Radiation Dose Monitoring for Future NASA Programs

20th Anniversary Symposium on Medipix and Timepix

Sept 18, 2019

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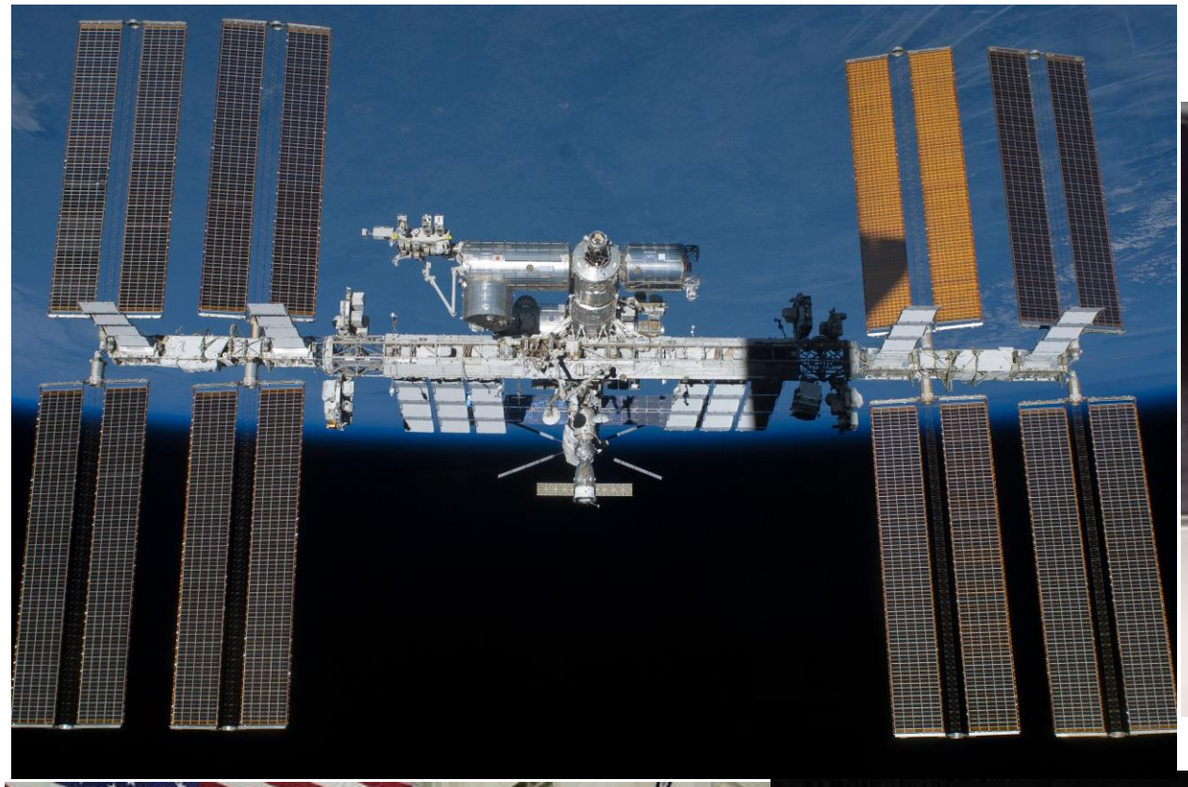
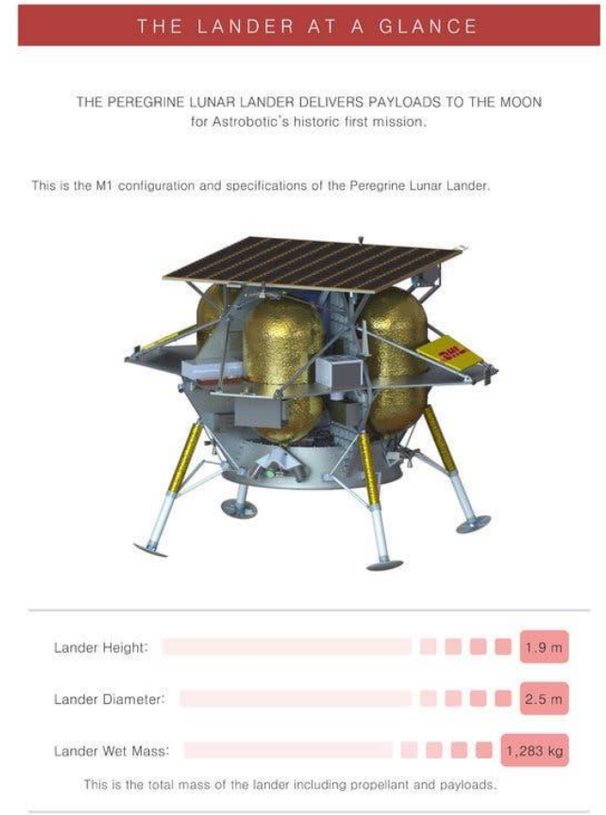
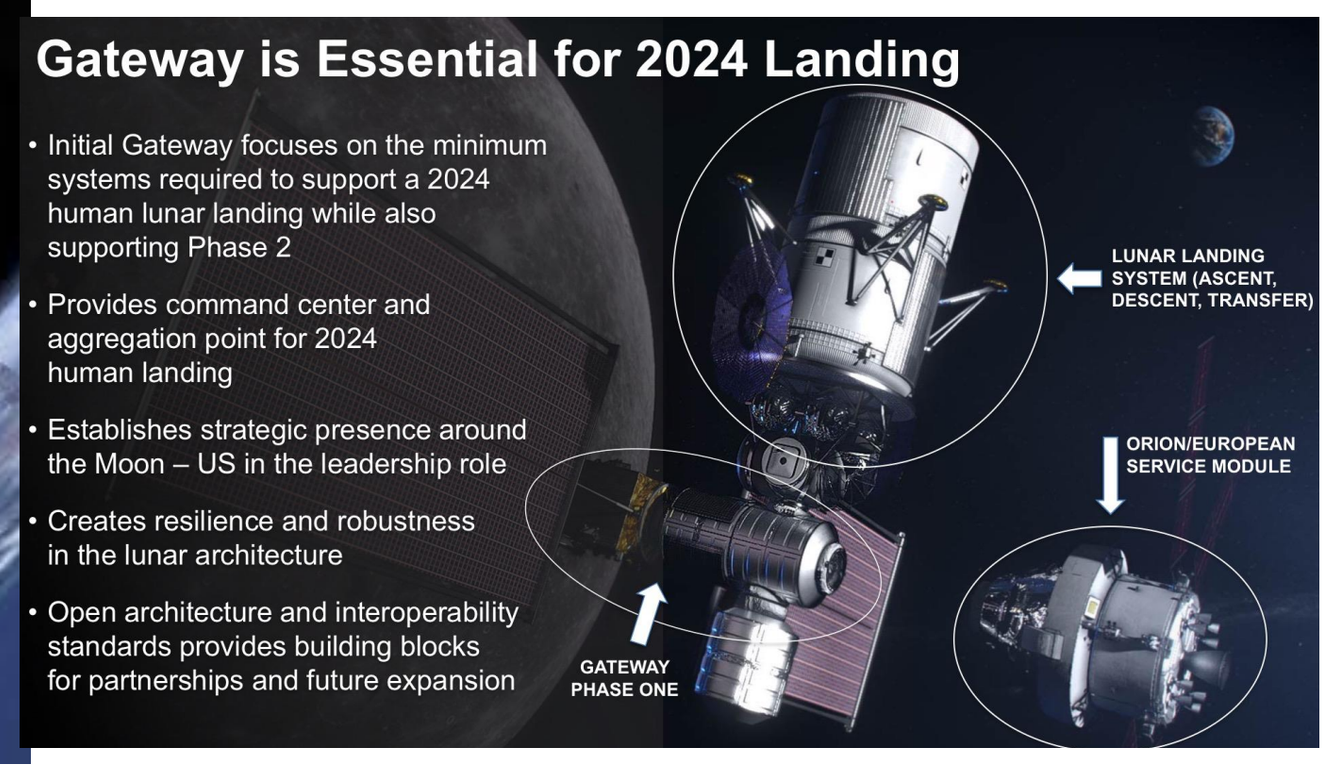
On behalf of the NASA Radworks Project

NASA JSC Space Radiation Analysis Group

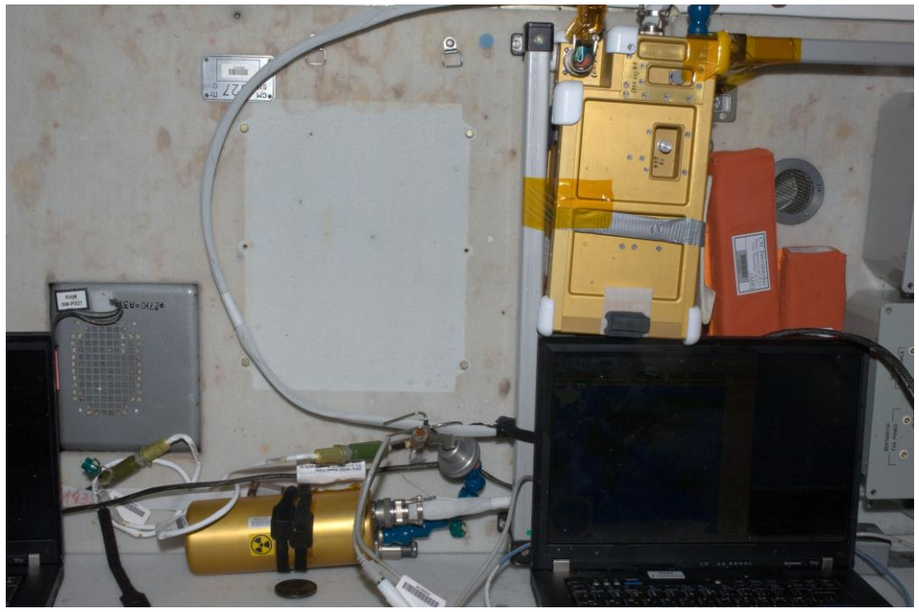
Vehicle Platforms







Why Timepix??



- Dose Monitoring for Space Shuttle relied on mix of distributed passive detectors and a tissue equivalent proportional counter (TEPC)

- ISS system evolved from Space Shuttle system to include numerous distributed passive detectors, a new TEPC design and ultimately a charged particle telescope/neutron spectrometer was developed.

As plans for Exploration missions beyond ISS-LEO were being developed, it became clear that more robust, low mass, systems would be needed (and no passive detectors)

<u>Main Advantages Recognized</u>

- Small mass, volume. Low power
- Large dynamic range in LET and flux/dose rate measurements possible
- Single layer particle identification

Past NASA Flight Dosimetry Projects using Timepix

All developed by the NASA Advanced Exploration Systems (AES) Project: RadWorks

- ISS Radiation Environment Monitor (REM)
  - Technical demonstration of Timepix aboard ISS
  - USB communication with ISS laptops
- Battery-operated Independent Radiation Detector (BIRD)
  - Fully independent of Orion vehicle systems
  - Used to make first measurements inside Orion in high altitude Earth orbit

Launched on Progress 48
1 August 2012
Our 7 year Anniversary

ISS Radiation Environment Monitor (REM)

CERN Accelerating science

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Timepix detectors track cosmic radiation on the ISS

On 31 July, an unmanned Russian Progress spacecraft was launched from Kazakhstan, carrying five Timepix detectors to the ISS

2 AUGUST, 2012 | By Katarina Anthony

Timepix detectors are USB-powered particle trackers based on Medipix technology developed at CERN. Each detector consists of the Medipix chip coupled to a silicon sensor and incorporated into a readout system about the size of a USB pen drive, developed at the Institute of Experimental and Applied Physics (IEAP) in Prague, Czech Republic.

The detectors have been used in a variety of disciplines from the study of cosmic rays to biomedical imaging. Now NASA is using them on board the ISS to accurately monitor radiation doses in space.

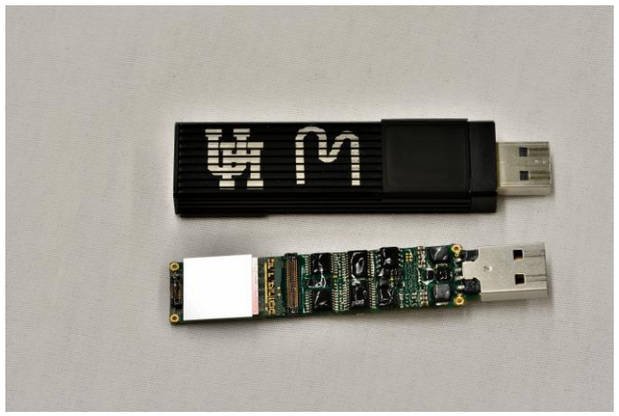
"There's nothing else in the world that has quite the capability of Timepix detectors to identify individual

Related Articles

From CERN to the clinic
Knowledge sharing | News | 29 May, 2018

Particle detectors meet

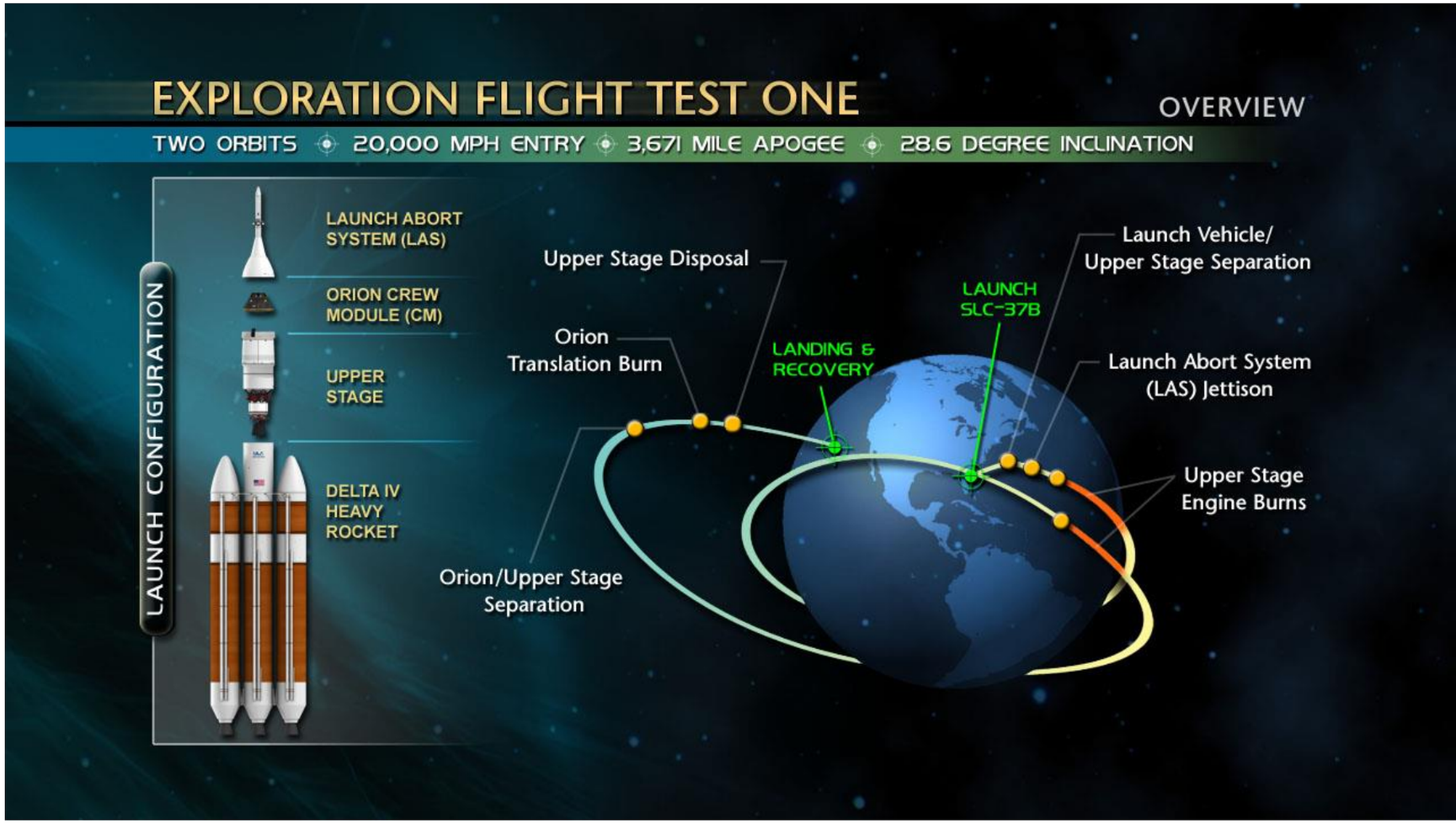
RADIATION ENVIRONMENT MONITOR PAYLOAD[1]



→ Modified IEAP Timepix Lite Units
- → 5 delivered to ISS in 2012
  - → 9 units flown in total
    - → 3 units currently on ISS
  - → 2 functioning and 1 disconnected
    - → 300 and 500 μm sensors
- → Payload support end in 2019

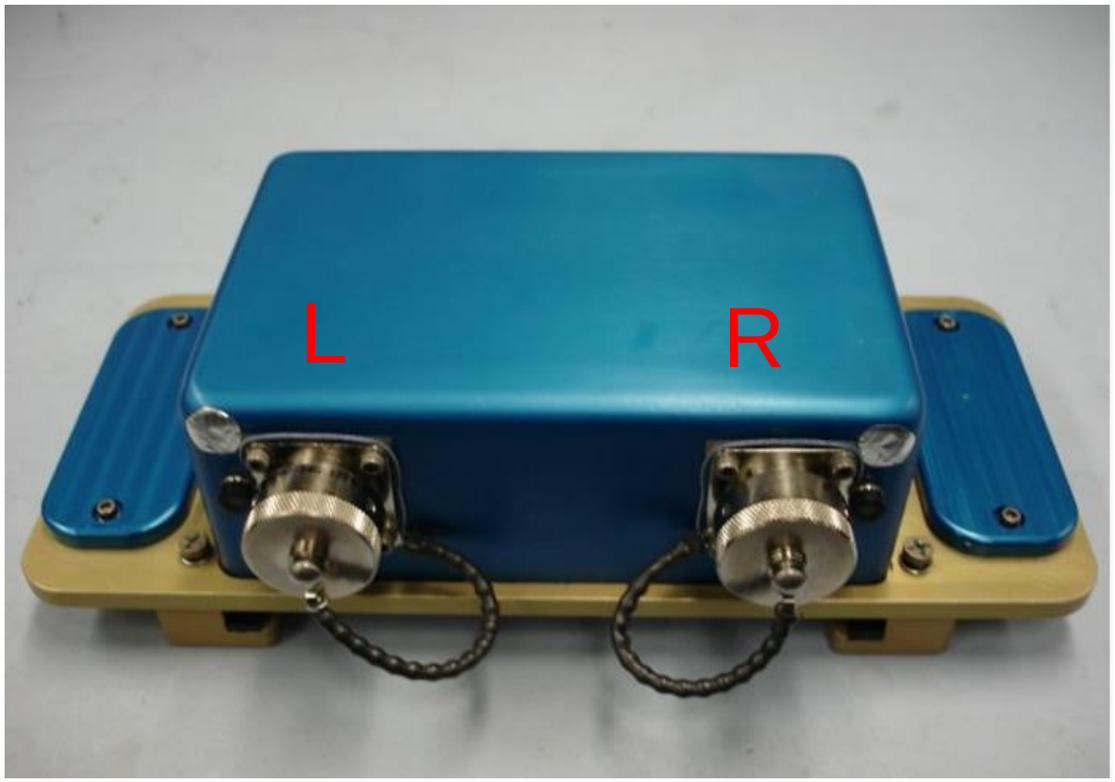
[1] N. Stoffle et al., *Timepix-based radiation environment monitor measurements aboard the International Space Station*, Nuclear Instruments and Methods in Physics Research A **782** (2015) 143–148.

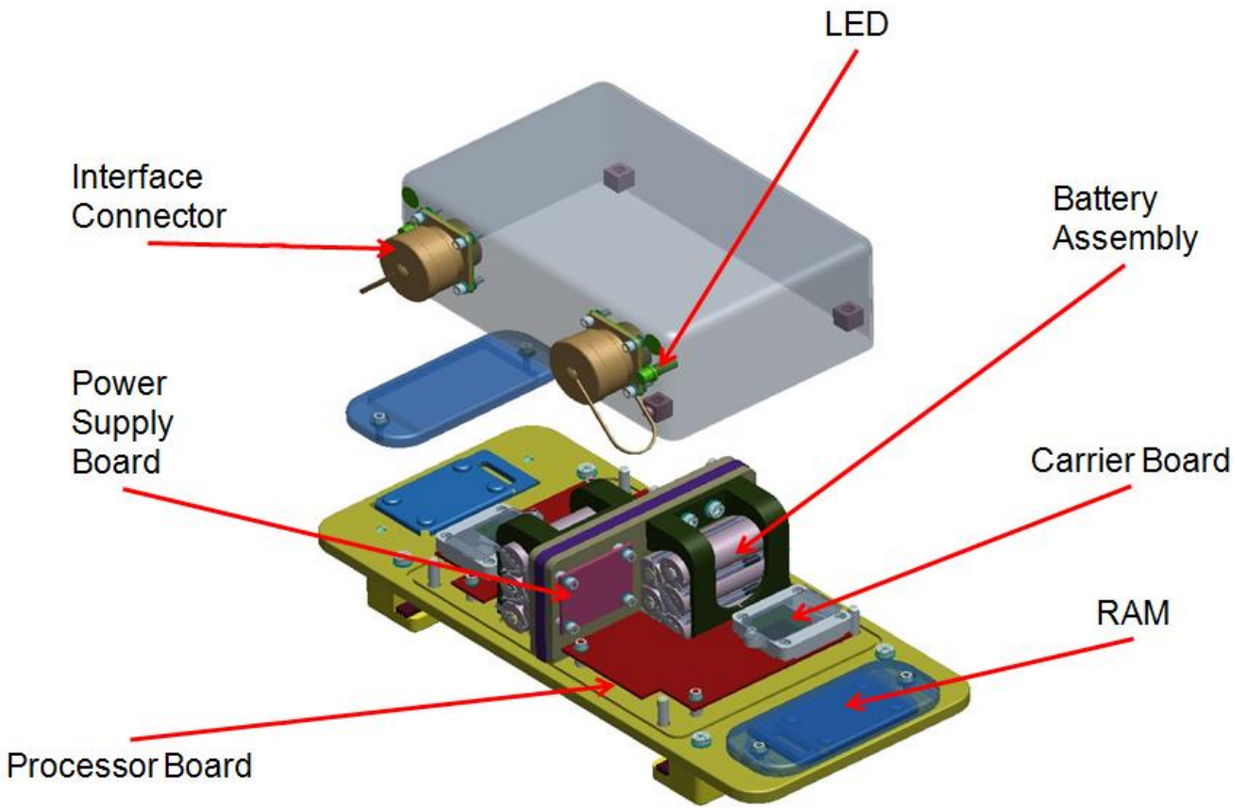
Exploration Flight Test-1 (EFT-1)



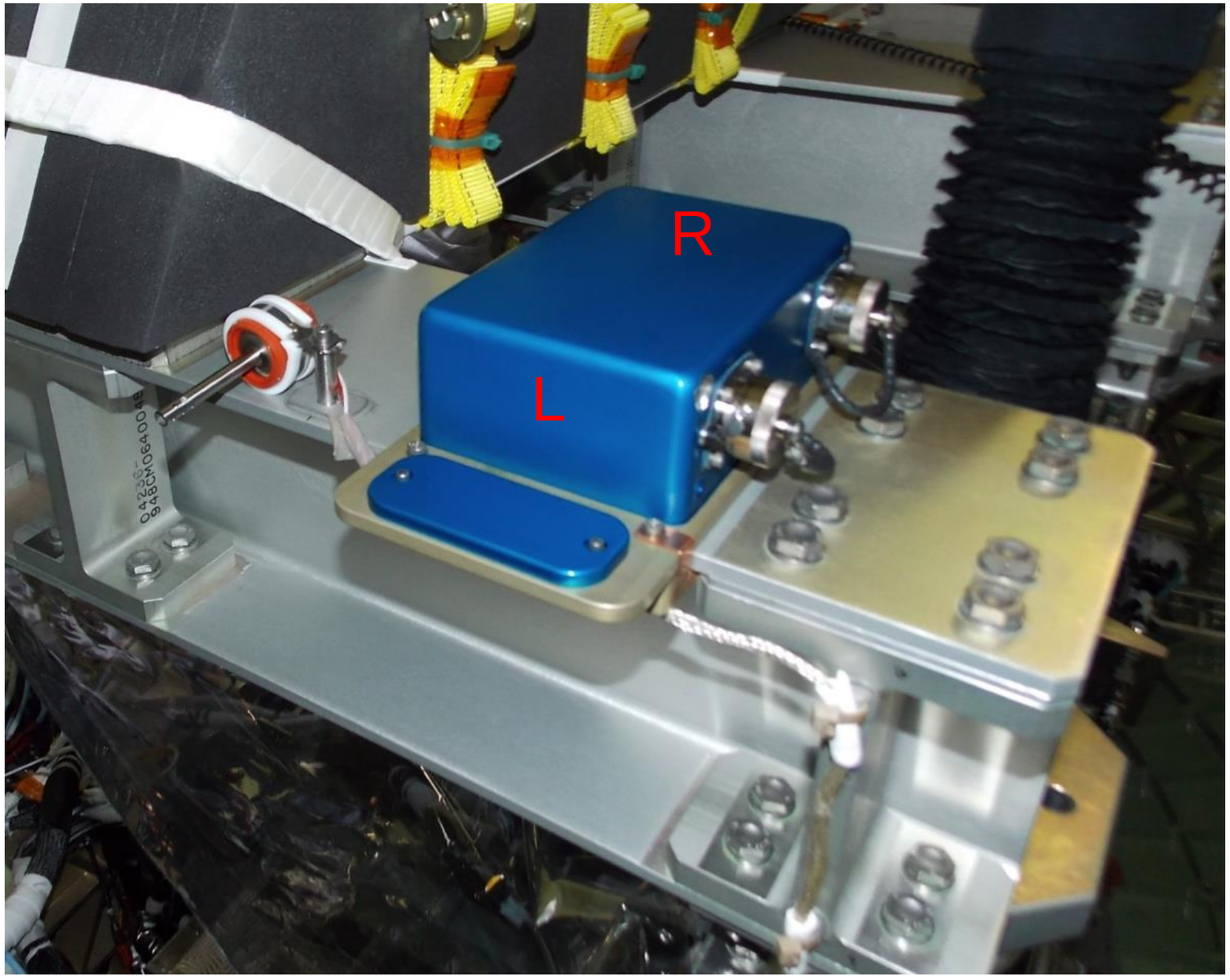
First test flight of the Orion Multi-Purpose Crew Vehicle. Without a crew, it was launched on December 5, 2014

BIRD – Battery-operated Independent Radiation Detector



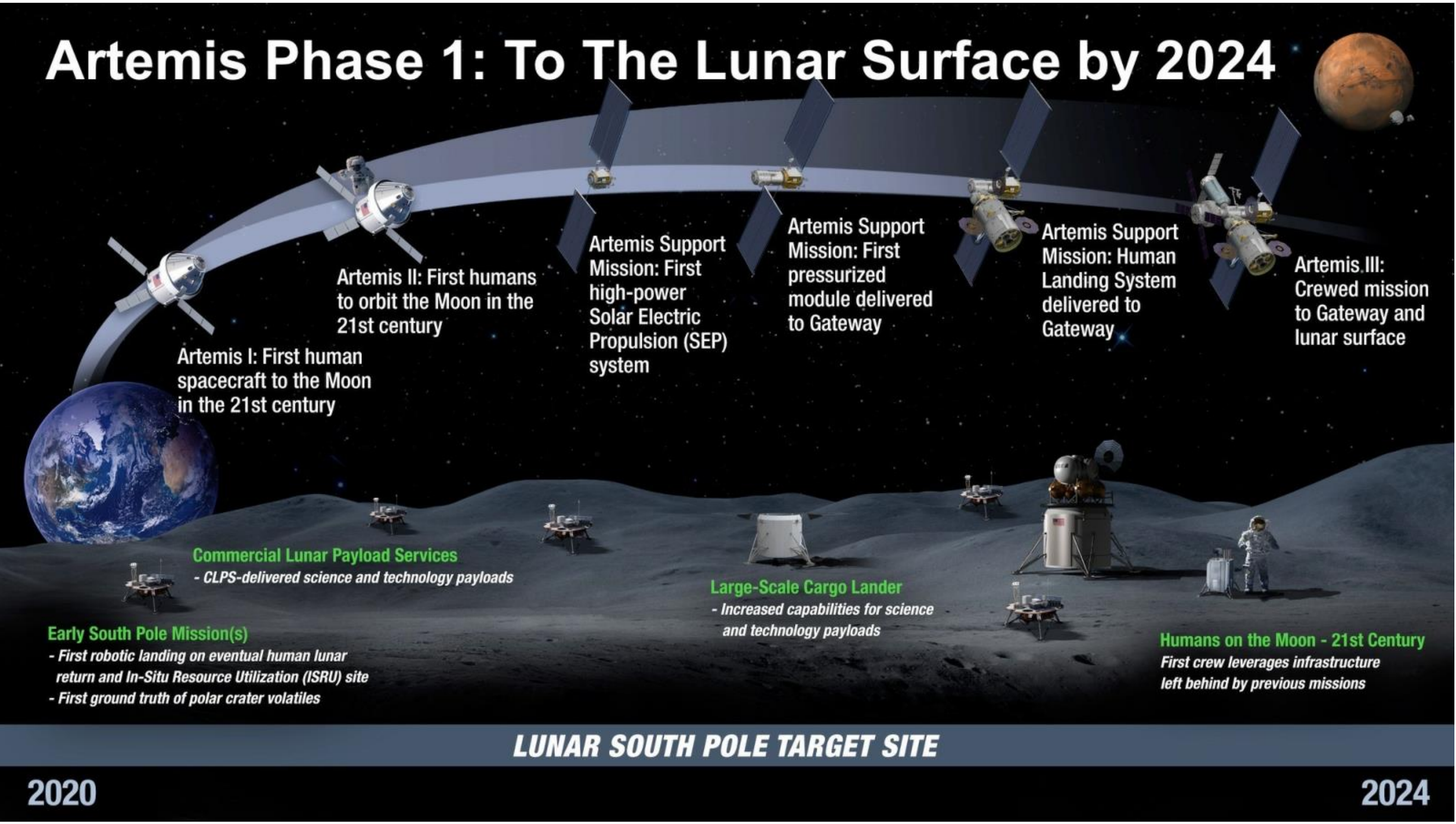


Installation on Orion



What are the Future Programs?

NASA's Exploration Plans – Lunar 2024



Achieving 2024 – A Parallel Path to Success

Artemis will see government and commercial systems moving in parallel to complete the architecture and deliver crew

CREW

NASA Programs SLS and Orion

Artemis I

First flight test of SLS and Orion as an integrated system

Artemis II

First flight of crew to the Moon aboard SLS and Orion

Artemis III

First crew to the lunar surface; Logistics delivered for 2024 surface mission

Between now and 2024, U.S. industry delivers the launches and human landing system necessary for a faster return to the Moon and sustainability through Gateway.

Commercially Provided Elements

CARGO

PPE

Power and Propulsion Element arrives at NRHO via commercial rocket

Pressurized Module

Small area for crew to check out systems prior to lunar transfer and decent

Human Landing System

Transfer

Transfers lander from Gateway to low lunar orbit

Descent

Descends from Transfer Vehicle to lunar surface

Ascent

Ascends from lunar surface to Gateway

Up to three commercial rocket launches, depending on distribution of the Transfer, Descent, and Ascent functions

Current-Future NASA Flight Dosimetry Projects using Timepix

All developed by the NASA Advanced Exploration Systems (AES) Project: RadWorks

- Radiation Environment Monitor 2 (REM2)
  Will provide long term dose monitoring for

- Hybrid Electronic Radiation Assessor (HERA)
  Complete integration in Orion

- Linear Energy Transfer Spectrometer (LETS)
  Commercial Lunar Payload Services (CLPS)
  Astrobotic mission to l

RADIATION ENVIRONMENT MONITOR 2 - HARDWARE UPDATES

Goal: Replace passive detectors with active instruments

→ Flight certification of Advacam MiniPIX units
and USB cables

→ 7 units/cables flown on SpX-16

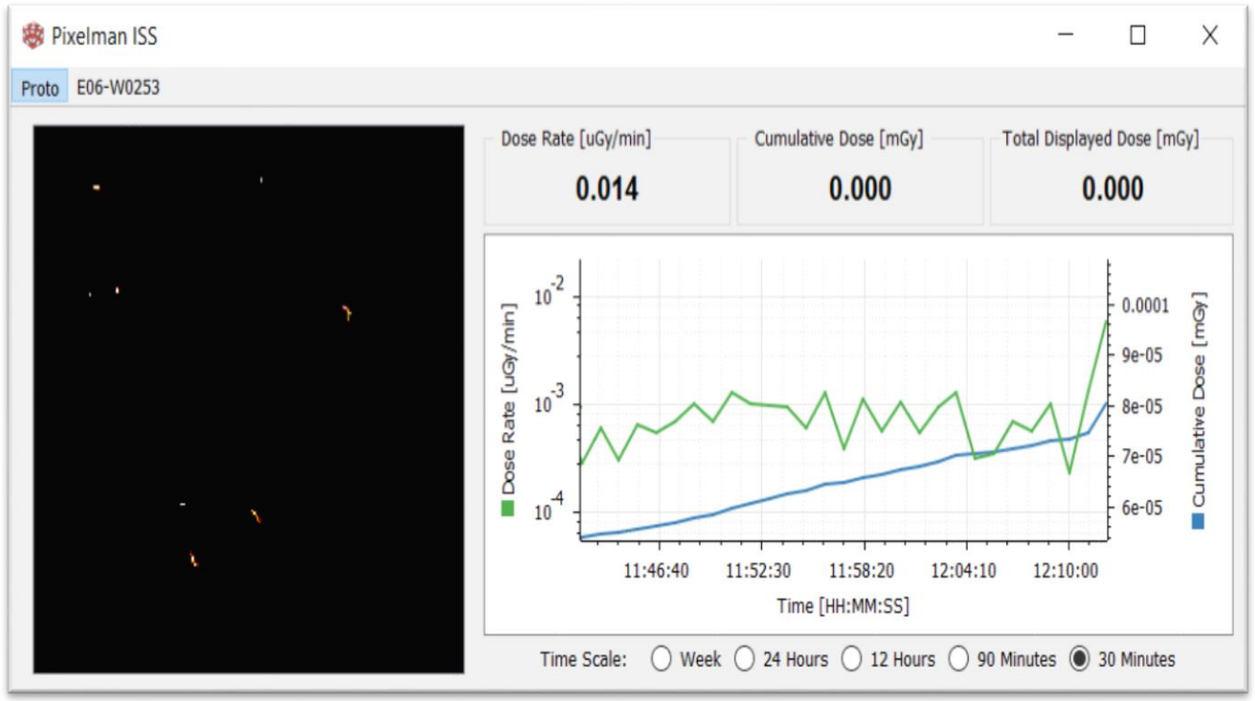
→ 6 flight spares ready for manifest

Benefits:

→ Increase cadence of area monitoring data

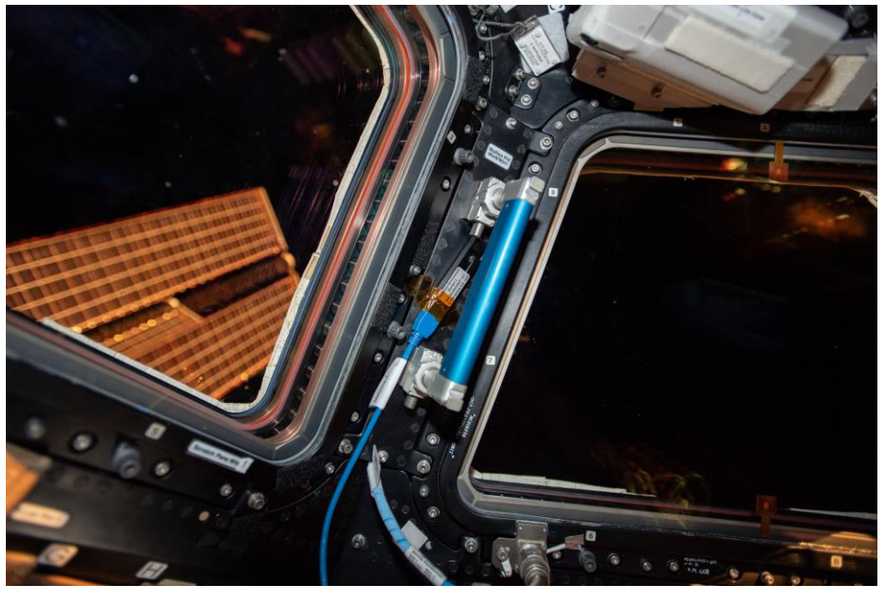
→ Minimize up/down mass

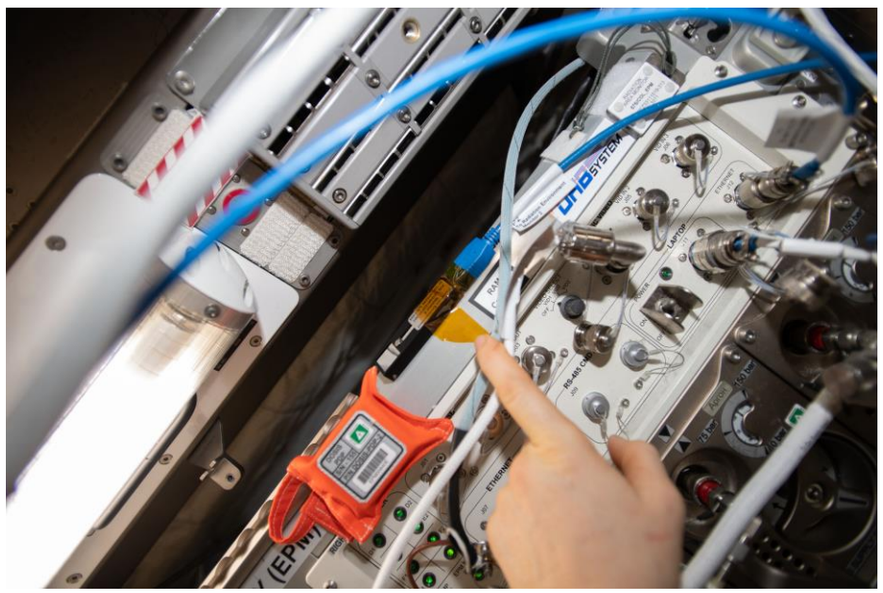
→ Reduce crew time for passive hardware retrieval/deploy

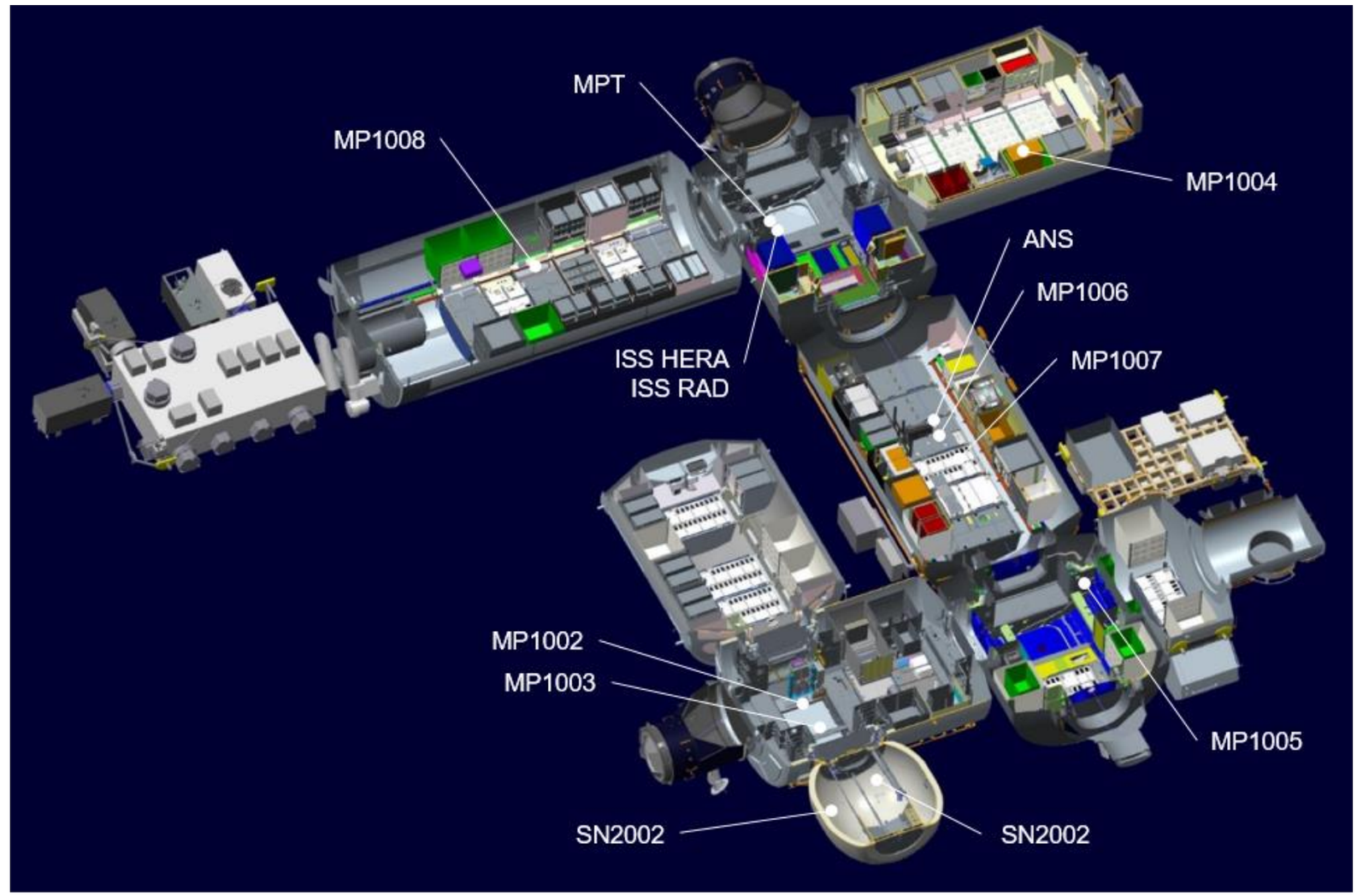


REM2 On-orbit Crew Display (PixelmanISS v2.0.0)

REM2 Locations







HYBRID ELECTRONIC RADIATION ASSESSOR (HERA)

→ Primary Exploration Mission monitoring hardware

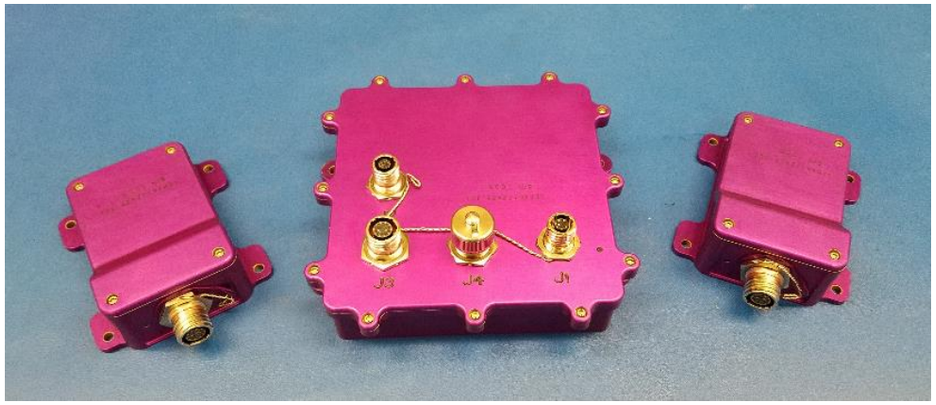
HERA (Hybrid Electronic Radiation Assessor) is a radiation detection system for the Orion MCPV

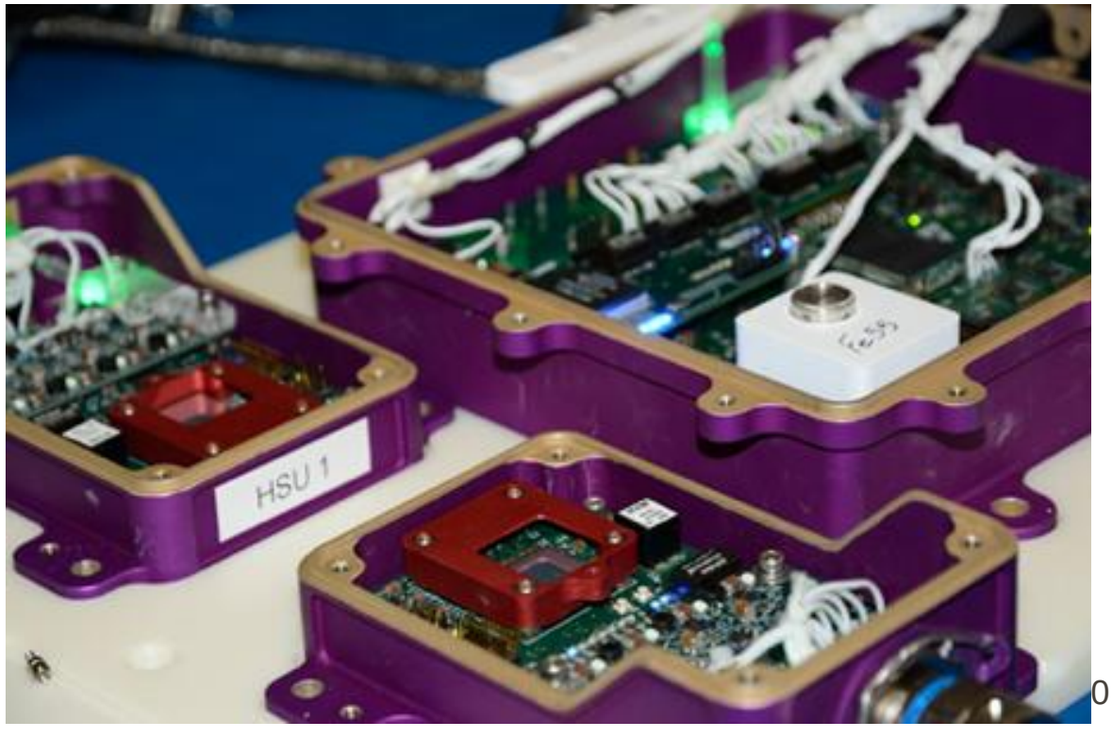
Primary duties are monitoring crew vehicle radiation levels and caution and warning

HERA consists of a central Hera Processing Unit (HPU) attached to 2 separate Hera Sensor Units (HSU)

Both HSU's + the HPU contain a Timepix hybrid pixel detector

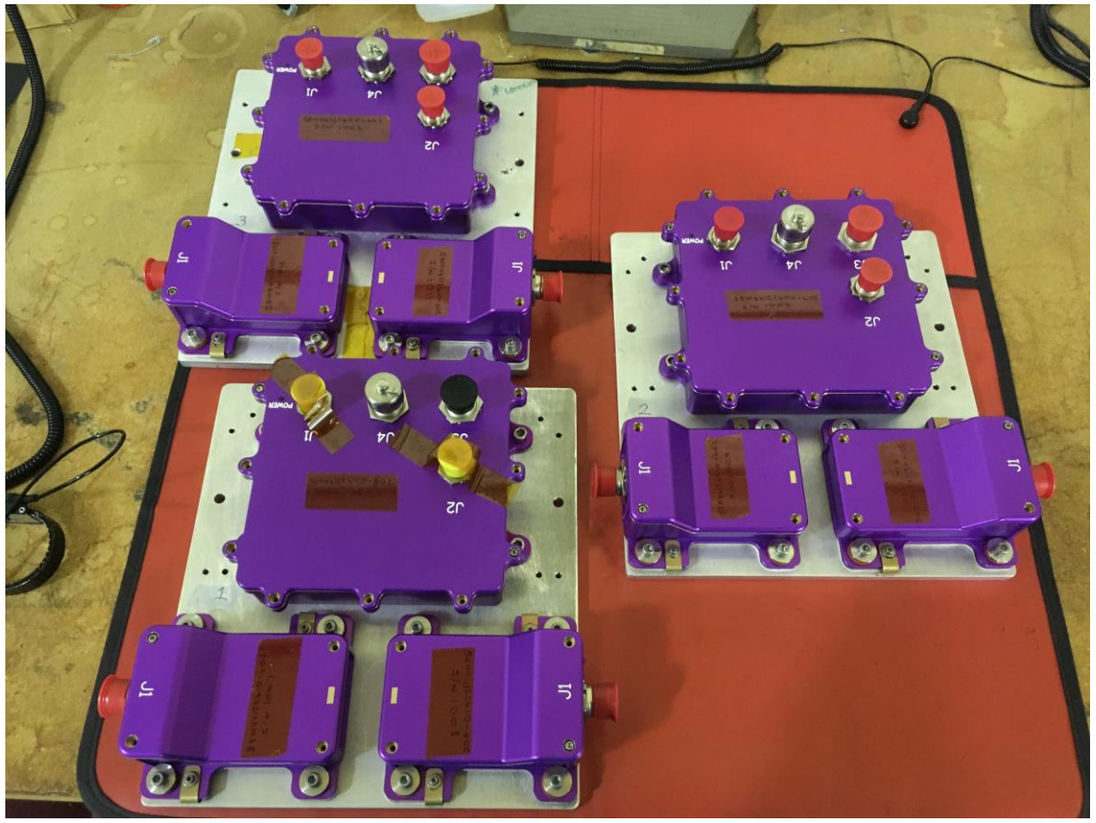
All data processing done on board, no raw data sent to ground





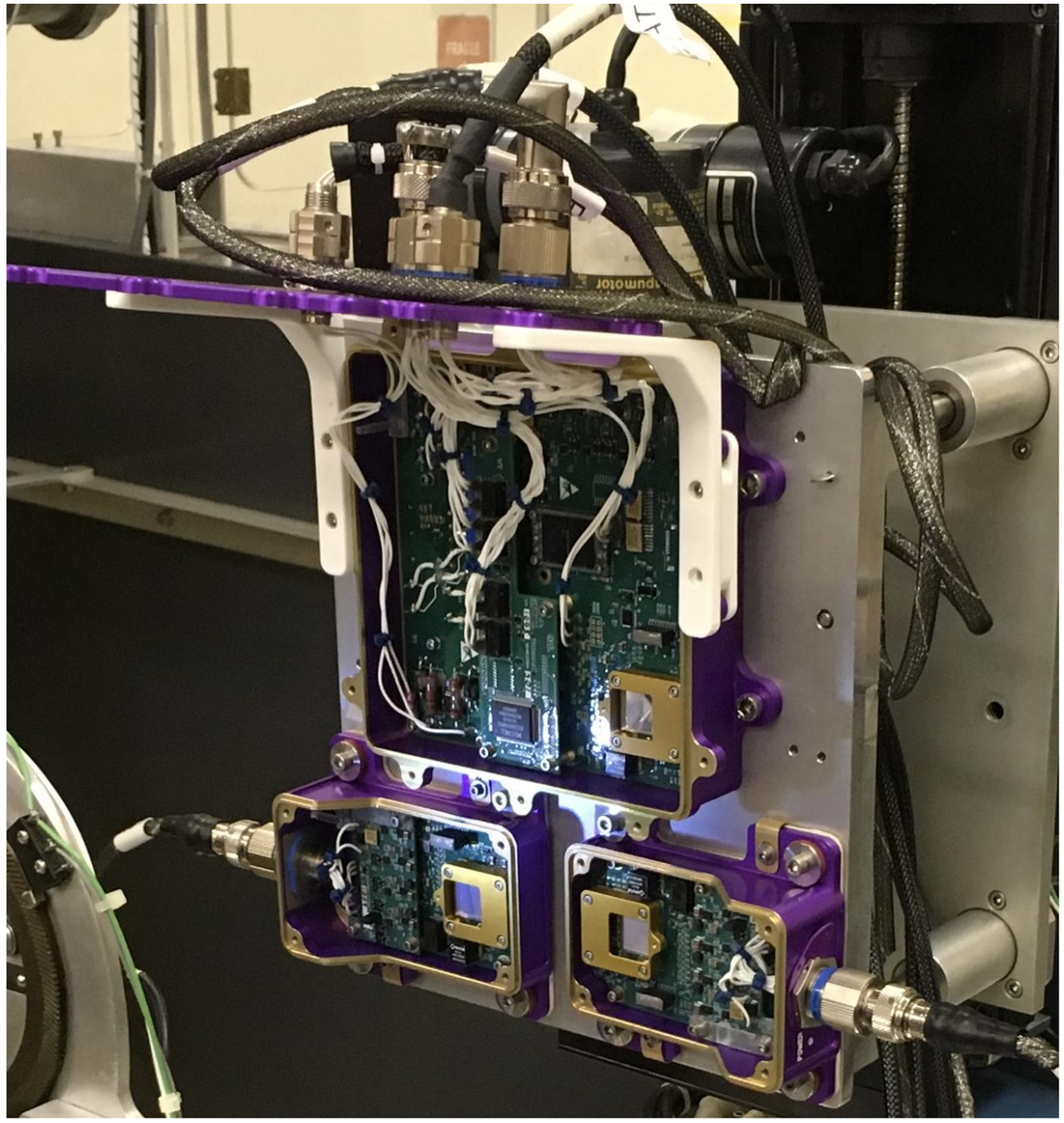
HERA Top Level Overview

- HERA for Artemis 2 is an upgraded system compared to A-1. Minor hardware changes and significant software upgrade (binning + data).
- Each HERA string consists of an HPU (HERA processing unit) and two HSU's (HERA Sensor Unit)
- Each HPU and HSU contains a Timepix hybrid pixel detector (3 per string)
- HERA for A-2 consist of two independent HERA strings (6 sensors total, placed around MCPV). A-1 is a single string system.
- Data processing onboard to provide dosimetry, science data, crew display and caution and warning data
- Mass = ~1.5 kg (not including cabling), power consumption 8W



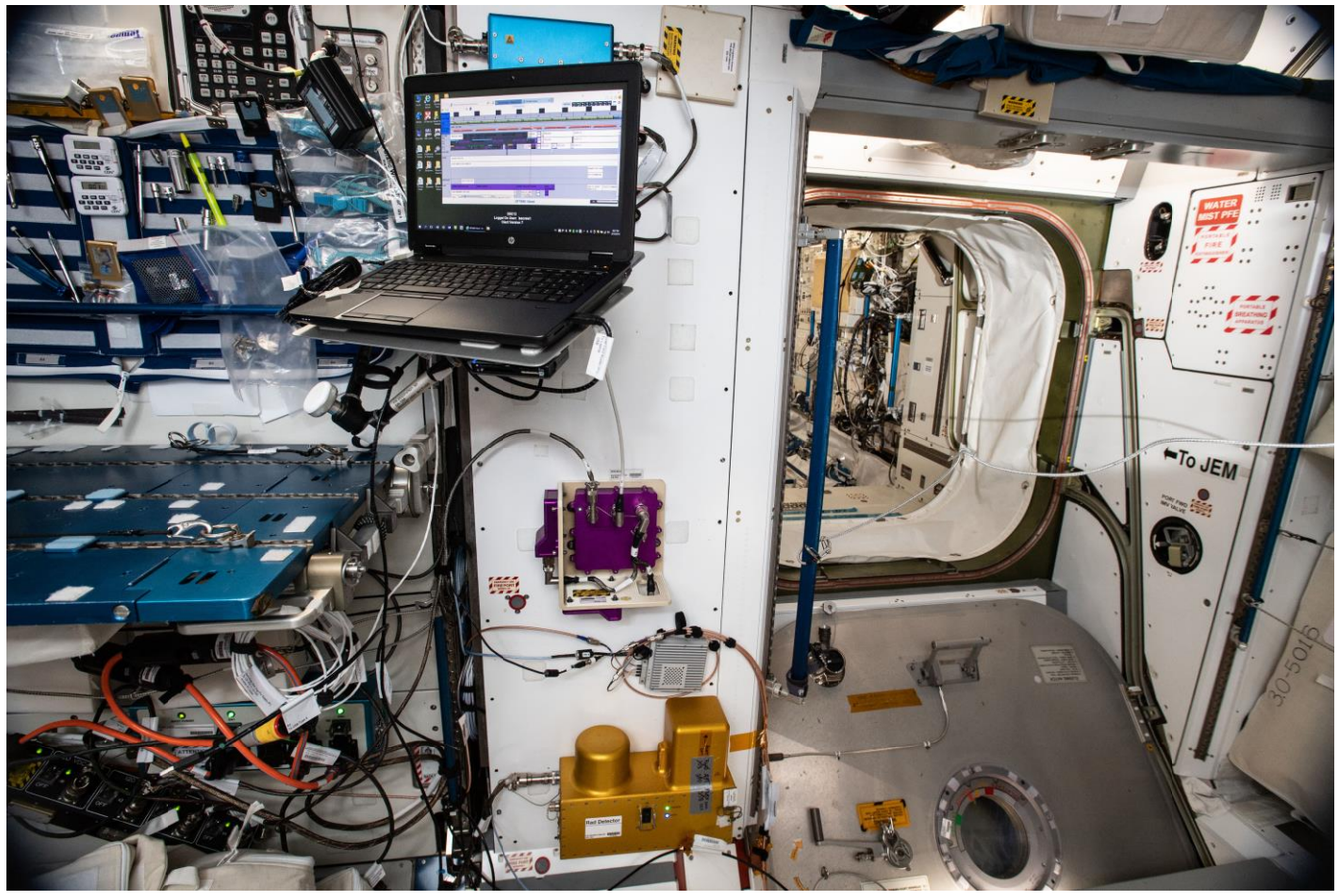
Three HERA Flight Strings during calibration at BNL Tandem

HERA Calibration



HERA String plugged in with lids open during calibration at BNL Tandem

ISS HERA PAYLOAD OBJECTIVES



ISS HERA deployed with RAD in Node 2

→ Test Artemis-1 HERA in the space environment

→ Verify system capability for 30+ days of continuous operation

→ Gain experience with hardware and data analysis in a mission environment

Artemis 2 Science Binning

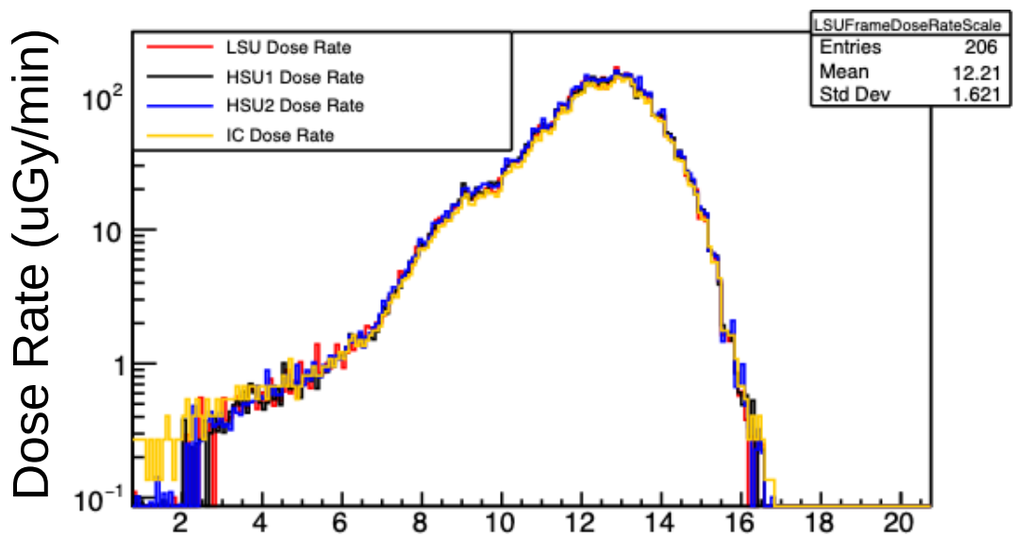
- HERA telemeters a 500 byte science message every minute
- Contains **per sensor dose rates** and **per sensor spectroscopic flux binning.**
- Flux bins on a 5 minute rotating schedule
- Flux binning turned off for high flux environments, between 100 uGy/min and 1 mGy/min depending on on spectral hardness of field.
- Science V&V testing at NSRL and CPC
- NSRL testing verifies spectroscopic capabilities
- CPC testing verifies dosimetry and flux measurer in a continuous charged particle beam.

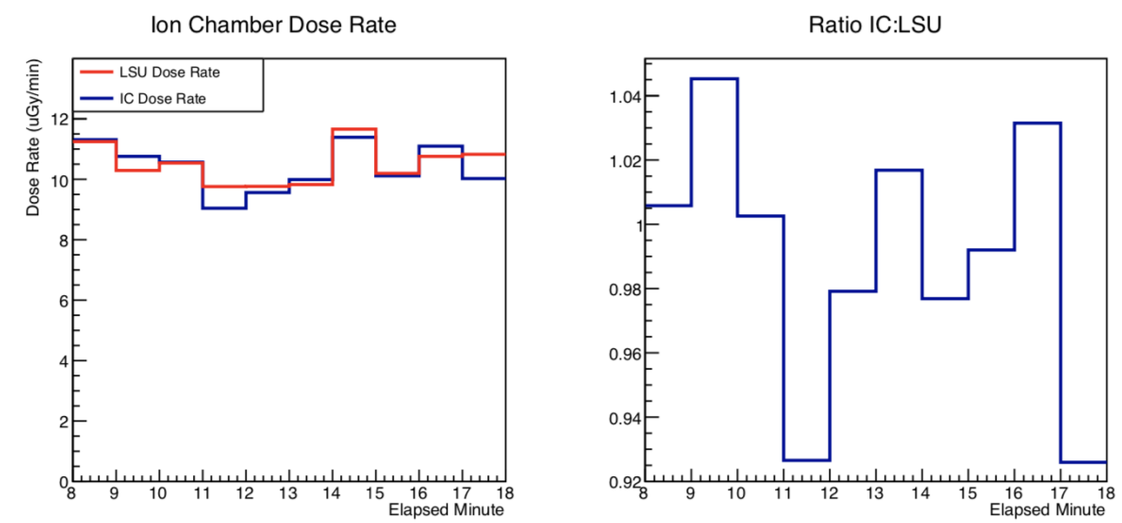
HERA Telemetry Binsets

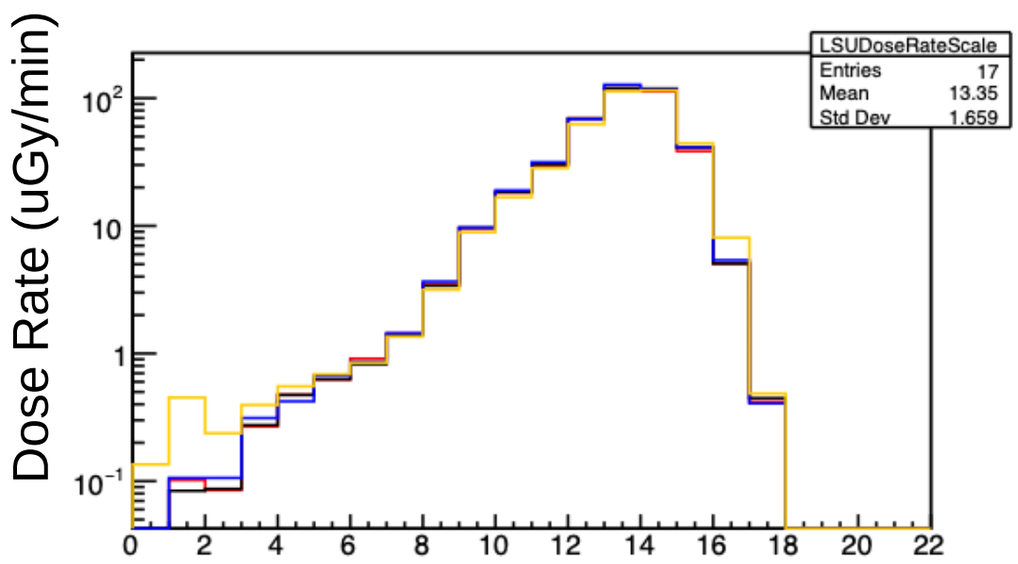
Binset	Description
1	All Proton Bins
2	Alphas/Photons/Electron/Unbin
3	CNO/Ne+/Interaction
4	LET (Log, 0.1-10 keV/um)
5	LET (Log, 10 - 1000 keV/um)

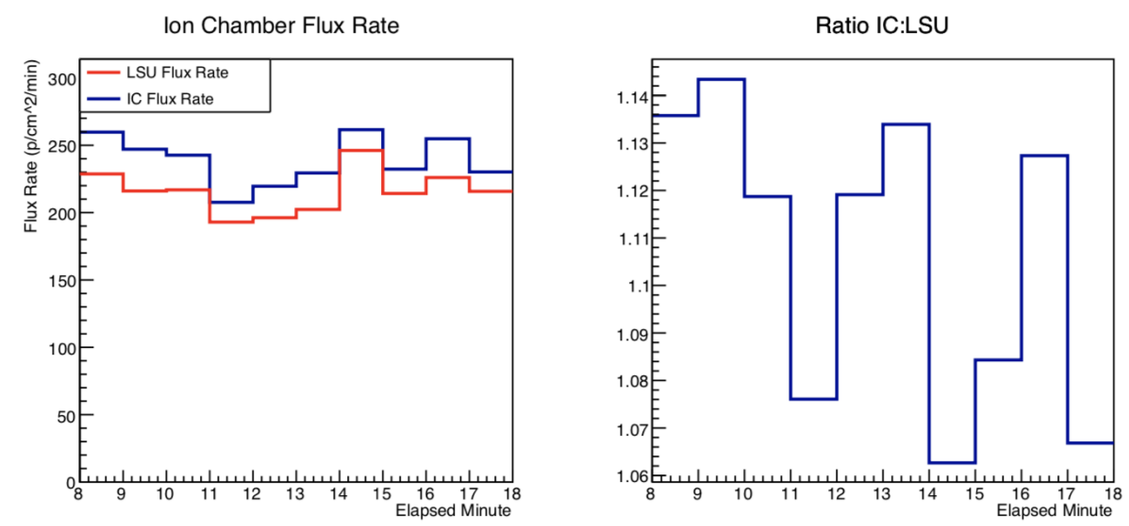
Bin	nBins	Energy Range	
Proton	21	5 MeV, 1 GeV+	~Log
Alpha	6	0 - 100 MeV+	Lin
CNO	19	100 MeV/A - 1.5 GeV/A	Log
Neon+	1	Inclusive	
Interaction	1	Inclusive	
Photon	13	5 keV - 50 keV	~Lin
Electron	1	Inclusive	

Dosimetry V&V at Chicago Proton Center







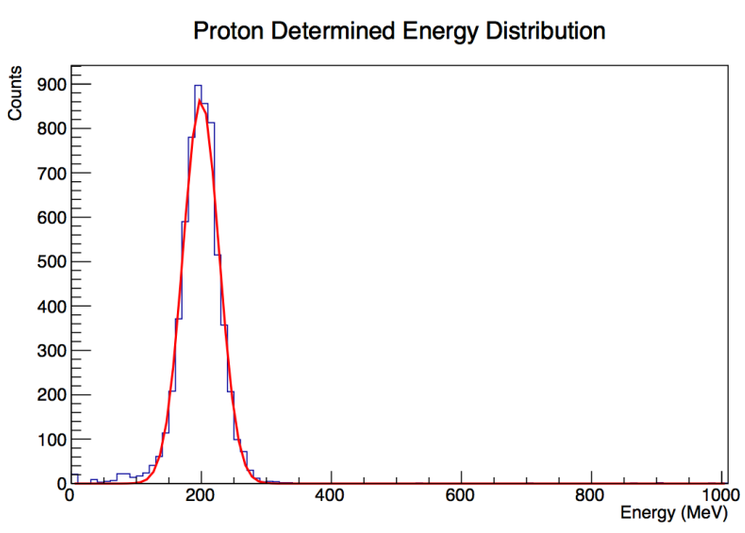


Simulated Belt Pass, 5 second bins from frame data (top), telemetry (bottom) vs Ion Chamber

10 uGy/min rate, HERA Telemetry Flux calculated only from particles identified as protons by binning algorithm

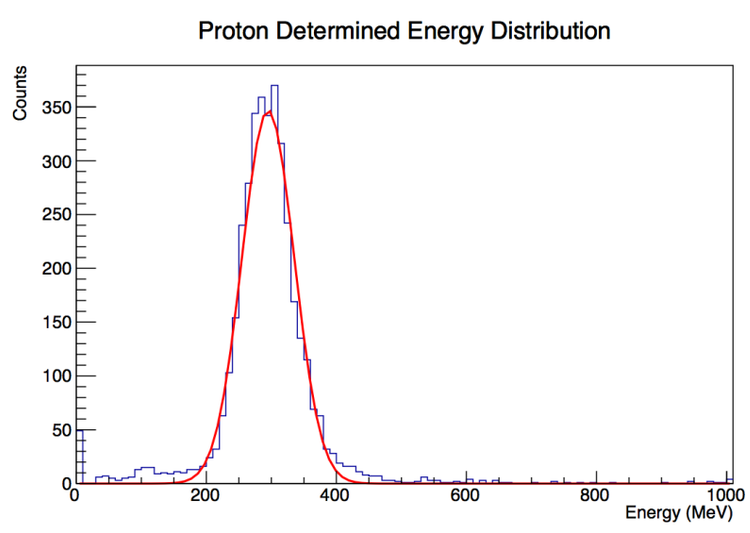
Particle Binning V&V at NSRL

- NSRL beam is a synchrotron with typical pulsed beam
- HERA configured to run with fixed frame lengths in order to test particle binning
- Shown below is determined proton energy using HERA GSE “extended” data.



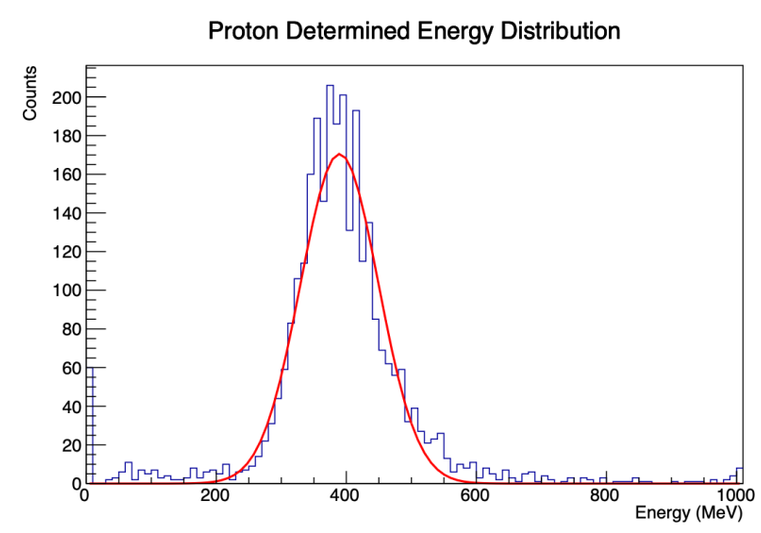
200 MeV Proton @ 60 Degrees

Mean = 199.4 MeV
Sigma = 27.7 MeV



300 MeV Proton @ 70 Degrees

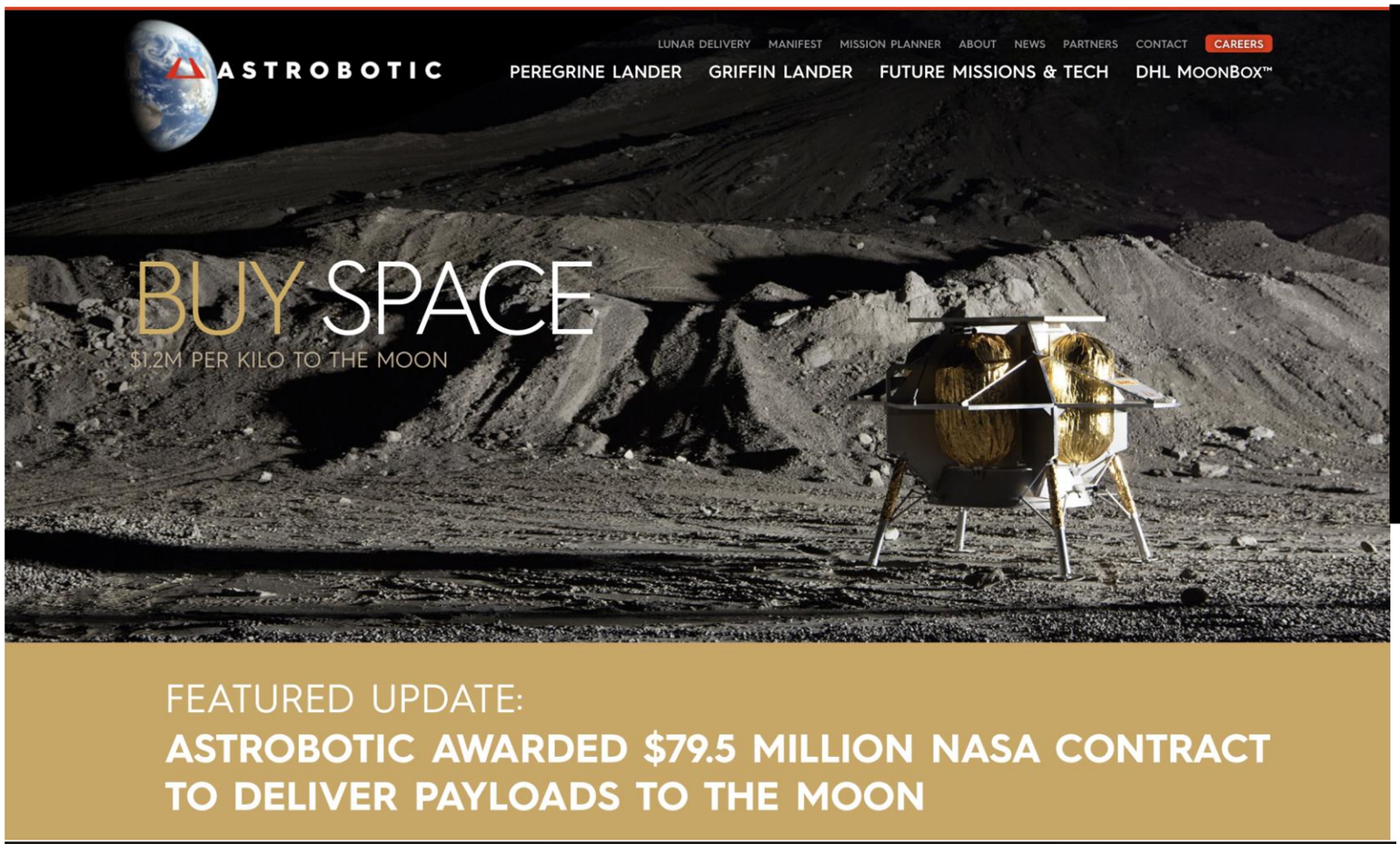
Mean = 295.6 MeV
Sigma = 48.69 MeV

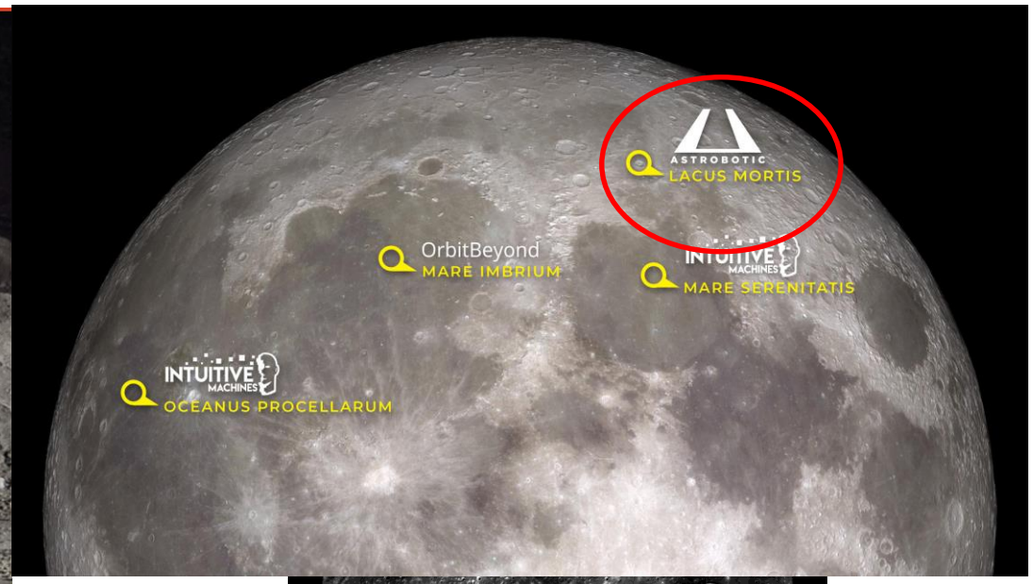


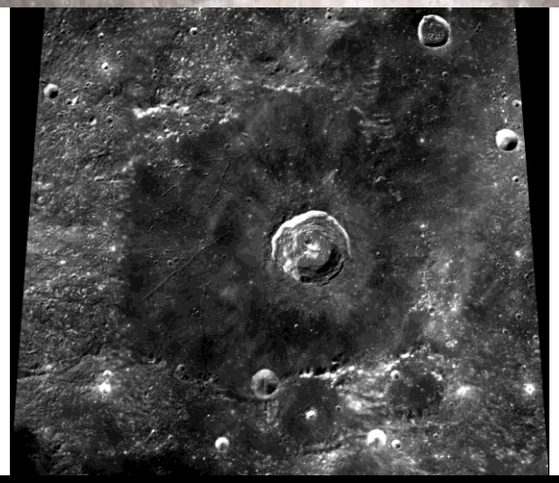
400 MeV Proton @ 70 Degrees

Mean = 381.47 MeV
Sigma = 59.9 MeV

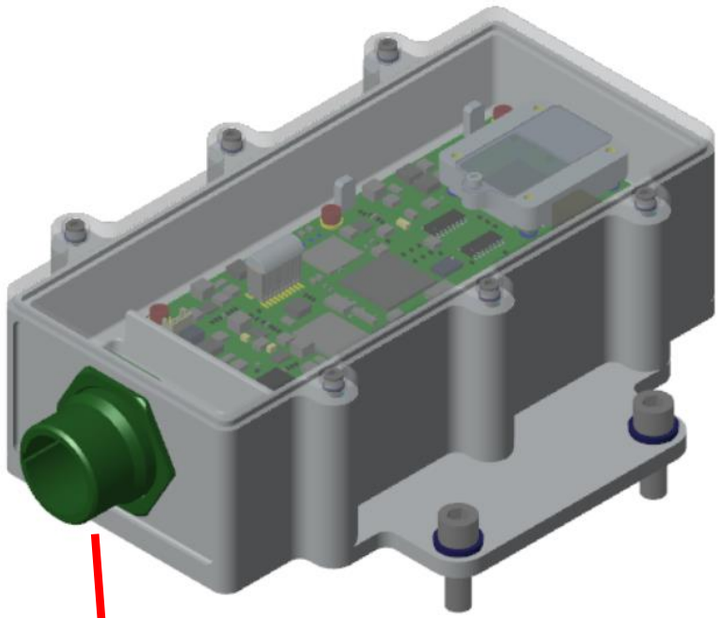
Linear Energy Transfer Spectrometer (LETS) on Astrobotic Lander

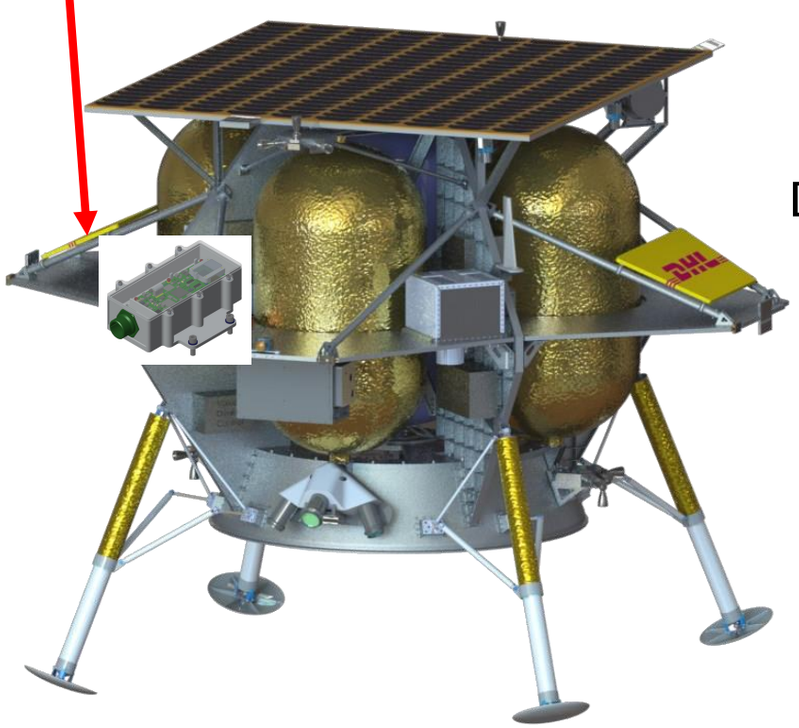


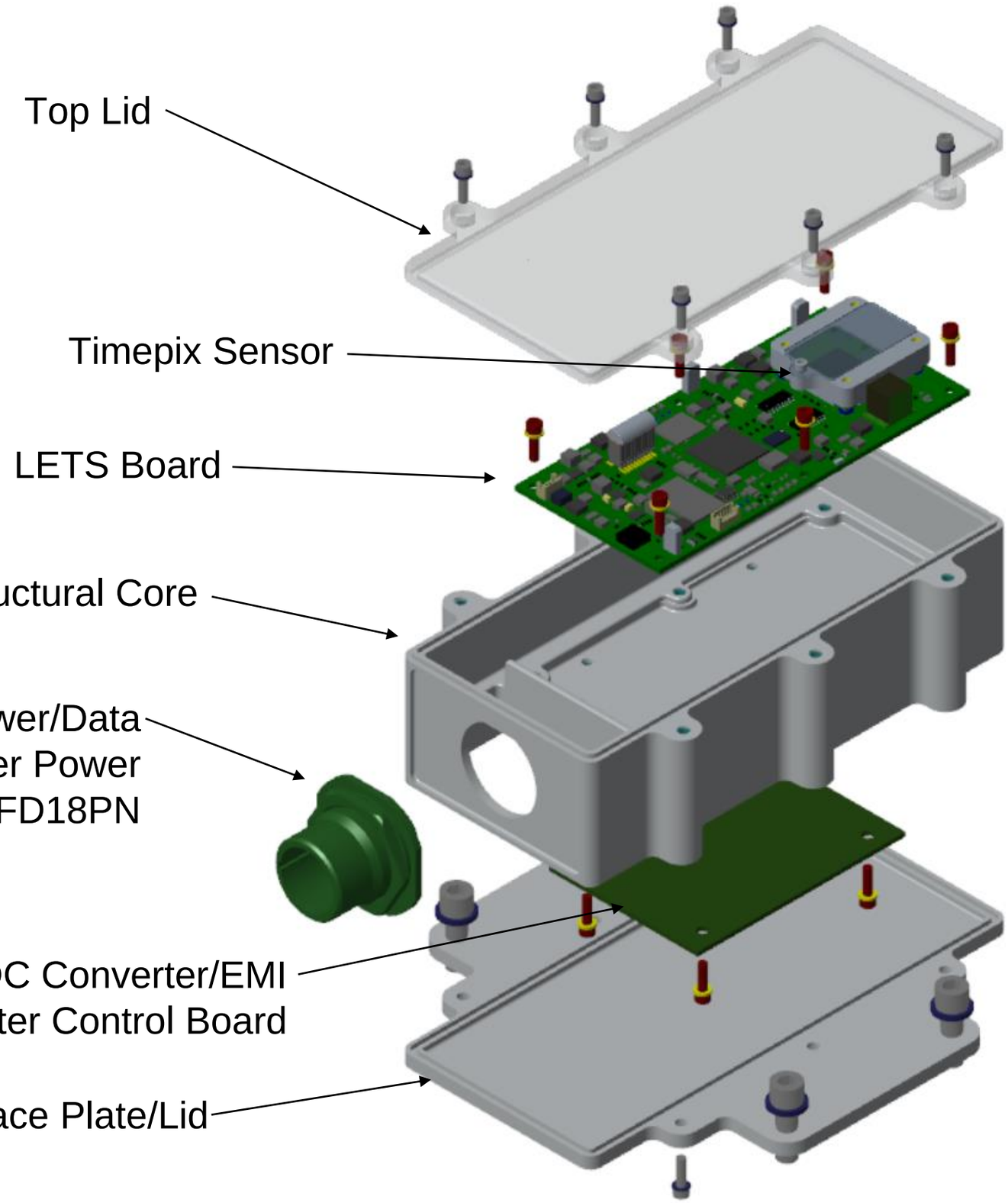




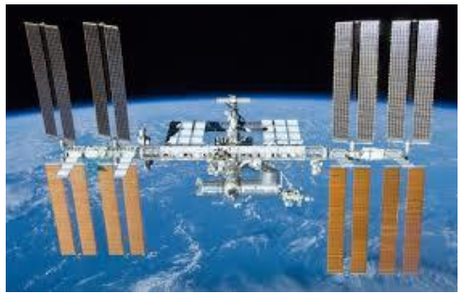
Linear Energy Transfer Spectrometer (LETS) Mechanical Design



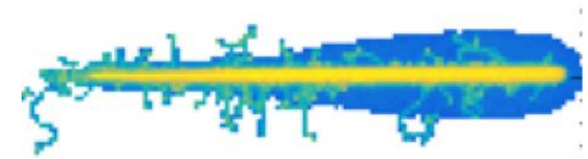




NASA Space Dosimetry with Timepix

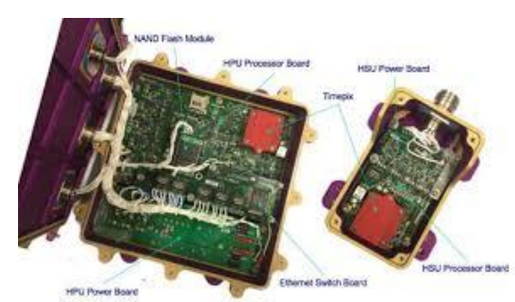


- Pixel detectors like Timepix directly image radiation track structure (like digital nuclear emulsion). Each track can be processed to reveal particle information.
- Pixel detector advantages for space are size, weight, power consumption and particle ID capabilities.
- REM2 (Radiation Environment Monitor) -> Single silicon Timepix + readout on laptop, data to ground from ISS
- BIRD (Battery operated radiation detector) -> Two Timepix + readout + onboard storage. Flew on Orion ETF 1 in 2014.
- HERA -> Three Timepix + readout + processing. For Orion capsule as part of Artemis program. Telemetry (Dose, LET and particle spectra) to ground. Currently flying on ISS.
- LETS (Lunar Linear Energy Transfer Spectrometer). Single Timepix + readout + processing ("Mini HERA"). Flying to moon 2021 as science instrument as part of NASA Commercial Lunar Payload services program.



Example measured track of SINGLE Si ion. Color is a calibrated energy scale. Processed to calculate deposited dose, LET and particle ID.

REM Detector on ISS



HERA Detector (Processing Unit (left), Sensor Unit (right)

Summary

- Successful transition of REM2 for dose monitoring inside ISS replacing passive detectors

- HERA for Artemis 1 complete and installed in Orion
  Key product for HERA is monitoring dose rates at various location inside Orion: tested up to 10 mGy/min.
  Also provides secondary science products -> LET and particle binning.

- HERA for Artemis 2 and beyond is on schedule to support planned mission dates

- LETS development on track for delivery to Astrobotic in April 2020 to be installed on Lander for 2021 launch

- Monitoring system for Lunar Gateway and Human Lander System in early development – will be Timepix based

- Possible future directions include focus on external in-situ space weather monitoring (electron precursor of SPE) , multilayer devices, further dosimetry/particle ID algorithm improvements, Timepix2....

- Onwards to the human Lunar 2024 landing…

Thank you for your attention!