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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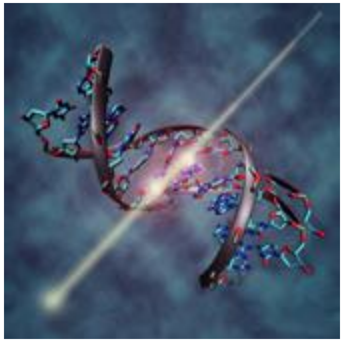
BioSentinel Project Objectives

- Advanced Exploration Systems (AES) Program Office selected BioSentinel to fly on the Space Launch System (SLS) Exploration Mission (EM-1) as a secondary payload
  - Payload selected to help fill **HEOMD Strategic Knowledge Gaps in Radiation effects on Biology**
  - Current EM-1 Launch Readiness Date (LRD): July 31, 2018

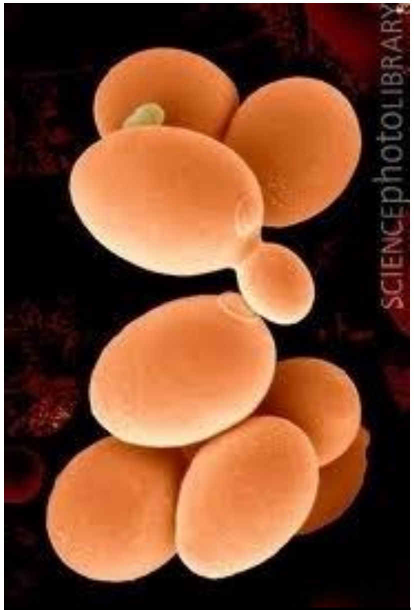
- Key BioSentinel Project Objectives
  - Develop a ***deep space nanosat*** capability
  - Develop a ***radiation biosensor*** useful for other missions
  - Define & validate **SLS secondary payload interfaces and accommodations** for a biological payload

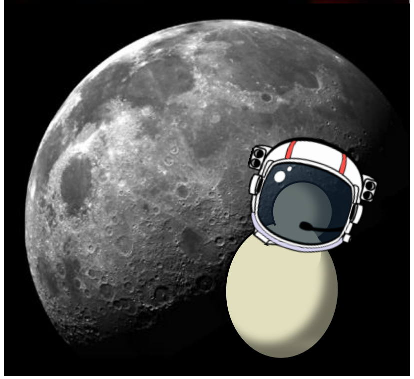


- Collaborate with two other AES selected missions (non-biological) for EM-1
  - Near Earth Asteroid (NEA) Scout (MSFC)
  - Lunar Flashlight (JPL)

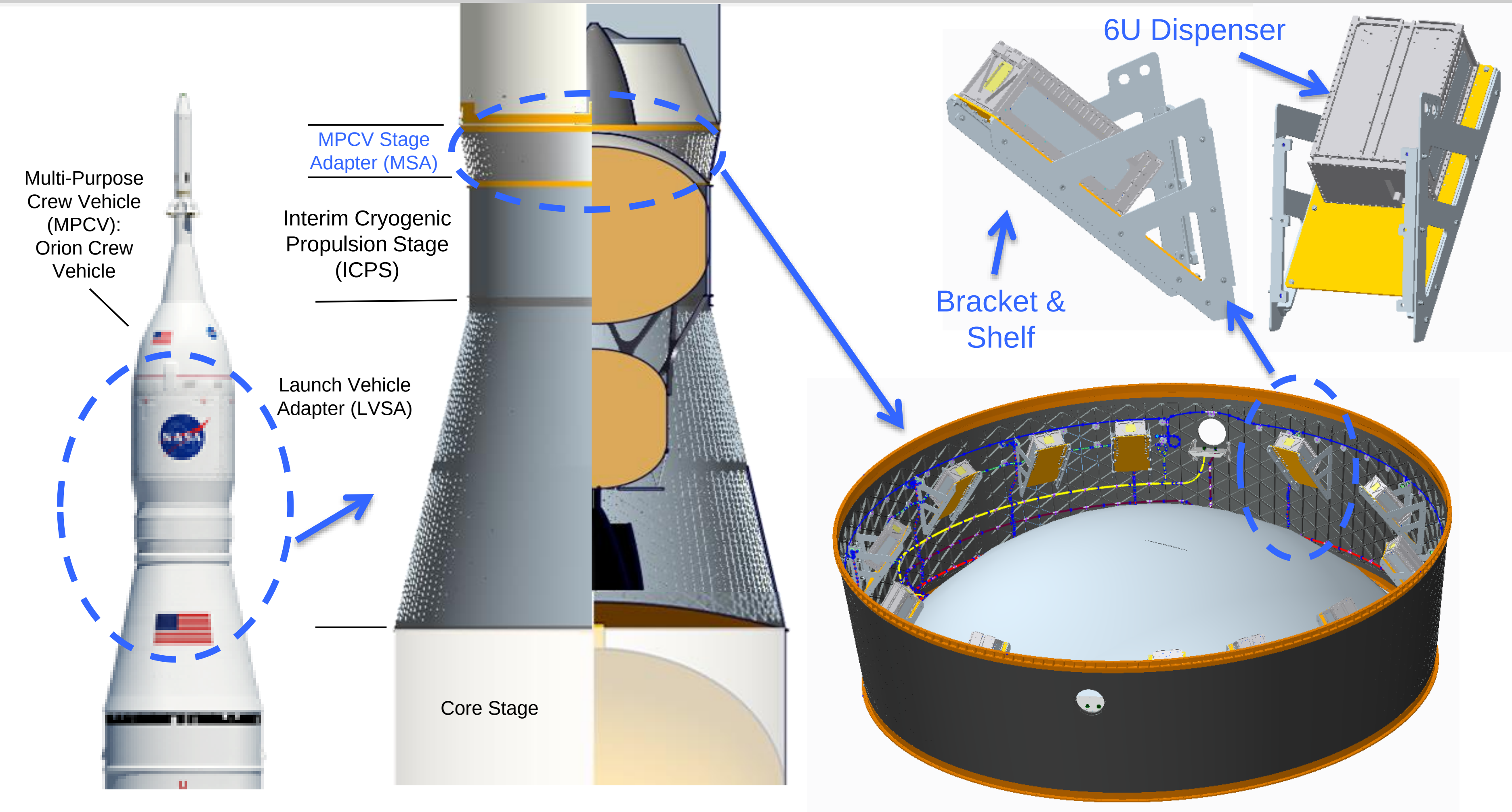
BioSentinel Science Concept

- Quantify DNA damage from space radiation environment
  - Space environment cannot be reproduced on earth
  - Omnidirectional, continuous, low flux with varying particle types
  - Health risk for humans spending long durations beyond LEO
  - Radiation flux can spike 1000x during a Solar Particle Event (SPE)
- Correlate biologic response with LET and TID data
  - **BioSensor** payload uses engineered *S. cerevisiae* yeast
  - Measures rate of Double Strand Breaks (DSB) in DNA
  - **Linear Energy Transfer (LET) Spectrometer** measures particle energy and count
  - **Total Ionizing Dose (TID) Dosimeter** measures integrated deposited energy
- Yeast assay uses microfluidic arrays to monitor for DSBs
  - Three strains of *S. cerevisae*, two controls and engineered strain
  - Wet and activate multiple banks of micro-wells over mission lifetime
  - DSB and associated repair enable cell growth and division
  - Activate reserve wells in event of a Solar Particle Event (SPE)





Secondary Payload Location on SLS EM-1



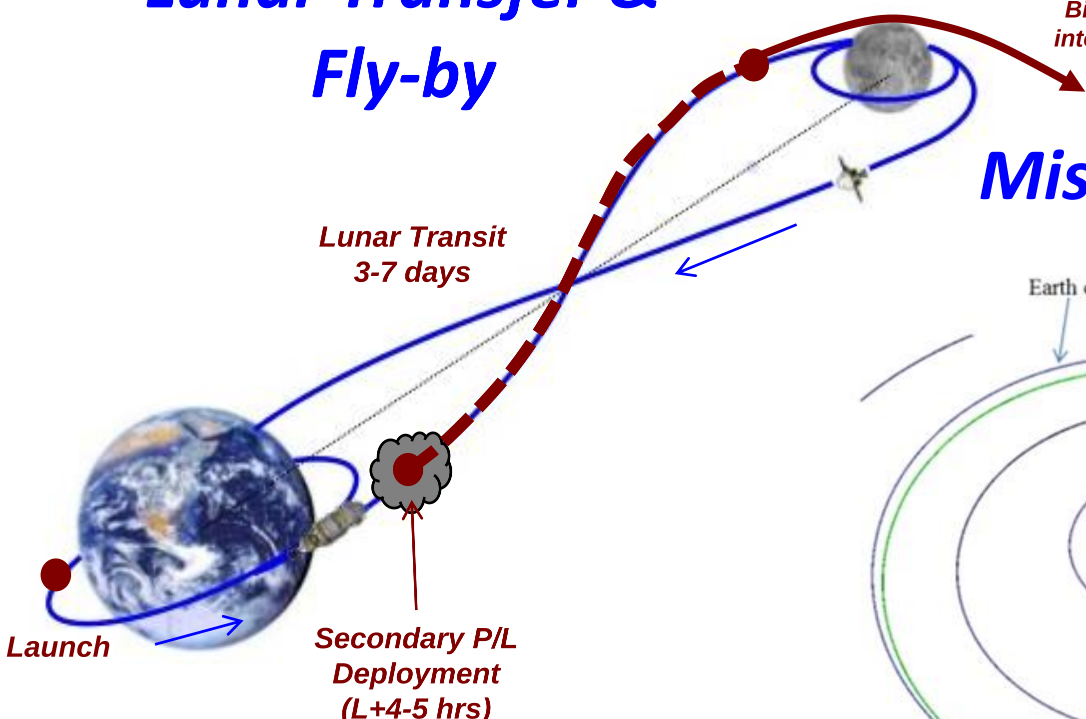
- 13 - dispenser locations that each support a 6U (14 kg) secondary payload
- 1 - bracket location allocated to a sequencer
- EM-1 only accommodates 6U payloads; EM-2 may accommodate 12U payloads

BioSentinel EM-1 Mission

Launch

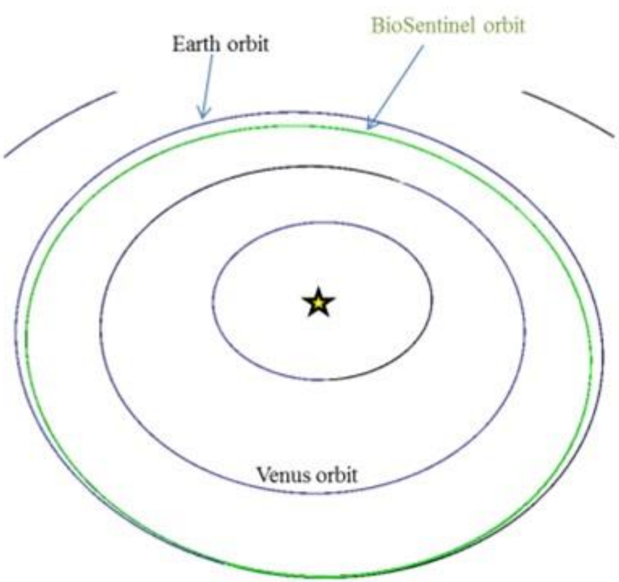
Artist's rendering of the Space Launch System

Lunar Transfer & Fly-by



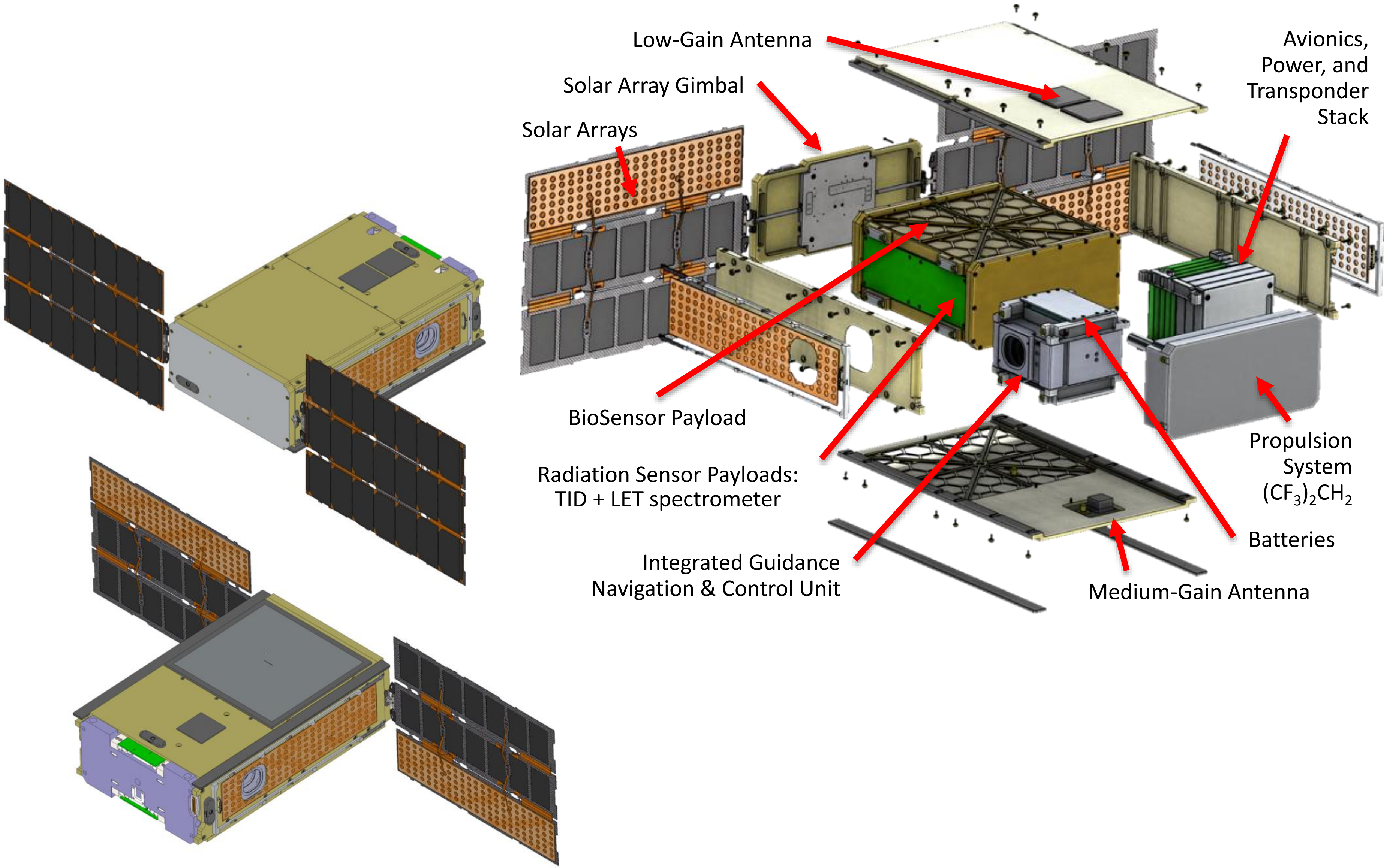
- Up to 13 secondary payloads deployed and powered within the same 2 hour window
- Low relative velocity between secondary payloads
- BioSentinel will not perform a delta-V maneuver, will follow IPCS into disposal orbit

Mission Orbit

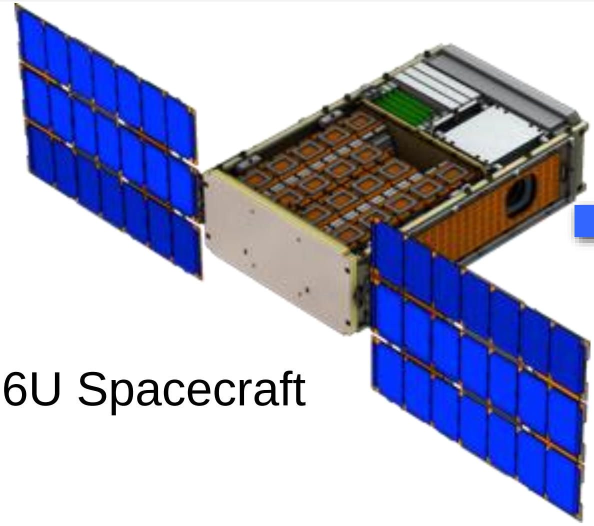


- Final orbit of secondary's to be determined
- Will likely be Earth-interior, heliocentric orbit
- Far outside the LEOs typically occupied by CubeSats
  - Range to Earth of 0.73 AU at 18 months
  - Far outside the protective shield of Earth's magnetosphere

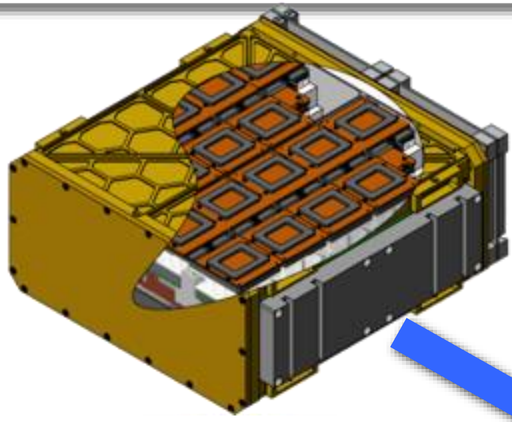
BioSentinel FreeFlyer Spacecraft: Physical Overview



BioSensor – Optical Measurement of Yeast in Fluidic Card Well

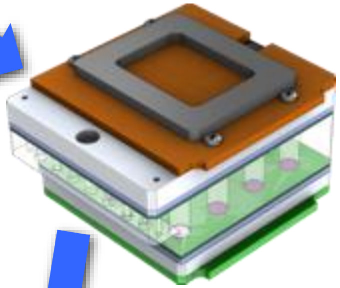


6U Spacecraft

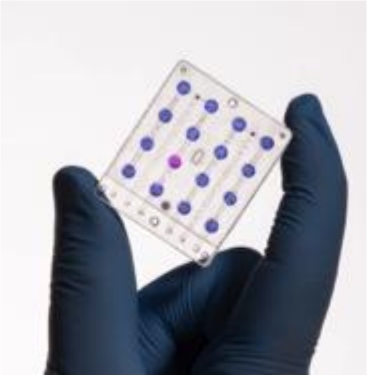


~4U BioSensor Payload

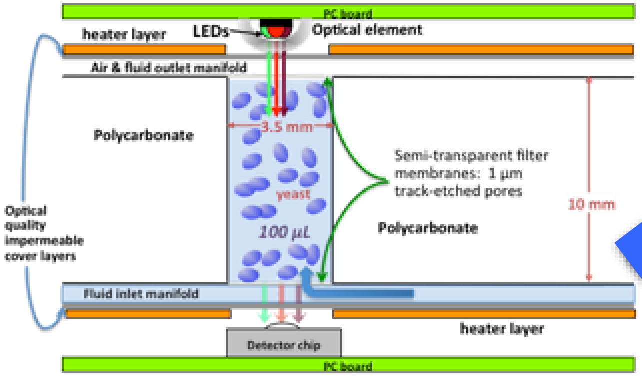
Microfluidic cards (x18)



Development Fluidic Card with Optical Detection System



Fluidic Card

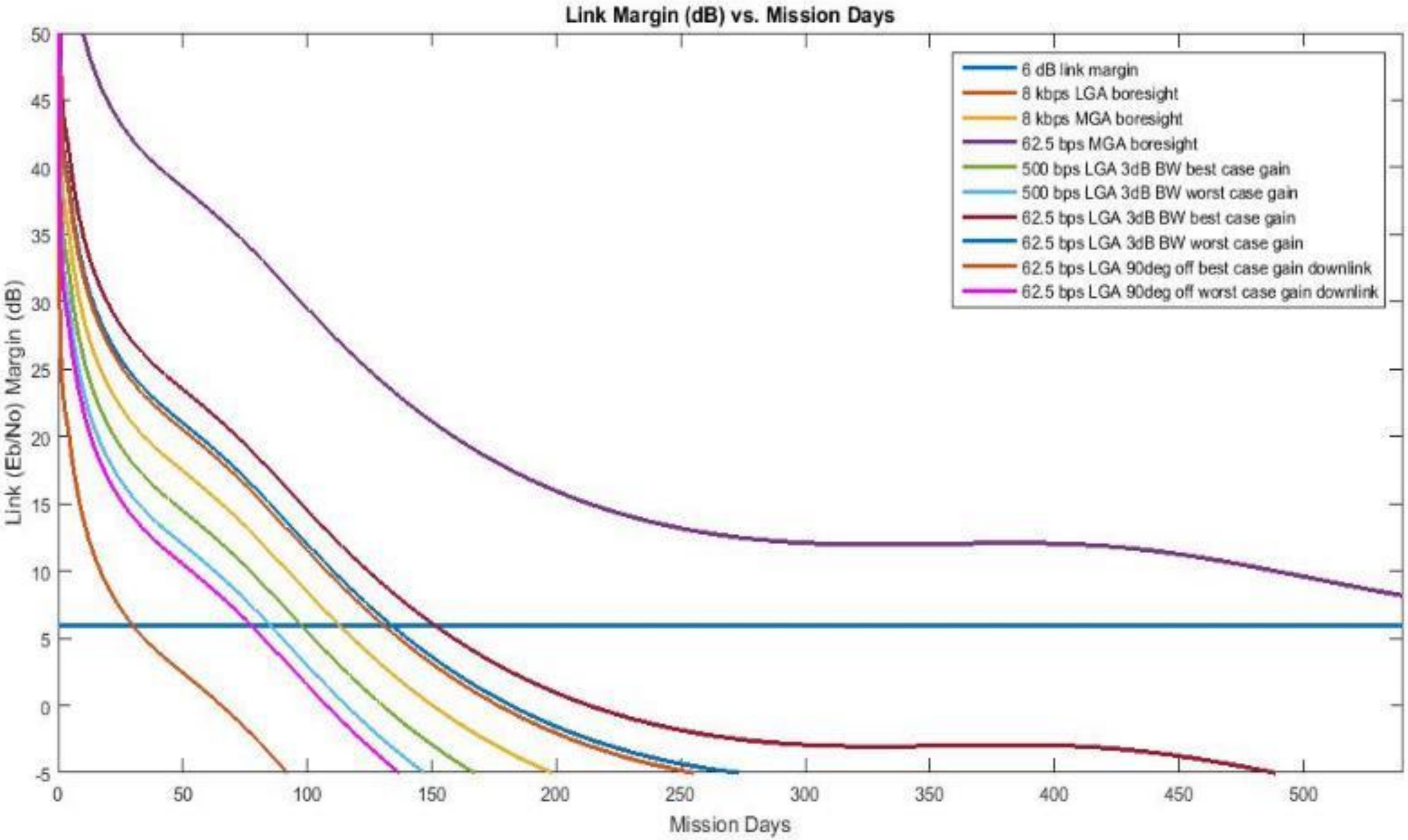


Fluidic Card cross section of a single well

FreeFlyer Mission Phases

Phase	Entry	Exit	Duration	Summary & Objectives
Pre-Launch	Loading of biology	L/V Lift-off	~6 months	• Configure FreeFlyer for launch, then power-off
Launch	L/V Lift-off	Deployment of FreeFlyer	~4 hours	• FreeFlyer is powered off • Survive launch environments and deployment
Initialization	Deployment of FreeFlyer	Completion of S/C checkout	~4-14 days	• Power-on, reduce tip-off rates, deploy solar arrays, transition to safe mode • Ground station initial acquisition and tracking • Check-out of S/C systems • Lunar fly-by likely to occur
Science	Nominal S/C SOH	Final science data received at SOC	12 month (goal of 18)	• Collect data from all payloads • Execute card experiments per science timeline • Respond to SPE events • Maintain bus SOH
Decommissioning (note, not same as Project Phase F)	End of Nominal Science Ops	S/C decommissioned (powered-off)	~7 days	• Ensure all data downlinked • Solar array switches open to ensure battery never recharges • Transmitter power-down

BioSentinel Link Margin (dB) vs. Mission Days



for turbo r=1/4, k=3568. Required Eb/No = 0.4 dB, Turbo r=1/2, k=1784 reqd=1.5 dB

BioSentinel Month-in-the-Life ConOps

Monitor Bus Functions

1. Wet new card (1x per month, ATS)
2. Collect science data (Continuous, RTS)
1. Refresh card (1x per month, ATS)
3. Transmit to DSN (2 to 4X per week, 2 – 4 hours per contact, ATS)

1

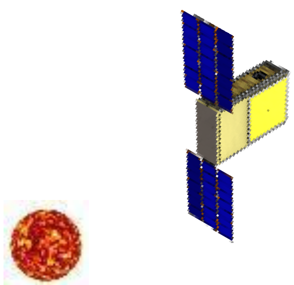
Major Functions	Subfunctions
Select card	• Determine fluidic card • Select µ-controller • Select pump and valve set
Apply Fluids	• Open inlet valve • Open plate valve • Open nutrient valves • Activate Pump
Configure Thermal Control	• Apply warm set points • Apply cold set points to other cards
Close System	• Close inlet valve • Close plate valve • Close nutrient valves • De-activate pump

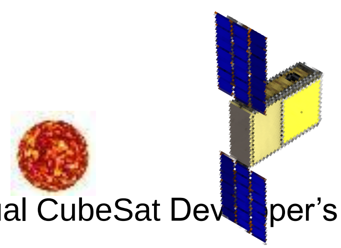
2

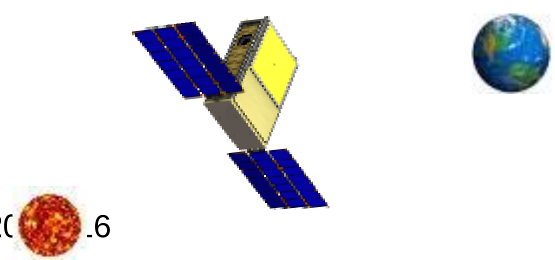
Major Functions	Subfunctions
Readout BioSensor (15 min cadence)	• Determine fluidic card • Select u-controller • Select and power well LEDs • Select and readout sensor • Iterate all wells
Readout TID sensor (5 min cadence)	• Apply power to sensor • Wait for stabilization • Sample analog readouts
Readout LET Spectrometer sensor (1 hour cadence)	• Acquire binned data • Store data in file system
Monitor for SPE	• Sample TID readout • Sample LET shutter info • Wet new card if SPE detected

3

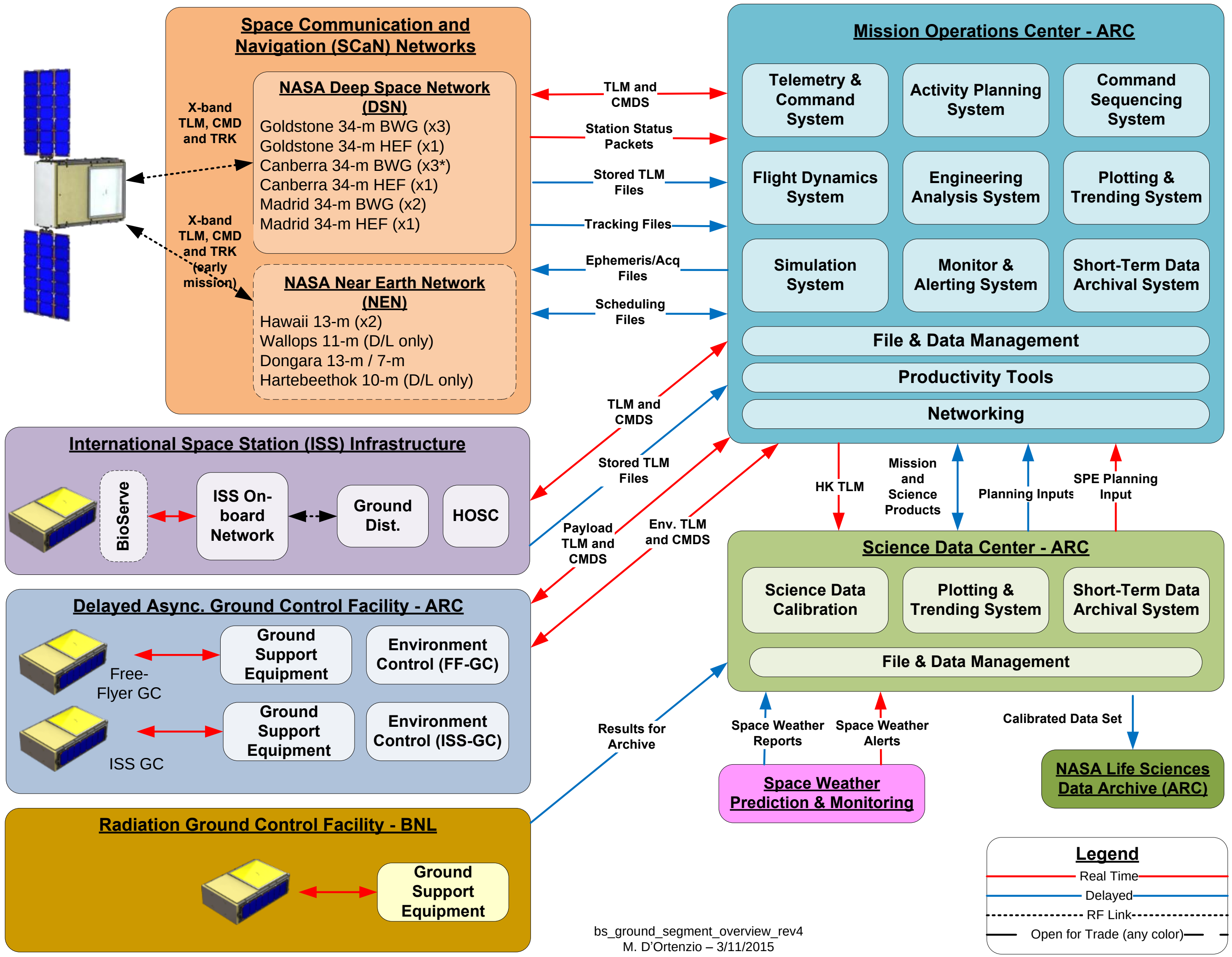
Major Functions	Subfunctions
Align spacecraft	• Determine vector to Earth • Slew to Earth vector
Power Tx	• Power transmitter
Broadcast data	• Broadcast SOH • On CFDP command, transmit BioSensor, LET, TID data
Deactivate Tx	• Power off transmitter
Realign spacecraft	• Slew back to sun vector







Ground System Architecture



Preliminary Operational Staffing Profile

Mission Phase	Length	Mission Operations Staffing Profile	Assumptions/Comments
Pre-Launch	~ 30 day	- 4x5 support for monitoring of FreeFlyer DSGC pre-launch profile	- DSGC must start while FreeFlyer is at KSC
Launch & Ascent	~ 1 day	- Full team will staff the MOC	- FreeFlyer is powered off. No real-time stream of data from S/C into the MOC during L&A
Early Operations (Start-up, Checkout and Safe Mode Entry)	~ 5-7 days	- 24x7 console support for L + 5 days to check out S/C bus systems, ensure payloads are functional, perform orbit determination and update activity plan	- Launch dispersions and deployment uncertainty will require FreeFlyer re-plan cycle. - No propulsive maneuver to achieve heliocentric orbit.
Early Science	2 mo.	- 8x5 console support to monitor first two biosensor experiments and to assist in planning and executing calibration activities as needed - Surge support if needed	- Autonomous momentum dumping
Routine Science	10 mo.	- One planning cycle every week with goal of two weeks - Uplink console supports once per week, available for other with notice - Continuous trending of S/C bus data - Console staff on-call to respond to SPE	- Review of DSN schedule every month, for three months in the future - Limited real-time changes to schedule and plan except for SPE response
Extended Science	6 mo.	- Continuation of Routine Science	

BACK-UP

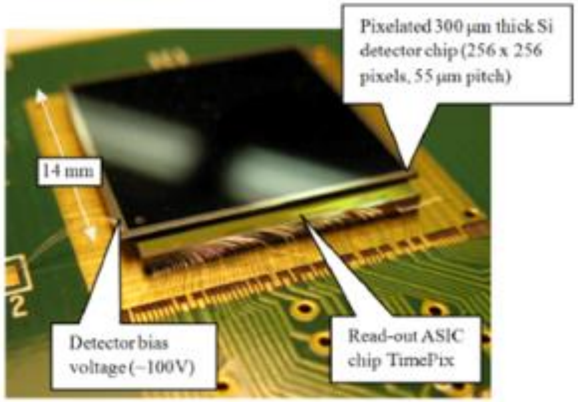
BioSentinel FreeFlyer Spacecraft Bus Summary

- LEON3 RT based C&DH
  - Embedded VxWorks OS with cFS/cFE
  - Port of LADEE FSW for Bus
  - Port of EcAMSat / SporeSat FSW for P/L
- 3-axis controlled GNC system
  - Blue Canyon XACT Integrated GN&C Unit
    - 3 Reaction Wheels
    - Star Tracker
    - CSS, IMU for safe mode
  - 5° pointing requirement
- Propulsion
  - 3D printed system from GT / LSR
  - Null tipoff rates and momentum management
  - Seven cold gas R236cf thrusters
  - ~60 sec Isp
  - ~130 grams propellant
- Communications
  - X-Band to DSN @ 62.5 - 8000 bps
  - LGA and MGA patch antennae
  - IRIS v2 coherent transponder
- Power
  - ~28.24 W generated power EOL
  - Deployable HaWK arrays from MMA
  - Panasonic 18650 batteries
  - ARC design EPS and switch controllers
- Structure
  - 6U nominal volume
  - ARC Nanosat heritage
  - EcAMSat provided baseline for BioSentinel development
- Thermal
  - Cold biased system
  - Heaters, thermistors, paint, reflective tape for control
- Supports Payloads
  - Yeast based BioSensor Payload
  - JSC LET Spectrometer
  - Teledyne based TID Dosimeter
  - 4U volume

LET Spectrometer & TID Dosimeter Radiation Monitoring

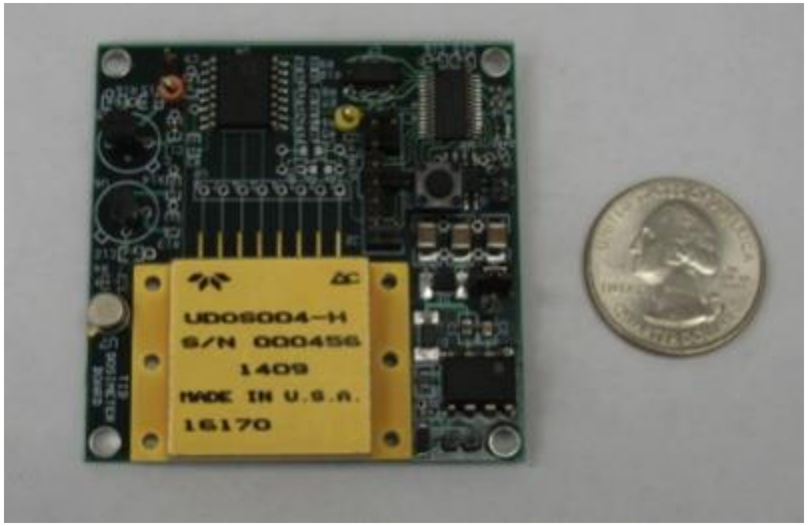
- Linear Energy Transfer (LET) Spectrometer Designed by JSC RadWorks specifically for the BioSentinel Project.

LET Spectrometer Engineering Development Unit (EDU)

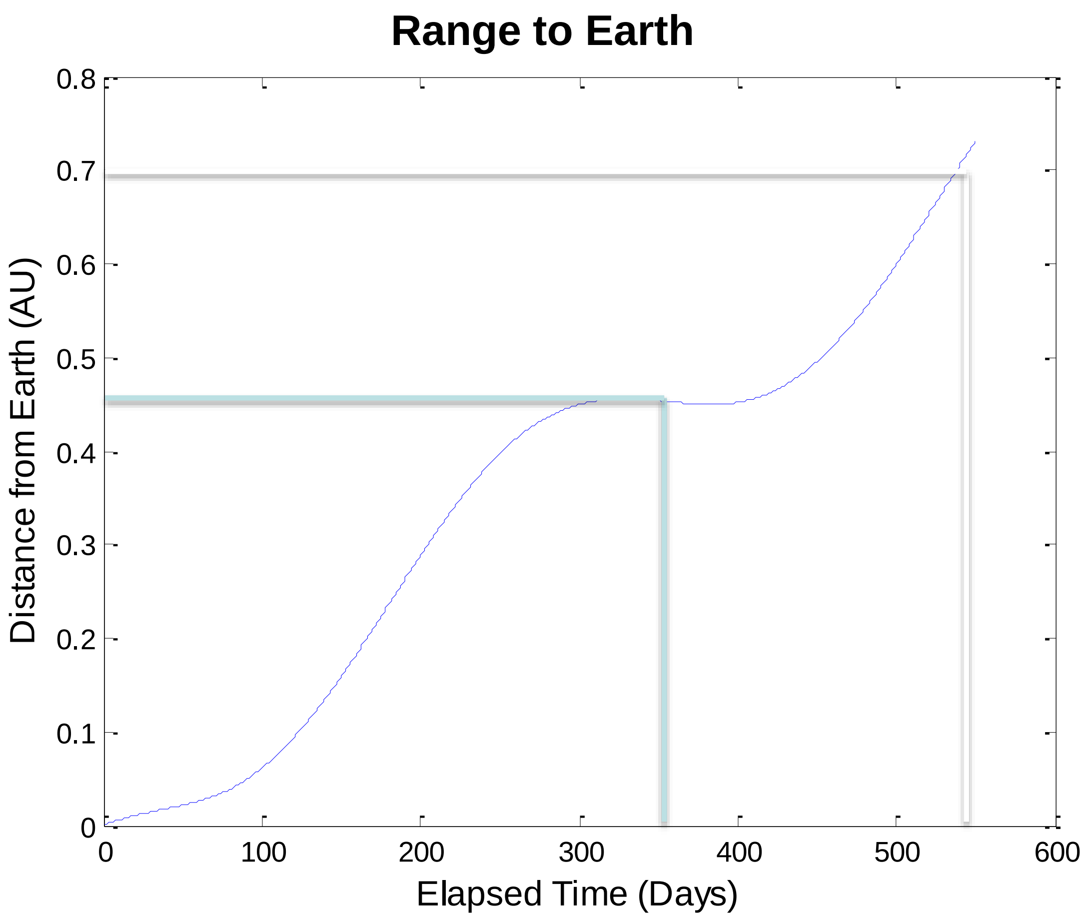


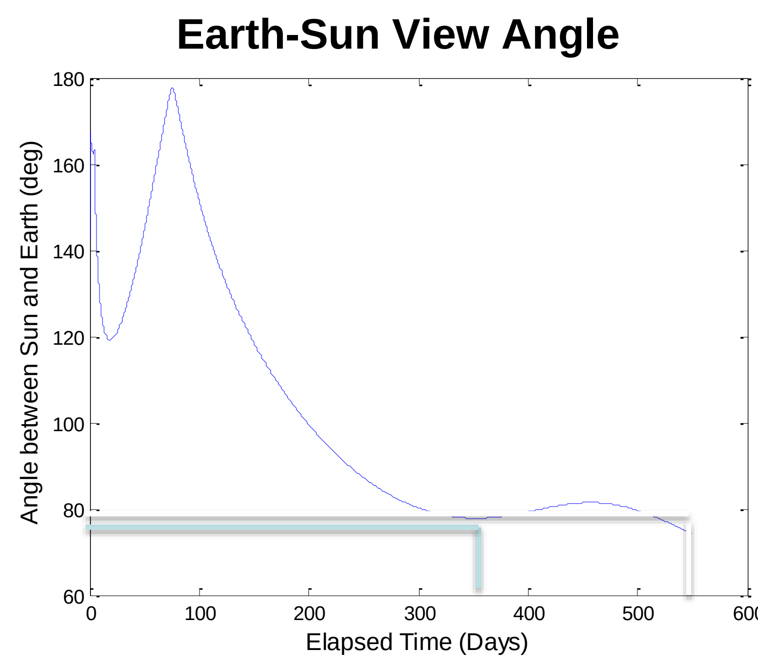
TimePIX Sensor

- Total Ionizing Dose (TID) Dosimeter using a Teledyne uDOS001 sensor, board design by ARC. Prototype board with dummy sensor



Entire presentation based on original Matt Nehrenz trajectory





BioSentinel Teaming

The Project Team

- Mission Management
  - Bob Hanel, Dawn McIntosh, James Chartres, Mario Perez, Elwood Agasid,
- Science
  - Sharmila Bhattacharya, Sergio Santa Maria, Diana Marina, Macarena Parra, Tore Straume, C. Mark Ott, Sarah Castro, Greg Nelson, Troy Harkness
- Payload
  - Tony Ricco, Travis Boone, Ming Tan, Charlie Friedericks, Aaron Schooley, Mike Padgen, Diana Gentry, Terry Lusby, Scott Wheeler, Susan Gavalas, Edward Semones
- Spacecraft and Bus
  - Hugo Sanchez, Matthew Sorgenfrei, Matthew Nehrenz, Vanessa Kuroda, Ben Klamm, Craig Pires, Shang Wu, Abe Rademacher, Josh Benton, Doug Forman

Affiliations NASA Ames, NASA JSC - RadWorks, LLUMC, Univ. Saskatchewan

Support NASA Human Exploration and Operations Mission Directorate (HEOMD); Advanced Exploration Systems Division – Jitendra Joshi, Jason Crusan Program Execs.