerts for terrestrial and space-based assets, and the collection of near 3D continuous data to aid in Earth-Sun space weather modeling.

The **LCARS** Array is also a Communications Infrastructure Mission supports mission data transport through multi-bandwidth comms including radio, terahertz, and laser for inter-**LCARS** and Lunar comms, and a deep space dish enhancing NASA's DSN. The proposed array includes an autonomous inter-**LCARS** network for high bandwidth data flow throughout the solar system.

This presentation provides detailed updates to overall mission concept including preliminary timeline for R&D and deployment by the end of 2050. This talk focuses on key technologies required during the next decade in order to support implementation, launch, and deployment in following decade. These technologies span broad range of domains including comms systems, AI automation, modular spacecraft, self-assembly spacecraft, modular observational bays, etc.

## Why the LCARS Array

### Data and Communications

- Data volume by current (and to be flown) NASA missions has exploded exponentially heading into the 10's of TB / day
- Instrument capabilities are limited by bandwidth even with modern compression algorithms (lossless or lossy)
- NASA Deep Space Network (DSN) communications must prioritize time slices for each SC
  - e.g. DSN time slicing provides only approximately 3 hours of Voyager SC data/day/SC
  - Potential important scientific discoveries have been missed because of time slicing
- New DSN antennae are exceptionally expensive in today's \$'s
- DSN bandwidth is limited as we start working with 10's of TBs of data per day per SC
  - High bandwidth Communications is very limited through Earth's atmosphere
  - Recently tested Laser communications while successful in near Earth must be highly refined to handle interplanetary pointing

### Solar Science and Space weather

- Space weather observatories are limited in capability regarding instrumentation, bandwidth, temporal and spatial resolution, etc.
- STEREO A/B showed the effectiveness of a system observatory view of the sun from three different solar sectors (with ACE at L1)
  - but STEREO had orbits that only worked for parts of the mission (Note: STEREO B is dead as of 10/9/2016)
- Solar Probe and Solar Orbiter are phenomenal missions providing discoveries beyond their original mission concept studies
  - but they can't see the "whole" sun all the time
- Space weather modeling accuracy demands a "whole" sun view allowing incremental and sometimes significant improvement in the ability to accurately predict times when Earth space assets are at risk as well as future Human assets in the solar system (Mars etc.)
- There is critical need for highly accurate space weather predictions for human presence on the Moon and Mars since both bodies spend significant amount of time in the Solar Wind exposed to Space Weather without a magnetic shield

## Preparing for LCARS Array Development

### LCARS is a 2040-2050 Decadal Mission

For NASA to be able to implement and launch LCARS by 2050, significant technological development is required:

- **Novel Communications Technologies**
  - Inter-SC COMM (Laser +Terahertz Gimble)
  - Autonomous Networking
- **Hardware:**
  - Terahertz and Laser Communications Systems
  - Gimble Deep Space Communications Dish
  - Multichannel/Multifrequency Radio Comms
- **Protocols:**
  - Interplanetary Communication Protocols (up to 18 minute packet delays)
  - Adaptive and Predictive AI protocol evolution
- **Novel Software Systems**
  - Self-writing Software Systems
  - Self-healing Software
  - Adaptive Data Analytics for Predictive Decision Making onboard each **LCARS** Spacecraft
- **Novel Spacecraft Technologies**
  - Multi-Component Modular Spacecraft
  - One or more transport rockets to final destination
  - Station Keeping engine at final destination
  - Modular Spacecraft Design with Self Assembly capability
- **Novel Sensor Module Technologies**
  - Modular Instrument Bays
  - Self-Docking Modules
  - Spacecraft ejection of defective modules
  - Large Redundant Data System
- **Data System Technologies**
  - Photonic or Quantum Storage Technologies
  - Large Redundant Data Systems
  - Self-Healing Hardened Systems
  - Storage Module Ejection and Replacement

## LCARS Communications: Why Terahertz (THz) Communications?

The exponential increase in data requirements for modern missions must be accommodated for **LCARS** implementation. Current vision for **LCARS** transmitters to be based on terahertz (THz) emissions.

- This choice has many benefits.**
- THz beam sizes at AU distances narrower than radio, limits aperture size and electronics sensitivity required
  - THz bandwidth (theoretically) is significantly higher than S-band (3.4 Mbps) and X-band (10 Mbps)
    - Already realized systems have reached 100 Gbps over close to a kilometer (Leitenstorfer et al., (2023)).
  - THz communications is implemented as phased array
    - Allows pointing corrections without adjusting satellite orientation using momentum wheels, saving on power consumption
  - THz Inter-Satellite Communication has been tested (Cui et al., 2021)
    - This testing was done for short range communications of 600 km
  - THz transmitter capable at AU distances is a critical path in technology advancement necessary for **LCARS** realization.

### References:

Alfred Leitenstorfer et al 2023 J. Phys. D: Appl. Phys. 56 223001  
D. Cui, W. Duar and R. Song, "The Progress of Terahertz Communication for LEO Satellite," 2021 IEEE 21st International Conference on Communication Technology (ICCT), Tianjin, China, 2021, pp. 1413-1416, doi: 10.1109/ICCT52962.2021.9657944.

## SH33D-3080

## 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  
Matthew Cooper, New Jersey Institute of Technology, Newark, NJ  
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  
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.



## The Vision of the LCARS Array

### What should Humanities Space Exploration and Expansion into the Solar System look like by the year 2050?

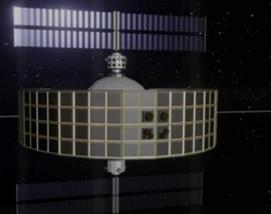
→ → → By the year 2050 there will be ← ← ←

A Lunar Base with reasonable communications capabilities

**Humans on Mars – and since they won't be coming back, we call that a Base!**  
Significant expansion of NASA's Heliophysics System Observatory by sending multiple different spacecraft to the outer planets, to Mars, to the Asteroid belts, etc  
Interstellar Probe will be on its way and New Horizons will still be working  
(Note: Voyager unfortunately will be dead in the VLISM)

## LCARS Array Novel Spacecraft and Instrumentation System

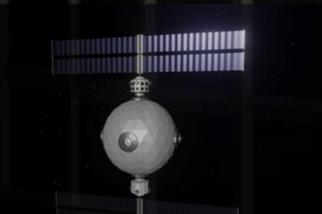
### LCARS Array Solar Side View



### LCARS Array Deep Space View



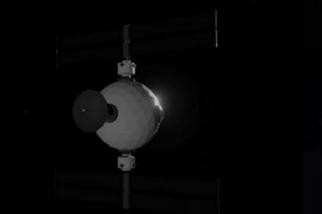
### LCARS Array Communications Front



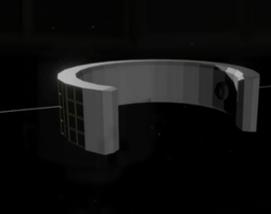
### LCARS Array Sensor Deck Front



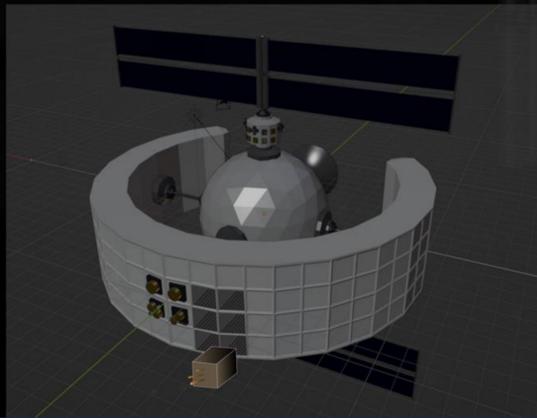
### LCARS Array Communications Rear



### LCARS Array Sensor Deck Rear



## LCARS Array Modular Instrument Docking Concept



Center for Solar-Terrestrial Research



## LCARS Array Mission and Intercommunications Concept

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

#### Primary COMMS:

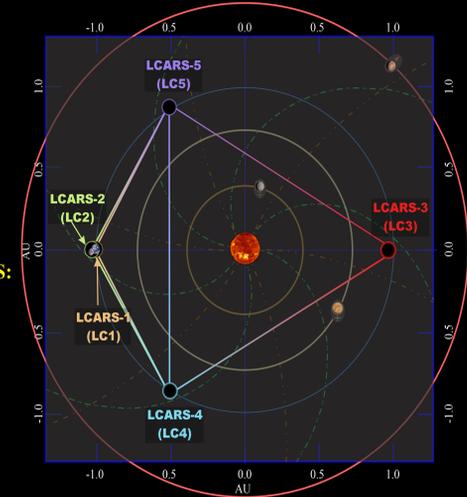
- Earth ↔ LCE1
- Earth ↔ LCE2
- LCE4 ↔ LCE4
- LCE1 ↔ LCE5
- LCE2 ↔ LCE4
- LCE2 ↔ LCE5
- LCE3 ↔ LCE4
- LCE3 ↔ LCE5

#### Secondary COMMS:

- Earth ↔ LCE4
- Earth ↔ LCE5

#### Future COMMS:

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

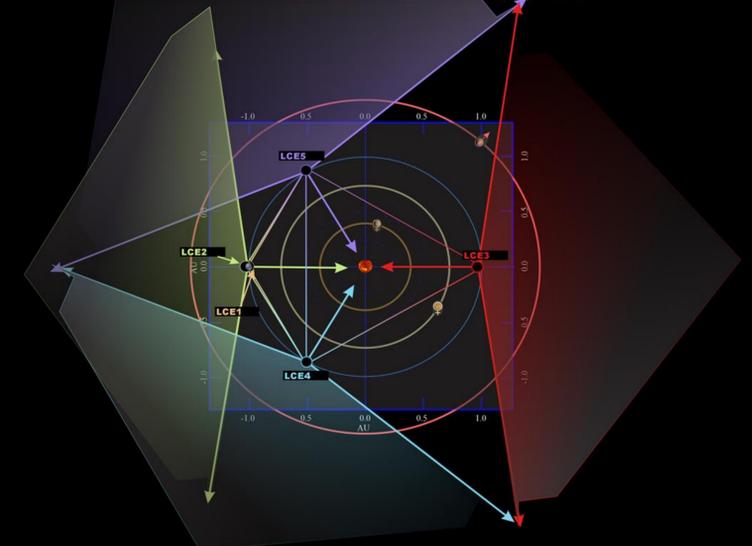


Lagrange Points for Earth-Sun System with Parker Spiral Ecliptic Plane magnetic field direction for a Solar Wind Speed of 400 km/s and 2000 km/s

## LCARS Array Deep Space Coverage

### Deep Space Communications System

Observational 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



### LCARS Array Mission Concept Summary:

The **LCARS** Array Mission Concept has the potential to significantly increase NASA's and Humanities exploration into the Solar System.  
The **LCARS** Array Mission Concept as currently developed identifies a significant amount of new technology development that must occur during this next Decadal period.  
The **LCARS** Array provides for high bandwidth and high data throughput communications throughout the inner solar system.  
The **LCARS** Array provides for a stable platform to perform high time and spatial resolution Solar studies over the entirety of the solar surface.  
The **LCARS** Array provides the necessary in-situ and remote solar wind observations to enable extremely accurate space weather forecasting based upon accurate solar storm forecasting capabilities.