BioSentinel Mission: “Canary in a Coal Mine”
- Quantify DNA damage from space radiation environment
  - Space environment cannot be reproduced on Earth; omnidirectional, continuous, low fluxes, variety of particle types
  - Health risk for humans spending long durations beyond low Earth orbit (LEO)
- Radiation flux can spike 1000x during a solar particle event (SPE)
- Yeast assay: microfluidic arrays monitor DSBr/repair
  - Three strains of S. cerevisiae: 2 controls, 1 engineered strain
  - Engineered strain quantifies double strand breaks (DSB)
  - Wet and activate multiple banks of microfluidics over mission lifetime
  - Double strand break & associated repair enable cell growth & division
  - Reserve wet-activated autonomously in case of SPE
- Correlate biological response with physical radiation measurements
  - Total ionizing Dose (TID) sensor measures integrated deposited energy
  - Linear Energy Transfer (LET) spectrometer bins and counts particle events

BioSentinel Mission Development of a Radiation Biosensor to Gauge DNA Damage and Repair Beyond Low Earth Orbit on a 6U Nanosatellite
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5 hours, 27,000 km
System Initiation

Summer 2018, KSC
SLS EM-1 Launch

5 Days, 380,000 km
Lunar Flyby

9 months
Duration equal to round trip asteroid mission

12 months, 0.44AU
Nominal mission duration

18 months, 0.75AU
Max mission duration equal to round trip Mars mission

Spacecraft Design: 6U Cubesat
- "A 6U (10 x 12 x 34 cm) nanosatellite
- First NASA biological study beyond LEO in over forty years (since Apollo)
- Results will be compared to data obtained in LEO (on International Space Station) and on Earth
- Active attitude control required for RF communication and solar power generation

Concept of Operations: Deep Space
Earth Range Over Time

- Secondary payload aboard Space Launch System (SLS) Exploration Mission-1 (EM-1)
- Launch from Kennedy Space Center (KSC)
- 11-18 month mission lifetime
- Earth-leading ~0.93 to 0.98 AU heliocentric orbit
- Total ionizing dose with 1.85 mm of aluminum shielding ~9.5 krad/yr over 1 year:
  - 0.65 krad in silicon, mean dose probability
  - 1.3 krad in silicon, 95% maximum dose probability (important for LET dose selection)

Fault Modes Definition: FMECA
- Performed spacecraft level Failure Modes, Effects, and Criticality Analysis (FMECA)
- Examined numerous processes below
- Example case is for a reaction wheel failure (RW, pictured on right)
- FMECA identified how each item would be addressed: flight software function, mission operations procedure, design update, minimum risk design approach, or a combination of these.

Fault Mitigation: Detection and Response
- Fault Management Plan defines items addressed by flight software
- Core Flight Services (CFS) Limit Check Module used for implementation
- Watch Points (WP) use on-board telemetry source (eventonic)
  - Watch Points mapped to software applications
  - 
- Added monitors to Intentional Off-Point Control Documents (IOCDs)
  - Identified thresholds and persistence for action
  - Action Points (APs) built on Boolean states of WP
  - Allows different thresholds based on operating modes
  - Added WP and APs based on success of LADEE mission fault plan and
  - Added WP and APs based on review with payload, mission operations, and spacecraft teams

Verification: Testbeds
- Electrical Power System (EPS) Engineering Development Unit (EDU) hardware
  - Used to replicate overall current and verify response
  - Generalized Nanosatellite Avalanches Testbed (G-NAT)
  - Testing data and general test protocols for sensors, actuators, and processors
  - An air bearing allows for three degrees of freedom (3-DOF) rotational motion within a Helmholtz cage
  - "Attitude truth" resolved from a set of infrared LEDs being tracked using a COTS digital camera

Summary
- BioSentinel is a deep space subsatellite mission that will require autonomous 3-DOF attitude control in a high radiation deep space environment
- 35 failure modes identified in FMECA with 35 possible implementations of mitigations in flight software
- Action Points table developed with Boolean logic for watch point combinations