Biological Effects of Radiation

Kerry Lee

NASA Johnson Space Center, Houston, TX

Outline

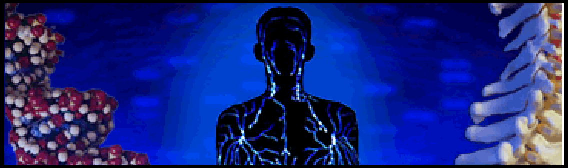
- Space Weather and SRAG
- Vocabulary Zoo
- ISS Instrumentation
- MPCV
    - BIRD Results from EFT-1
    - HERA Overview for EM-X Missions
    - ConOps for SPE Contingency
- Radiation Risk

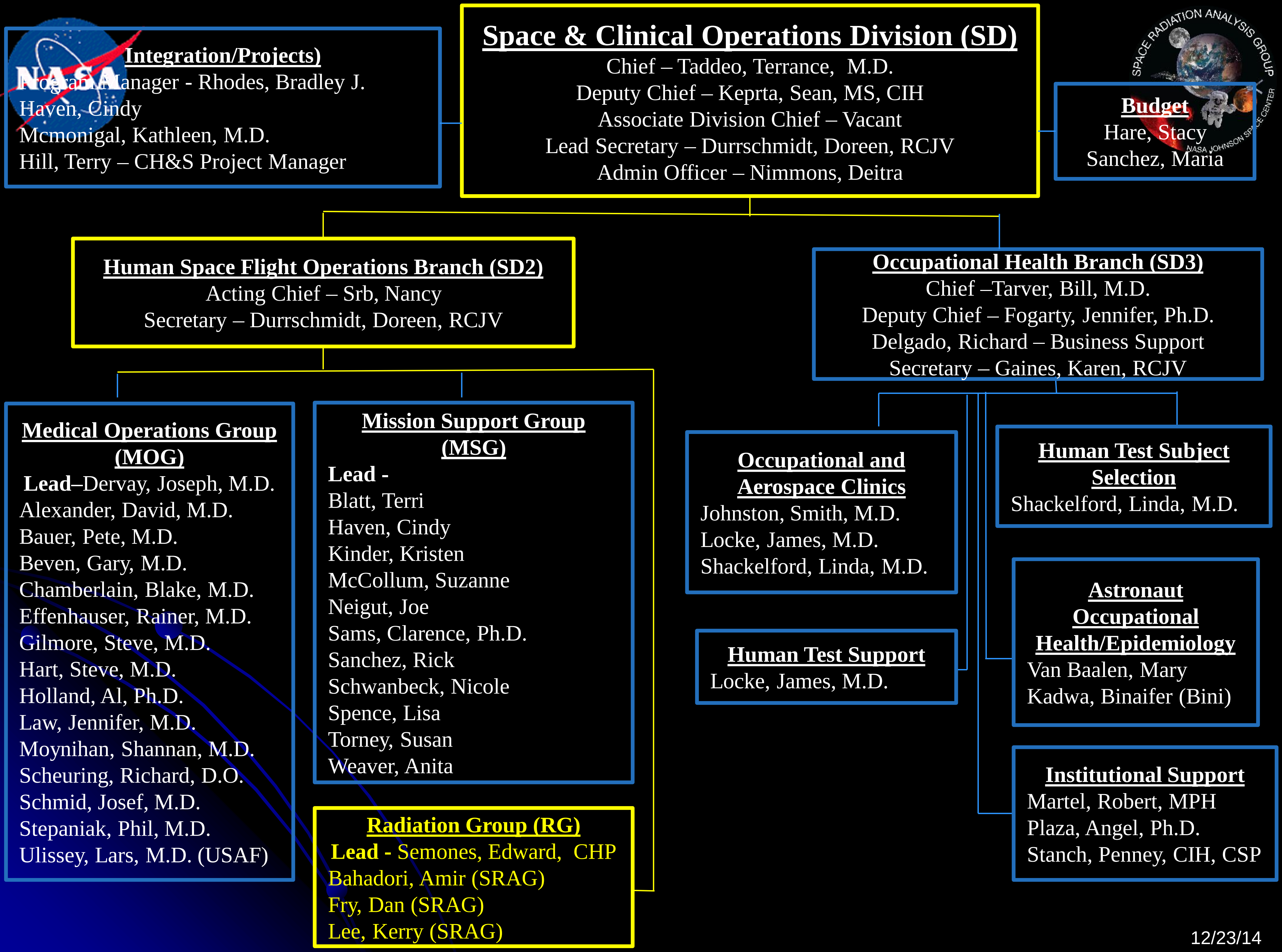
Space Radiation Analysis Group

- Located at the Johnson Space Center in Houston, TX

- SRAG, est. 1962
  - Real-time console operations
  - Crew, ambient monitoring
  - Pre-flight planning
  - Design evaluations

- Radiation Health Office
  - Interpretation
  - Record Keeping
  - Risk Estimation
  - Crew Selection





Space & Clinical Operations Division (SD)

Chief – Taddeo, Terrance, M.D.
Deputy Chief – Keprta, Sean, MS, CIH
Associate Division Chief – Vacant
Lead Secretary – Durrschmidt, Doreen, RCJV
Admin Officer – Nimmons, Deitra

Integration/Projects)

Program Manager - Rhodes, Bradley J.
Haven, Cindy
Mcmonigal, Kathleen, M.D.
Hill, Terry – CH&S Project Manager

Budget

Hare, Stacy
Sanchez, Maria

Human Space Flight Operations Branch (SD2)

Acting Chief – Srb, Nancy
Secretary – Durrschmidt, Doreen, RCJV

Medical Operations Group (MOG)

Lead–Dervay, Joseph, M.D.
Alexander, David, M.D.
Bauer, Pete, M.D.
Beven, Gary, M.D.
Chamberlain, Blake, M.D.
Effenhauser, Rainer, M.D.
Gilmore, Steve, M.D.
Hart, Steve, M.D.
Holland, Al, Ph.D.
Law, Jennifer, M.D.
Moynihan, Shannan, M.D.
Scheuring, Richard, D.O.
Schmid, Josef, M.D.
Stepaniak, Phil, M.D.
Ulissey, Lars, M.D. (USAF)

Mission Support Group (MSG)

Lead -
Blatt, Terri
Haven, Cindy
Kinder, Kristen
McCollum, Suzanne
Neigut, Joe
Sams, Clarence, Ph.D.
Sanchez, Rick
Schwanbeck, Nicole
Spence, Lisa
Torney, Susan
Weaver, Anita

Radiation Group (RG)

Lead - Semones, Edward, CHP
Bahadori, Amir (SRAG)
Fry, Dan (SRAG)
Lee, Kerry (SRAG)

Occupational Health Branch (SD3)

Chief –Tarver, Bill, M.D.
Deputy Chief – Fogarty, Jennifer, Ph.D.
Delgado, Richard – Business Support
Secretary – Gaines, Karen, RCJV

Occupational and Aerospace Clinics

Johnston, Smith, M.D.
Locke, James, M.D.
Shackelford, Linda, M.D.

Human Test Subject Selection

Shackelford, Linda, M.D.

Human Test Support

Locke, James, M.D.

Astronaut Occupational Health/Epidemiology

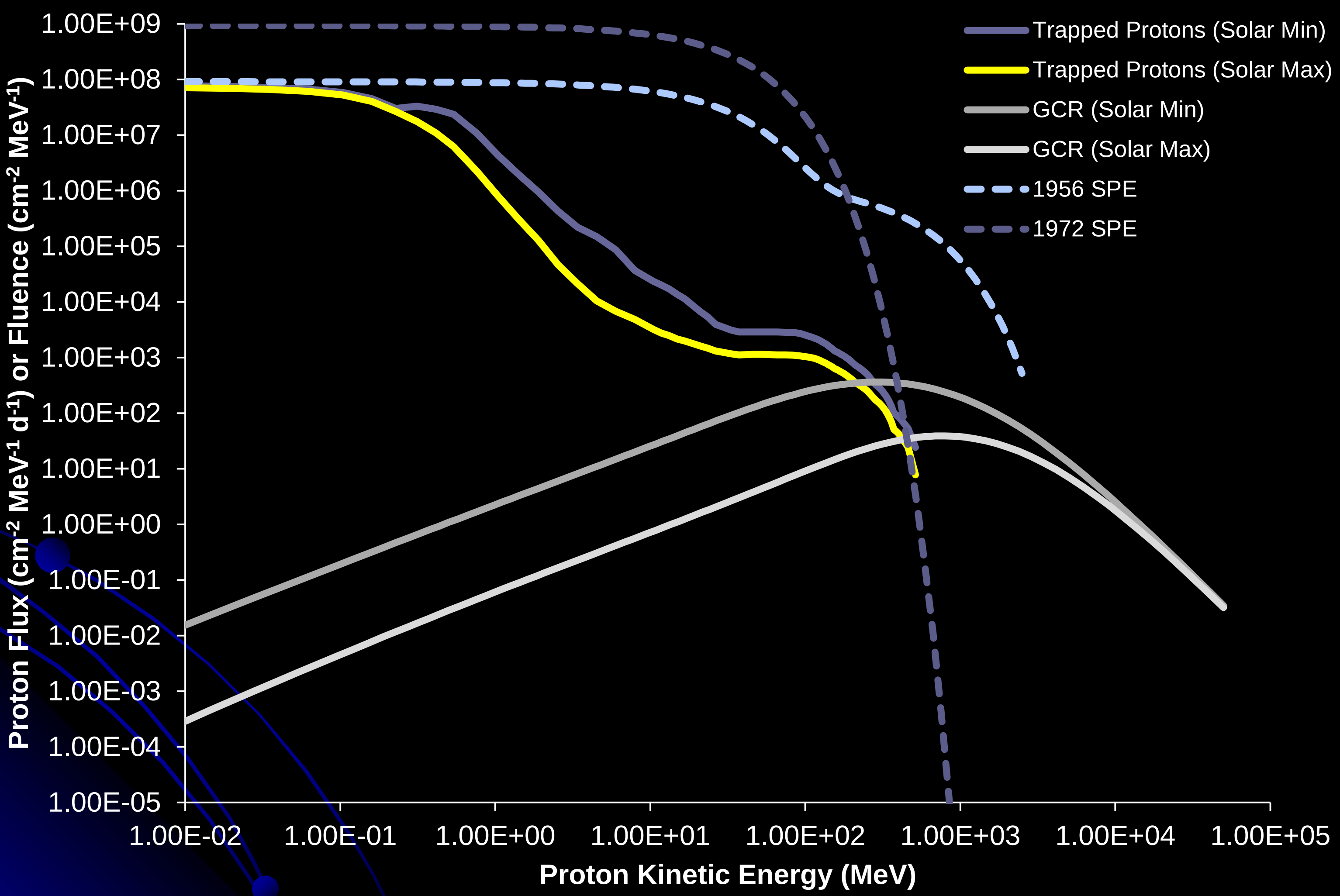
Van Baalen, Mary
Kadwa, Binaifer (Bini)

Institutional Support

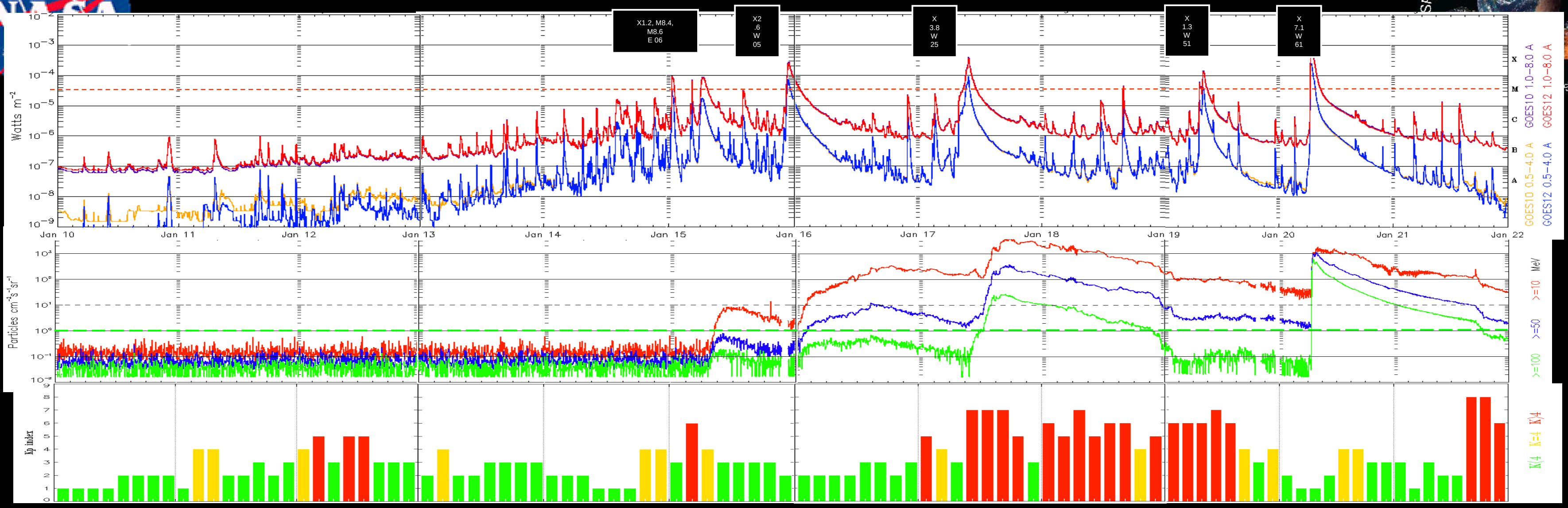
Martel, Robert, MPH
Plaza, Angel, Ph.D.
Stanch, Penney, CIH, CSP

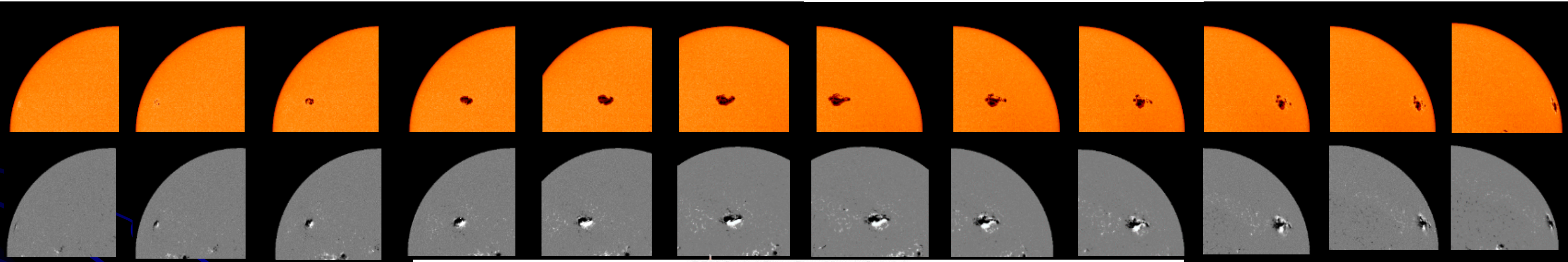
12/23/14

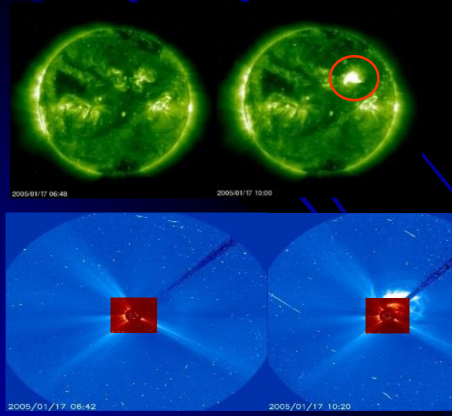
Radiation Sources

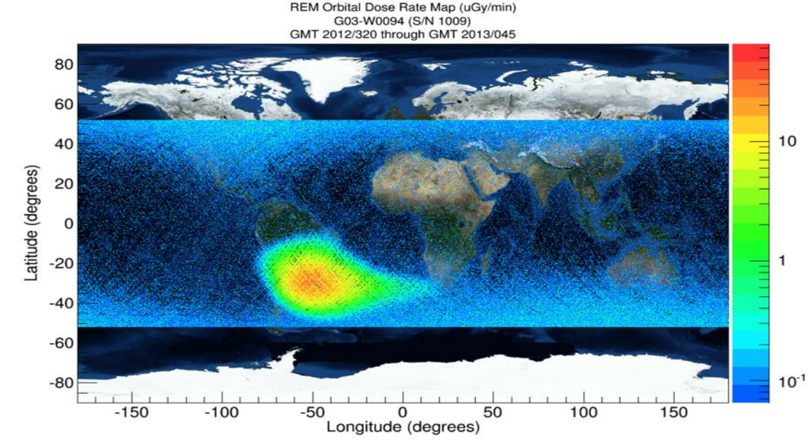


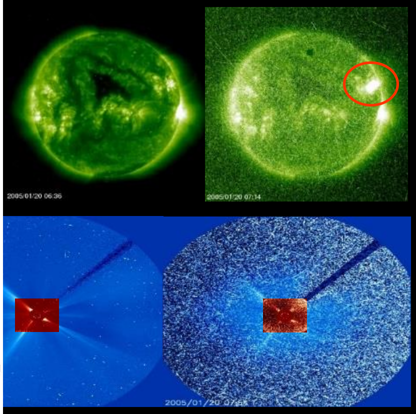
NOAA Active Region 0720 January 10, 2005 - January 21, 2005







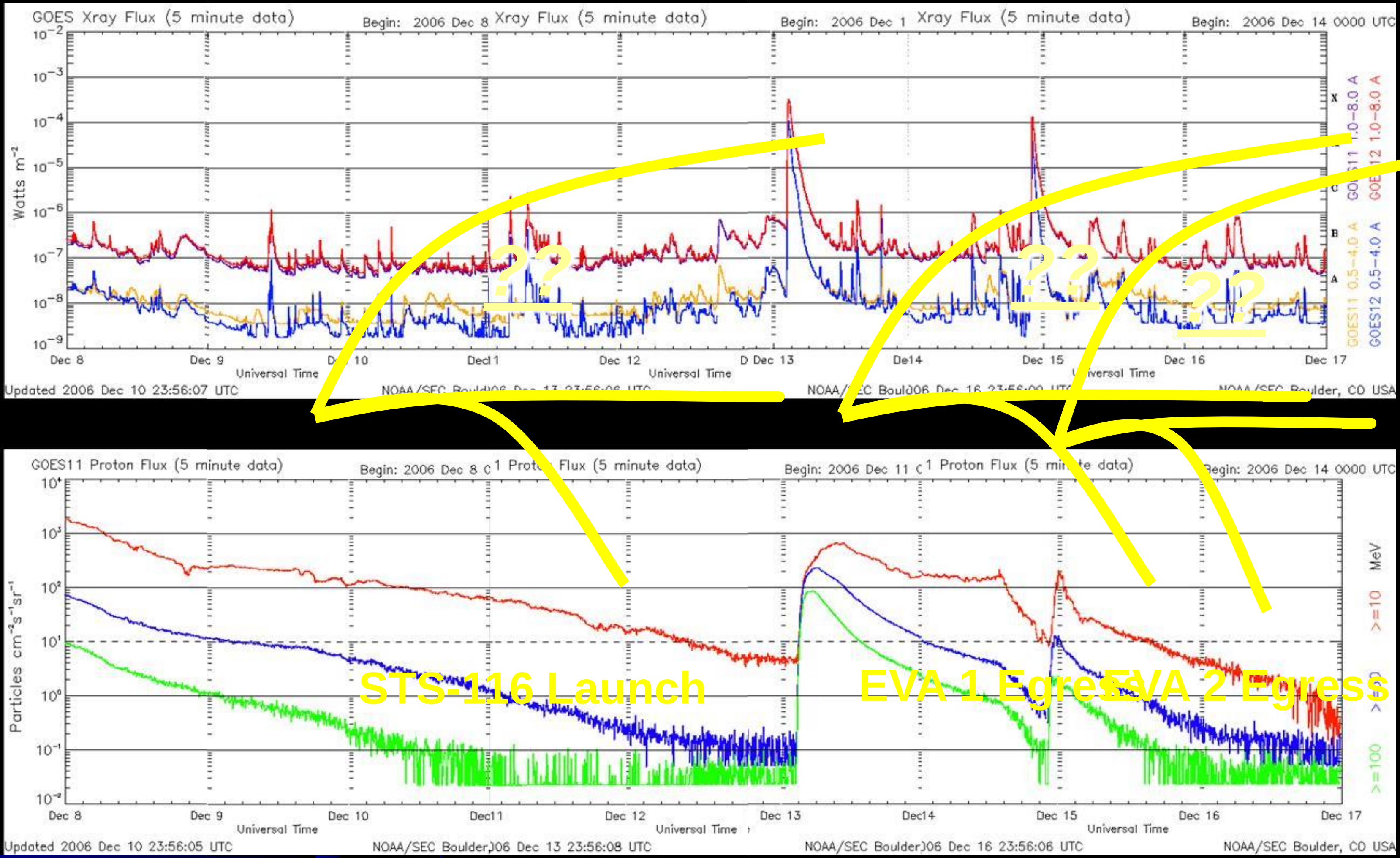




Solar images from SOHO, a project of international cooperation between ESA and NASA. GOES data courtesy of NOAA Space Weather Prediction

STS-116: Example Progression

Probability?



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STS-116 Launch

EVA 1 Egress

EVA 2 Egress

Space Weather Terminology: Words are Important

- **Solar Flare** – large amount of electromagnetic energy released from the Sun. In particular, X-ray emission is monitored as there is an observed correlation between X-ray energy release and particle acceleration. The electromagnetic energy release has no operational impact. The X-rays has much lower intensity than dental x-rays
- A **Solar Particle Event** (SPE) is denoted by observation of proton flux of Solar Energetic Particles (SEP) greater than a given energy (e.g. >10MeV or >100 MeV)
- **Coronal Mass Ejection** (CME) – results when the energy released by a flare is great enough to throw solar mass (mostly protons) with a velocity great enough to escape the Sun's gravity and magnetic fields. CMEs take 1-3 days to arrive at Earth and disturb the geomagnetic field.

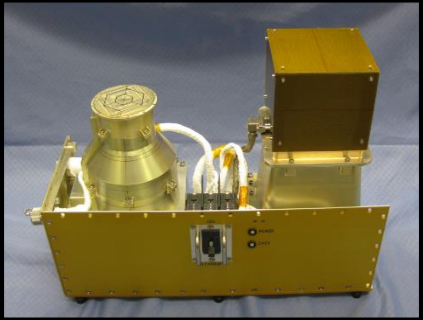
Visual Terrestrial Analogy

Biological Radiation Terminology

- Dose
  - Measureable quantity of Energy per mass (J/kg = Gy)
- Dose Equivalent
  - Dose multiplied by a biological effectiveness quality factor (Q), that is a function of LET (Linear Energy Transport) (units of Sv)
- Equivalent Dose
  - Dose multiplied by radiation type specific weighting factor. This weighting factor is a function of particle type and energy
- Effective Dose
  - A way to determine whole body radiation effects by weighting equivalent dose within an organ by the organs tissue weighting factor and summing over the exposure to all organs.
- Radiation Cancer Risk
  - A calculated chance of some given radiation exposure to result in cancer

ISS Instrumentation

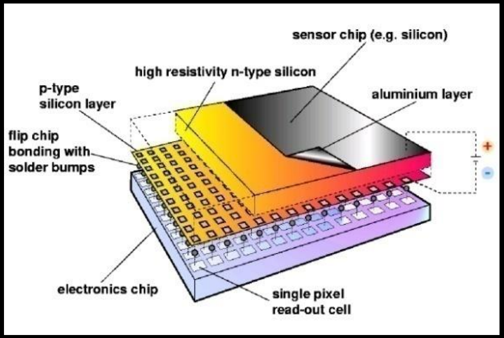
- CPDS – Charged Particle Directional Spectrometer
- REM – Radiation Environment Monitor
  - Active dosimeter with USB interface
- TEPC – Tissue Equivalent Proportional Counter
  - Located in ISS Service Module
- IV-TEPC – new TEPC detector
  - Moves about ISS every 4-6 weeks
- ISS-RAD – Radiation Assessment Detector

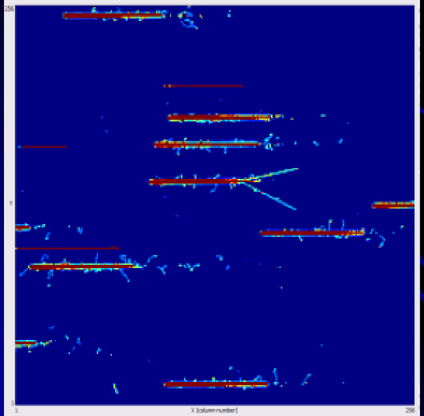


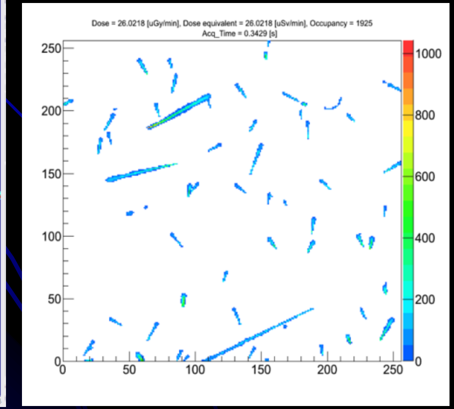
Radiation Environment Monitor (REM)

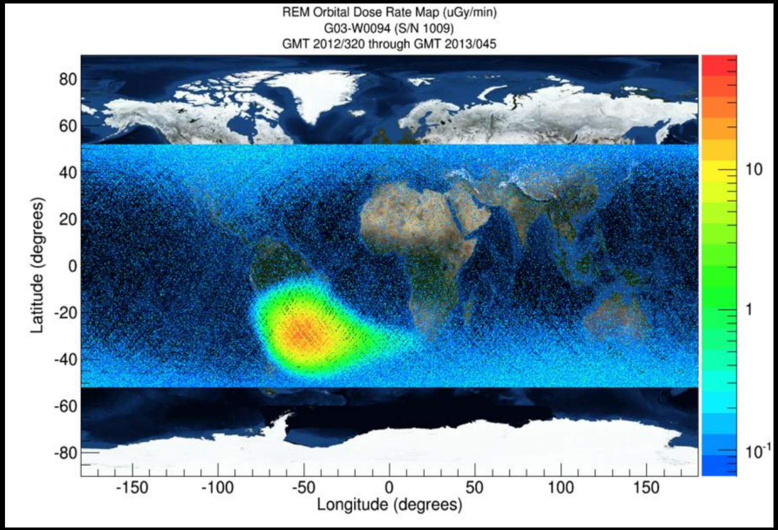
The Timepix Detector

- Developed as a High Energy Physics application of medical imaging technology
- Hybrid Pixel Detector with independent counting and readout circuitry in each pixel footprint
- 256 x 256 pixel grid with total area of 2 cm2



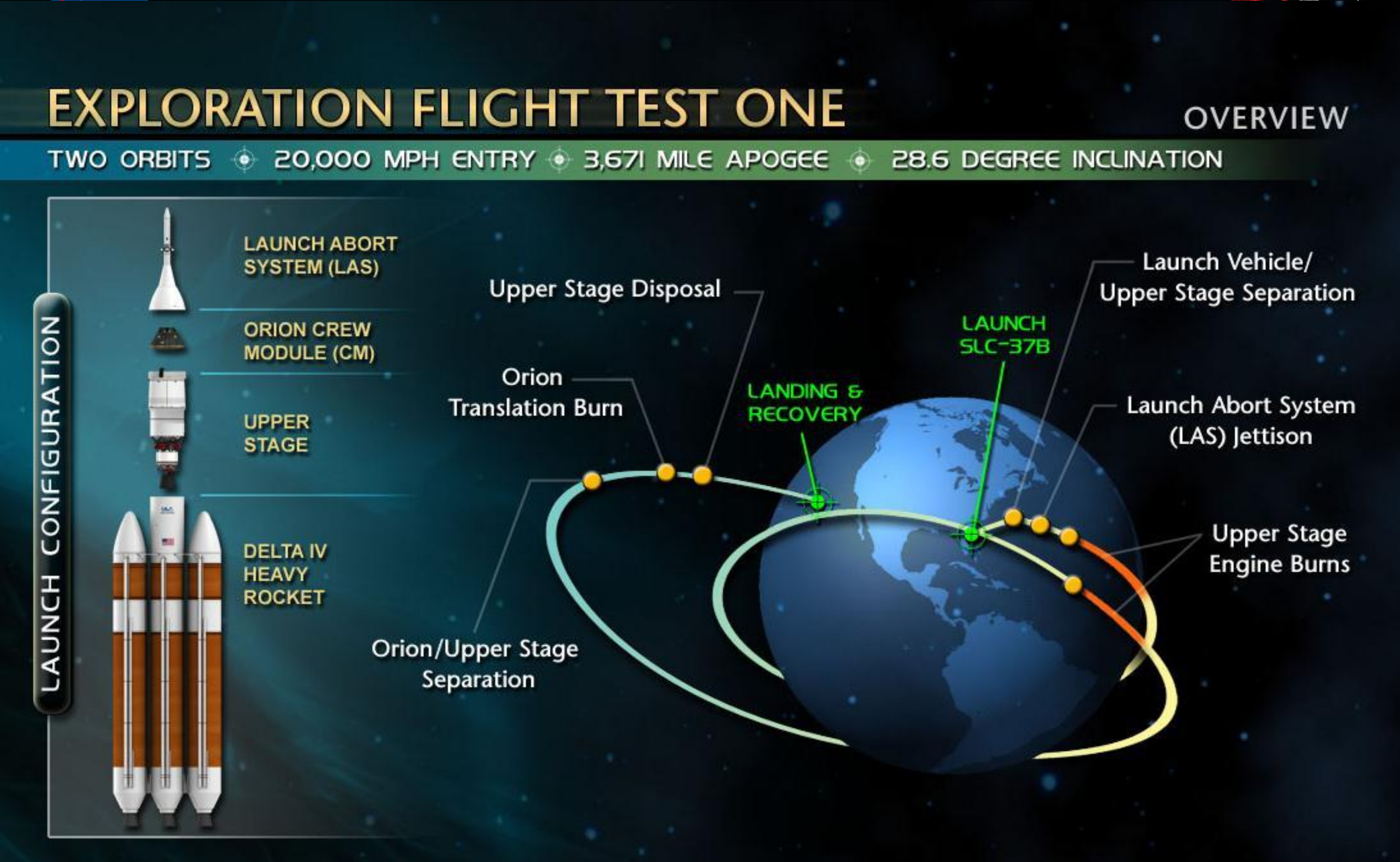






Pixel Detector Image from Medipix collaboration website: http://medipix.web.cern.ch/medipix/img/medipix2/web_flipchip.gif

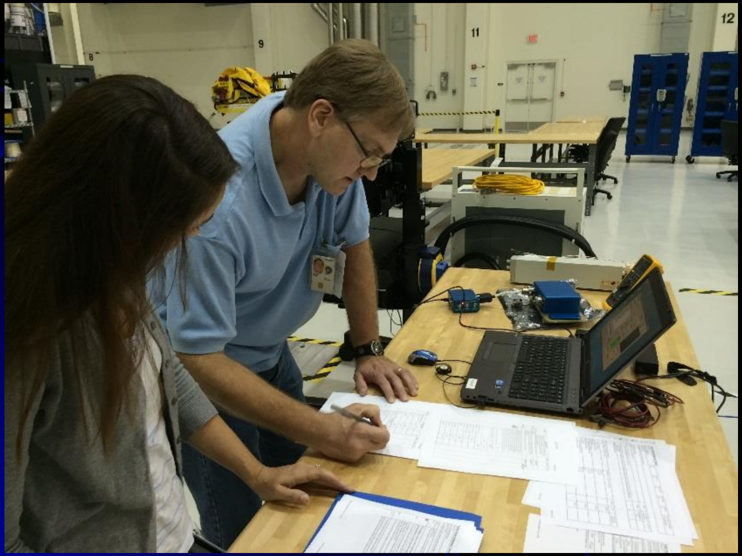
Exploration Flight Test 1 – Dec 5, 2014



Credit: NASA

BIRD Overview

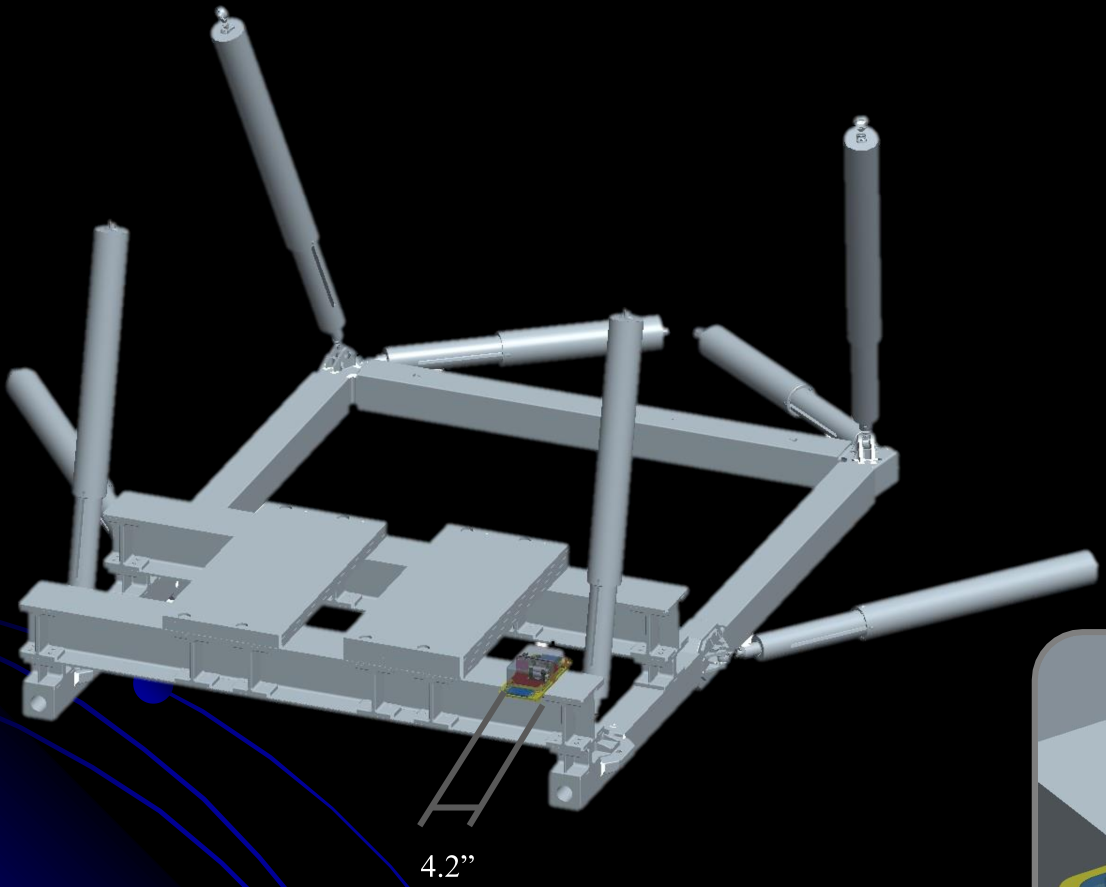
- Oct. 2014: Flight hardware shipped to KSC
- Nov. 2014: Installed into EFT-1 vehicle
- 5 Dec. 2014: EFT-1 Launch
- 9 Dec. 2014: Recovered from vehicle
- Feb. 2015: Data report delivered to HQ
- June 2015: NASA Technical Publication (NASA/TP 2015-218575)

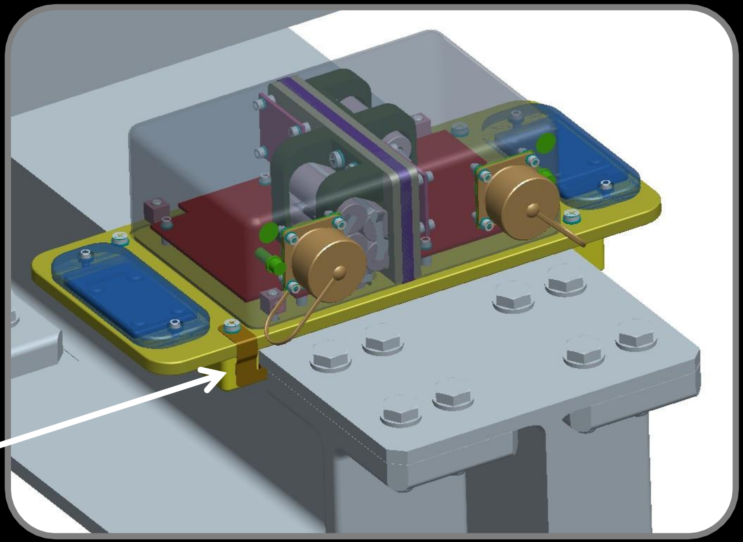


BIRD Preflight checkout at KSC

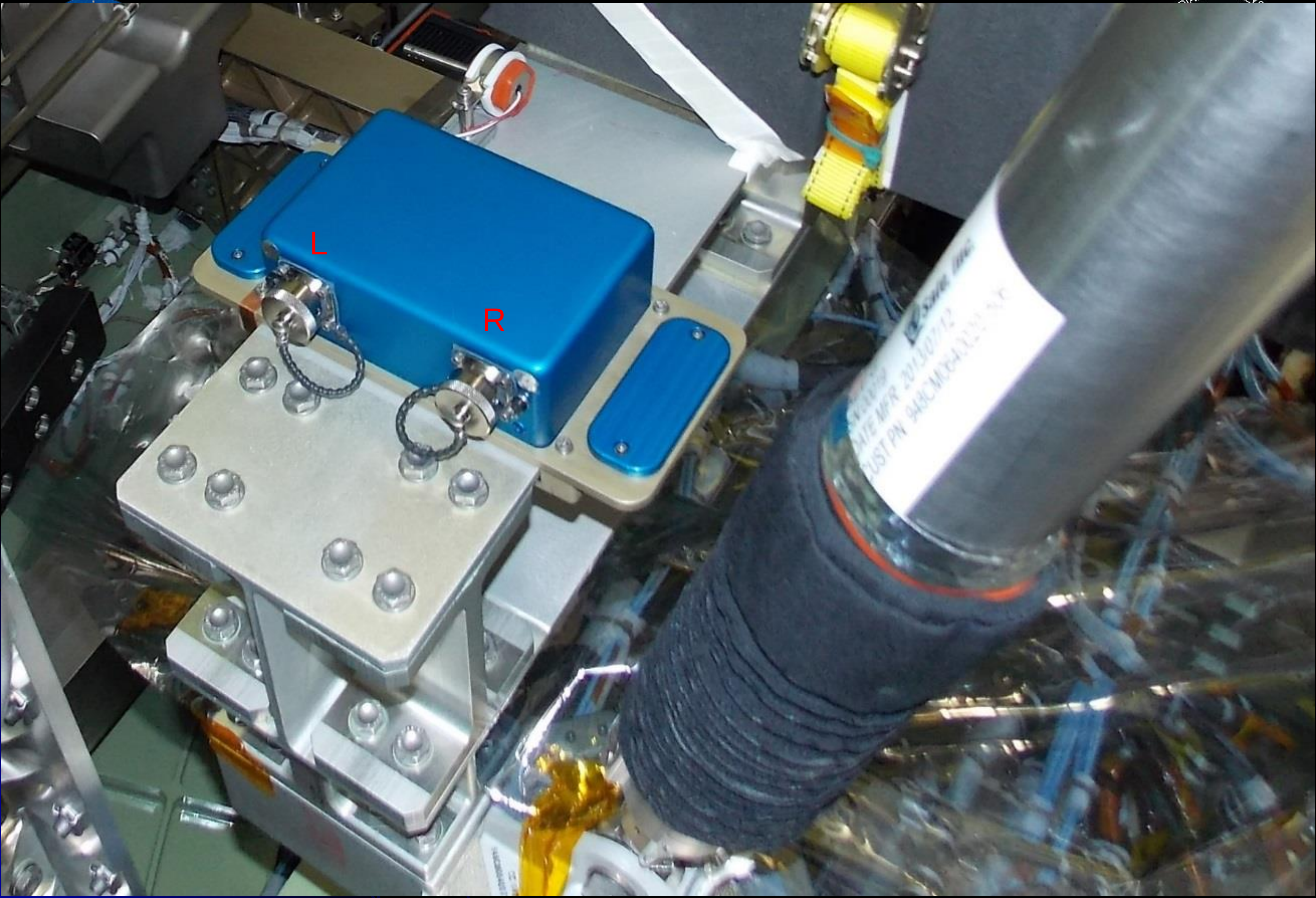
Hardware post flight

Vehicle Attachment

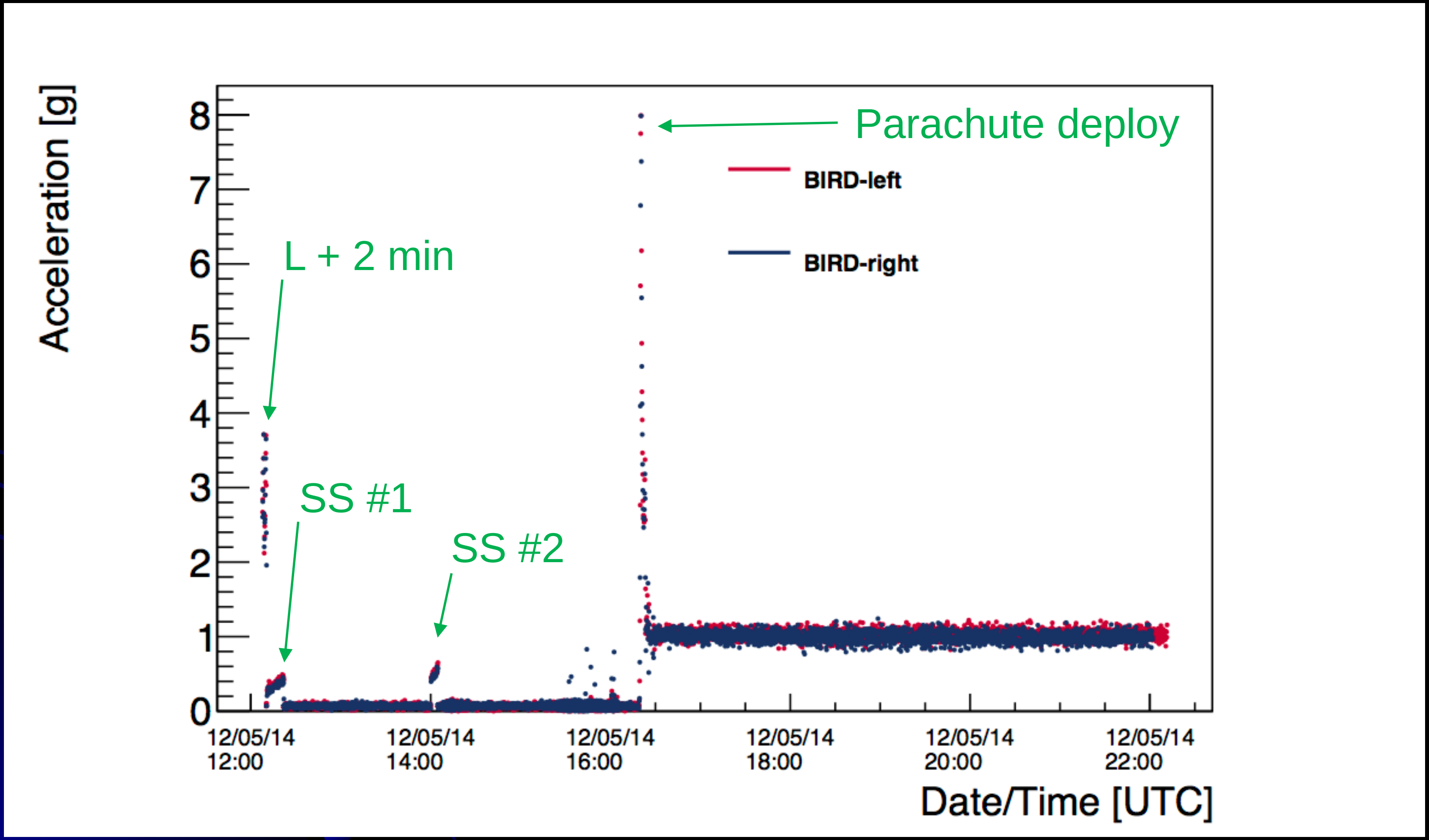




Copper bonding strip positioned to contact an alodined surface


L
R

Acceleration



Parachute deploy

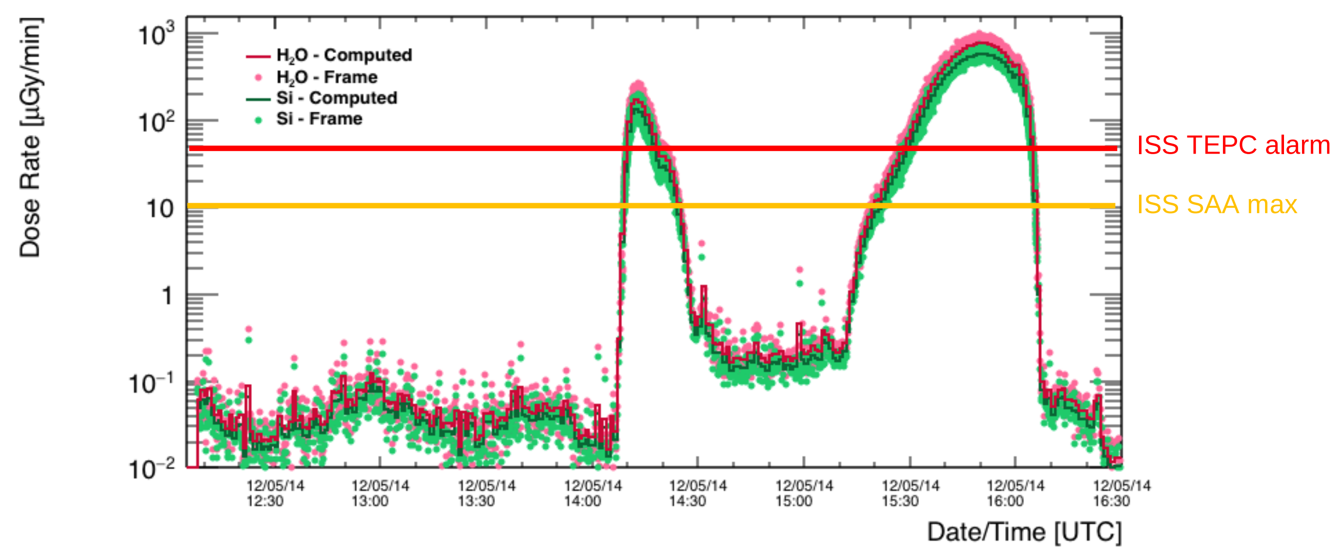
L + 2 min

SS #1

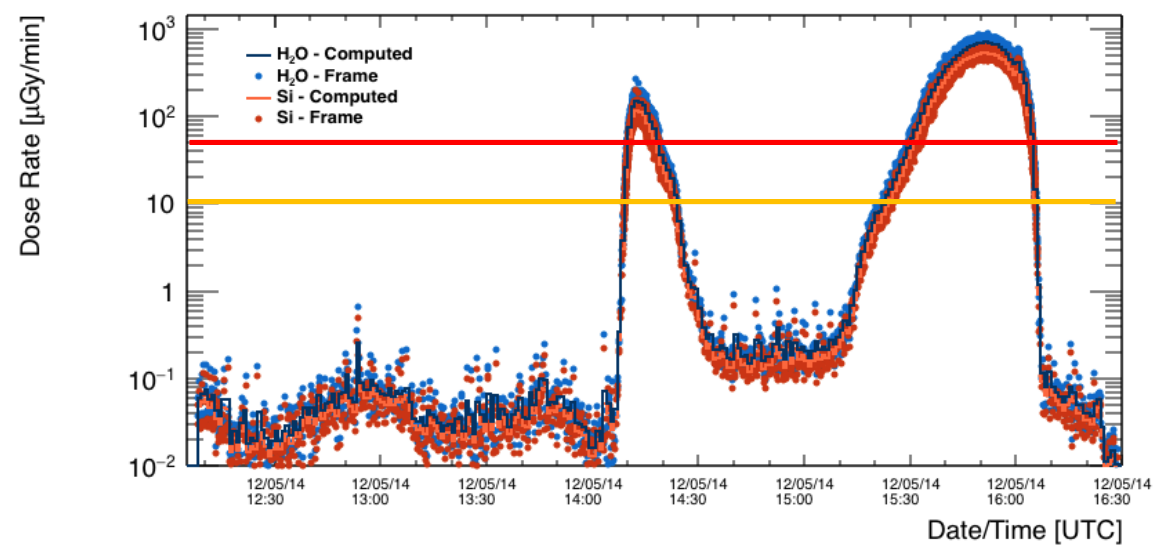
SS #2

Absorbed Dose Rates

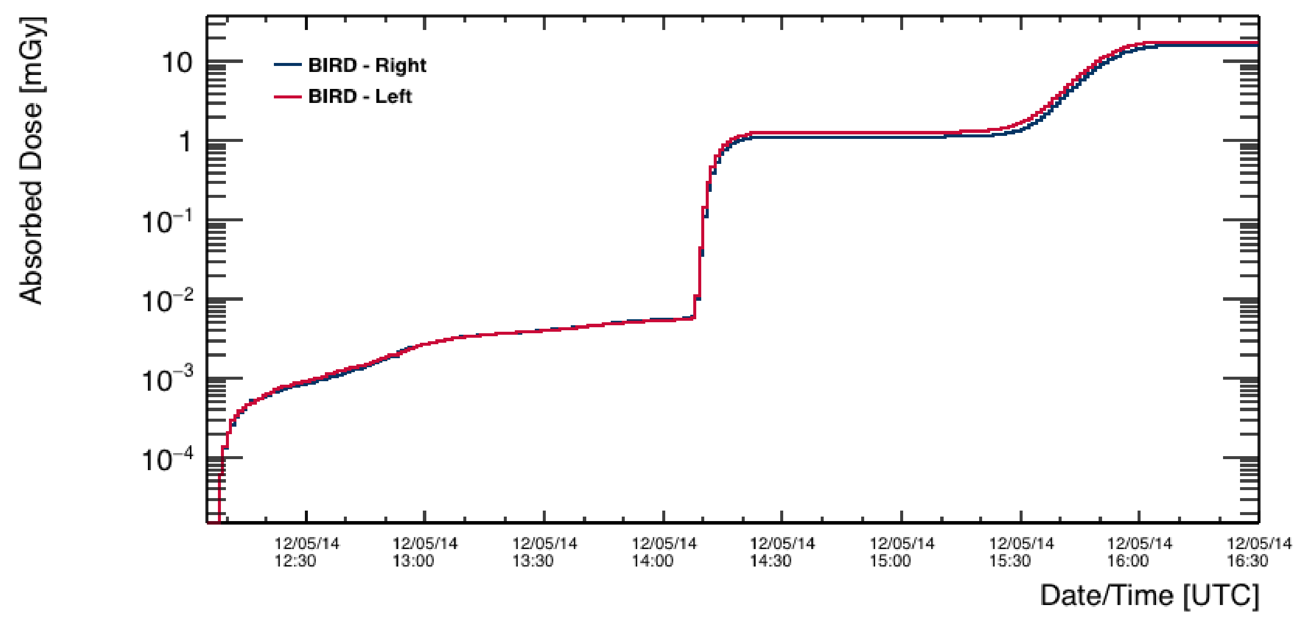
Left Detector



Right Detector



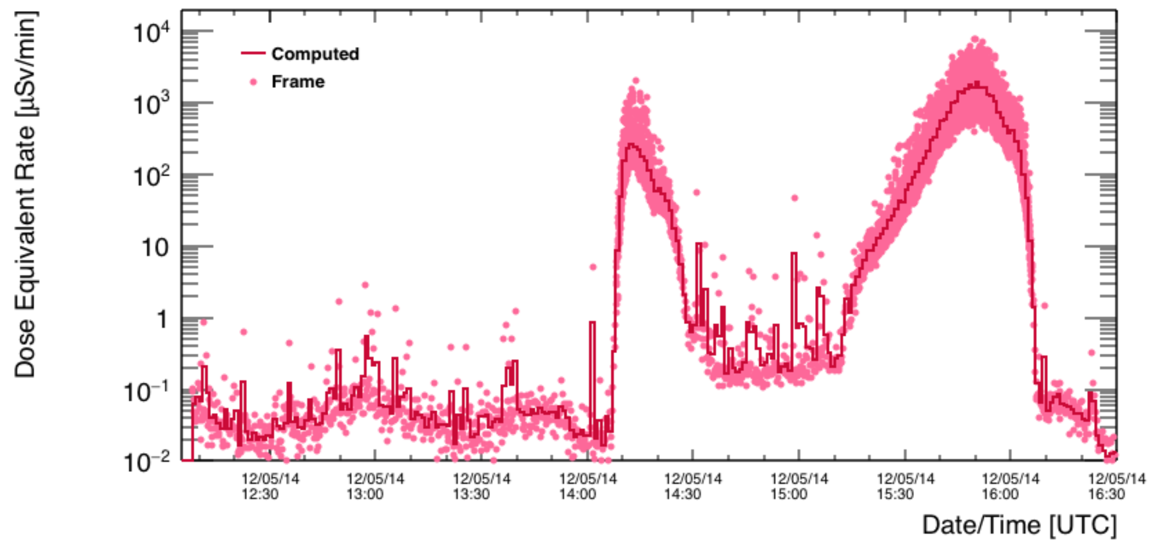
Cumulative Absorbed Dose



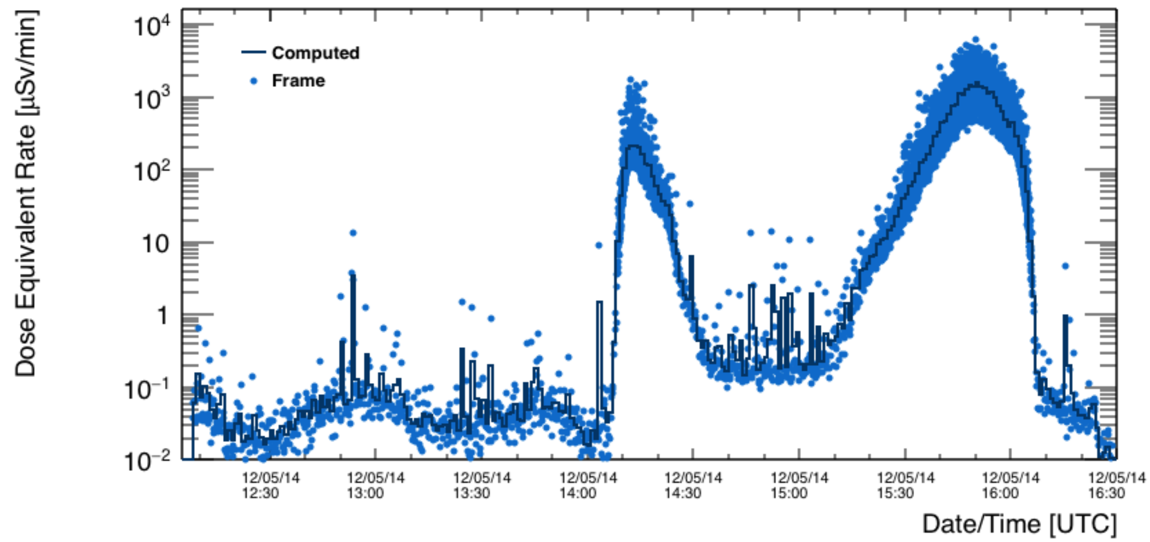
	BIRD [mGy]	RAM [mGy]	ISS-TEPC [mGy]
Left	17.9	15.1 ± 0.3	0.015
Right	15.7	13.5 ± 0.2	

Dose Equivalent Rates

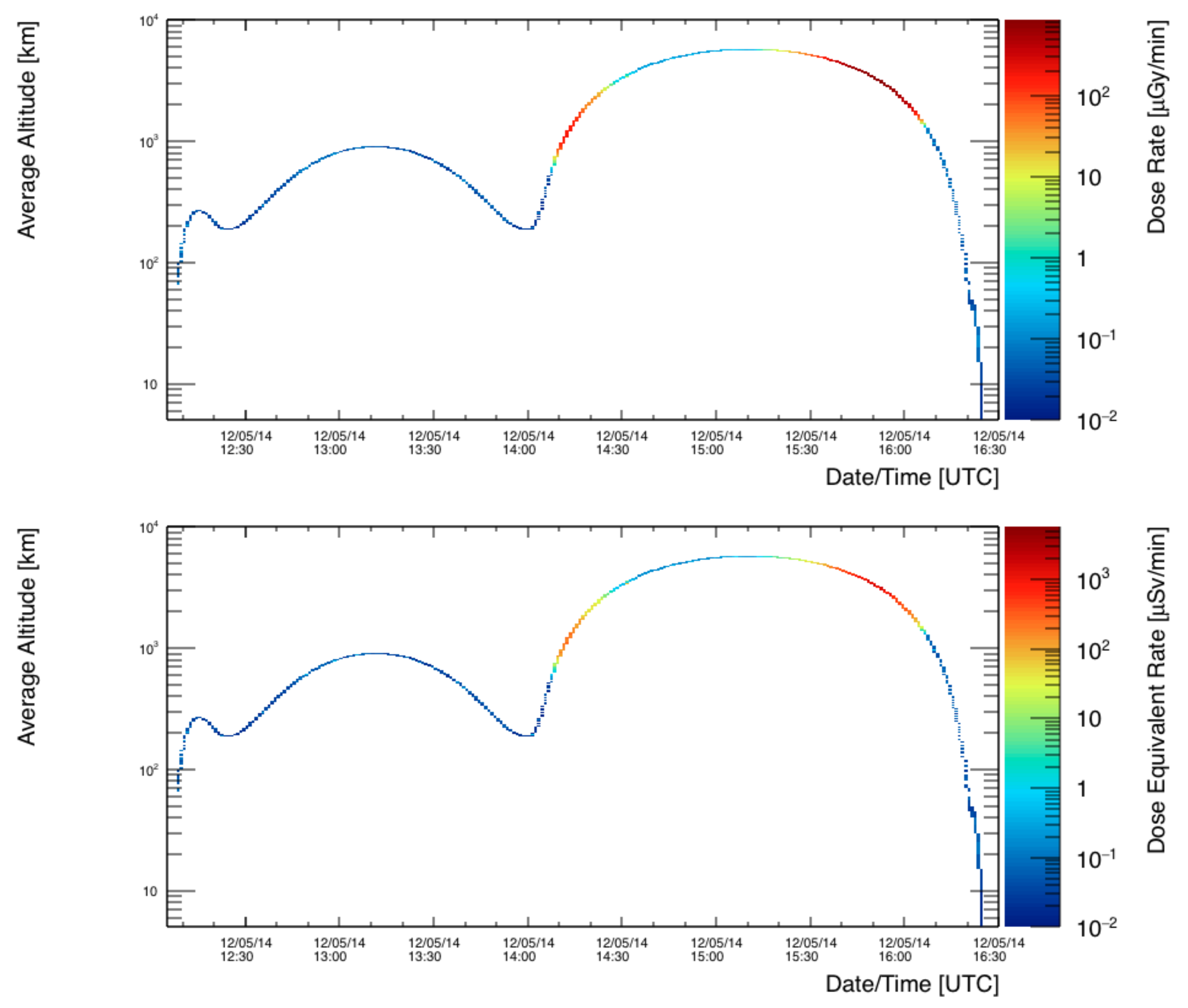
Left Detector



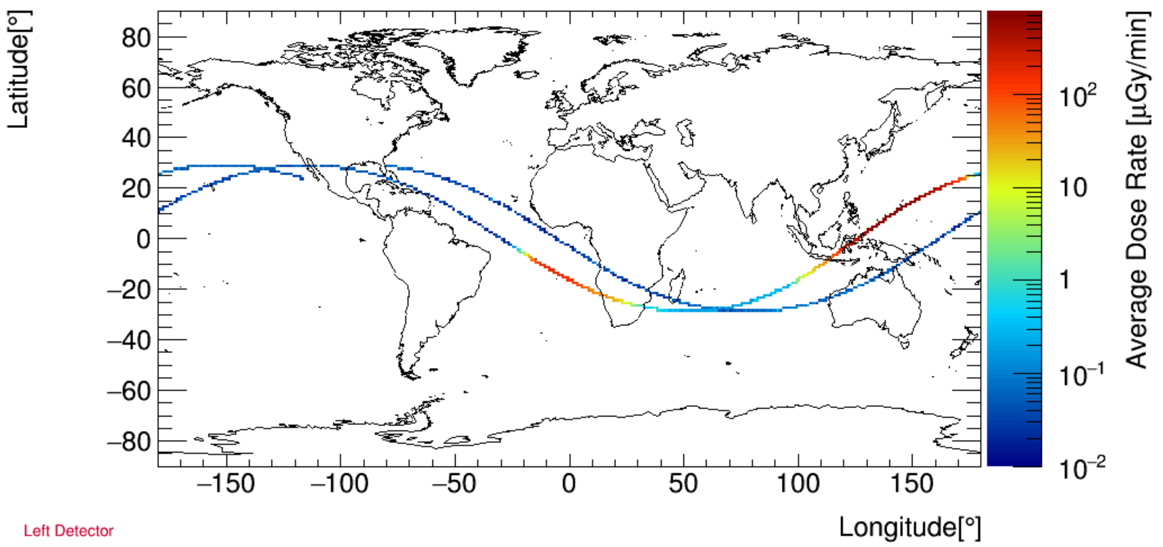
Right Detector

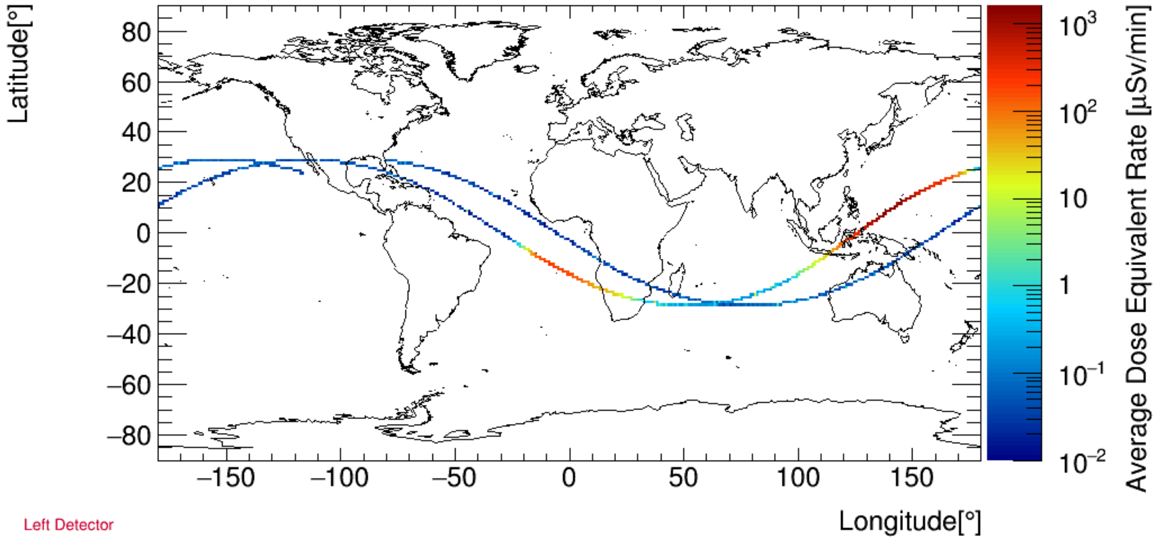


Rates vs. Altitude and Time



Rates vs. Latitude/Longitude

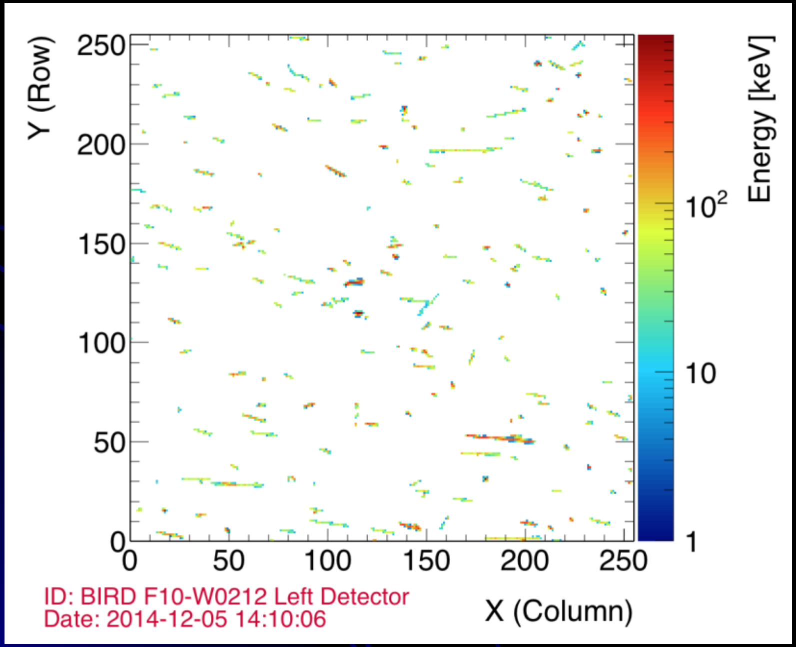


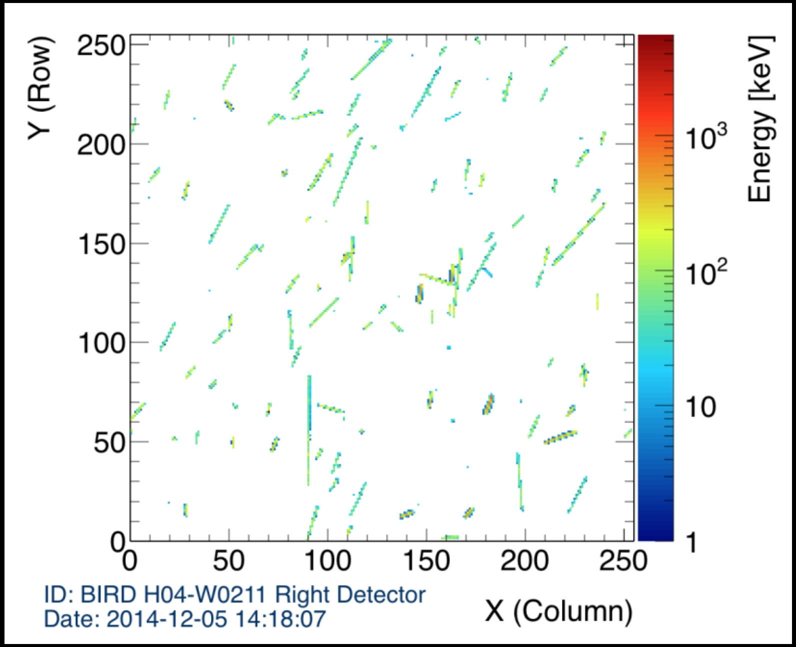


Google Earth Video

Anisotropy

- Trapped proton environment below about 2000 km is known to be anisotropic



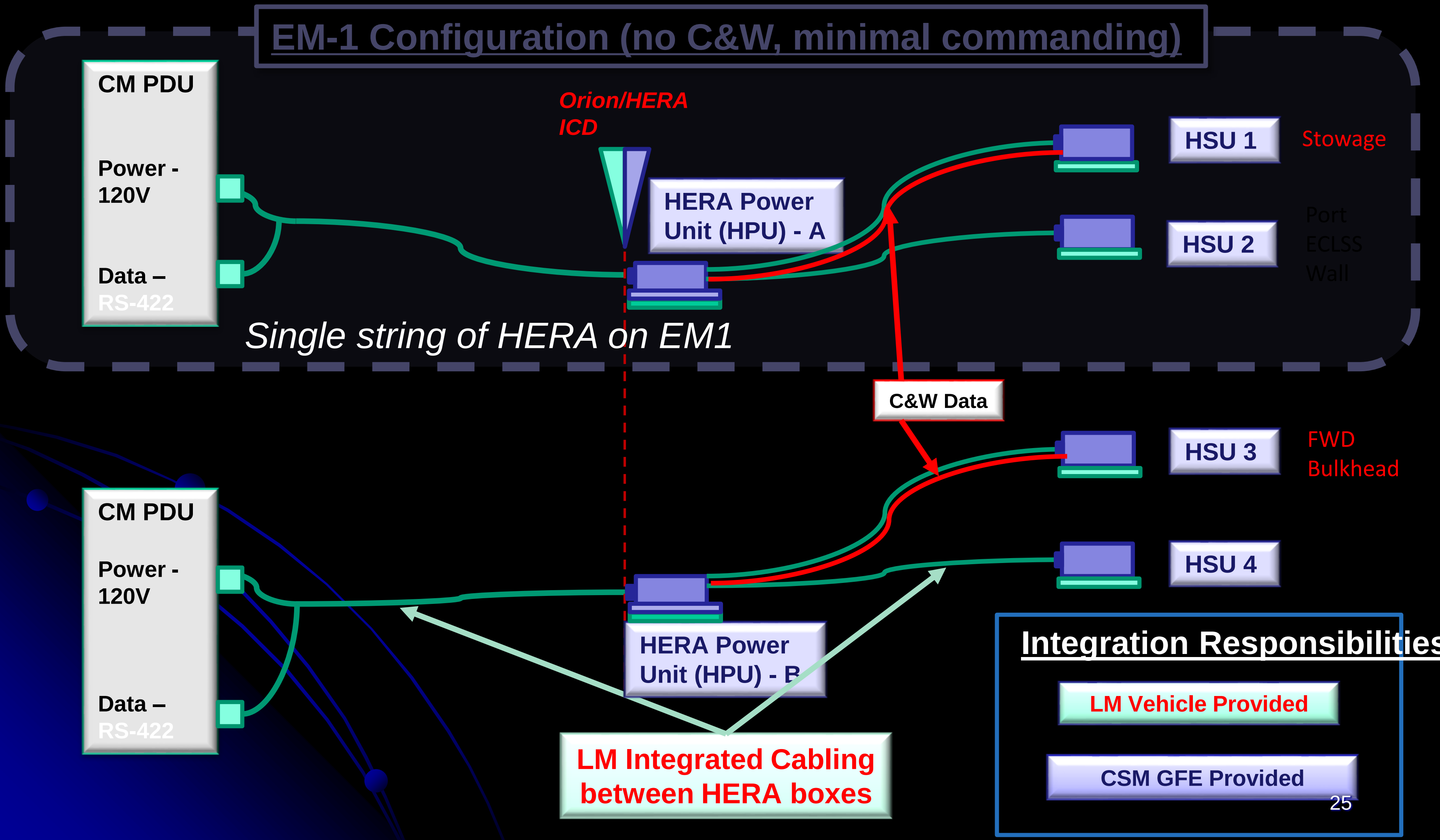


EFT-1 Summary

- EFT-1 presented a unique opportunity
  - First measurements in Orion MPCV
  - Information about EM-2
- Detector operation
  - Met all expectations
  - No apparent data corruption
- Data
  - Two peaks caused by spectral changes
  - Max absorbed dose rate about 1 mGy/min
  - Absorbed dose 1000x ISS TEPC

HERA EM-1 & EM-2 Integration Configurations

Proposed HERA Hardware Block Interface Diagram for Power / Data



EM-1 Configuration (no C&W, minimal commanding)

CM PDU

Power - 120V

Data – RS-422

Orion/HERA ICD

HERA Power Unit (HPU) - A

HSU 1

Stowage

HSU 2

Port ECLSS Wall

Single string of HERA on EM1

C&W Data

CM PDU

Power - 120V

Data – RS-422

HSU 3

FWD Bulkhead

HSU 4

HERA Power Unit (HPU) - B

LM Integrated Cabling between HERA boxes

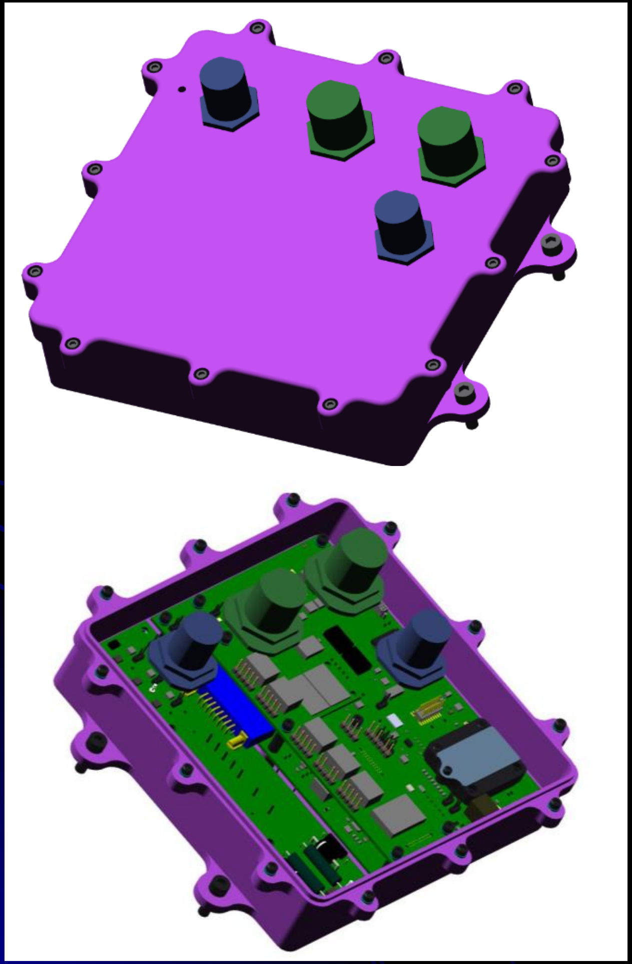
Integration Responsibilities

LM Vehicle Provided

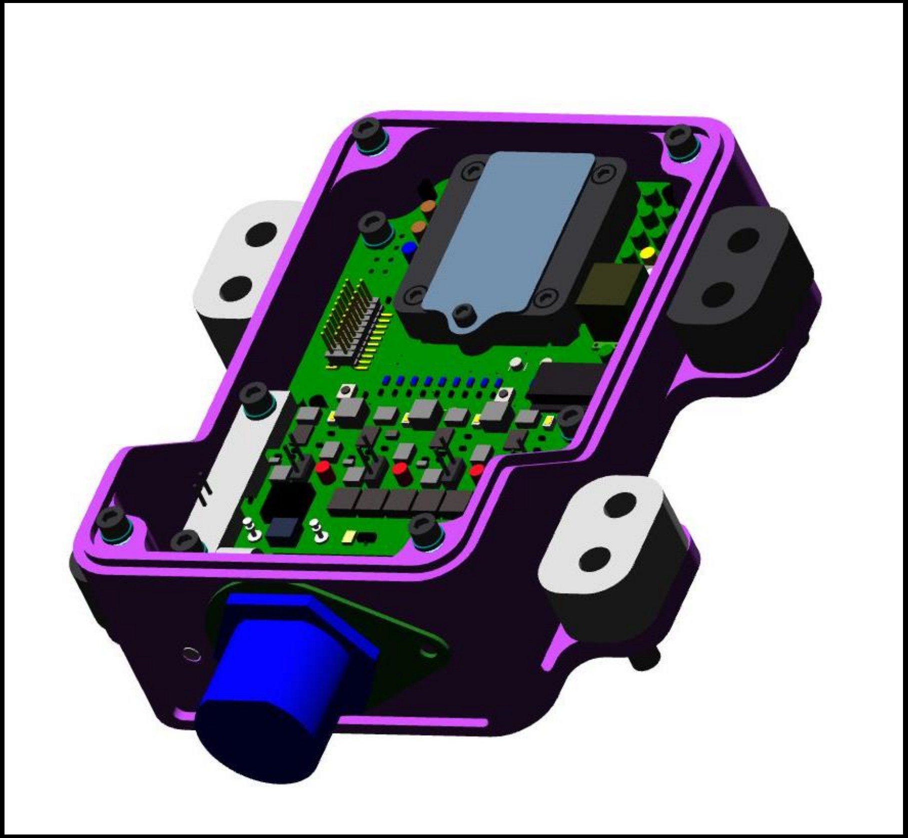
CSM GFE Provided

HERA Power and Sensor Units

- HERA Power Unit (HPU)



- HERA Sensor Unit (HSU)



SPE Contingency Plan Scenarios: (Effective Dose due to King '72 SPE)

Scenario 1:
D&E stowage on top

Crew1: 114 mSv
Crew2: 117 mSv
Crew3: 119 mSv
Crew4: 113 mSv

Scenario 3:
D&E stowage in 8 boxes on top

Crew1: 109 mSv
Crew2: 122 mSv
Crew3: 111 mSv
Crew4: 106 mSv

Scenario 4:
D&E stowage in 16 boxes on top

Crew1: 105 mSv
Crew2: 117 mSv
Crew3: 106 mSv
Crew4: 98 mSv

Scenario 5:
18 boxes on top and 20 canisters in WMS

Crew1: 95 mSv
Crew2: 110 mSv
Crew3: 106 mSv
Crew4: 98 mSv

Scenario 2:
Ideal stowage configuration

Crew1: 85 mSv
Crew2: 102 mSv
Crew3: 100 mSv
Crew4: 98 mSv

A little about Risk

- Calculated quantity – cannot be measured
- Our best knowledge of radiation: tissue interaction, cells damage/repair, mutation, cause of earlier death
- Risks include cancer, CNS, cardiovascular disease
- Based off of limited human statistics (A-Bomb survivors and Nuclear accidents)
- Based off animal exposure studies with relatively high doses
- Extrapolation of mouse models to humans
- Extrapolation of short high doses to low doses over long periods of time

ERROR BARS ARE BIG

- Deep space missions over ~100days exceed the current NASA limit
- NASA risk limit: 3% REID at upper 95% CI

Basic Radiation Safety and Engineering Problems

- Reduce Time of Exposure
  - Deep space missions lengths are fixed by destination and propulsion system

- Increase Distance from Source
  - Space radiation is ubiquitous

- Increase Shielding
  - Space missions are severely mass limited due to high launch costs
  - Shielding is ineffective against GCR

Role of Dosimetry

- Tools for evaluating risk
  - Environmental models
    - Trapped particles (protons and electrons)
    - GCR (modeled as H through Ni)
    - SPE (probabilistic modeling)
  - Particle transport (HZETRN)
  - Vehicle models and human phantoms
  - Risk models
- Dosimetry provides “anchors” for the tools above
  - RAM/CPD data used to determine relative contributions of GCR and trapped protons for ISS
  - MPCV missions: HERA + RAM/CPD

Risk Models

- Evolution of radiation risk models at NASA
  - Pre-2012: effective dose approach
    - LSS mortality-based risk coefficients
    - Gender and age dependency
    - Leukemia and solid cancer risks
  - NSCR 2012*: organ risk approach
    - Risks for organs tracked separately
    - LSS incidence-based risk coefficients
      - UNSCEAR
      - BEIR VII
      - Preston et al
    - Never-smoker status
  - Future*: normal weight population, NTE, circulatory effects, CNS effects, etc.

**Cucinotta, Kim, and Chappell. Space Radiation Cancer Risk Projections and Uncertainties – 2012. NASA/TP-2013-217375.*

Quality Factor

- Pre-2012
  - Function of LET in water
  - ICRP 26 then ICRP 60
- NSCR-2012*: NASA QF
  - Track structure-based model
  - Function of Z, β
  - Various adjustable parameters informed by radiobiology data
  - Important contributor to uncertainty

Cucinotta, Kim, and Chappell. Space Radiation Cancer Risk Projections and Uncertainties – 2012. NASA/TP-2013-217375.

Uncertainty Assessment

- NASA risk limit is inherently statistical
- Monte Carlo sampling used to determine overall uncertainty distribution
- Subjective probability density functions
  - NCRP Report No. 126
  - Risk models
  - DDREF (Bayesian analysis)
  - Quality factor

Summary

- SRAG Operations for future exploration missions need additional forecasting capability due to being unprotected in free space
- The ConOps for a radiation contingency event on MPCV is established and the details are being worked. Protection is possible below required limit without flying any parasitic mass
- MPCV radiation instrumentation is being built
- Risk is the quantity that the NASA radiation requirement is built on. Better understanding of biological effects of radiation are needed to reduce the error