

## ABSTRACT

A Space-borne communication and sensor array outside of Earth's orbit usable for Inner Solar System Communications (ISS Comms), Deep Space Network Communications (DSN Comms), and space weather is under study. We present updates of ongoing mission concept development for the

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

LCARS Space Platforms would be placed at key solar system locations, autonomously warning Earth and protecting space assets. Each LCARS Space Platform (LCARS<sub>sp</sub>) orbits the Earth-Sun Lagrange points:

- Surveillance of interplanetary medium and solar observations.
- Interplanetary and Heliospheric communications

The Lagrange point utility is shown 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).

Each LCARS<sub>sp</sub> 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 that supports mission data transport through multi-bandwidth comms including radio, terahertz and laser for inter-LCARS<sub>sp</sub> and Lunar comms, and a gimbed deep space dish enhancing NASA's DSN. The proposed array includes an autonomous inter-LCARS<sub>sp</sub> network for high bandwidth data flow throughout the solar system.

We present detailed updates to our mission concept including timeline\* for R&D and deployment by 2050. We focus on key technologies required during the next decade to support implementation, launch, and deployment by 2050. These technologies span broad range of domains including comms systems, AI automation, modular spacecraft, self-assembly spacecraft, modular observational bays, retractable and variable shaped deep space reflector, etc.

\*Timeline elements are still under development and not shown with this poster

## Why the LCARS Array

### Data and Communications (see Schonfeld et. al, 2023, DOI: 10.3389/spas.2022.1051527)

- Data volume by current (and to be flown) NASA missions has exploded exponentially heading into the 10's of TB / day
- Instrument capabilities are hampered by bandwidth limitations even with modern compression algorithms (lossless or lossy)
- NASA Deep Space Network (DSN) and Near Space Network (NSN) 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:

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| <ul style="list-style-type: none"> <li>• Novel Communications Technologies           <ul style="list-style-type: none"> <li>• Inter-SC COMM (Laser +Terahertz Gimble)</li> <li>• Autonomous Networking</li> </ul> </li> <li>• Hardware:           <ul style="list-style-type: none"> <li>• Terahertz and Laser Communications Systems</li> <li>• Gimble Deep Space Communications Dish</li> <li>• Multichannel/Multifrequency Radio Comms</li> </ul> </li> <li>• Protocols:           <ul style="list-style-type: none"> <li>• Interplanetary Communication Protocols (up to 18 minute packet delays)</li> <li>• Adaptive and Predictive AI protocol evolution</li> </ul> </li> <li>• Adaptive Deep Space Dish Capabilities:           <ul style="list-style-type: none"> <li>• Gimble pointing</li> <li>• Central receiver</li> <li>• Lightweight Dish materials (e.g. Mylar)</li> <li>• Deployable and Retractable Dish</li> <li>• Variable Dish Surface Area w/ R &lt;= 35m</li> </ul> </li> <li>• Novel Spacecraft Technologies           <ul style="list-style-type: none"> <li>• Multi-Component Modular Spacecraft</li> <li>• One or more transport rockets to final destination</li> <li>• Station Keeping engine at final destination</li> <li>• Modular Spacecraft Design with Self Assembly capability</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>• Novel Software Systems           <ul style="list-style-type: none"> <li>• Self-writing (AI) Adaptive Software Systems</li> <li>• Self-healing (AI) Redundant Software Systems</li> <li>• Adaptive / Predictive Data Analytics – e.g. Predictive Decision Making onboard each Spacestation</li> </ul> </li> <li>• Novel Sensor Module Technologies           <ul style="list-style-type: none"> <li>• Modular Instrument Bays</li> <li>• Self-Docking Modules</li> <li>• Spacecraft ejection of defective modules</li> <li>• Large Redundant Data System</li> </ul> </li> <li>• Data System Technologies           <ul style="list-style-type: none"> <li>• Photonic or Quantum Storage Technologies</li> <li>• Large Redundant Data Systems</li> <li>• Self-Healing Hardened Systems</li> <li>• Storage Module Ejection and Replacement</li> <li>• Autonomic Data Management</li> </ul> </li> <li>• Novel Power System Capability           <ul style="list-style-type: none"> <li>• Solar Panels used for minimum power requirements</li> <li>• Replaceable Solar Arrays and Fuel Cells</li> <li>• Embedded Fuel Cell Array used for Operations               <ul style="list-style-type: none"> <li>• Primary power for Comms</li> </ul> </li> <li>• Power provided per Bay Unit for experiments               <ul style="list-style-type: none"> <li>• Each bay unit provides <math>V_{max}</math> power</li> <li>• Coupled bays provide <math>N * V_{max}</math> power</li> </ul> </li> </ul> </li> </ul> |
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## 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.

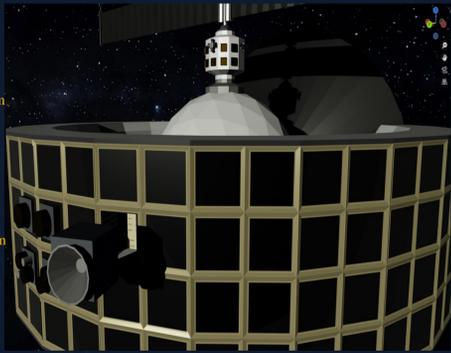
### References:

Alfred Leitenstorfer et al 2023 J. Phys. D: Appl. Phys. 56 223001  
D. Cui, W. Duan 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.

## LCARS Array Modular/Variable Instrumentation Bays

### LCARS Instrumentation platform concepts:

- Array of Instrument Bays (units or cells)
- Minimum bay size is a "unit"
- Shown as 4 units tall for presentation not design
- Design: CubeSat unit = 10 x 10 x 10 (cm)
- Shown configuration: single unit = -1 x 1 x 1 (m) or a 4 m tall Instrument platform.
- With CubeSat size = 1 unit then 4-meter-tall platform houses 40 instrument bays in z direction
- As shown, 2 bays with -x pointing plus
- 4 bays with near -x pointing plus
- 22 bays with varying x,y pointing
- Finally, bays on outside with comms pointing for sampling of in-situ plasma (not shown), sample background, etc.
- With CubeSat size = 1 units then Instrument Platform houses max of 280 instruments
- Single instruments can be 1 unit in size or can be configured to utilize multiple units.
- Instruments using N>1 units benefit from N\*power and N\*data based upon:
  - Instrument Size requirements and/or
  - Instrument Power Requirements and/or
  - Instrument Data Throughput Requirements



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### The Lagrange Communication

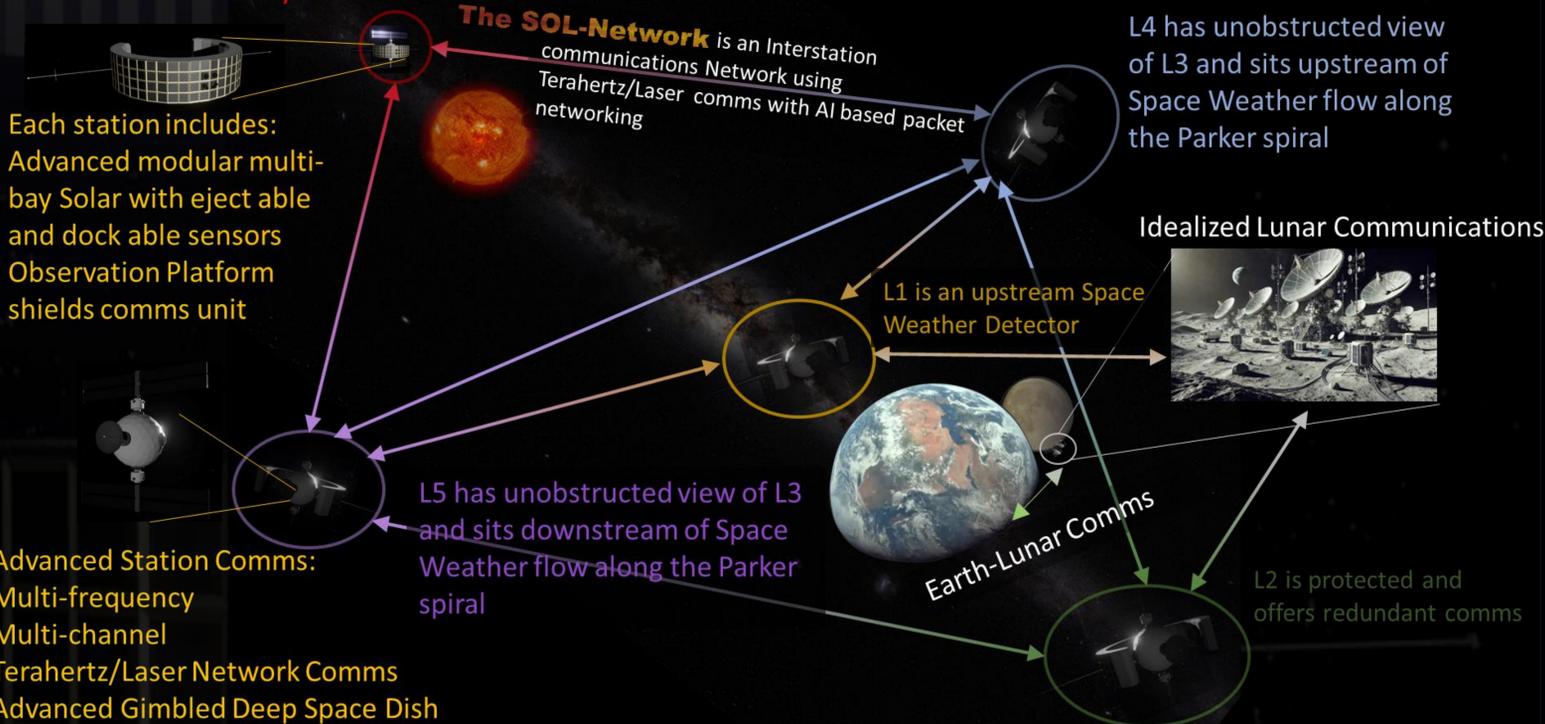
## Advanced Realtime Space-weather (LCARS) Array

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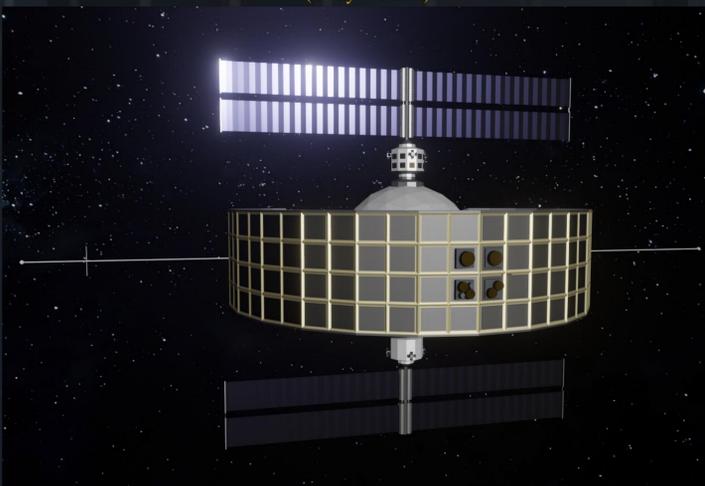
L3 is behind the sun and can see L4 and L5, offers communications for missions obscured by sun

## LCARS Vision Is a Space Station at each of the Earth-Sun Lagrange Points

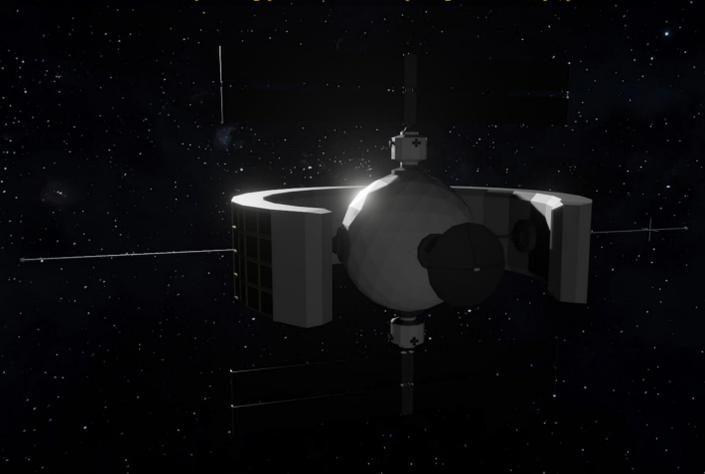


## Concept LCARS Space Platform / Spacecraft

Front showing Modular/Reconfigurable Instrument bays (1 bay = 1 unit)



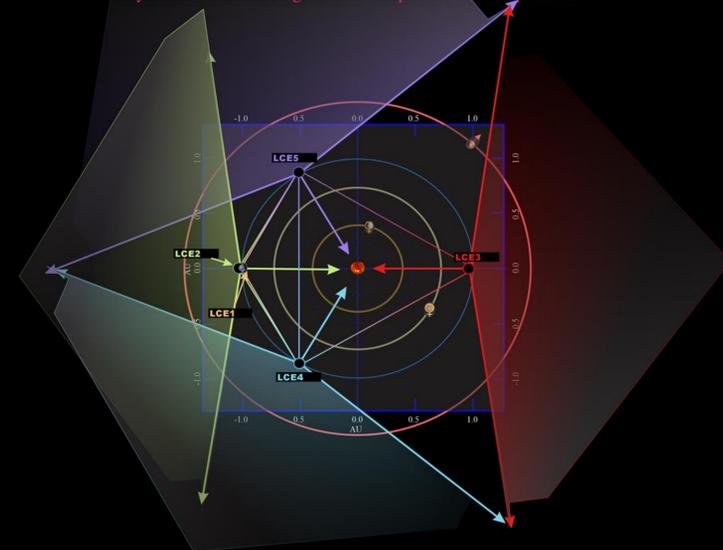
Rear view showing shielded Primary Platform used to house operational systems; power, computers, storage systems, data processing systems and Communication arrays along platform surface plus gimble deep space dish



## 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 Deep Space Comms

- Primary ~1 meter Dish
- Gimble Dish for variable pointing capability
- Expanding Reflector behind primary dish for enhance gain requirements
- Expanding Reflector capable of anything from > 1m to 30 m in size for hyper gain requirements
- Variable Reflector shape for complex signal requirements
- Variable shape from linear to parabolic+ allows for enlaced signal analysis for higher foreground to background capability

