Mission Assurance Approaches and Results for a Proposed Commercial Off-the Shelf (COTS) Mars Mission: Mars Helicopter

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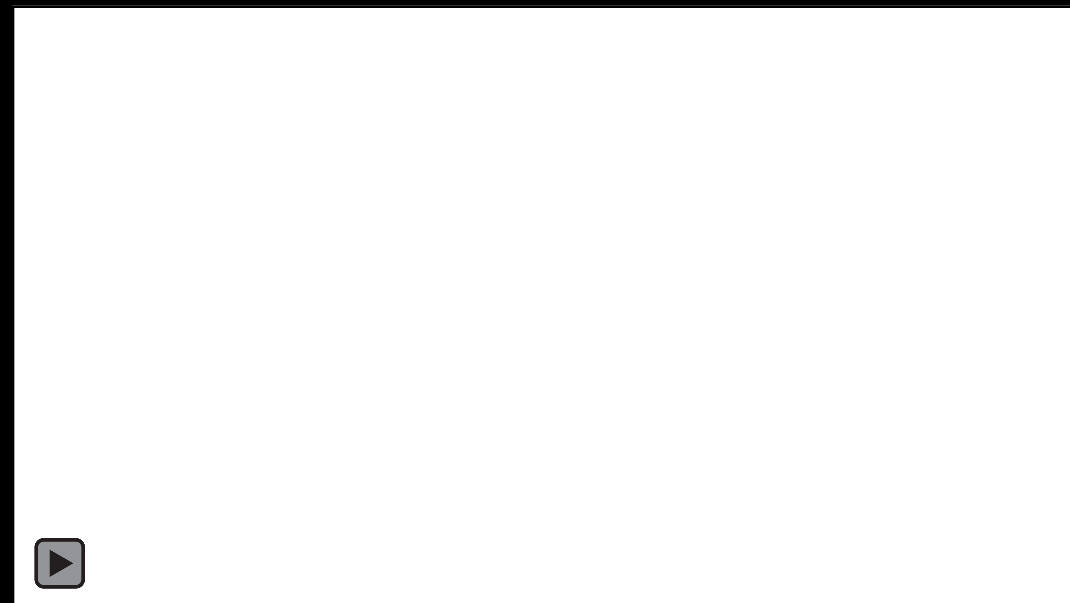
Introduction and Motivation

- **Mars Helicopter (aka Ingenuity) is an JPL internally funded *Technology Demonstration Mission Concept***
- **Entirely COTS-based mission concept**
- **Need to implement adapted radiation hardness assurance (RHA) approaches due to cost limitation and tight schedule**

Pre-decisional information for planning and discussion only.

Conceptual Mission Overview

- **Proposed Objectives:**
  - **Design and complete Earth testing of Ingenuity prototype**
  - **Conduct five test flights on Mars**
  - **Generate technology performance data**
  - **Demonstrate traverse planning with future Mars rover missions**



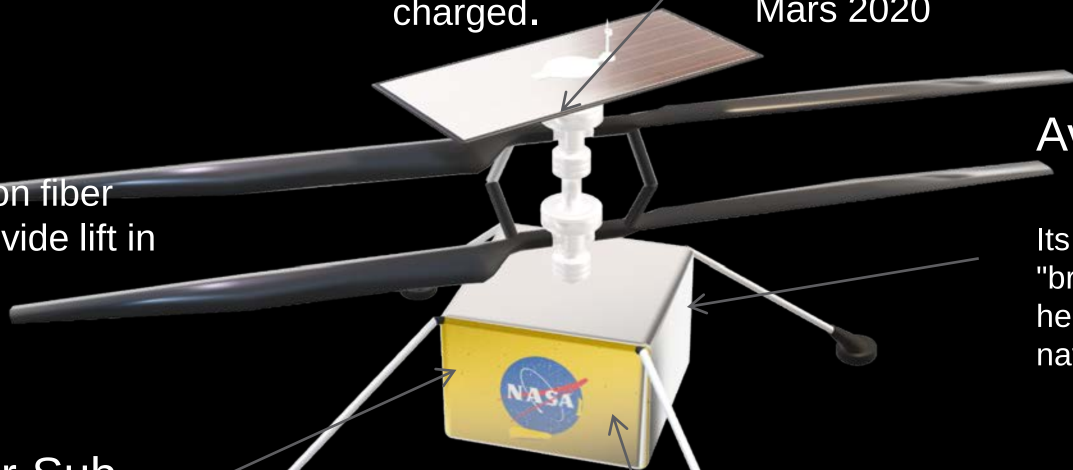
*NASA's Mars Helicopter Testing Enters Final Phaser. [Online]. Available:https://www.jpl.nasa.gov/news/news.php?feature=7417

Challenges:

- **Very thin Martian atmosphere**
- **Mass allocation of 1.8kg**
- **Autonomous operation**
- **Multiple take-off and landings**
- **Relatively harsh environment**
- **Limited time scale and budget**

DO NO HARM

Proposed Architecture Overview



SOLAR PANEL

A solar panel helps keep the battery charged.

ANTENNAS

Radio antennas that communicate with Mars 2020

BLADES

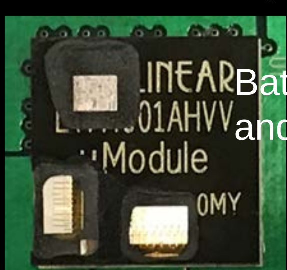
Made of carbon fiber foam core provide lift in the thin Mars atmosphere.

Avionics

Its avionics — or "brains" — help the helicopter function and navigate.

Power Sub-System

Batteries, charging, and power delivery

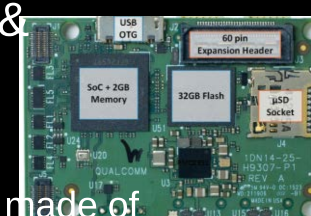


Sensors, Cameras & Autonomy

Sensors that collect data on how fast the helicopter is traveling and in which direction. Flight "vision"

LEGS

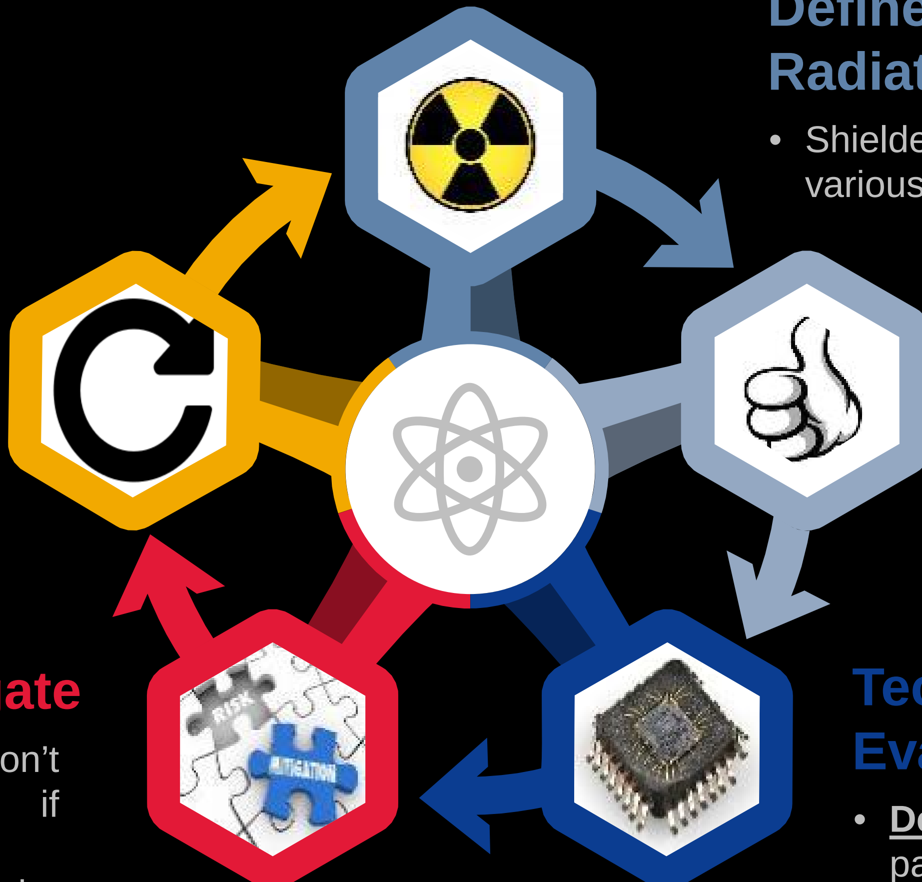
Ultra-light legs made of carbon fiber tubes to help it land after flight



*Artist's illustration of concept architecture

Pre-decisional information for planning and discussion only.

Radiation Hardness Assurance Overview



Define & Evaluate Radiation Hazard

- Shielded contributions from various environments

Set Survivability Requirements

- Determine TID, DD, and SEE limits and thresholds

Technology Evaluation

- **Develop and evaluate** parts list
- Analyze/test/analyze
- Determine "tall tent pole" hazards

Replace or Mitigate

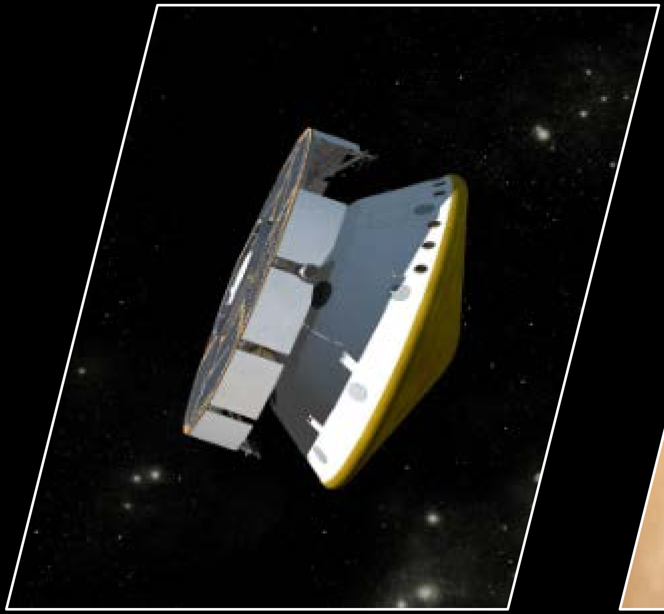
- Replace parts that don't meet requirements if possible
- Mitigate what can't be replaced.

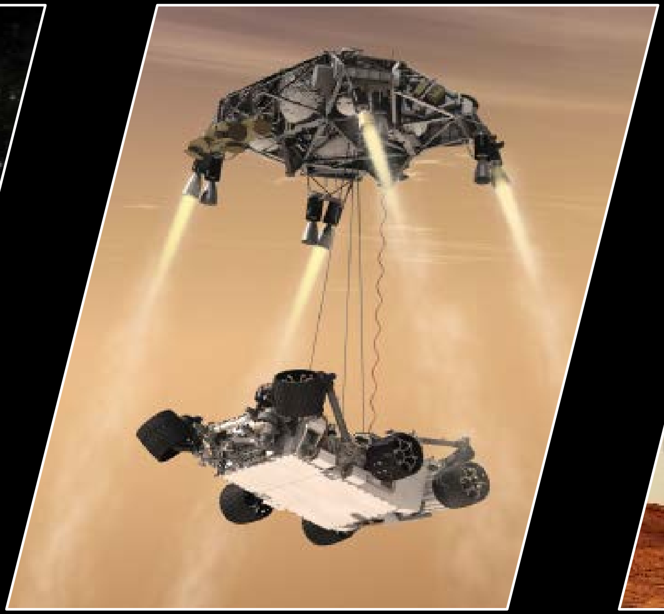
Peel & Iterate

- Re-evaluate at the system-level
- Attack the next "tent pole"

K. A. LaBel, A. H. Johnston, J. L. Barth, R. A. Reed and C. E. Barnes, "Emerging radiation hardness assurance (RHA) issues: a NASA approach for space flight programs," in IEEE Transactions on Nuclear Science, vol. 45, no. 6, pp. 2727-2736, Dec 1998.

Mission Concept Environment





CRUISE/APPROACH

ENTRY, DESCENT,
& LANDING

EGRESS & OPERATIONS

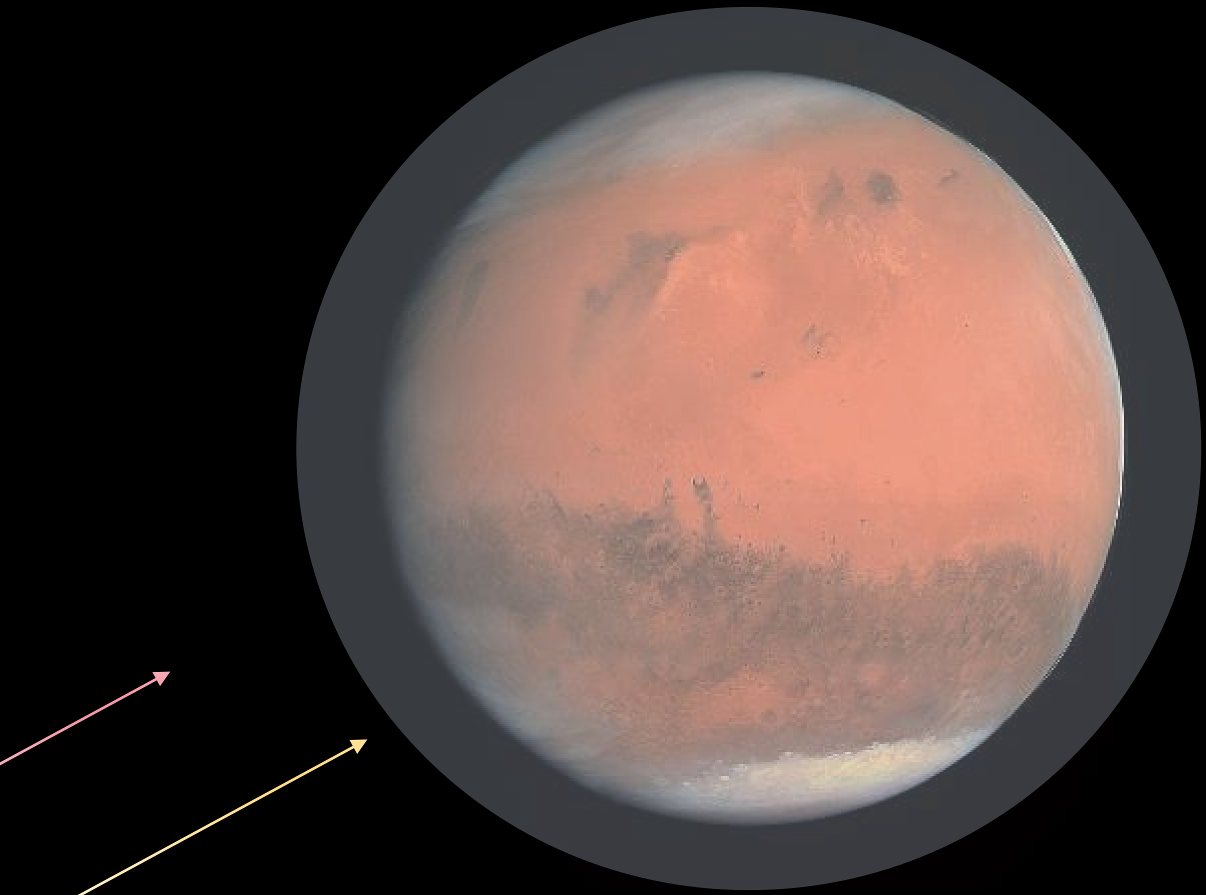
RHA Phase 1: Cruise

- Seven to nine month cruise period
- Standard interplanetary solar minimum galactic cosmic ray (GCR) model
- Nearly all Ingenuity's electronics powered *OFF*

RHA Phase 2: Landed

- Martian surface model
- Goal of *at least* 10 hours of powered *ON* operation

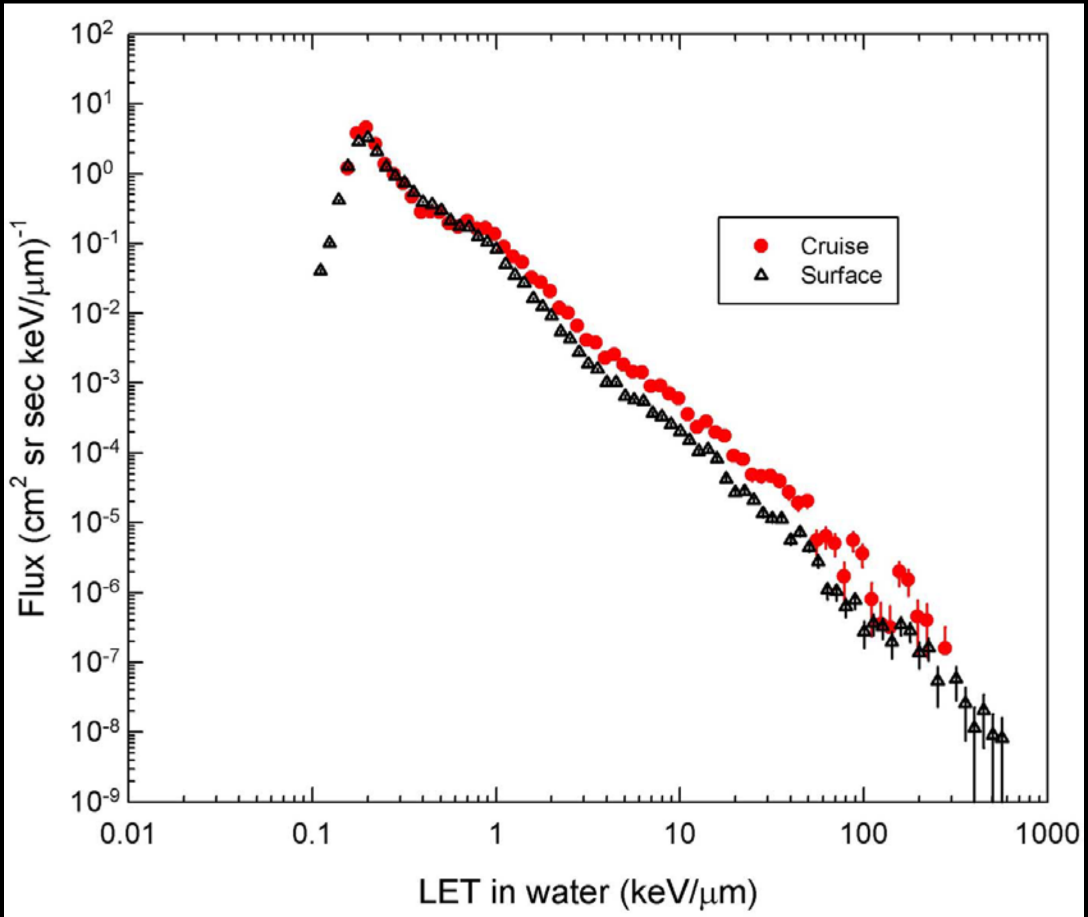
Mars Surface Model



- **Atmosphere will stop nearly all solar energetic particles**
- **Optical shadowing of planet reduces GCR flux in half**
- **Generic atmospheric model is equivalent to 2-3 inches of aluminum**
- **Reduces GCR flux by another factor of 2**
- **Use solar maximum GCR model**

L.C. Simonsen, J.E. Nealy, L.W. Townsend, and J. W. Wilson ,"Radiation Exposure for Manned Mars Surface Missions", NASA TP 2979, 1990

Mars Surface Model



D. M. Hassler, C. Zeitlin, R. F. Wimmer-Schweingruber, B. Ehresmann, S. Rafkin, J. L. Eigenbrode, D. E. Brinza, G. Weigle, S. Böttcher, E. Böhm, S. Burmeister, J. Guo, J. Köhler, C. Martin, G. Reitz, F. A. Cucinotta, M.-H. Kim, D. Grinspoon, M. A. Bullock, A. Posner, J. Gómez-Elvira, A. Vasavada, J. P. Grotzinger, and M. S. L. S. Team, “Mars’ Surface Radiation Environment Measured with the Mars Science Laboratory’s Curiosity Rover,” Science (80-.)., vol. 343, no. 6169, Jan. 2014.

Single Event Effects RHA Approach

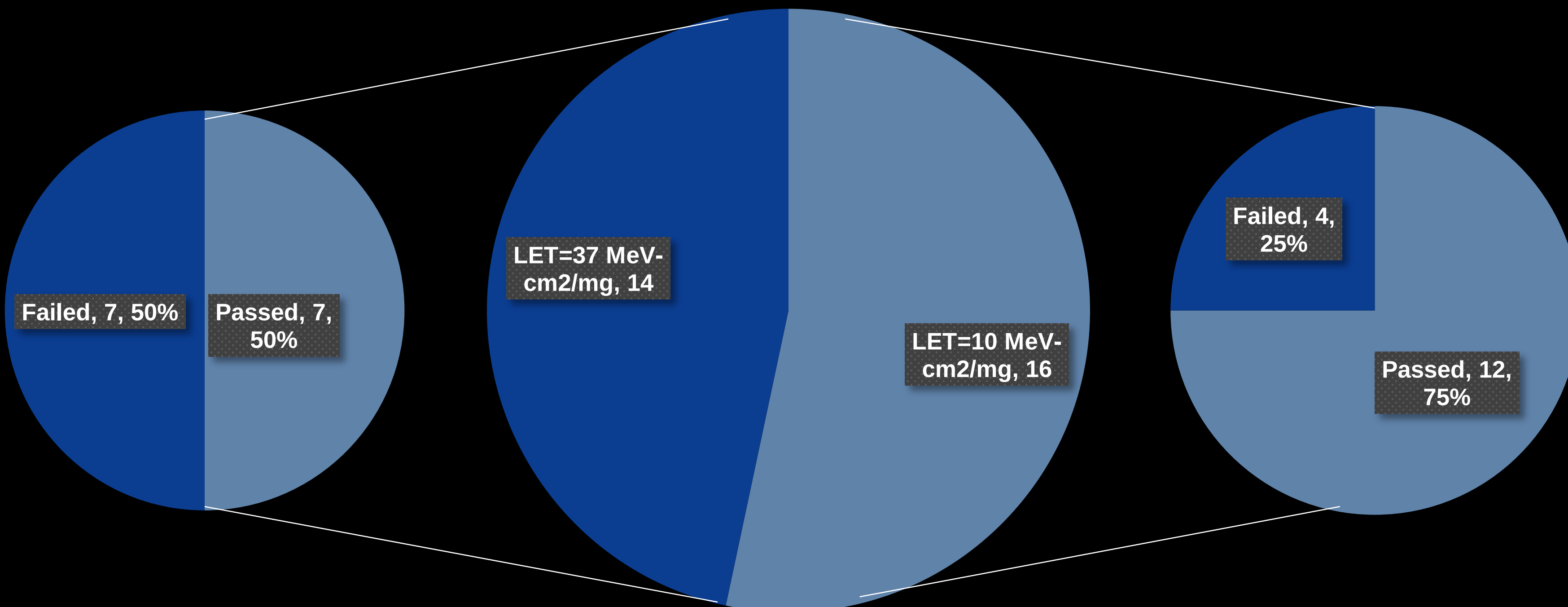
- ~~No testing (bound the risk through analysis)~~
- ~~Adopt PETS 3 mission requirements~~
- ~~Perform board-level proton test~~
- Adopt our own LET requirements
  - Given an operational time of 10 hours and the Mars surface radiation model…
  - Assumed a worst-case saturated cross-section and used a conservative step function with varying LET_{TH}
  - Settled on an LET_{TH} requirement of 10 $MeV\text{-}cm^2/mg$ that yielded a 99.99% success probability against Single-Event Hard Errors (SEHE) for the Martian surface
  - Continued use of 37 $MeV\text{-}cm^2/mg$ for electronics powered on during cruise phase

R. L. Ladbury and M. J. Campola, "Bayesian Methods for Bounding Single-Event Related Risk in Low-Cost Satellite Missions," in *IEEE Transactions on Nuclear Science*, vol. 60, no. 6, pp. 4464-4469, Dec. 2013

R. Ladbury, J. M. Lauenstein and K. P. Hayes, "Use of Proton SEE Data as a Proxy for Bounding Heavy-Ion SEE Susceptibility," in IEEE Transactions on Nuclear Science, vol. 62, no. 6, pp. 2505-2510, Dec. 2015.

Test Overview and Results

- **30 devices were screened for single-event latchup (SEL) or gate rupture/burnout (SEGR/SEB)**



Failures and Mitigation Approaches

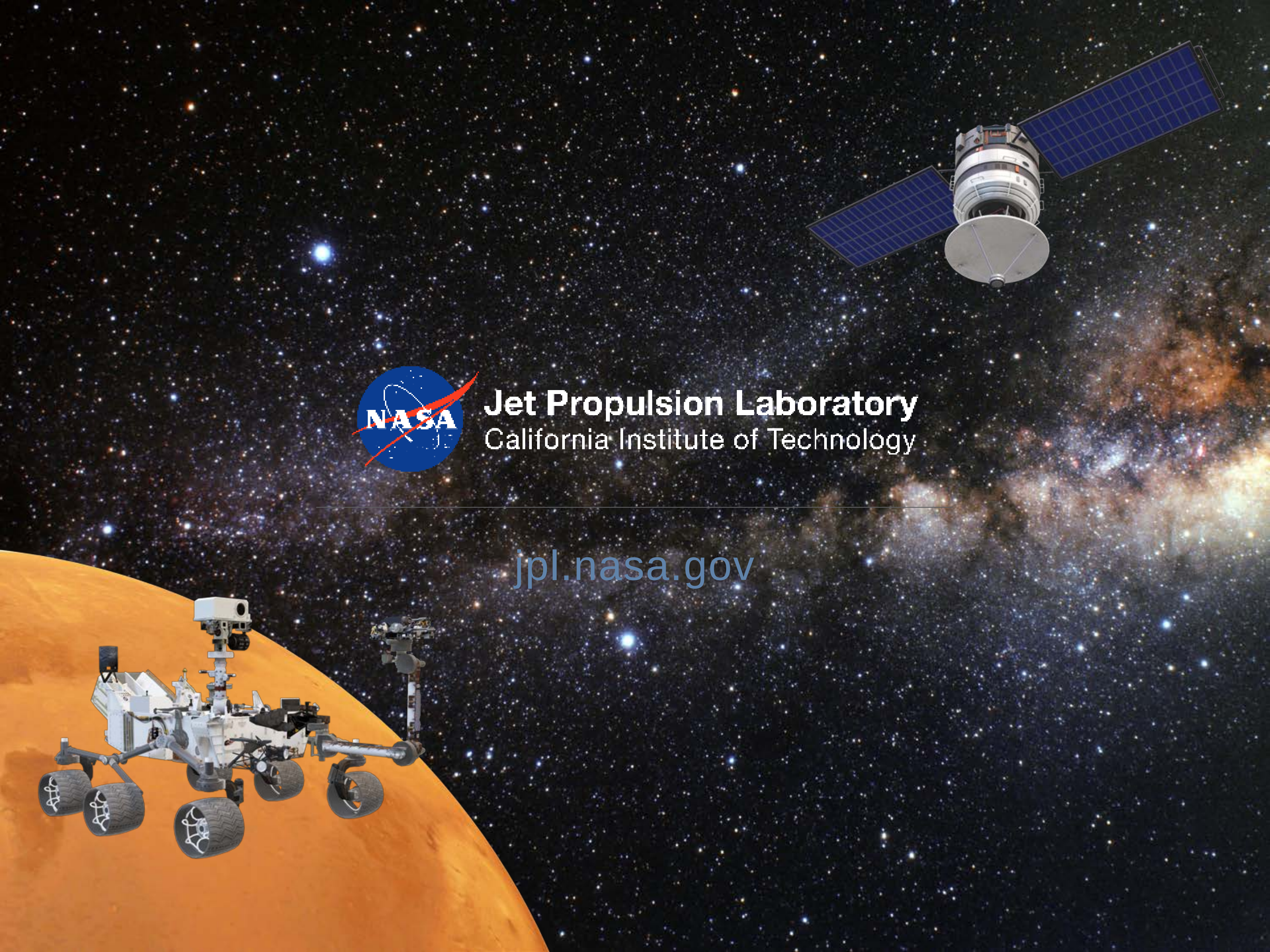
- **Devices that failed and could be replaced were**
- **Two devices exhibited “non-destructive” SEL, but could not be replaced**

  H. N. Becker, T. F. Miyahira and A. H. Johnston, "Latent damage in CMOS devices from single-event latchup," in *IEEE Transactions on Nuclear Science*, vol. 49, no. 6, pp. 3009-3015, Dec 2002.

- **Current-limiting mitigation was employed**
  - **Proposed technique of using an FPGA output pin to power the devices is under consideration**
  - **Current limiting resistor**

Conclusions

- **Same RHA approaches, more willingness to accept risk**
- ***Define the environmental threats***
  - **Would be operating in a fractionally GCR dominated environment nearly devoid of protons**
- ***Set survivability requirements***
  - **A desired 99.99% probability for success against SEHE**
  - **Set LET thresholds to 10 or 37 MeV-cm^2/mg (depending on mission phase)**
- ***Apply existing data and/or test sensitive components***
  - **Removed failed devices if possible**
- ***Explore mitigation solutions as required***
  - **Current limiting of SEL sensitive devices**
- ***Iterate this process beginning with most critical threats***
  - **Once SEHE is dealt with, fold test observables and literature-based soft-error analysis into the system-level**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