Orion Exploration Mission 1: Proposed Radiation Measurements in Cislunar Space

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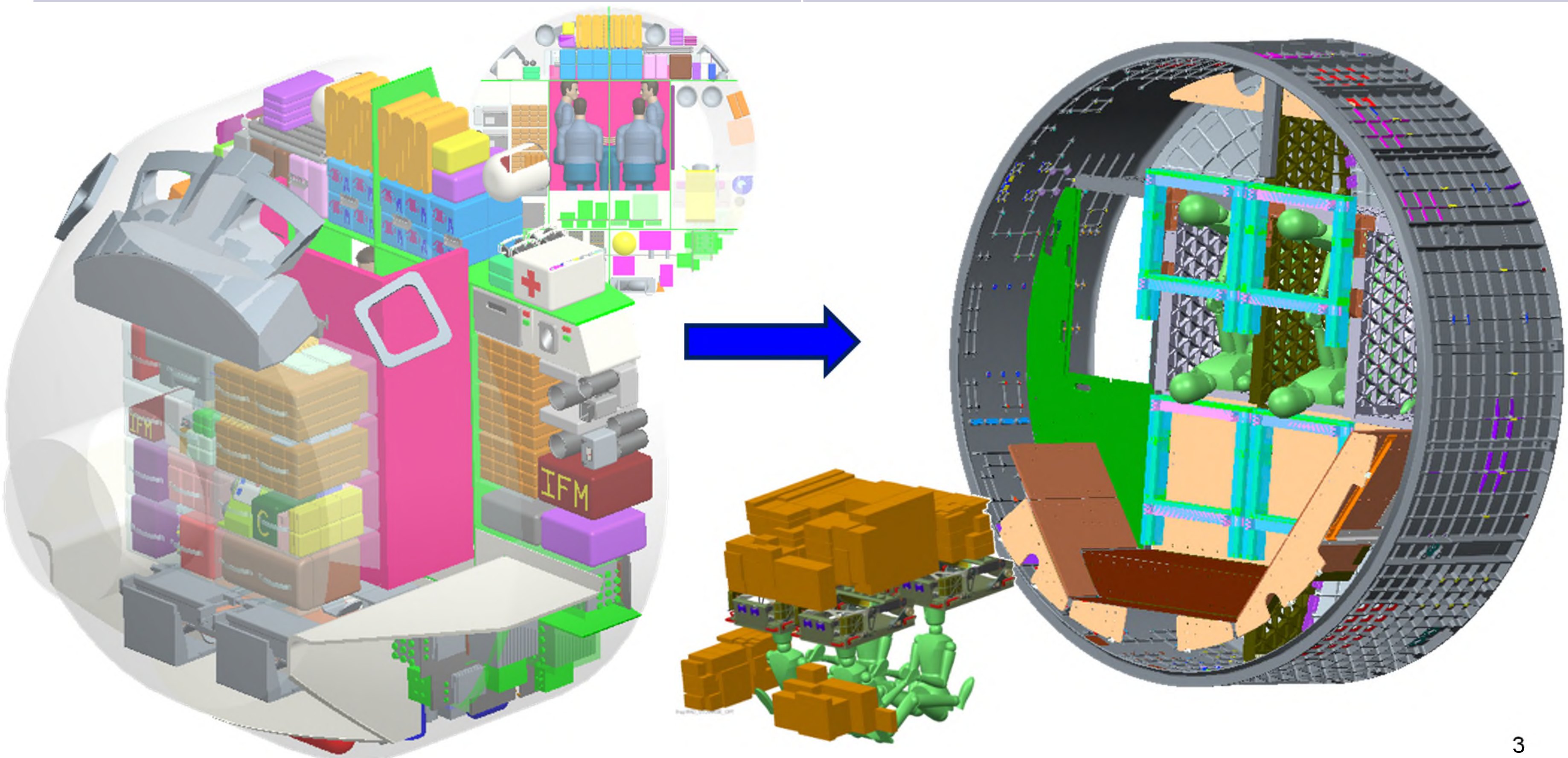
Orion MPCV

- **Orion is an Exploration Class spacecraft**
  - Designed for Exo-LEO (not geomagnetically shielded) radiation environment
- **European Service Module for EM-1 and EM-2**
  - Collaboration with Airbus/ESA
- **Crew Ionizing Radiation Protection**
  - First standalone spacecraft to incorporate crew radiation protection in the early design
    - Consistent with ALARA (As Low As Reasonably Achievable) principles
  - Radiation analysis is performed on the full detail, manufacturing quality CAD model of the spacecraft
    - Iterative process, performed by the contractor integral to the design engineering effort
  - Orion radiation protection solution evolved with the vehicle design trade space
    - Lift-off mass is an important design driver
    - Successful crew radiation protection strategy was enabled by familiarity with vehicle design and optimization of radiation analysis procedure
  - Current baseline improves the crew protection (i.e., reduces exposure) by a factor of ~3x, down to E ~ 100 mSv / Design reference SPE (King Aug '72)

SPE Response Scenario

2006	2016
Safe haven partially in the bays	Safe haven completely in the bays
Cabin reconfigured to optimize shielding	Cabin reconfigured to optimize shielding
216 kg of dedicated radiation shield	0 kg of dedicated radiation shielding



Nominal Cabin Configuration

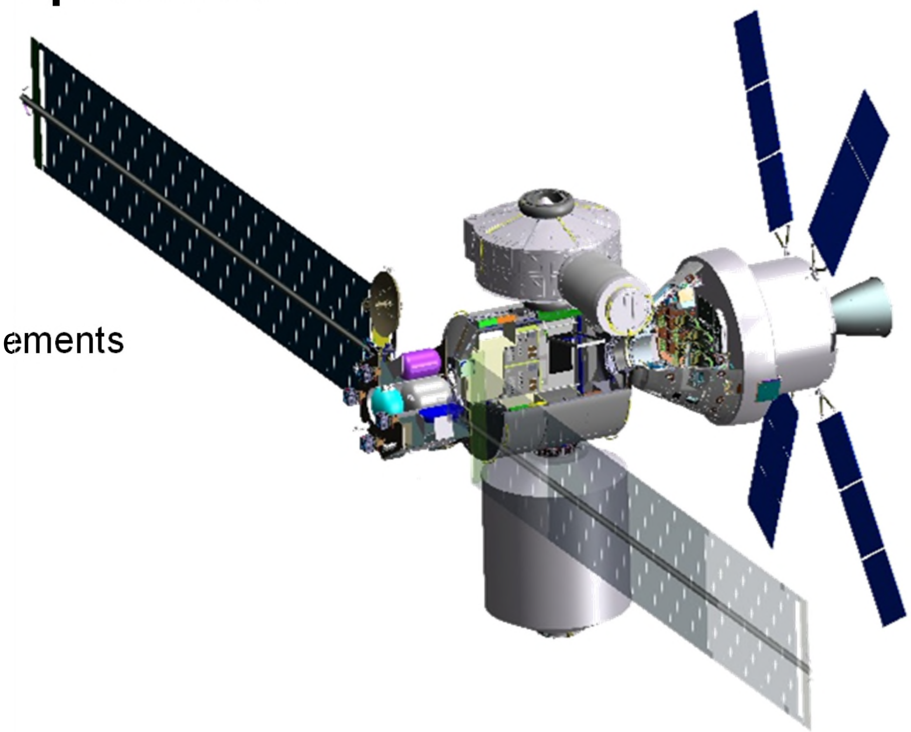
Cabin Reconfigured for SPE

Radiation Shelter Evaluation

- NASA JSC Building 9
- Orion medium-fidelity mockup
- July-Aug 2016

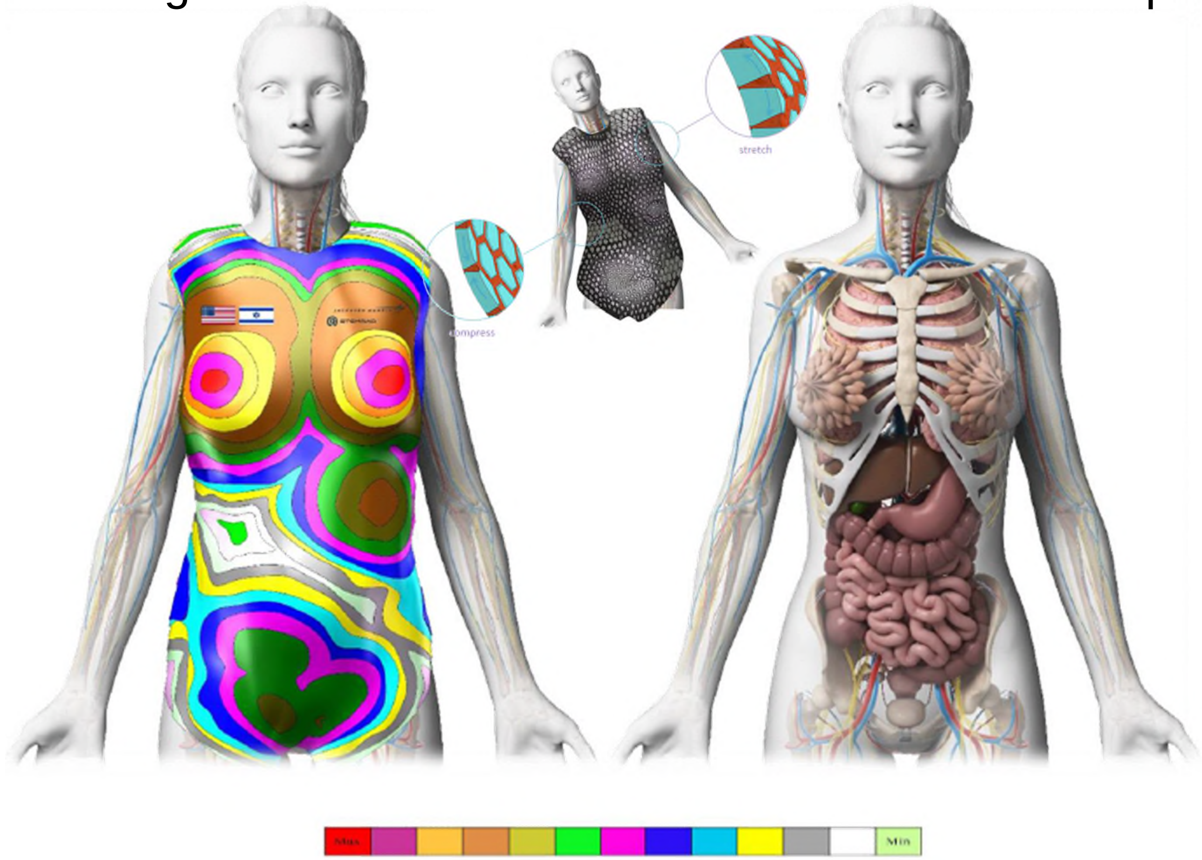
Exploration Architectures

- **Additional Exploration capabilities beyond Orion and SLS**
- **NASA NextSTEP program: development of deep space habitation**
  - NASA anticipates first flight opportunities in Early to Mid 2020s
  - Lockheed Martin has participated in Phase 1 and has been selected for Phase 2
    - Goal of phase 2 is delivery of ground prototype units to NASA
- **Expanded vision for crew radiation protection**
  - Leverage Orion lessons learned
    - Early design for radiation protection
    - Shielding augmentation by repurposed mass
    - Radiation analysis as enabler of ALARA
  - New strategies
    - Emphasis on mobility and portability between elements
    - Individual SPE radiation shield (vest)



AstroRad Radiation Vest

- **International Collaboration Lockheed Martin & StemRad**
  - Leverages StemRad manufacturing expertise
  - Analysis shows ~2x increase in protection
    - SPE, Orion-representative shielding, vest mass = 26 kg
  - Ergonomic evaluation in the Orion & ISS mock-ups

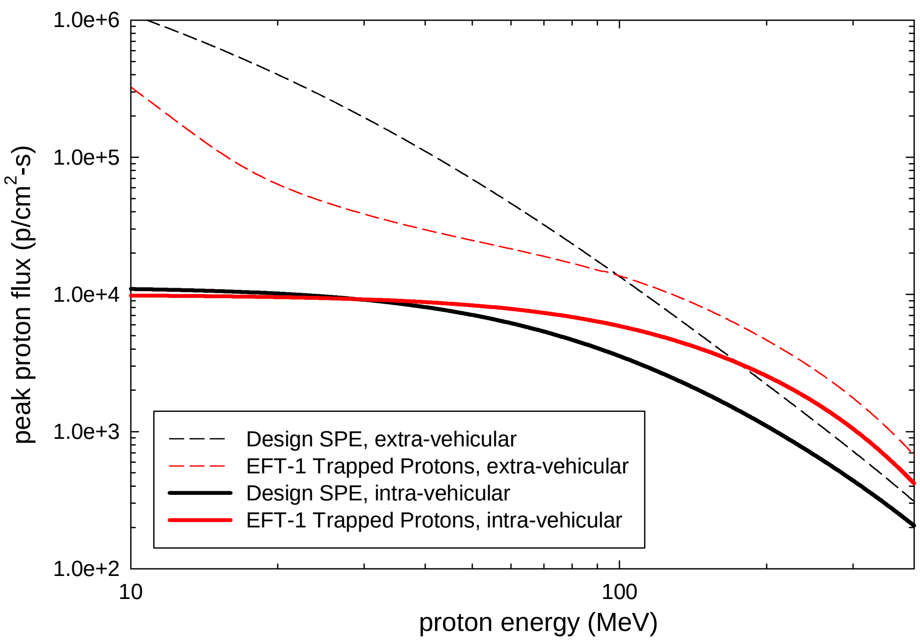


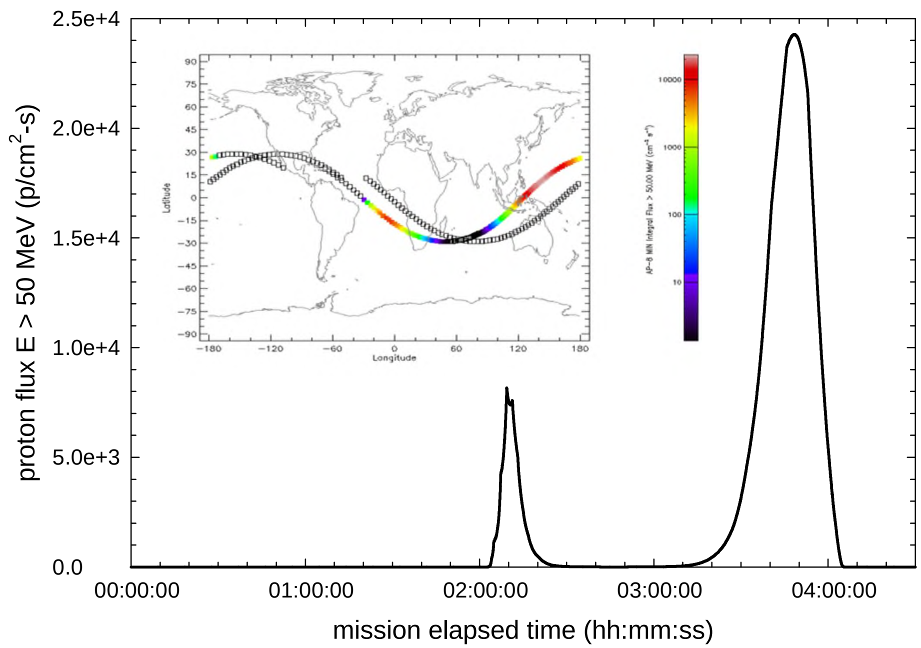
Radiation Hardening Assurance

- **Electronic components are susceptible to ionizing radiation too!**
- **Orion RHA effort is of unprecedented complexity**
  - Modern EEE parts in a complex software configurable Avionics system
    - http://mil-embedded.com/articles/orion-avionics-designed-reliability-deep-space/
  - 120 V power system
  - Exo-LEO environments
  - Safety requirements
  - Dynamic mission phases
  - International collaboration (ESA/Airbus)
- **First ever NASA spacecraft to implement an Ionizing Radiation Control Plan (IRCP)**
  - Contractual document that imposes a uniform set of ionizing radiation requirements across components / providers
  - EEE Parts radiation testing: LET, sample size, particle range, similarity, derating
  - SEE circuit analysis in Radiation Assessment Matrix (RAM)
    - TID is secondary concern
- **System integration of radiation effects**

Exploration Flight Test 1

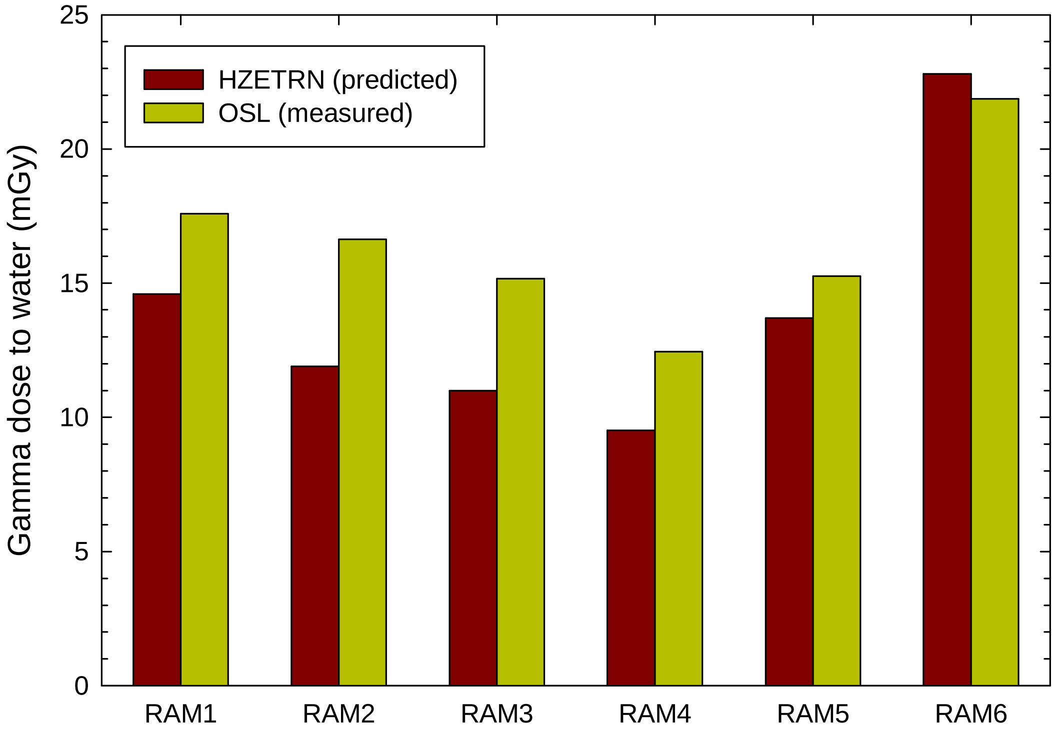
- **Two-orbit flight successfully completed Dec 5, 2014**
- **High altitude, high eccentricity orbit to max altitude 3,600 mi**
- **Van Allen proton belts environment was modeled with AP-8**
  - Intravehicular peak flux comparable to the design reference Oct '89 SPE
- **Dynamic environment**
  - Second stage jettison "SM separation" occurred close to peak flux environment





Radiation Area Monitors

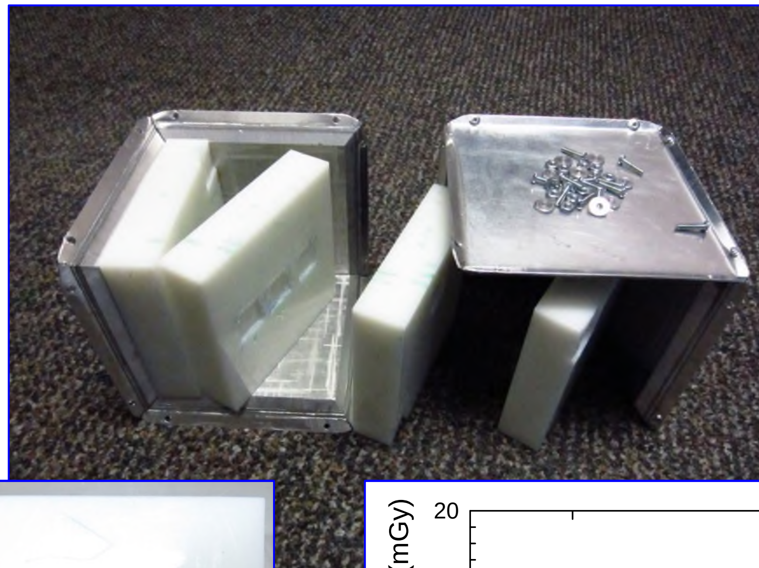
- **Passive Dosimeters (OSLDs)**
  - Incorporated in the vehicle as an Opportunity (no associated requirements)
  - Provided & processed by NASA SRAG
  - Pre-flight intravehicular environment predictions by Lockheed Martin agree w/ measurements within factors 0.96-1.4x

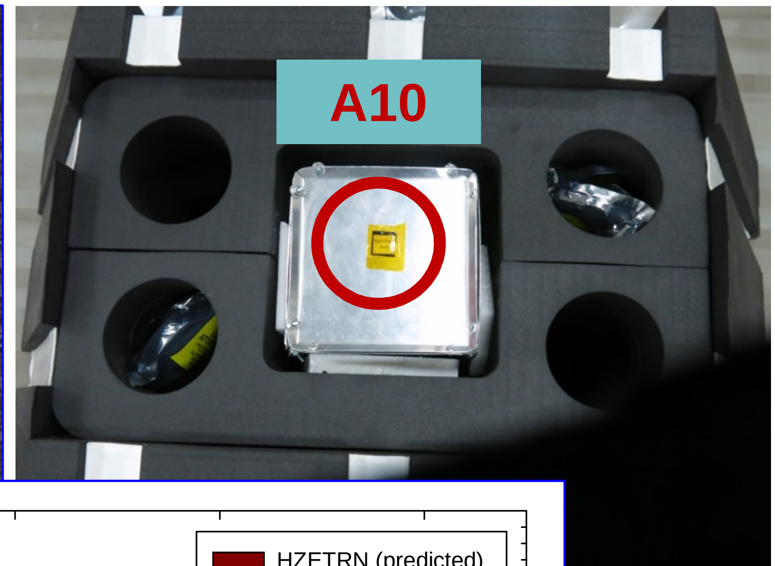


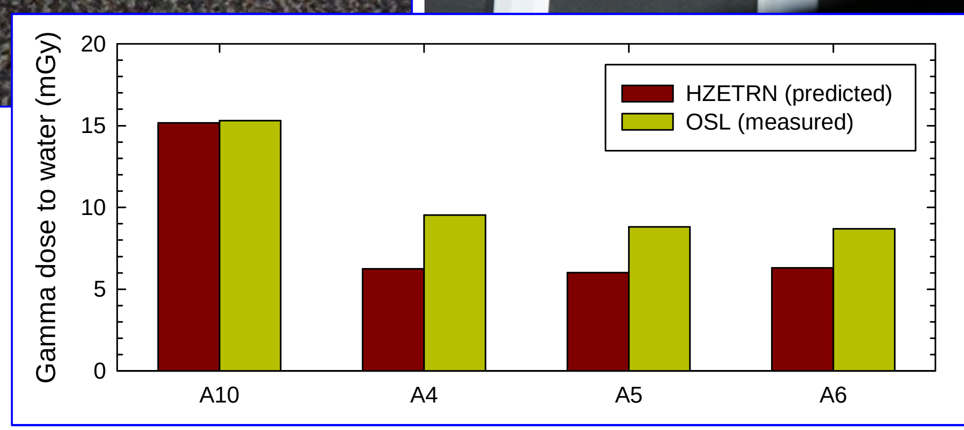
RAM locations	
RAM1	CIAS pallet
RAM2	aft bulkhead, ctrl stowage bay
RAM3	aft bulkhead, WMS
RAM4	fwd bulkhead inside tunnel
RAM5	conical section, thick shielding
RAM6	conical section, thin shielding

Exploration Design Challenge

- **Education outreach initiative of NASA, LM, and NIA**
  - Space radiation shielding design by high school team was flown on EFT-1
  - OSLDs for EDC were provided courtesy of Oklahoma State University
    - Credit: Brandon Doull, Eduardo Yukihara

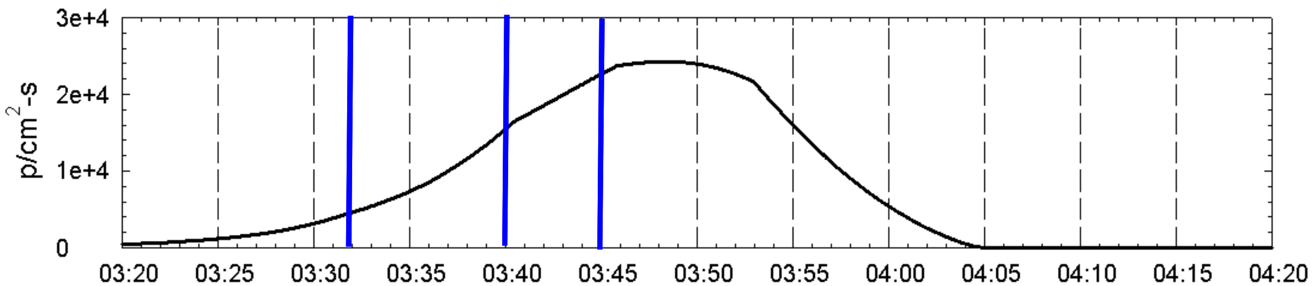






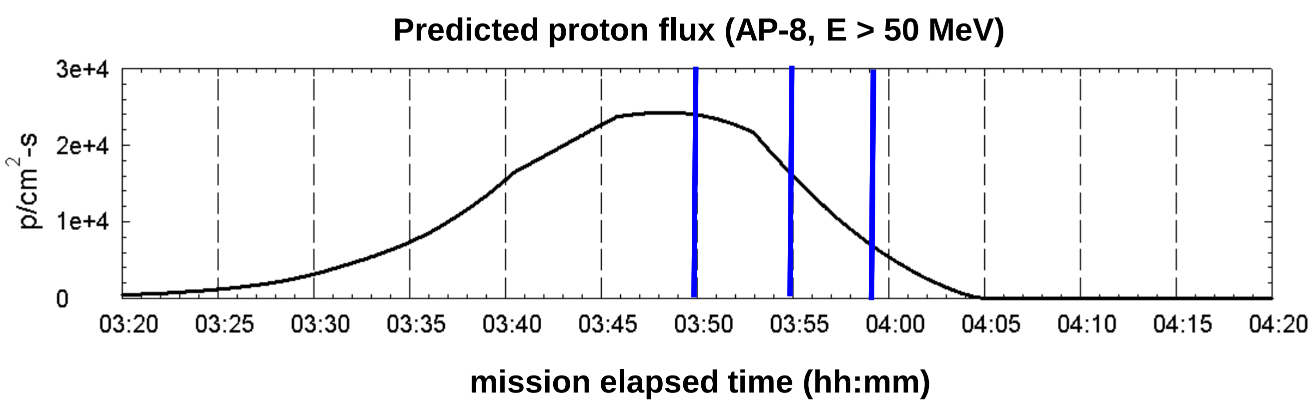
EFT-1 Flight Test Camera

Predicted proton flux (AP-8, E > 50 MeV)

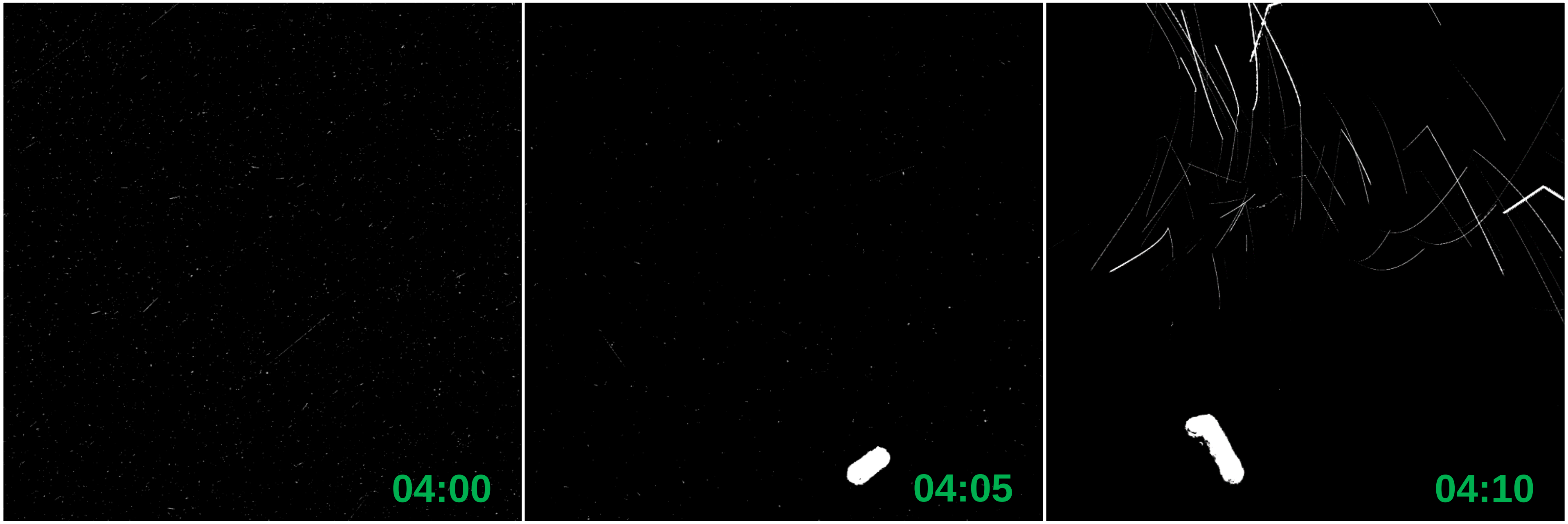


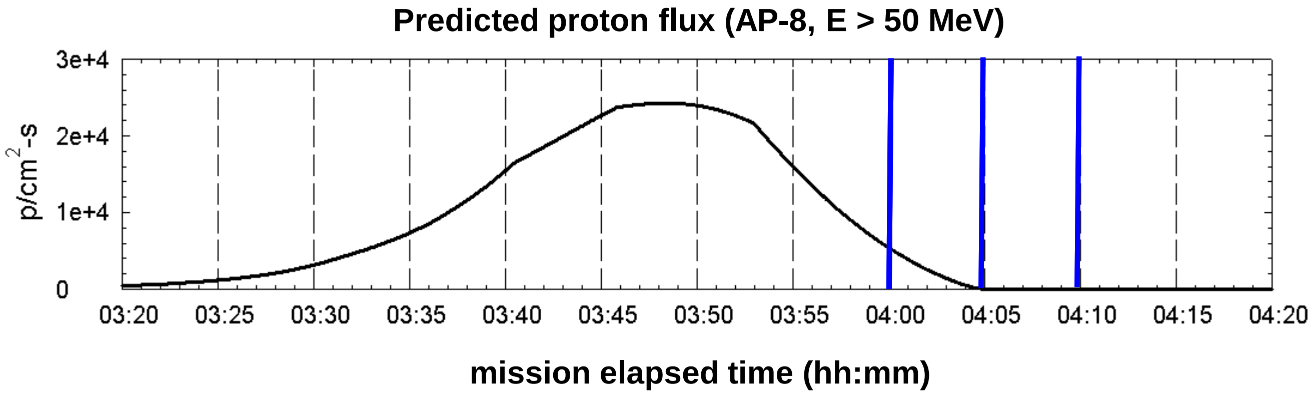
mission elapsed time (hh:mm)

EFT-1 Flight Test Camera

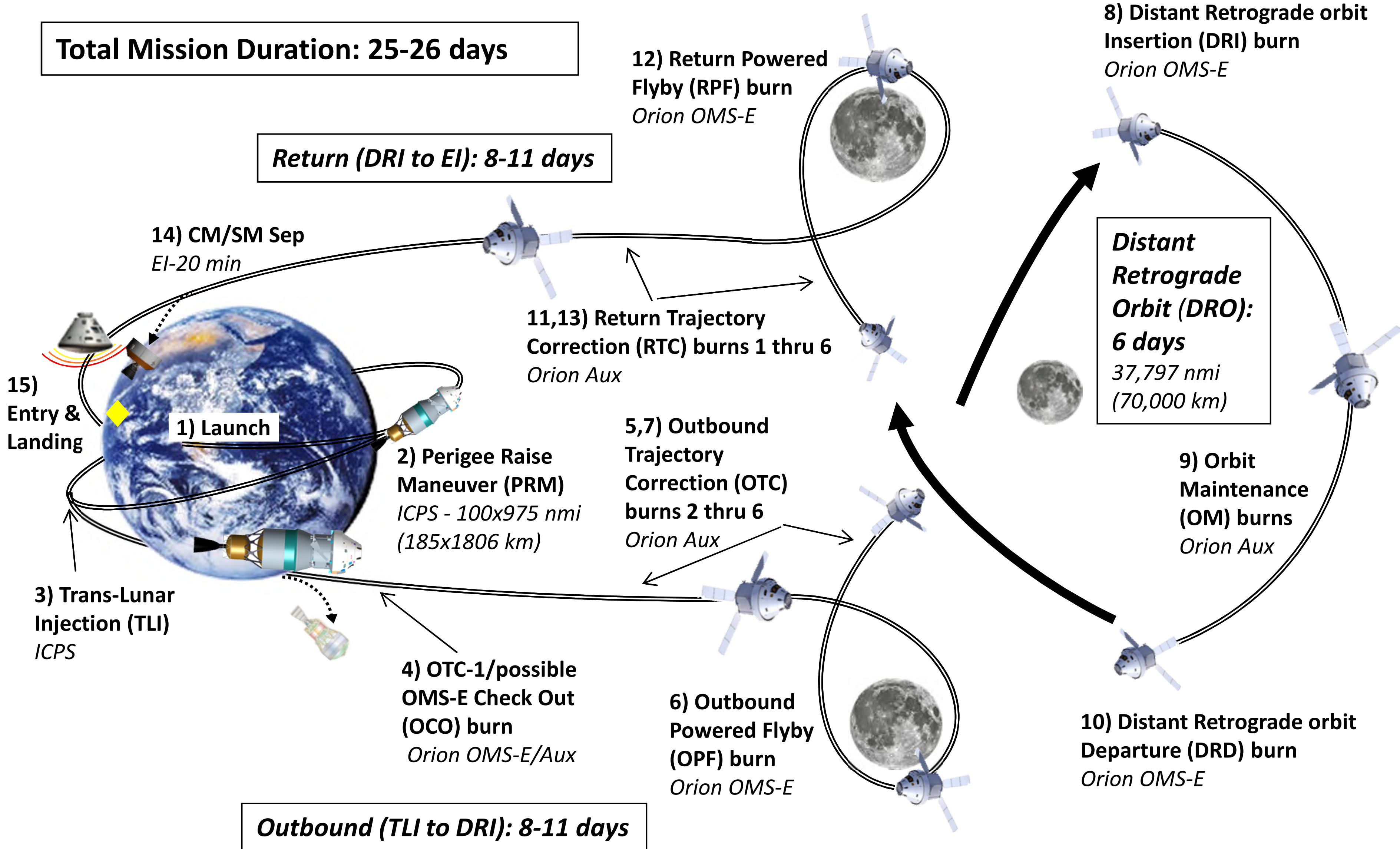


EFT-1 Flight Test Camera



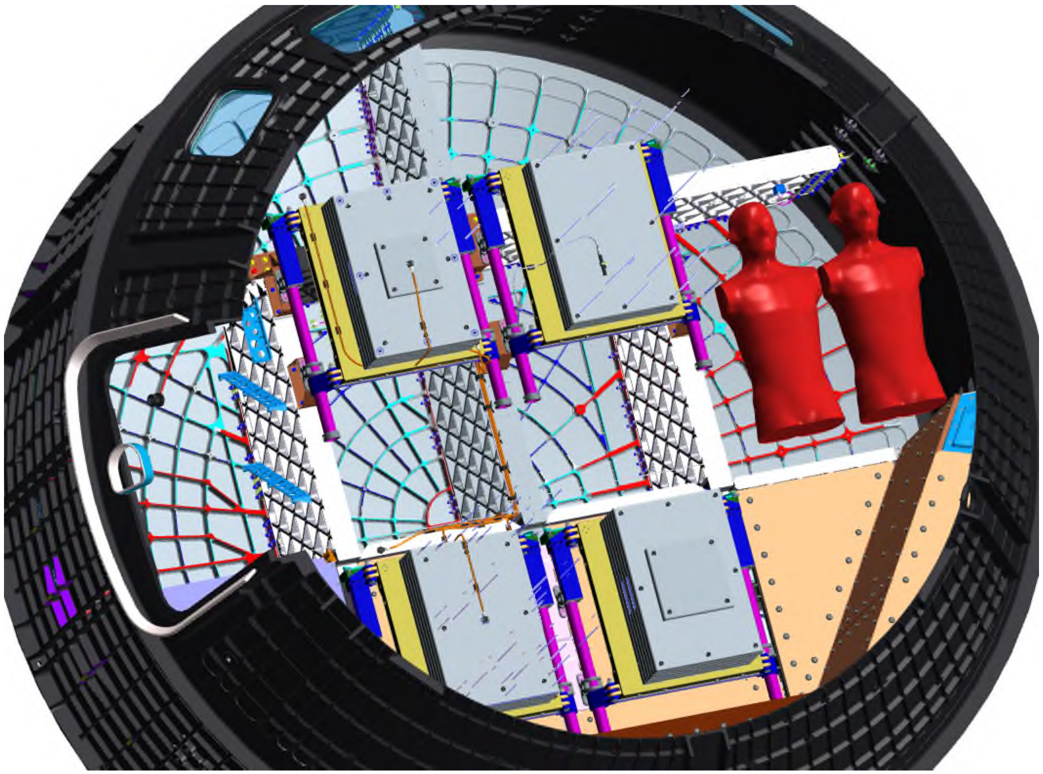


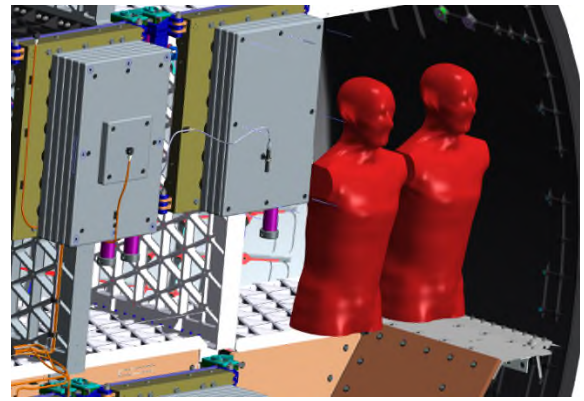
Exploration Mission 1

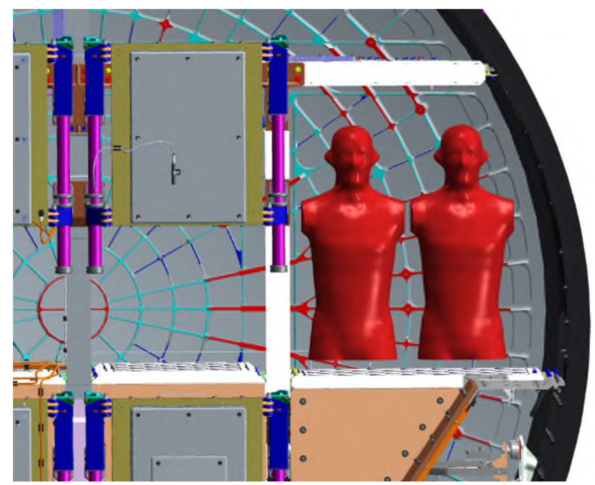


EM-1 Radiation Measurements

- **Radiation phantoms to offset ballast and add science value**
  - Two RANDO phantoms provided by DLR and ISA
  - ISA phantom fitted with the AstroRad vest
  - Opportunity for international dosimetry intercomparison







EM-1 provides a unique opportunity for exo-LEO anthropomorphic phantom dosimetry inside a human rated spacecraft

Ground Rules

- **Vehicle Integration**
  - Phantom location will be driven by vehicle constraints (Mass Properties)
  - No impacts to the vehicle
    - Payload restraint engineering
    - No power or data assumed available from the vehicle
  - Rely on payload provider for Flight Certification
    - Focus on Safety / Hazard Review (e.g., loads, vibration, outgassing, thermal)
    - Inputs required for vehicle level analyses
  - Internal cabin environment:
    - Pressure: 14 to 18 psia nominal (0 psia contingency)
    - Temperature: -7 ºC to +45 ºC (19 ºF to 117 ºF) (bounding extreme range)
- **Science component**
  - Passive dosimetry with large international involvement
  - Active dosimetry highly desired subject to integration constraints
    - Self contained power/memory/switch-on, additional flight certification (thermal, batteries)
    - Separate environment contributions (van Allen / Solar protons vs. GCR)
    - Local measurements to assess AstroRad shielding effectiveness
  - CAD shielding analysis & environmental predictions
  - Science data are to be published in major peer-reviewed journal(s)

Conclusion

Your help is requested:

- **Support/participate in the EM-1 radiation phantom dosimetry intercomparison**
- **Identify/ provide active dosimetry for the EM-1 radiation phantom measurement**
- **Suggest other science experiments on EM-1 (radiation- or non-radiation)**

Ultimate goal is improving astronaut safety and enabling Exploration