CESIUMASTRO

SPACE & DEFENSE SYSTEMS

Lunar Communication Programs

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United Nations Center Vienna
Lunar C-PNT Workshop
13 February 2025

CONTENTS
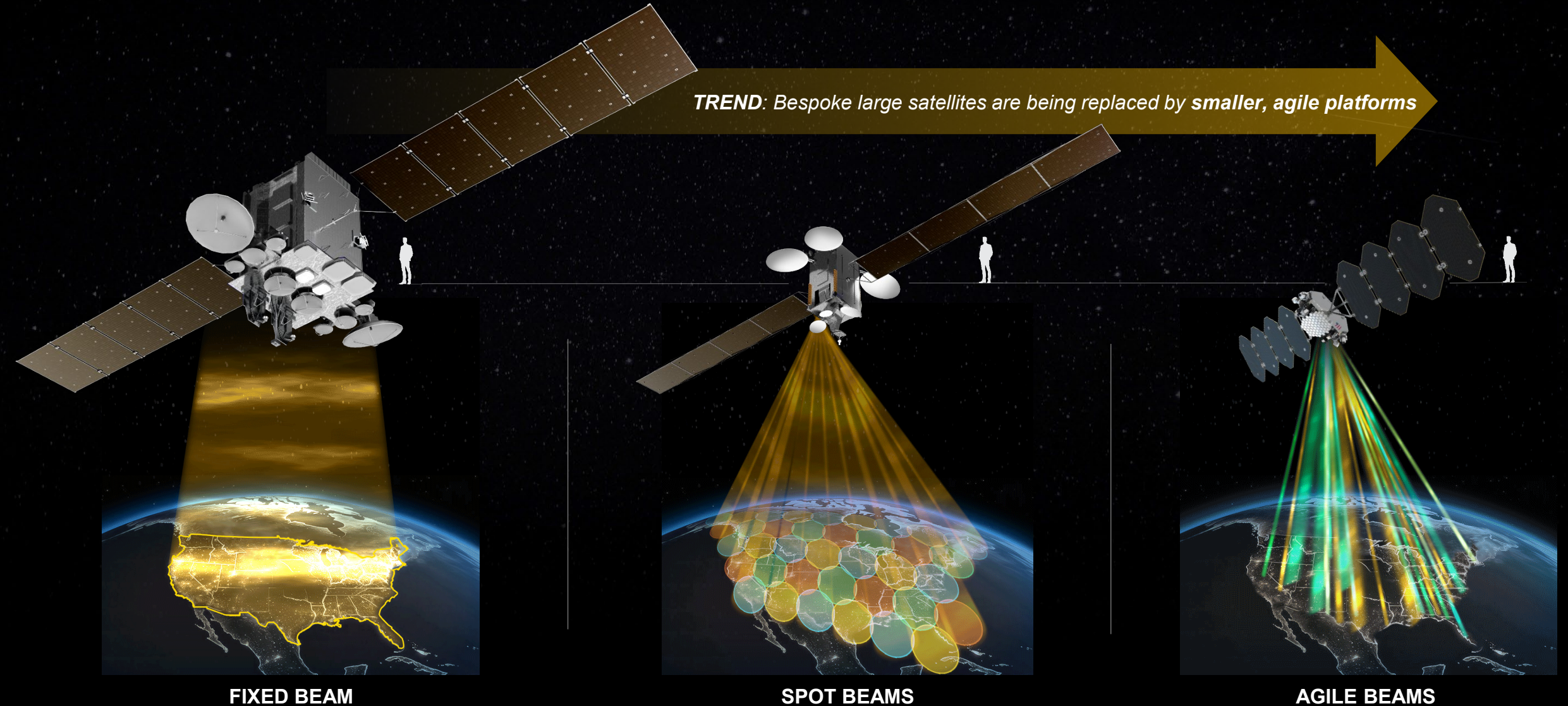
- CESIUMASTRO AT-A-GLANCE

- LUNAR PROGRAMS AND STRATEGIES

- LUNAR RANGING AFS PROGRAM FOR NASA MARSHALL SPACE FLIGHT CENTER

- THE FUTURE

SATELLITE TELECOMMUNICATION TRANSFORMATION

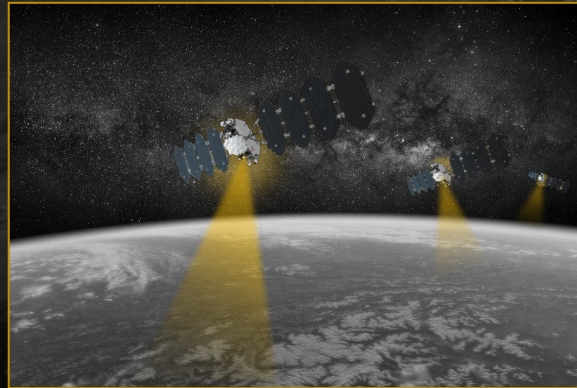**TREND**: *Bespoke large satellites are being replaced by* ***smaller, agile platforms***

FIXED BEAM

SPOT BEAMS

AGILE BEAMS

WHAT WE DO

CESIUMASTRO DELIVERS SECURE RF COMMUNICATIONS SOLUTIONS USING PROPRIETARY ACTIVE PHASED ARRAY TECHNOLOGY
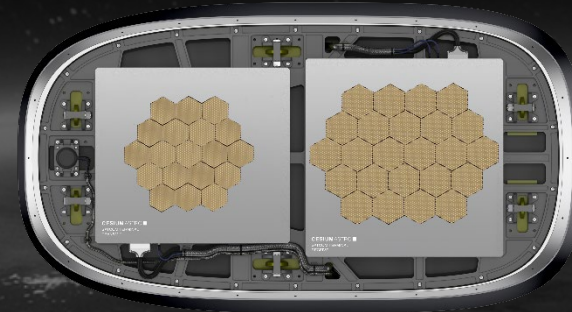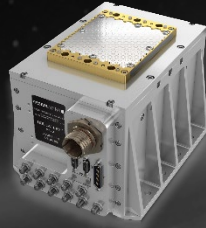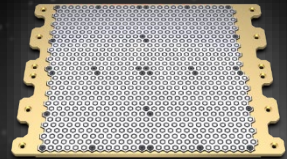
SPACE PAYLOADS

AIRBORNE TERMINALS

GROUND TERMINALS

CESIUMASTRO

CESIUMASTRO AT A GLANCE

OUR EXPERIENCE

+$157M
Equity Funding Raised

+300
Employees

+40%
Master's and PhD

1,350+
Combined Years of
Space Experience

OUR CUSTOMERS

SIERRA SPACE
AXIOM SPACE
MISSILE DEFENSE AGENCY
ROCKETLAB
Honeywell
AIRBUS
OneWeb
NORTHROP GRUMMAN
SDA SPACE DEVELOPMENT AGENCY
DARPA
LOCKHEED MARTIN
U.S. AIR FORCE
L3HARRIS
SE
iqt IN-Q-TEL
BLUE ORIGIN
CACI EVER VIGILANT
AFRL
NASA
BAE SYSTEMS
MAXAR TECHNOLOGIES
ORBITAL EFFECTS
Raytheon Technologies

OUR INVESTORS

AIRBUS VENTURES
KLEINER PERKINS
TROUSDALE VENTURES
DBJ Development Bank of Japan
L3HARRIS
JLR
Honeywell
ANALOG DEVICES AHEAD OF WHAT'S POSSIBLE
FRANKLIN TEMPLETON
LAVROCK VENTURES
HEICO
iqt IN-Q-TEL

OFFICES ACROSS THE USA and EUROPE

OFFICAL PRODUCT LINES

NIGHTINGALE	VIREO	SKYLARK	ELEMENT	SOFTWARE
SINGLE-BEAM OPERATION	MULTI-BEAM OPERATION	SATELLITE COMMUNICATION TERMINAL	INTEGRATED SATELLITE	CORE TO OUR PRODUCTS

NIGHTINGALE
- Single-beam connectivity
- Electronically steerable, shapable beam
- TRL 9, working on-orbit for various customers
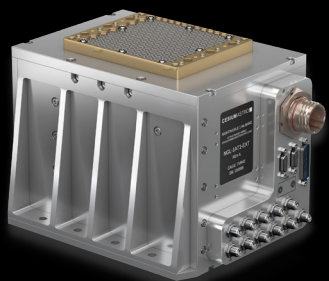
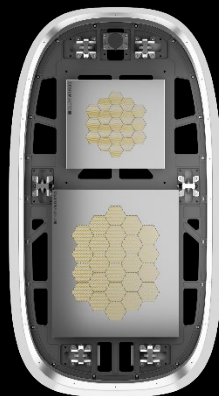**VIREO**
- Multi-beam operation to connect multiple users simultaneously
- Electronically steerable, shapable beams
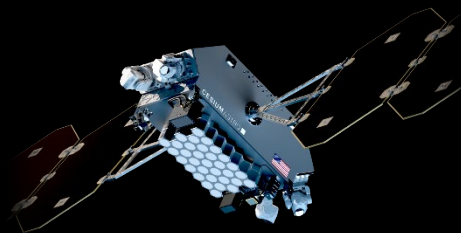- Processor and arrays scale to mission requirements

SKYLARK
- Constellation agnostic to roam across networks
- Multi-beam for make-before-break connectivity
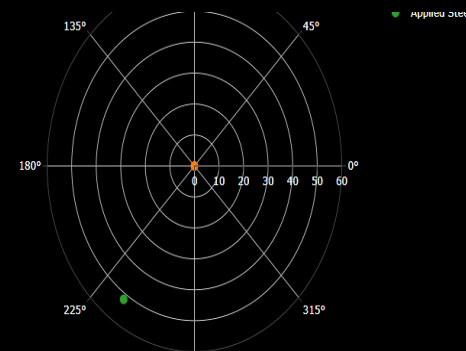- Multi-orbit (LEO to GEO) for flexible connectivity options

ELEMENT
- Purpose-built to host active phased array comms systems
- Supports SDA Transport Layer mission requirements
- Reconfigurable to different AESA payloads

SOFTWARE
- Supports waveforms or user customizable solutions
- Supports modulation, demodulation, and coding algorithms
- ActiveTrack software directs the antenna
- Reconfigurable during the mission / use

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ENABLING LUNAR COMMUNICATION, POSITION, NAVIGATION, AND TIMING (C-PNT)

Robust, global, Earth-based infrastructure enabling always-on connectivity

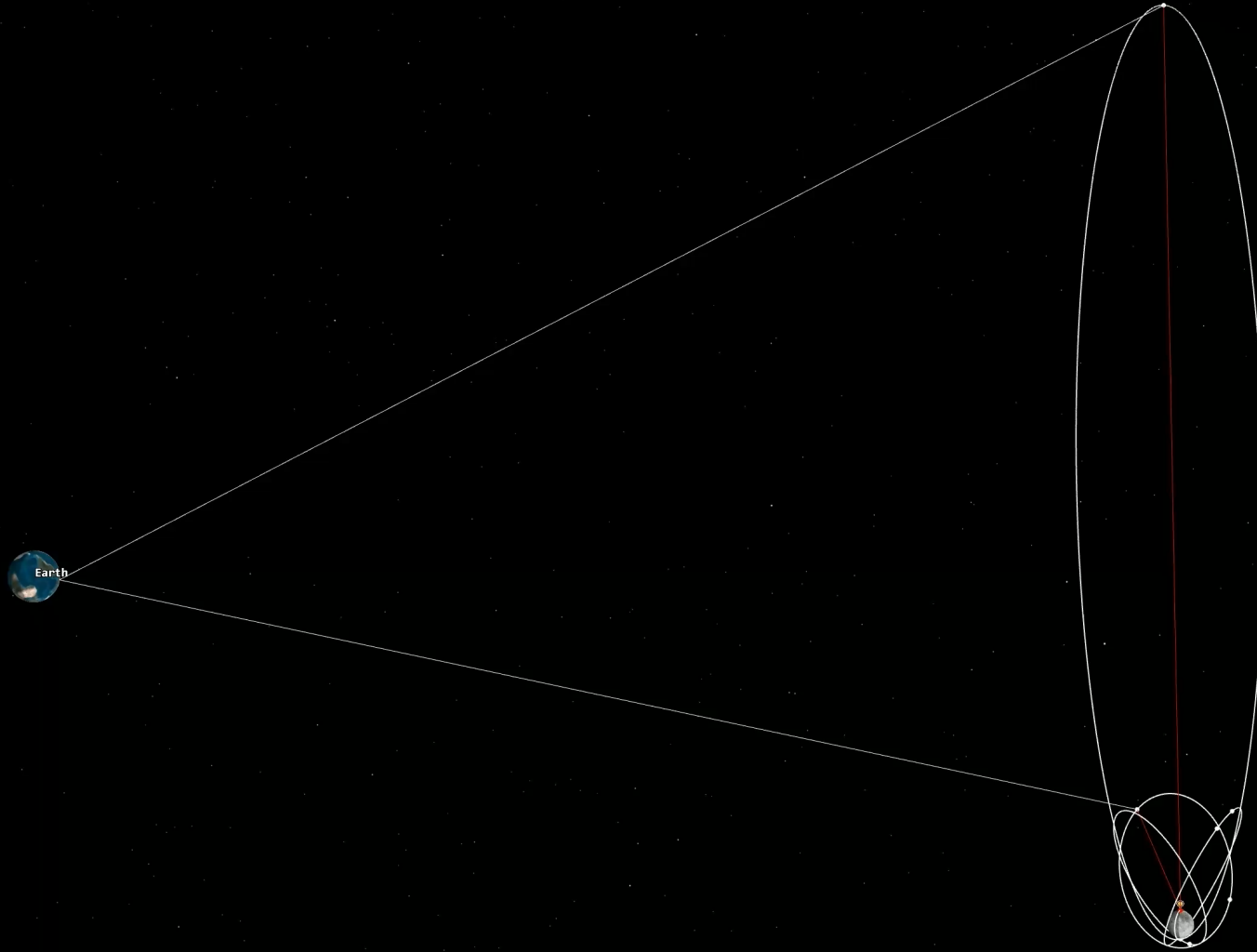Lunar relay satellites provide multi-user access, PNT, and SAR services

Connectivity infrastructure at-scale supporting expanded operations and life support

Wireless services for rovers that will unlock the secrets of the Moon
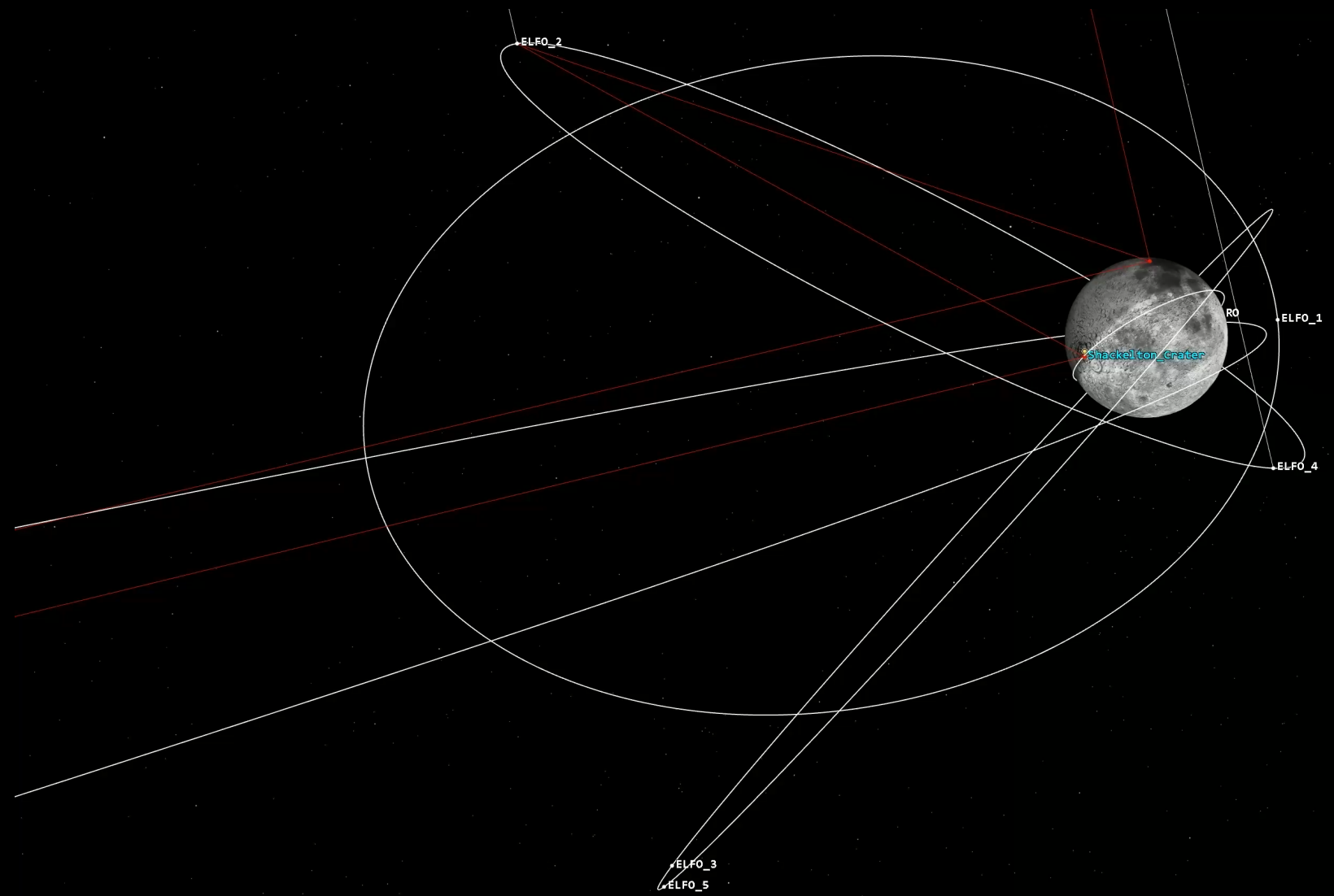
Human exploration and settlement

BENEFITS OF ELECTRICALLY STEERABLE ANTENNAS

Aretemis_Lander TopoCentric Axes
7 Aug 2024 17:01:00.000   Time Step: 60.00 sec
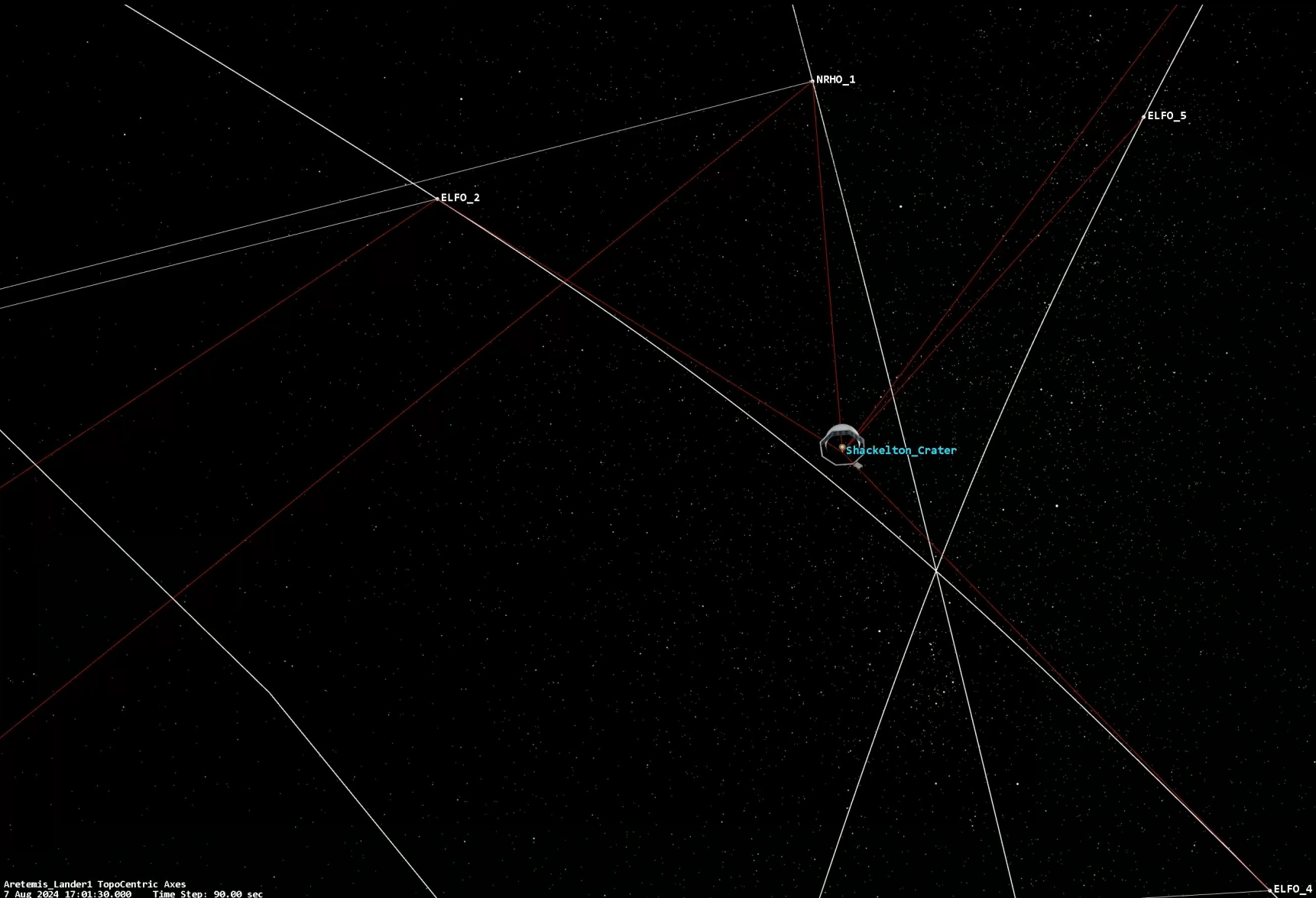
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BENEFITS OF ELECTRICALLY STEERABLE ANTENNAS

BENEFITS OF ELECTRICALLY STEERABLE ANTENNAS

NRHO_1

ELFO_5

ELFO_2

Shackelton_Crater

ELFO_4

Aretemis_Lander1 TopoCentric Axes
7 Aug 2024 17:01:30.000   Time Step: 90.00 sec

PROGRAMS: AUGMENTED FORWARD SIGNAL (AFS)

CesiumAstro is partnering with **NASA Marshall Space Flight Center** to provide radios supporting key *LunaNet* specifications for Augmented Forward Signal (AFS) Position, Navigation, and Timing (PNT).

AFS is critical capability required for upcoming NASA missions such as Artemis and other commercial lunar missions.

AFS enables PNT in the lunar and cislunar environments similar to GNSS/GPS provide services for Earth.

The contract delivers 1 receive radio with the option for 1 transmit radio for NASA ground testing.
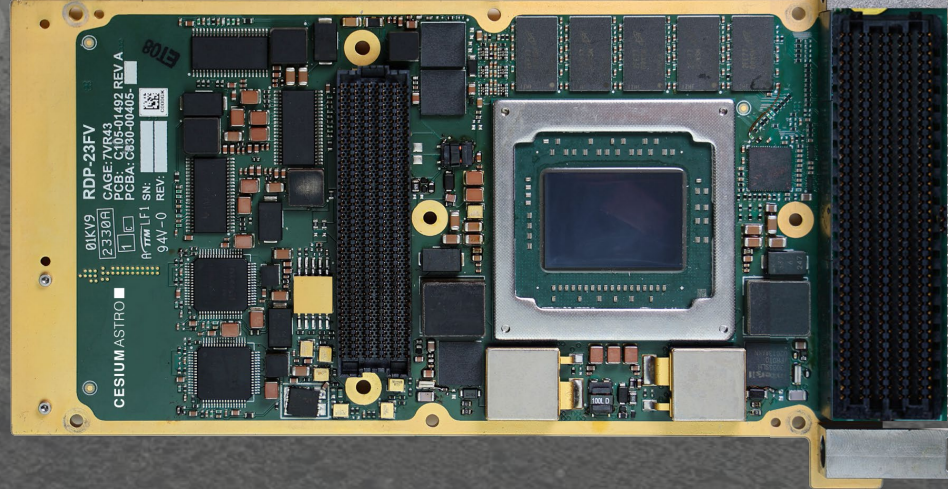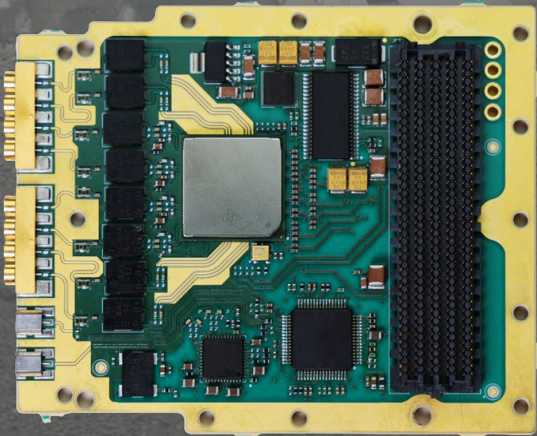
PROGRAMS: EMU SUIT COMMS

CesiumAstro partnered with **Axiom Space** to deliver software defined radios for the Axiom Extravehicular Mobility Unit (AxEMU) spacesuit.

The AxEMU spacesuit enables Artemis III astronauts' operations on the lunar surface and aboard the International Space Station.

CesiumAstro's SDRs support communications for the AxEMU, enhancing surface connectivity both between spacesuits and with NASA's Human Landing System.

Product Line: Vireo: 12 software-defined radios + EDUs
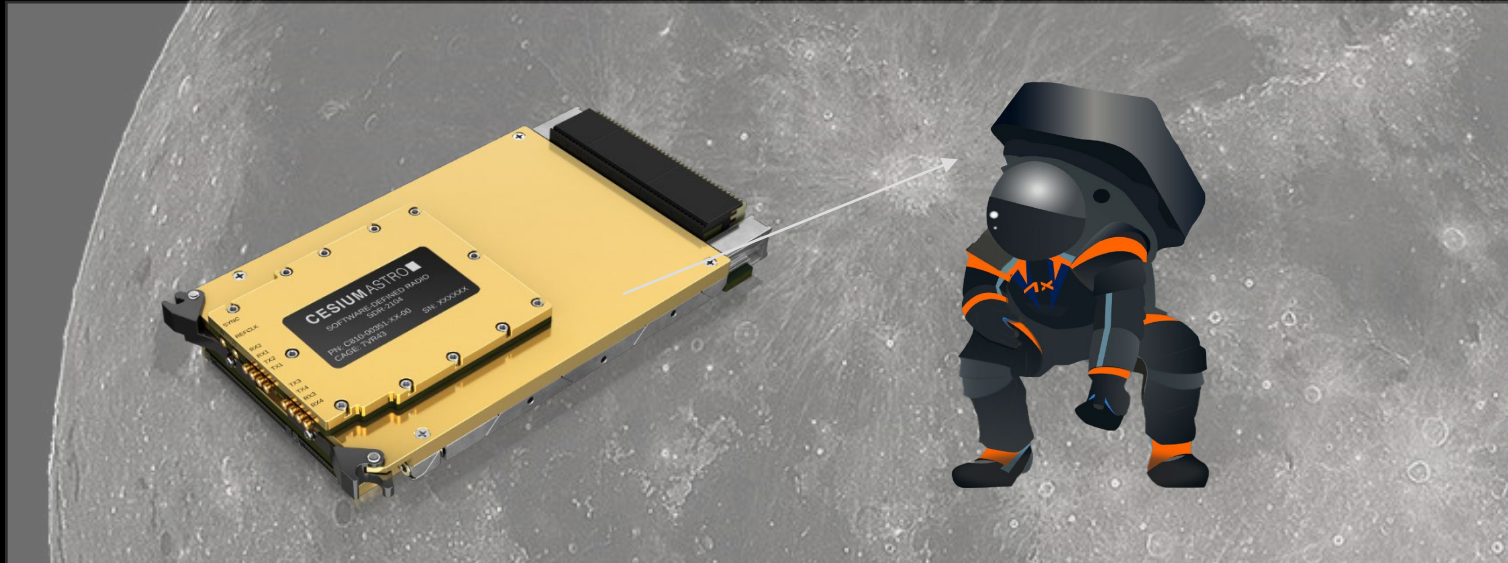
AXIOM SPACE

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ACTIVE PROGRAMS + KEY PURSUITS

Intuitive Machines Satellites (Lunar Data Network)

ispace Relay Satellites CLPS 12

Starpath Space
Lunar Rover
Radios

Astrobotic Griffin CubeRover

ispace Lander CLPS 12

Venturi Astrolab
Lunar Rover
Mission Computers

AFS PROGRAM: SPACEVPX CARD WITH MEZZANINE

RF Mezzanine

Memory Mezzanine
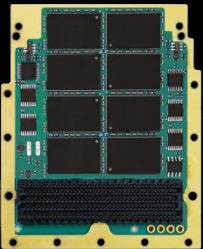
Reconfigurable Digital Processor (RDP)

In/Output Mezzanine

LEO - GEO

Scalable Reconfigurable Processing Unit (RPU)

SDR Module		SDR Module	SBC Module	Switch Module	Power Supply Module
RF Mez	● ● ●	RF Mez	Mem Mez	IO Mez	
RDP Card		RDP Card	RDP Card	RDP Card	

Customized Backplane

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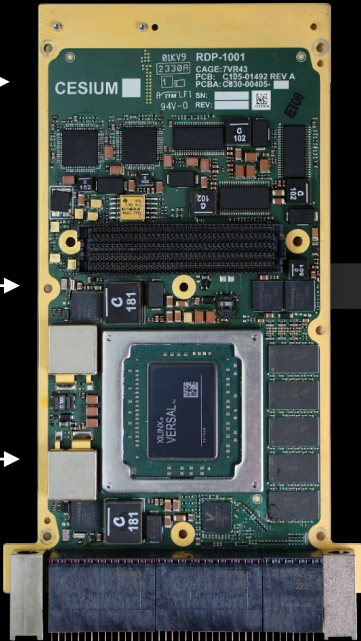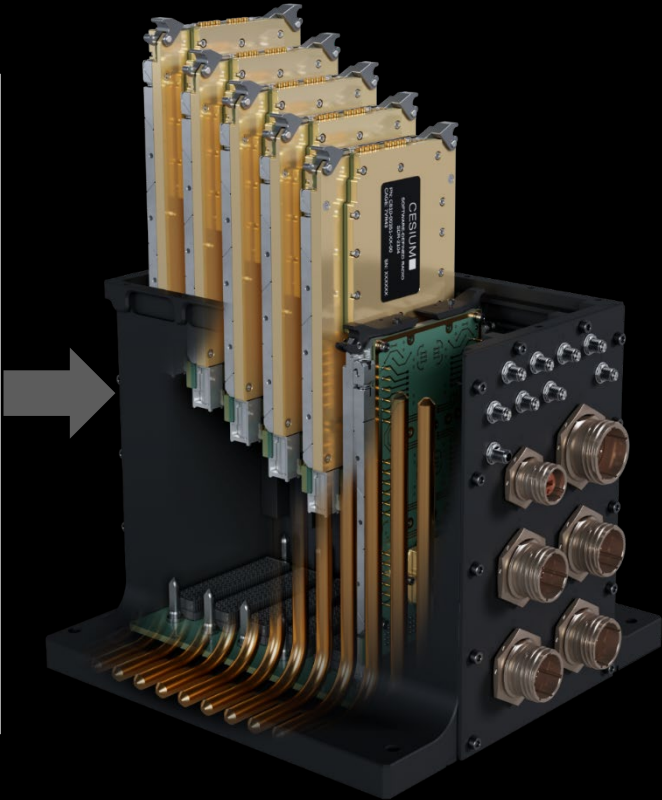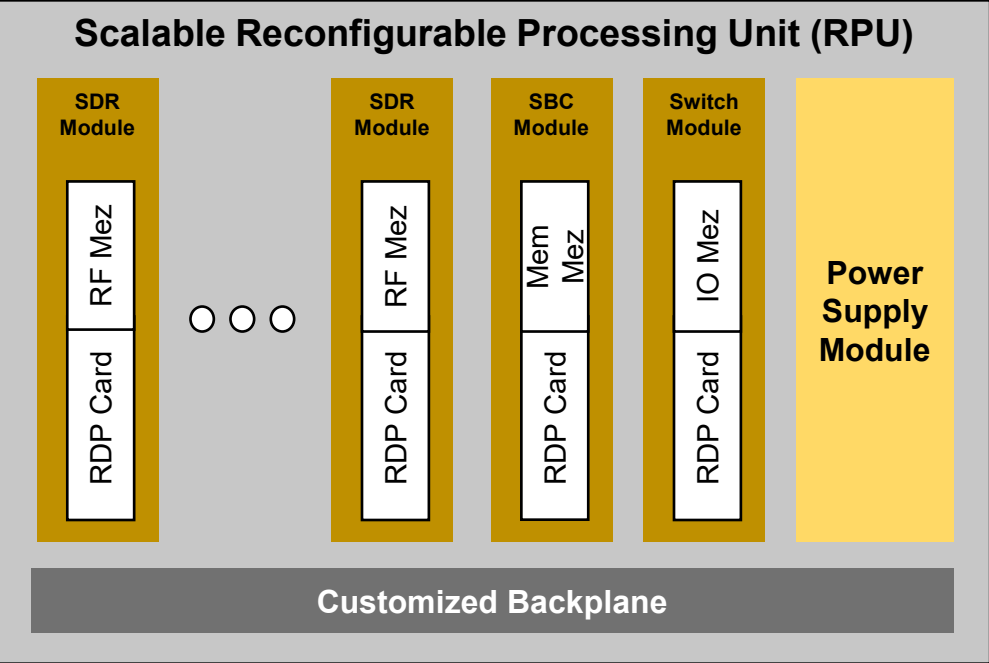
AFS PROGRAM: SOFTWARE DEFINED RADIO

Key Features

- 4 Tx and 4 Rx channels
- Up to 1 GHz Bandwidth
- Xilinx Versal baseboard with RF mezzanine
- RF Mezzanine
  - Multiple tuning bands 600 MHz – 12 GHz
  - Direct sampling RF Mez update ready Q2 2025 for sampling up to 64 Gsps (eliminate need for analog UDCs)
- Supports TDD and FDD operation
- BPSK, QPSK, DVB-S2X, and CCSDS waveforms
- Symbol rates > 500 Msym/sec
- Card-to-card LO and timing synchronization for MIMO, beamforming, and direction-finding applications

Mechanical

- Mass: 900 g
- Power: 30 to 100 W, depending on utilization
- Size: 160 x 100 x 25 mm
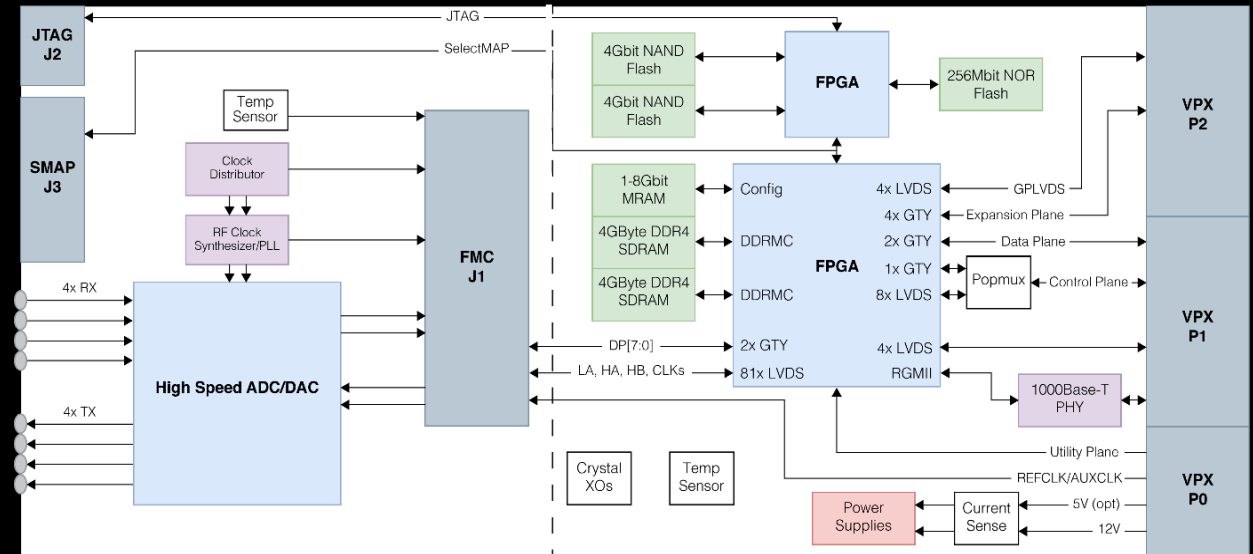
RF Mezzanine   Reconfigurable Digital Processor

CESIUM ASTRO ■

AFS PROGRAM: SOFTWARE DEFINED RADIO

Xilinx Versal Prime 1802 FPGA
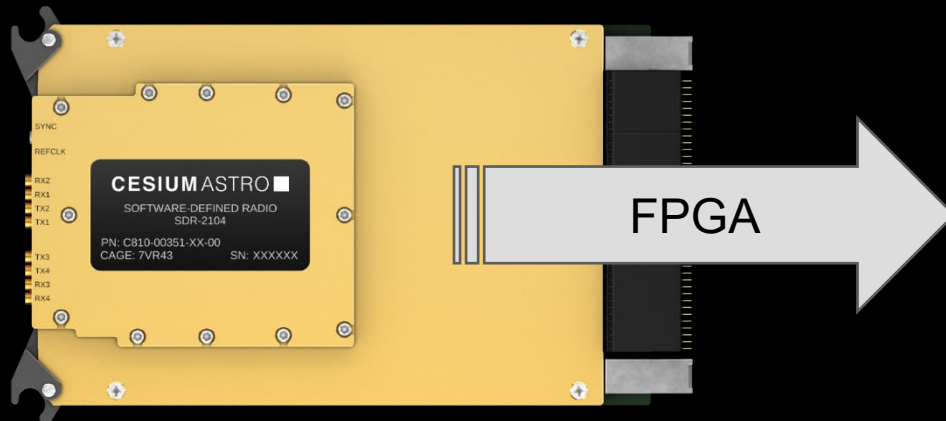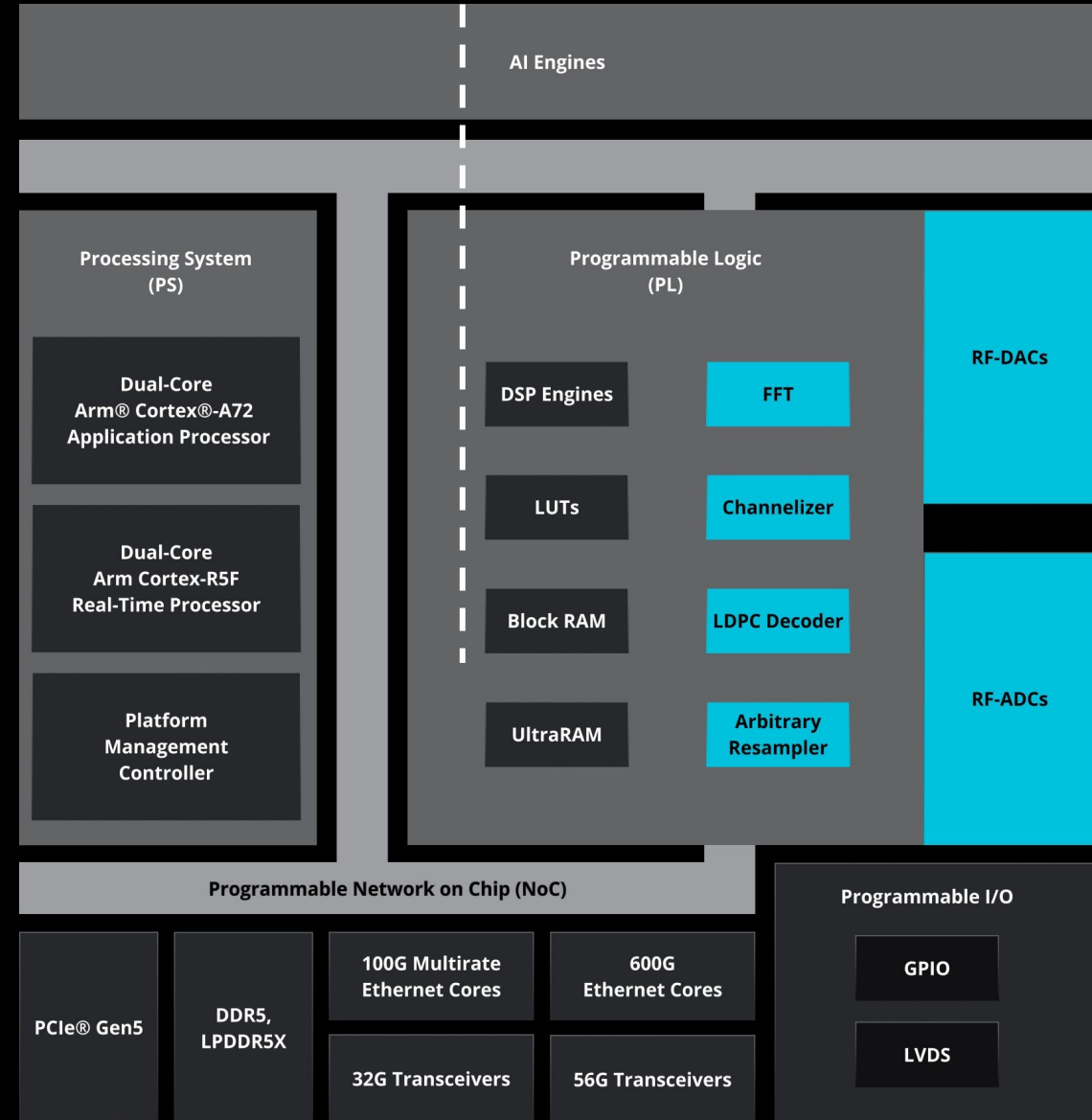**Silicon Real Estate for Full Stack LunaNet**

- 2x A72 for Application Processing (NASA cFS, CFDP, LunaNet higher layers)
- 2x Cortex R5F real-time microcontrollers
- DSP for Mod/Demod
- AI Core IP for Ephemeris Propagation
- Programmable Logic, NoC, Comms
-

FPGA

Xilinx Versal 1802

AI Engines

Processing System (PS)

Dual-Core Arm® Cortex®-A72 Application Processor

Dual-Core Arm Cortex-R5F Real-Time Processor

Platform Management Controller

Programmable Logic (PL)

DSP Engines

LUTs

Block RAM

UltraRAM

FFT

Channelizer

LDPC Decoder

Arbitrary Resampler

RF-DACs

RF-ADCs

Programmable Network on Chip (NoC)

PCIe® Gen5

DDR5, LPDDR5X

100G Multirate Ethernet Cores

32G Transceivers

600G Ethernet Cores

56G Transceivers

Programmable I/O

GPIO

LVDS

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AFS PROGRAM: MODULATED PHASE RECOVERY
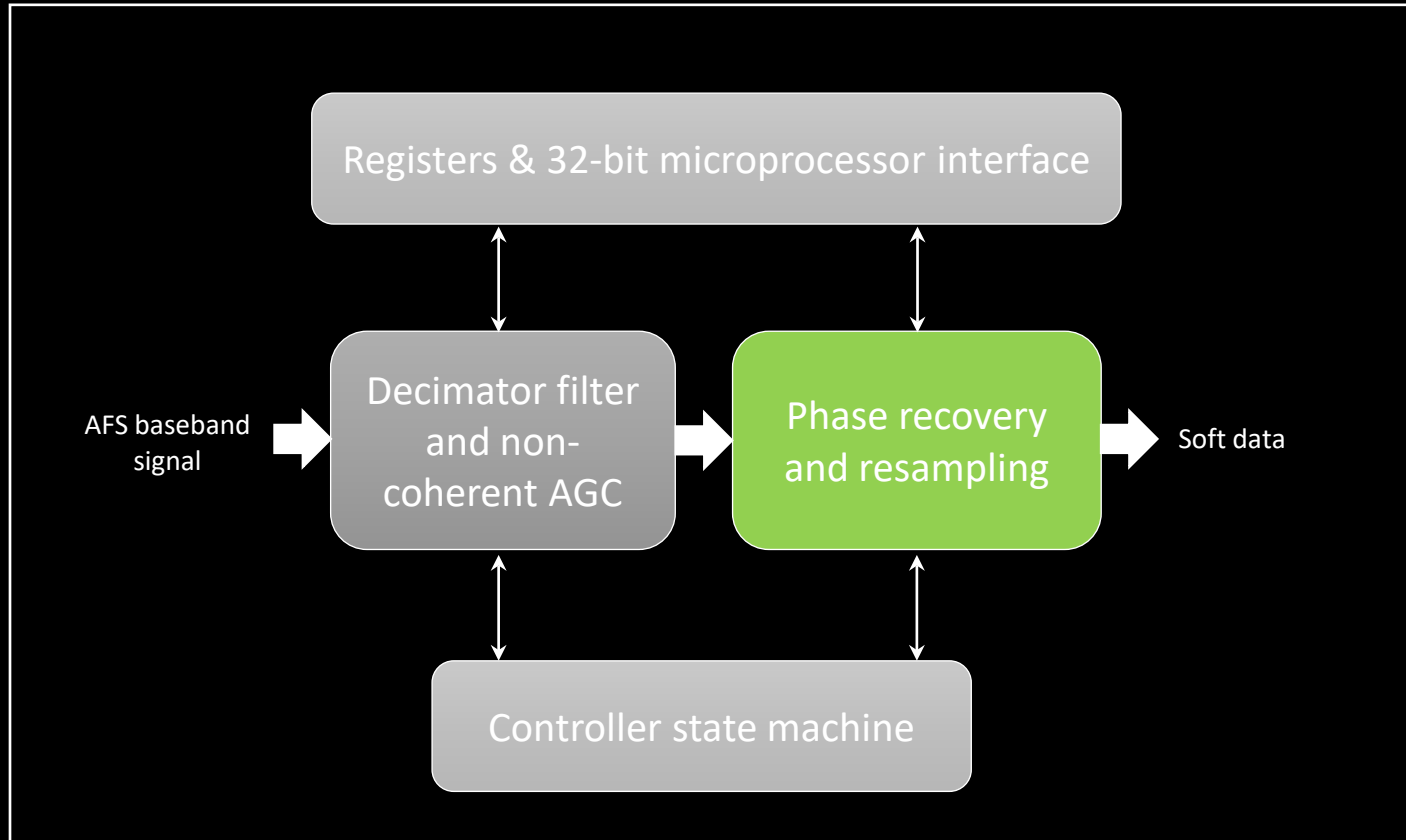
- AFS modulated signal proposed in the LunaNet framework aims at providing lunar GPS-like services to support future lunar exploration [1] (e.g., NASA Artemis)

- The AFS modulation shares many aspects with GPS, namely two signals are provided, low-rate code for coarse/acquisition (C/A) alongside a higher rate code for finer precision measurements [2]

- Receiver will acquire the phase to produce a one-way pseudo-range measurement

- Further processing of navigation messages (e.g., FEC decoding) is not required

[1] LunaNet Interoperability Specification Document Draft Version 5 August 31, 2023.
[2] LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LSIS), Draft Version 1, August 31, 2023.

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AFS PROGRAM: RECEIVER DESIGN OVERVIEW
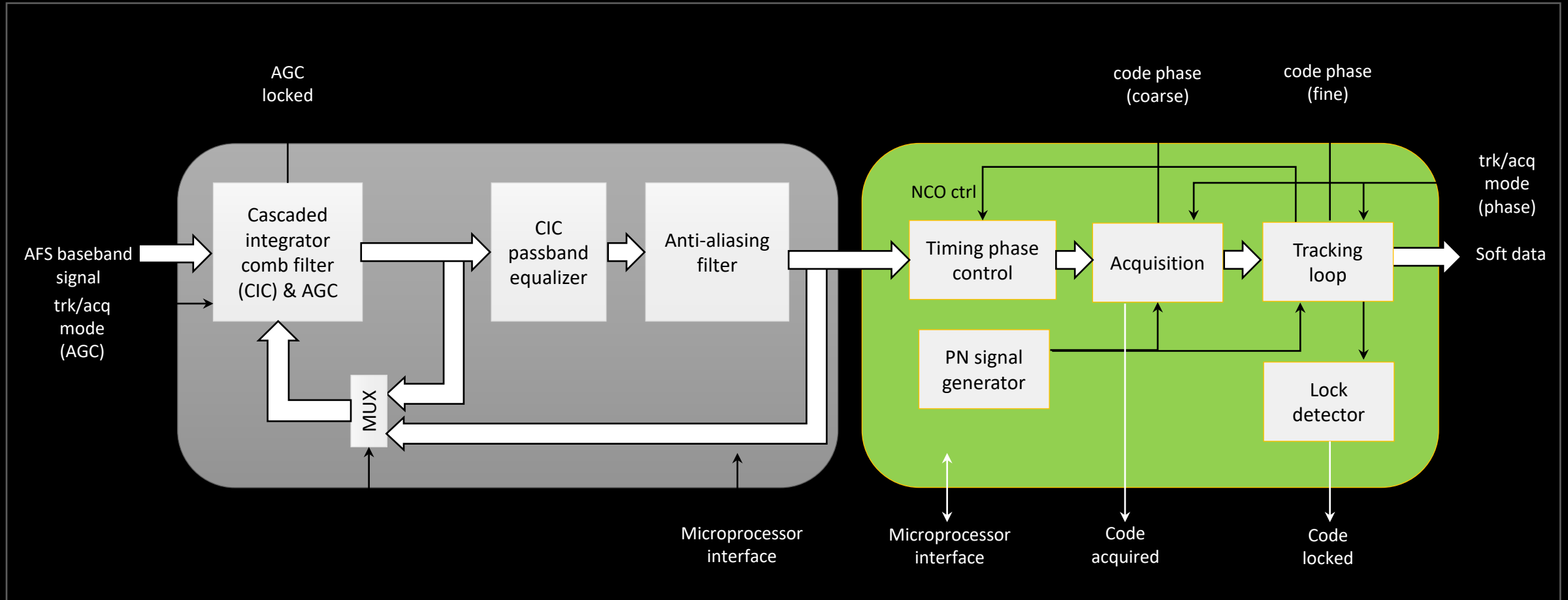
AGC = automatic gain control, NCO = numerically controller oscillator, PN = pseudo noise
PN signal is a Global Positioning System (GPS) L1 C/A Code as defined in GPS-ICD-200 Section 3.2.1.3.

AFS PROGRAM: RTL DEVELOPMENT PROGRESS

- ❑ Decimator and non-coherent automatic gain control (AGC)
  - ▪ CIC and AGC block ✓
    - o Multi-stage CIC filter ✓
    - o Non-coherent AGC ✓
  - ▪ CIC filter equalizer ✓
  - ▪ Anti-aliasing filter (if needed)

- ❑ Phase recovery, resampling and coherent automatic gain control (AGC)
  - ▪ Reference GPS L1 C/A code generator ✓
  - ▪ Timing phase control ✓
    - o Numerically controlled oscillator ✓
    - o Farrow interpolation filter ✓
  - ▪ Code acquisition block ✓
  - ▪ Code tracking loop block ✓
    - o Loop filter ✓
    - o Early-late gate detector ✓
  - ▪ Code lock detector ✓

- ❑ Controller state machine (in progress)

- ❑ Registers and 32-bit microprocessor interface

- ❑ AXI interface block for the receiver

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AFS PROGRAM: TEST STRATEGY

- Receiver Python model development ✓
- Validation of RTL design against Python model (in progress)
- Functional testing of RTL on the bench with third-party GPS generated stimulus
- Performance evaluation under various propagation conditions using channel emulator
- Software Interface CesiumAstro Transport Protocol (CTP) over RS-422
- Nasa Core Flight System (cFS) APP read over CTP

AFS PROGRAM: BENCHTOP PACKAGING
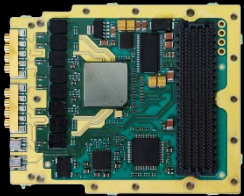
RF Mezzanine EM
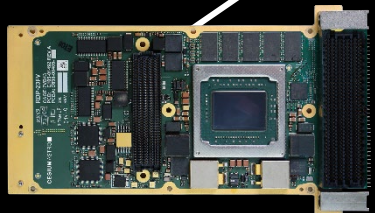
RDP Baseboard EM

Open Frame Chassis
- Integrated backplane
- Custom rails to accommodate module clamshell housing
- Integrated ATX power supply

3U RTM

- Open frame chassis to facilitate troubleshooting
- COTS power supply and air-cooled COTS chassis
- COTS power and ground backplane with support of RTMs
- EM Version of the SDR-2104 (form, fit, and function)
- Development Kit will be comprised of the following:
  - SDR-2104 or RDP EM Card Slice
  - Test Equipment, 3U VPX Power and Ground Platform, ELMA, 39E01BWX6ZY2VCC0-T2
  - PCBA, 3U VPX, Universal Rear Transition Module
  - Board Support Package for Custom sw/fw development

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AFS PROGRAM: INTERFACE EMULATOR

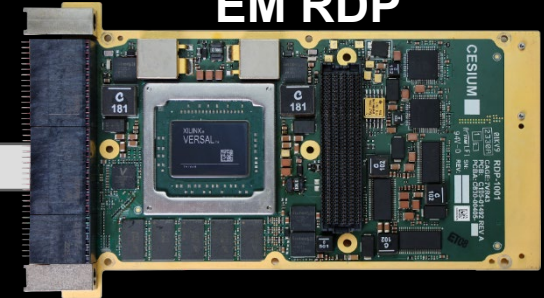**EM SpaceVPX Backplane**
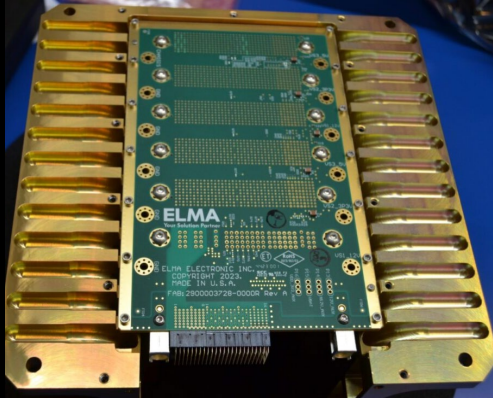
EM Chassis

Interface Emulator

R & D USE ONLY

J8 J10 J12
J7 J9 J11
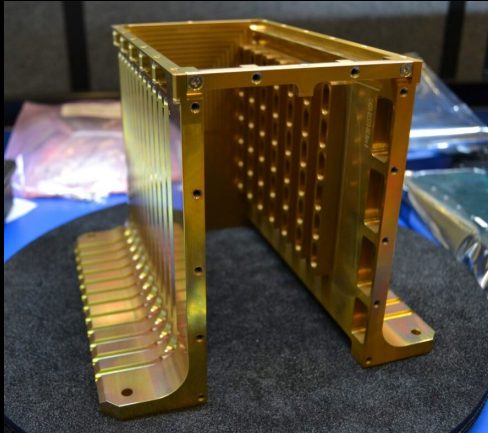
EM I/O Card

EM RDP

COTS OpenVPX Power Card

Interface Emulator for digital flight-like testing, RF components removed

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THE FUTURE IS NOW

- CesiumAstro is strategically positioned to be an infrastructure communication, position, timing, and navigation payload provider for a variety of upcoming missions

    - CesiumAstro is providing hardware and software for present and upcoming missions

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THANK YOU

CESIUM ASTRO ■

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[4]

REFERENCES

[1] LunaNet Interoperability Specification Document Draft Version 5 August 31, 2023.

[2] LunaNet Signal-In-Space Recommended Standard - Augmented Forward Signal (LSIS), Draft Version 1, August 31, 2023.

[3] Grenier, A., Giordano, P., Bucci, L., Cropp, A., Zoccarato, P., Swinden, R., & Ventura-Traveset, J. (2022) Positioning and velocity performance levels for a lunar lander using a dedicated lunar communication and navigation system. NAVIGATION, 69(2).

[4] https://www.nasa.gov/image-article/nasa-releases-new-high-resolution-earthrise-image-2/

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APPENDIX: ESA ANTENNA COMPARISON TO GIMBAL

Gimbaled Antenna Considerations
- Gimbal mechanisms complex, higher mass and volume
- Mechanical failure risk, lifespan depends on pointing duty cycle
- Requires deployment and operation software

Static Antenna Considerations
- Simple, requires SC attitude maneuvering, increasing effector duty cycles
- Not ideal for relay comms

Active Phased Array Considerations
- Beam steering without moving parts, eliminating mechanical failure points
- Fast, adaptive beamforming
- Multiple simultaneous links
- Resilient to Lunar dust and thermal cycling, no exposed mechanism to seize or degrade

Active Phased Array ideal for Lunar Relay:
- ✓ **Adaptive Communication**
- ✓ **Multi-link Capability**
- ✓ **Long-term reliability**