Jet Propulsion Laboratory
California Institute of Technology

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(Proposed) Space Environments and Effects Monitoring with a Cubesat for JPL Earth and Planetary Science Missions: "Black Box"

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On behalf of the Natural Space Environments Group

Jet Propulsion Laboratory, California Institute of Technology

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Topics

- Overview
- Added value, benefits, and products of a black box
- Hazardous environments that the black box would measure
- Sensor makeup
- Characteristics
- Recommendation

What is it?

- The “Black Box” would be a small environment monitor designed to support mission planning, anomaly investigations, and the design of future JPL missions
  - Affordable
  - Low power, low volume, low mass
  - Engineering

For example, on-board radiation monitoring sensors could provide key information to aid in anomaly investigations

Anomaly Database

Distribution by Anomaly Diagnosis

Diagnosis	Number
ESD-Internal	**74**
ESD-Surface	59
ESD-Uncategorized	28
Surface Charging	1
Total ESD and Charging	**162**
SEU-Cosmic Rays	15
SEU-Solar Particle Event	9
SEU-South Atlantic Anomaly	20
SEU- Uncategorized	41
Total SEU	**85**
Solar Array –Solar Proton	9
Total Radiation Dose	3
Materials Damage	3
South Atlantic Anomaly	1
Total Radiation Damage	**16**
Micrometeoroid/Debris Impact	10
Solar Proton Event- Uncategorized	9
Magnetic Field Variability	5
Plasma Effects	4
Atomic Oxygen Erosion	1
Atmospheric Drag	1

Diagnosis	Number
Sunlight	1
IR Background	1
Ionospheric Scintillation	1
Energetic Electrons	1
Other	2
Total Misc.	**36**

Mission Lost/Terminated Due to Space Environment

Vehicle	Date	Diagnosis
DSCS II (9431)	Feb 73	Surface ESD
GOES 4	Nov 82	Surface ESD
DSP Flight 7	Jan 85	Surface ESD
Feng Yun 1	Jun 88	ESD
MARECS A	Mar 91	Surface ESD
MSTI	Jan 93	SEE
Hipparcos	Aug 93	Total Ionizing Dose
Olympus	Aug 93	Micrometeoroid
SEDS 2	Mar 94	Micrometeoroid
MSTI 2	Mar 94	Micrometeoroid
IRON 9906	1997	SEE
INSAT 2D	Oct 97	Surface ESD

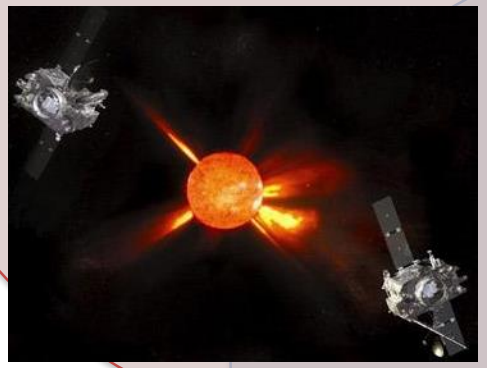
H. C. Koons, J. E. Majur, R. S. Selesnick, J. B. Blake, J. F. Fennell, J. L. Roeder, and P. C. Anderson, "The Impact of the Space Environment on Space Systems," *Proceeding of the 6th Spacecraft Charging Technology Conference*, Sep. 2000.

Pre-decisional information – For planning and discussion purposes only.

Added Value and Benefits

Anomaly Investigation

- Identify anomalies and upsets
- Correlate to the environment
- Support mitigation strategies



Mission Ops Planning

- Adapt to the space environment
- Initiate precautionary measures
- Support extended mission decisions
- Understand mission reliability and survivability

Black Box

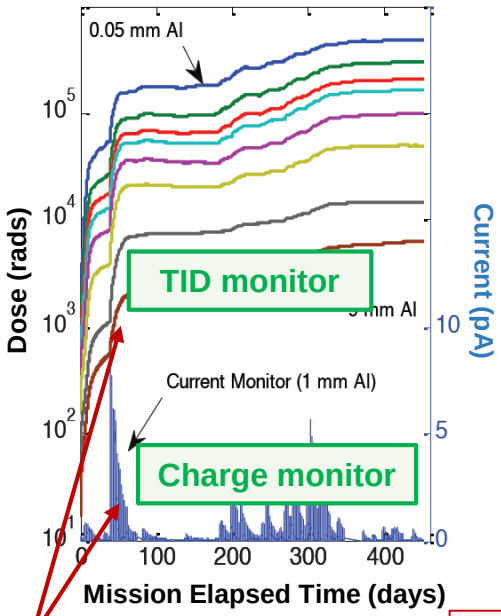
- Simple
- Affordable
- Minimum impact on projects

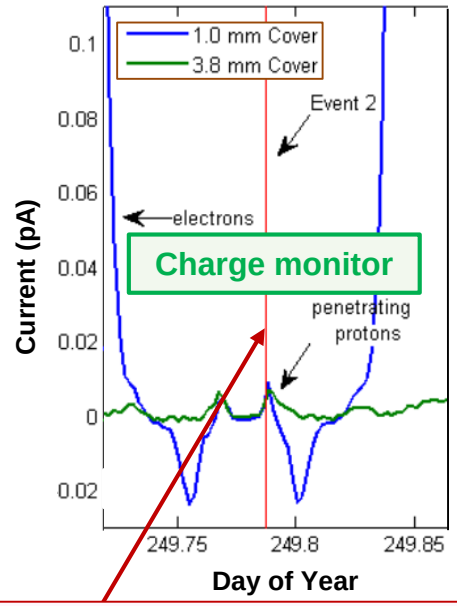
Future Designs

- Acquire data to improve reliability and survivability of future missions
- Optimize shielding design

Potential Benefits and Products

Van Allen Probes TID and Charge sensors' example products





October 2012 Solar Event

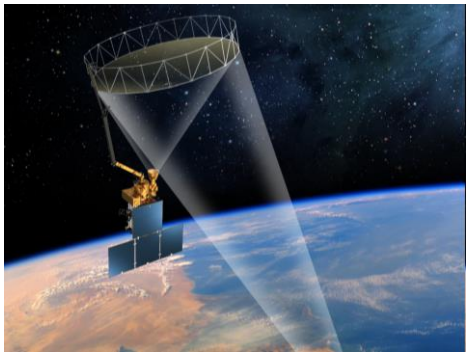
Kirby et al., IEEE Aerospace Conference, 2016

Memory scrubbing anomaly in VAP s/c was correlated to penetrating energetic protons thanks to their radiation monitor

Jason-3 Ongoing Anomaly

Many Thales spacecraft include the CARMEN (CARacterization and Modeling of ENvironment) radiation monitor dedicated to measure the space environment

The data set from the CARMEN monitor onboard Jason-3 is very valuable to the investigation of an ongoing GPS anomaly believed to be induced by the radiation environment



SMAP Anomaly

Knowledge of the local space environment could have significantly reduced the time and effort in the investigation and possibly identify the cause

On-board radiation monitoring sensors provide key information to aid in anomaly investigations

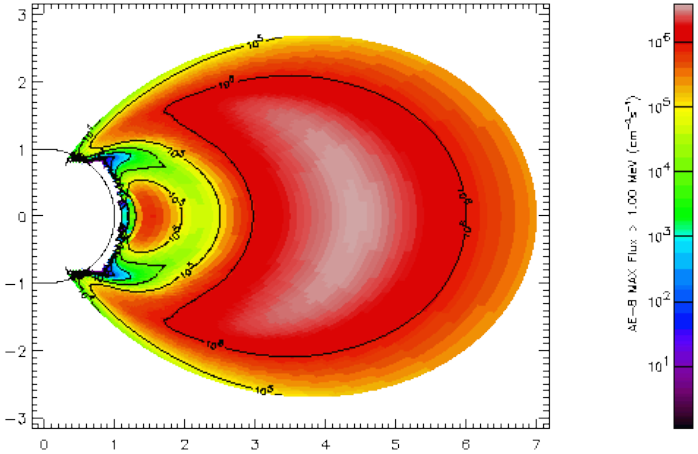
What if we had a Black Box in previous missions?

- **Cassini:**
  - Had higher-than-expected SEU rates in SSDR → Could have used the data for model improvement for future missions
  - Could have provided the data for anomaly investigation for CAPS over-current and failure of USO
- **Juno:**
  - Could provide measurements of actual high energy particle environments, and characterize environment inside and outside the vault
  - Could provide valuable information for potential anomaly investigations
  - Could provide data for model improvement → could have influenced the Europa design
- **Mars (e.g., MSL, MER, etc.):**
  - Could use data for MMRTG power output monitoring
  - Could provide data for potential anomaly investigations (e.g., SEU)
  - Could provide data for future human mission planning (e.g., dose): complement to RAD
  - Better monitor dust environment (for MER)
- **SMAP:**
  - Could provide data for anomaly investigation
    - The root causes of the current anomaly are attributed to several different phenomena (SET, charging transients, solder joint failure, etc.). But, no definite proof has been determined yet.
  - A camera could have provided a movie for antenna deployment → deployment assurance and public engagement

Hazardous Environments

Most hazardous effects are associated to the following space environments:

- **Total Ionizing Dose (TID) effects:**
  - Current estimates are based on statistical models (like AP9/AE9 for Earth). These models are only capable of providing statistical estimates of the environment
  - The space environment is variable and complex. The Black Box will characterize the in-situ, real-time and cumulative dose on spacecraft

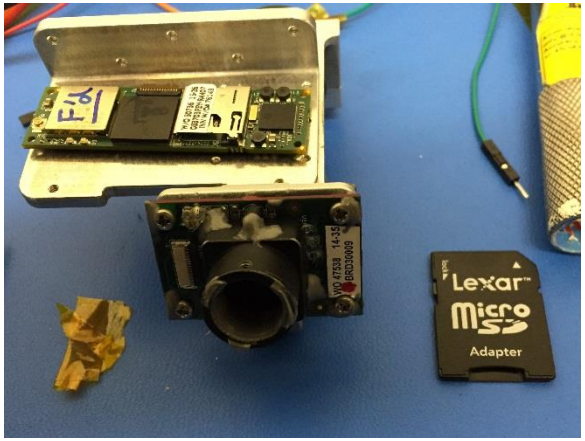


- **Internal Electrostatic Discharges (IESD):**
  - The Black Box will provide a unique dataset capable of characterizing the electron environment responsible for IESD

- **Single Event Effects (SEE):**
  - The dynamics of the South Atlantic Anomaly are difficult to predict and not included in the models. The Black Box would provide detailed time dependent SEU rates at the location of the spacecraft

Black Box Sensors - Baseline

- Three baseline sensors selected based on simplicity, cost and added value:
  - **TID monitor**
  - **SEU monitor**
  - **Charge monitor**
  - **Camera** (optional module)
- Sensors would not be mission critical
- No technology development required
- TID, SEU, and Camera are based on commercial parts
- Charge monitor will be developed in-house; schematic completed
- Additional candidate sensors:
  - Transient pulse monitor
  - UV sensor
  - X-ray sensor
  - Contamination sensor



MarCO camera
(Gumstix module and 0.3 MP Aptina-based camera module)

Sensor	Environment Quantified	Dynamic range	Induced Effect on Spacecraft
Total Ionizing Dose (TID)	Energy deposition by high energy protons and electrons	Up to 1 Mrad	Long-term failure due to ionizing radiation (rad, rad/s)
Single Event Upset (SEU)	High-energy protons and heavy ions	Up to $2 \cdot 10^6$ SEU/min	Dynamic SEU rates on components and related anomalies
Charge	Spectral range of high-energy electrons	Up to 0.5 nA	Proxy for Internal Electrostatic Discharges (IESD)

Characteristics of Sensor Concept

- **Not mission critical**
- **No fault propagation**
  - Faults would not propagate from the unit to the rest of S/C
  - The Black Box would not interfere with the S/C
- **Minimum impact on projects**
  - Simple design
  - Affordable
  - Standard interface
  - Single point interface to S/C bus
  - Single C&DH channel
  - EM available for early interface testing
  - Allocated power switch; can be turned off by the S/C
  - Small mass, volume, power, and data rate

BUDGETS – Baseline Sensors (no camera)	
Power	< 1.5 W
Mass	~ 500 g (sensors/electronics) ~ 500 g (packaging)
Volume	~ 5 x 10 x 10 cm
Data rate	~ 3 bps (TID + SEU + Charge sensors)

BUDGETS – Camera Module	
Power	< 1 W
Mass	~ 30 g (camera system) ~ 250 g (packaging)
Volume	~ 5 x 5 x 5 cm
Data rate	~ 4 GB from camera (video of deploying S/C structures will be stored in local memory)

Concept Overview -- Factsheet

What is it?

It is a small environment monitor designed to support mission planning, anomaly investigations, and the design of future JPL missions

On-board radiation monitoring sensors provide key information to aid in anomaly investigations

Includes three baseline sensors selected based on simplicity, cost, and added value

- TID, SEU, and Charge monitors (baseline)
- A camera to monitor deployments is added as an optional module

Sensor	Environment Quantified	Dynamic range	Induced Effect on Spacecraft
Total Ionizing Dose (TID)	Energy deposition by high energy protons and electrons	Up to 1 Mrad	Long-term failure due to ionizing radiation (rad, rad/s)
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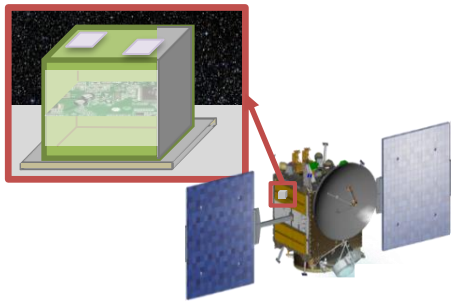
Characteristics

- Stand-alone, autonomous unit
- Universal, modular design
- Minimizes spacecraft-specific re-designs and facilitates production of recurrent units
- Design allows for a daisy chain of units internal/external to the S/C
- UART interface to S/C bus
- 28 V power interface (baseline)



	Baseline sensors	Camera module
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Volume	~ 5 x 10 x 10 cm	~ 5 x 5 x 5 cm
Data rate	~ 3 bps	~ 4 GB from camera (stored in local memory)

Approach

- Not mission critical
- No fault propagation, do no harm
- No technology development required
- Simple and affordable design
- Type II development
- Standard, single-point interface to S/C
- Small mass, volume, power, and data rate

Frequently Asked Questions and Short Answers

Does it have a mass/power allocation? **YES**

Is it fault tolerant? **NO; faults will not propagate to the S/C**

Can it help mission success? **YES**

Can you provide for it in the design, but fly without it? **YES**

Recommendations

We recommend the inclusion of a Black Box in future JPL spacecraft

TID, SEU, and Charge monitors are simple, affordable, and provide necessary information to quantify radiation-induced threats to the S/C

A camera module could be added to monitor deployments when necessary

A Stand-alone architecture is feasible, affordable, and has minimum impact on projects

The Black Box is not mission critical
A Type II development is recommended. The development plan guarantees fault containment

An affordable Catalog cost to projects is key to ensure product continuity
It can be achieved by including commodity parts as part of the development of the first unit

NASA's Vision:
Space Environment Capability Leadership Team (CLT) Input to NESC/EMB

Space Environments Strategic Vector

	2017 → 2022	2022 → 2027
Outcomes	• Integrated partnerships with NOAA, DOD, and the international space environments and effects community for LEO space weather/environments with NASA lead for interplanetary space • Easy access by spacecraft designers to space environment measurements, spacecraft anomaly data, and material parameters • Collaborative community of space environments experts across NASA Centers • Design-optimization strategies for spacecraft mission design and operations to withstand the extremes of the space environment	• Develop robust spacecraft system designs and terrestrial infrastructure immune to effects of extreme space weather events • Improve knowledge of space environments and interactions with space systems wherever NASA missions operate • Improve knowledge of the micrometeoroid and debris threat environments in Earth orbit and interplanetary space • Develop space environments durability and space weather prediction capabilities to support future planetary habitat operations and long duration spacecraft in interplanetary space
Benefits	• Reduction of risk due to space environment interactions • Reduction in cost and schedule risk required to develop, optimize, certify and implement space environments requirements for current and future spacecraft • Reduced cost to programs through better access to existing data sets and expertise (eliminates repeating tests that have already been done and reinventing knowledge that can be shared)	• Mitigate nationwide disruption to spacecraft operations and terrestrial power grids due to extreme space weather events • Address space environmental hazards at the mission design phase so that need for operational mitigation is eliminated by proper understanding of the space environment and its interactions with spacecraft systems • Efficient access to experts and information across multiple Centers improves design efficiency and reduces mission design costs
Capabilities	• Establish agency level space environment and effects program to fund space environment model and tool development and maintenance, laboratory testing, and flight opportunities • Tasks and personnel are shared between field centers • Formal collaboration, via Space Act Agreement, with ESA and JAXA to exchange space environment and effects information • Participation in International Standards for Space Environments • Continued support for space environments heritage test facilities	• Develop and deploy standard natural environmental monitoring instruments on every NASA mission • Robust program to monitor state of near-Earth orbital debris and other relevant threat environments • Improved environmental models, validated with data, to support human missions to Mars and robotic exploration of outer planets • Space Weather forecasting capability including solar weather satellites at different solar longitudes off the Sun-Earth line.

THANK YOU!

QUESTIONS?