National Aeronautics and Space Administration

# BioSentinel: DNA Damage-and-Repair Experiment Beyond Low Earth Orbit

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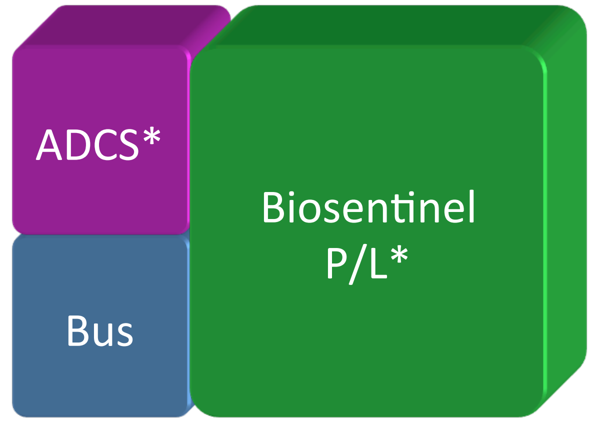
# *Mission Goals and Objectives*

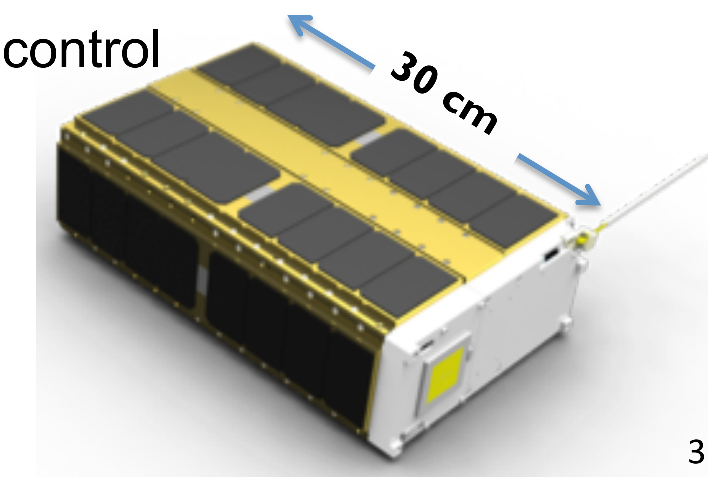
- Demonstrate simple model organisms as “biosentinels”
  - Biologically based sensors for hazards to humans
    - Particularly for radiation, beyond low Earth orbit (LEO)
    - Compare/correlate to physical radiation measurements
  - DNA damage: 1st space demo. of biosentinel concept
  - Validate radiation damage models for biology
  - Develop “transfer standards” from biosentinels to humans
  - Support development of radiation protection
  - Inform mitigation strategies, actions
- Conduct life science studies in multiple space environments relevant to human exploration
  - Deconvolute effects on biological systems

## Implementation




- 6U autonomous nanosatellite
  - 4U payload, including radiation sensors
  - ≥ 2U for bus + ADCS including μpropulsion
  - ~ 14 kg total mass
  - ~ 23 W average power (deployable solar panels)
  - Mission duration: 18 months

- Identical BioSentinel payload developed for ISS
  - similar μ-gravity but LEO radiation environment
- Identical P/L for delayed-synchronous ground control
  - 1 x*g*; low radiation
- Radiation exposure ground studies (e.g. BNL)
  - 1 x*g*; acute, defined radiation doses




**ADCS = attitude determination-and-control system; P/L = payload*

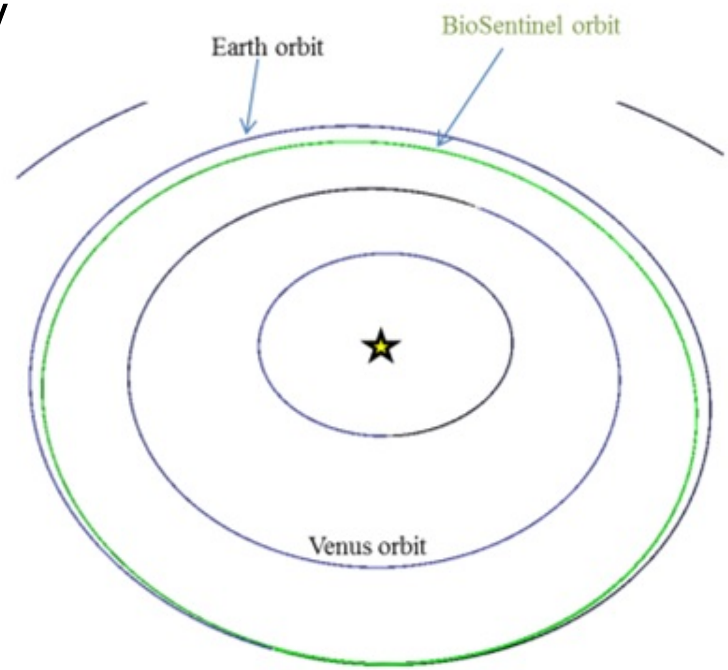
## Launch

Artist's rendering of the Space Launch System

- Launched as a secondary payload on **EM**-1
  - **E**xploration **M**ission 1: 1st flight of NASA's Space Launch System
- Exact deployment orbit of 2° payloads still being determined
- Will likely be Earth-trailing, heliocentric orbit
- Far outside the LEOs typically occupied by CubeSats

  … and far outside the protective shield of Earth's magnetosphere

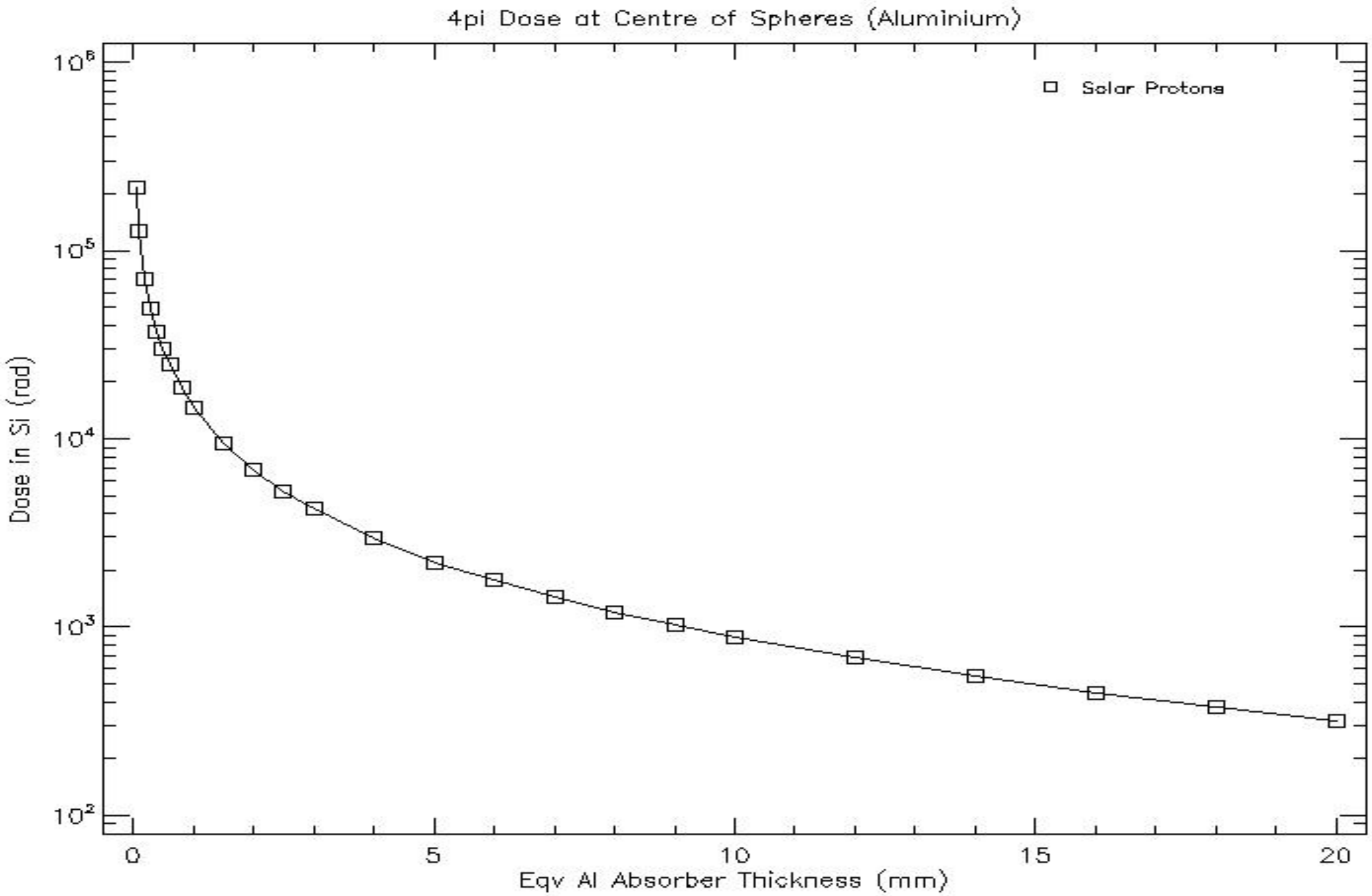
## Orbit




A representative orbit that BioSentinel might occupy

# Radiation Environment

Total Ionizing Dose (Si) for Ambient Flux + single Solar Particle Event



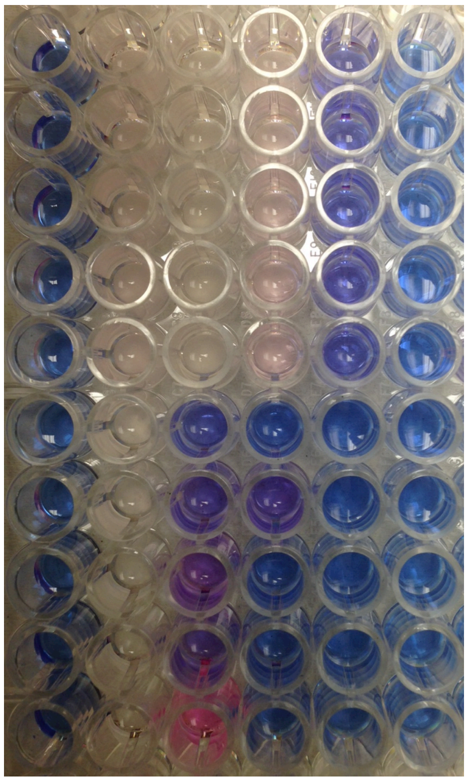

Model:
SHIELDOS
E-2Q

# *BioSentinel Measurement Science Concept*

- What: Yeast radiation biosensor measures DNA damage caused by space radiation: specifically*, double strand breaks (DSBs)*
  - As eukaryotes, yeast have repair mechanisms in common with human cells
- Why: Space radiation's unique spectrum cannot be reproduced on Earth
  - It includes a range of high-energy particles, each with its own energy distribution
  - It is omnidirectional, continuous, and of low flux
  - It poses a health risk for humans spending long durations beyond LEO
  - During a solar particle event (SPE), radiation flux can spike to 1000x nominal levels
- How: Before launch, engineered *S. cerevisiae* cells (brewer's yeast) are dried & placed in arrays of microwells
  - In space, a group of wells is rehydrated every few weeks
  - Yeast cells remain dormant until activated by a DSB
  - Gene repair initiates growth
    - *One repaired DNA DSB can trigger exponential growth in 1 well*
    - *Growth & metabolic activity are monitored optically in all wells*
  - Multiple microwells are always in "active sentinel mode"
  - Extra wells are activated in the event of an SPE

# BioSentinel Science: Proof-of-Concept Lab Data

Yeast recombination assay and its response to gamma irradiation



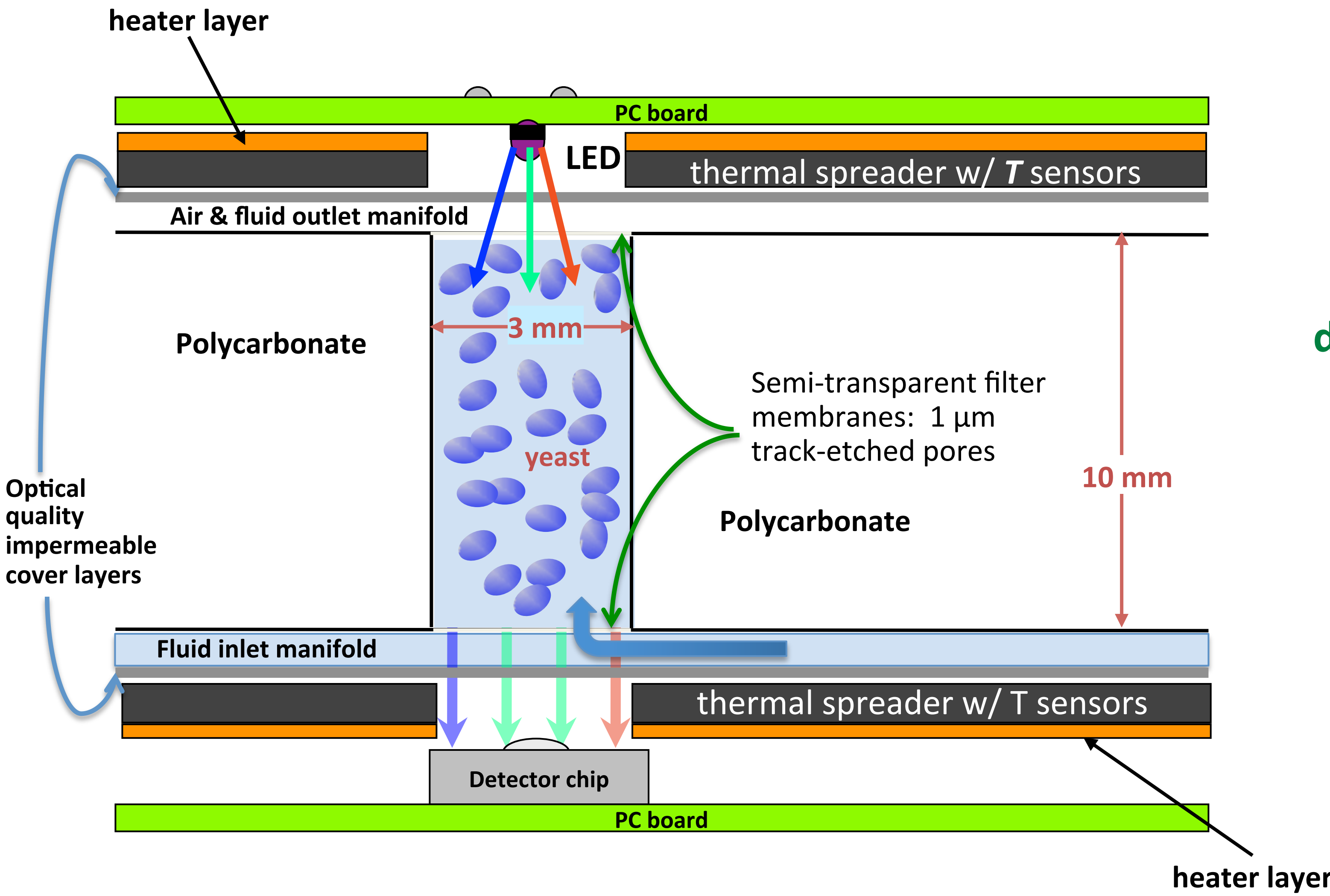

3 days at 23°C

**alamarBlue turns pink when cells are metabolically active**

| Gamma ray dose ($^{137}Cs$) | Recombination rate | Fold increase |
|---|---|---|
| No gamma | $1.13 \times 10^{-6}$ | 1 |
| 25Gy | $5.02 \times 10^{-6}$ | 4.4 |
| 50Gy | $9.69 \times 10^{-6}$ | 8.6 |
| 100Gy | $1.43 \times 10^{-5}$ | 12.7 |
| 181.2Gy | $2.09 \times 10^{-5}$ | 18.5 |

Spontaneous recombination rate: ~ 1 event in a million

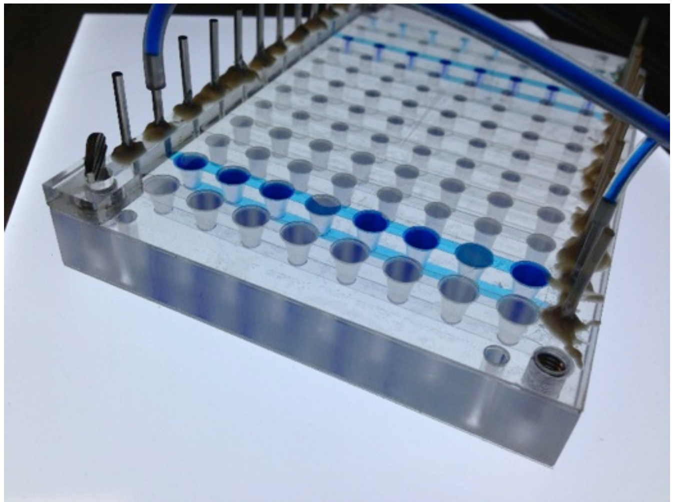
# *Biology/Fluidic/Optical/Thermal Configuration*




3-color LEDs for optical density (OD) and cell metabolic activity: track population during growth, metabolism *via* dye

Detector for OD *and* viability measurement using 3-color absorbance

# Biological Support & Measurement Systems

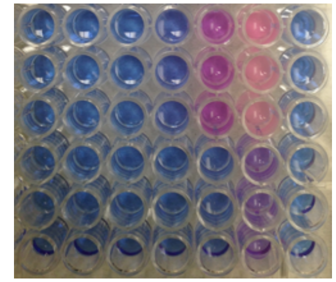


**Requirements**

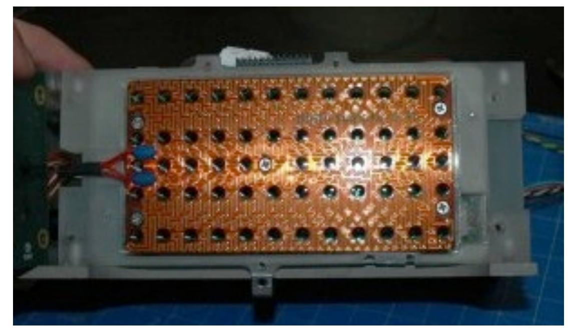
- support biology in stasis and growth
- enable & perform measurement

- **Configuration:** 4U containment vessel
  - 1 atm internal pressure, low RH
- **3 ea. 96-well fluidics cards**
  - 12 "banks" of 8 wells per card (36 banks total)
    - 2 banks activated per month; 2 – 4 banks on "SPE standby"
  - Sterilize by autoclaving
  - Organisms fly in dry state in wells, rehydrate to activate
  - Capability to refresh reagents in wells
  - Low-permeability "semi-hermetic" fluidic cards & bags
- **Pumps, Valves, Tubing, Media**
  - external to cards; tubes and bags ~hermetic (to keep dried yeast dry)
  - redundancy / isolation as container volume permits

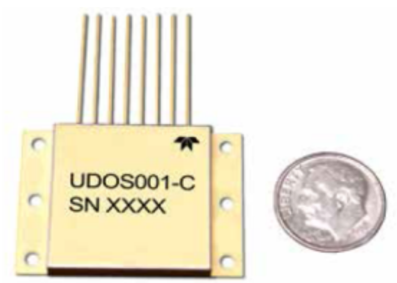
# *Sensors & Measurement System*



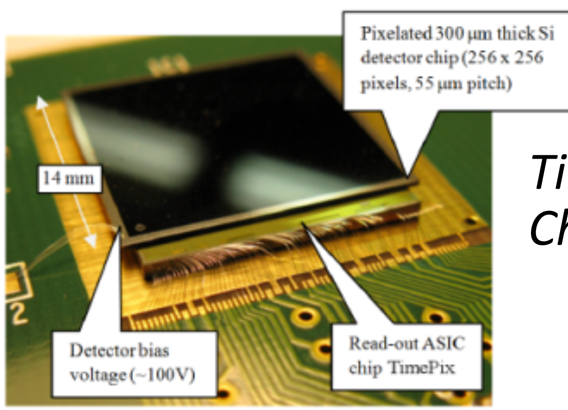
- **Optical absorbance measurement per well**
  - Dedicated 3-color optical system at each well
  - Measure dye absorbance & optical density (cell population)



- **Dedicated thermal control system per card**
  - 0.5 – 1 °C uniformity, accuracy, stability
  - multiple temp. sensors per card & throughout container
- **Pressure & RH sensors** in payload volume
- **Radiation sensors**
  - 1 – 2 LET "spectrometer" chips & 2 integrating dosimeters
  - Frequent measurement & caching of results; selective downlink

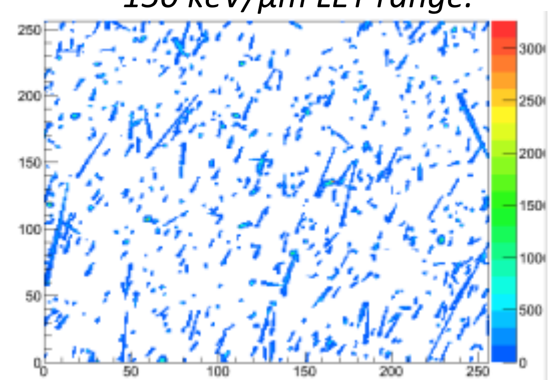



*Teledyne dosimeter*



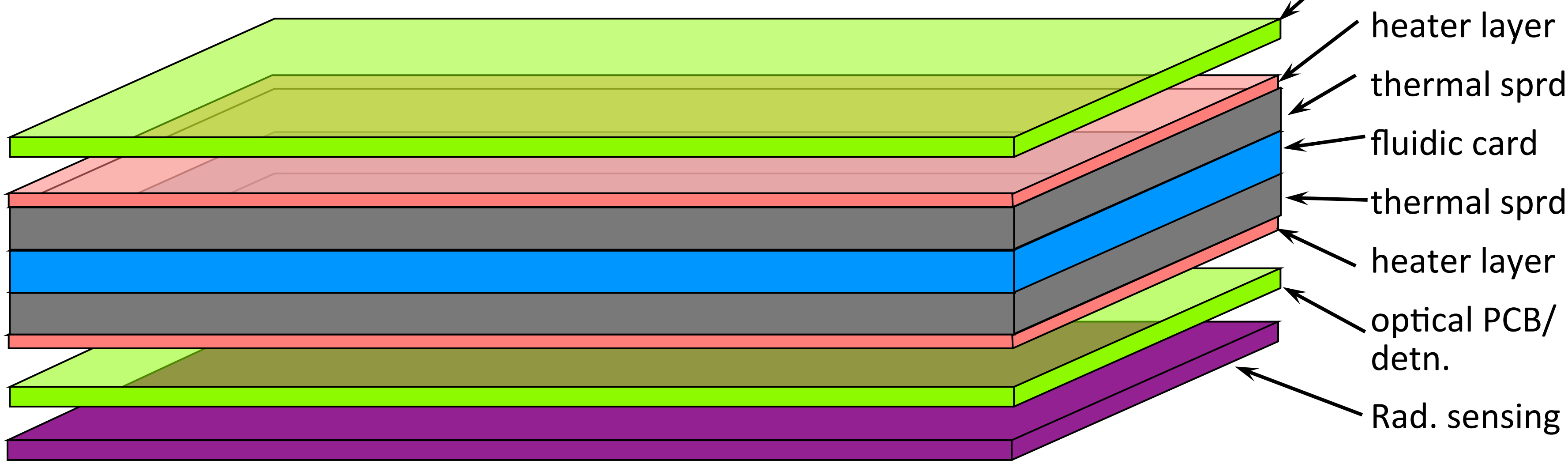

*TimePix Chip*

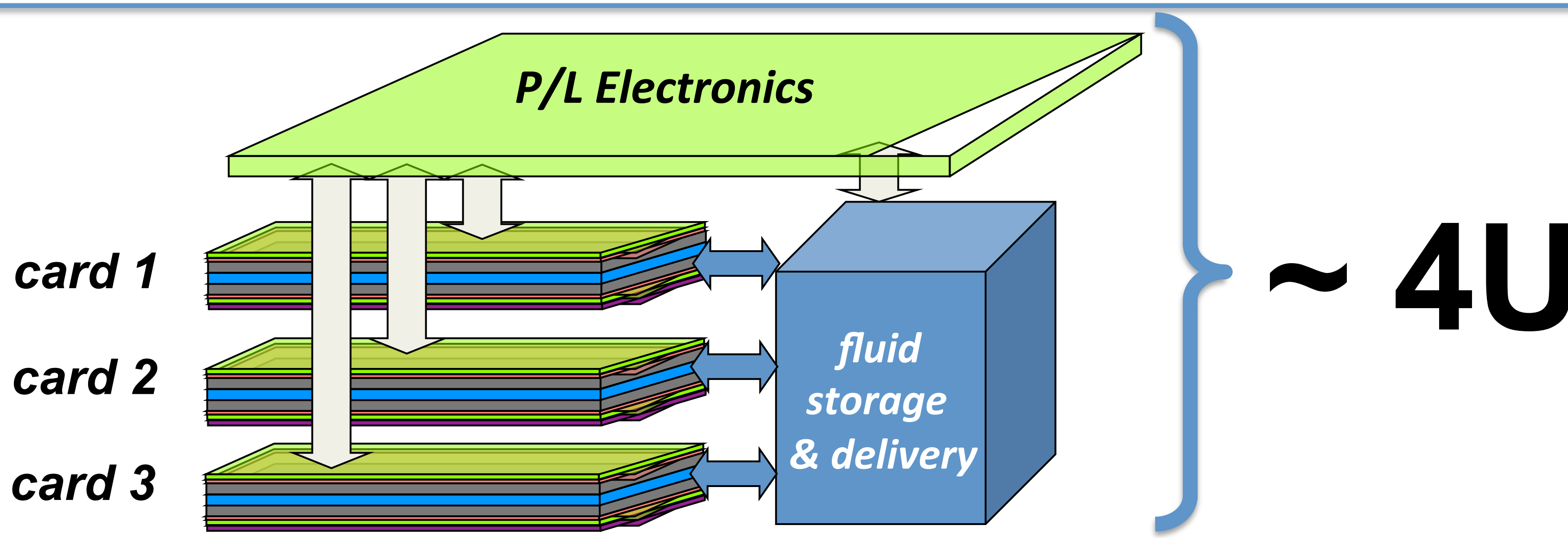
*Typical TimePIX frame: 256x256x14 bits; 0.25 – 150 keV/μm LET range.*



# BioSentinel

## Biology / fluidics / optical / thermal / radn. configuration



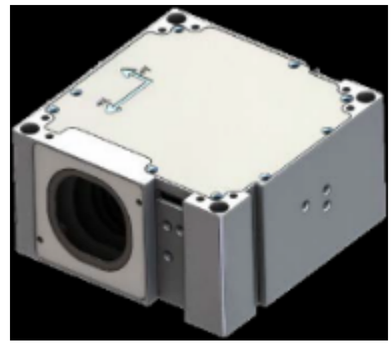
## Environmental Constraints & Considerations

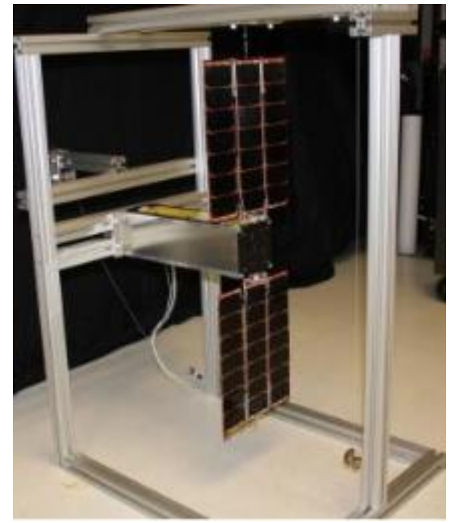
- Higher exposure to radiation than previous CubeSats* operating in LEO
  - Approximately 5 kRad total ionizing dose anticipated
  - Non-destructive single events (such as SEUs) motivate > 20 MeV-$cm^2$ tolerance, destructive single events (SELs, SEBs) require > 37 MeV-$cm^2$ tolerance
- Distance from Earth eliminates use of GPS for position determination, magnetometers for attitude determination, torquer coils/rods for attitude control
- Solar radiation pressure will be largest disturbance torque

**O/OREOS rec'd. similar 18-month dose but it was trapped electrons & protons; mission duration 6 months nominal*

# Subsystem Considerations

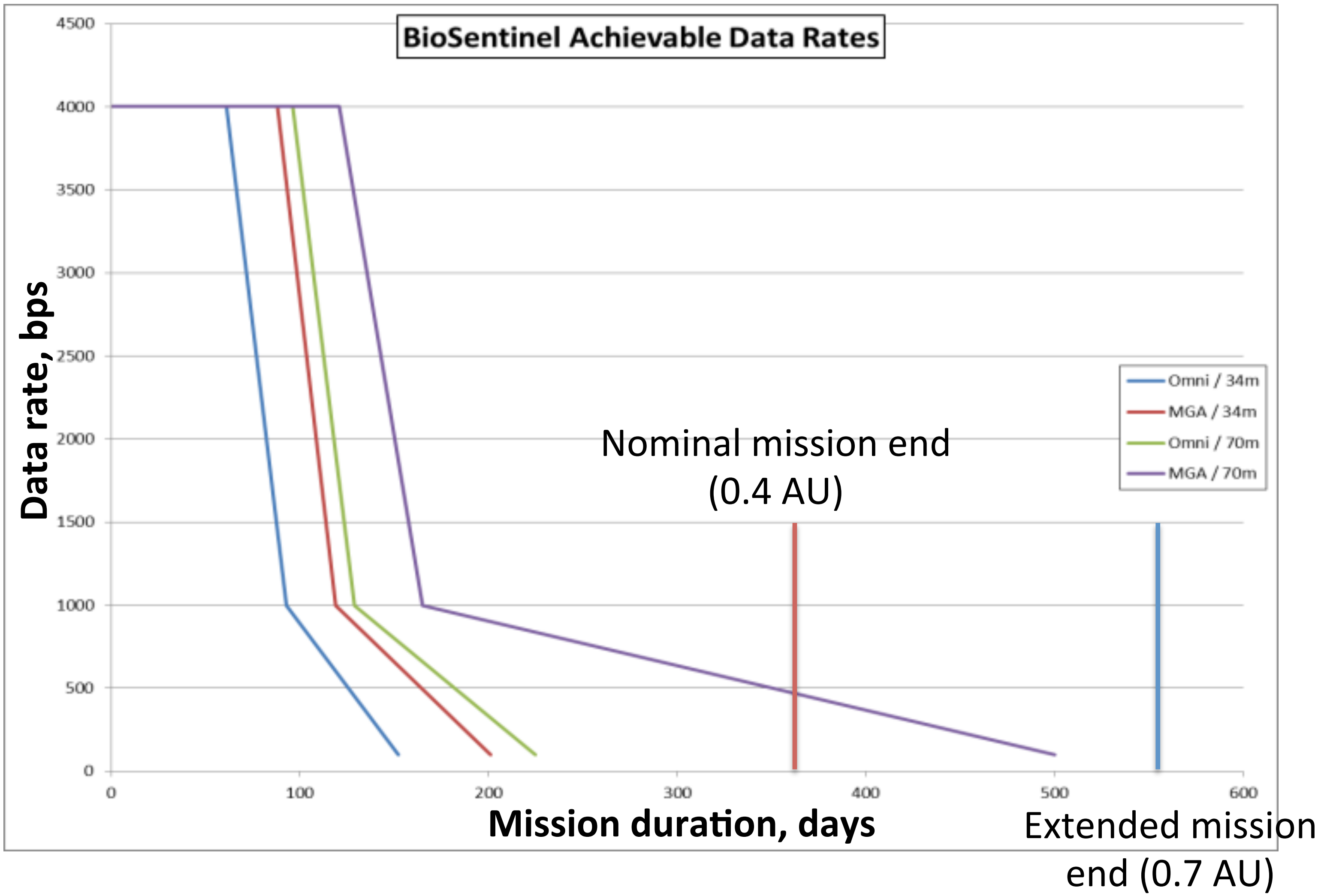
- Deployable solar panels required to generate sufficient power (> 30 W rating)
- Traditional CubeSat S-band/UHF radios insufficient at mission operating orbit (~ 1 AU)
  - X band preferred (up and down) for deep-space missions
- Propulsion required for both detumble and momentum management
- Very capable command & data handling system required
- Radiation tolerance is critical: component choice, recovery strategies, selective shielding





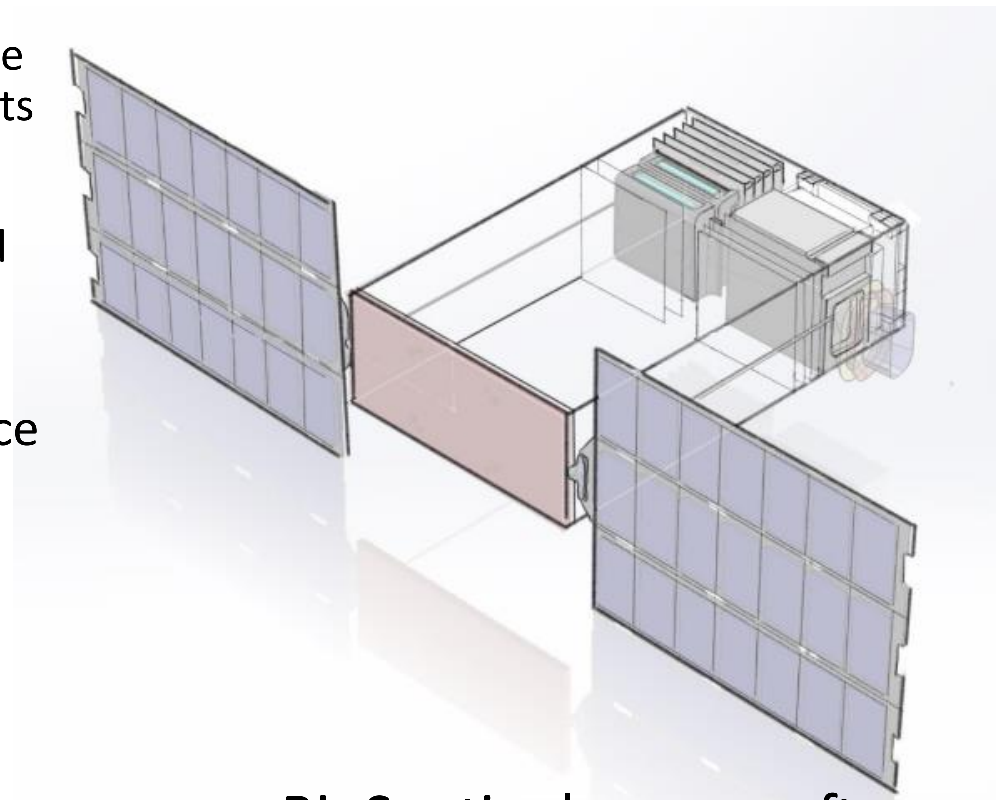
Candidate components under consideration for the BioSentinel mission

# Estimated Data Rates



# *BioSentinel (Potential) Firsts and Challenges*

- 1st NASA biology studies beyond LEO in 4 decades
  - Enabling comparison across multiple radiation & gravitation environments
- 1st 6U CubeSat to fly beyond LEO
  - Challenges for communications and attitude control
- 1st CubeSat to combine both active attitude control and a biology science payload
  - Payload includes autonomous measurement response to SPEs
- 1st CubeSat to combine both active attitude control and propulsion subsystems
- 1st CubeSat to integrate a third-party deployable solar array



BioSentinel spacecraft design concept


# The Team

- Management
  - Bob Hanel, Elwood Agasid, Debra Reiss-Bubenheim, Colleen Smith
- Science
  - Sharmila Bhattacharya, Macarena Parra, Tore Straume, Sergio Santa Maria, Diana Marina, Bob Bowman, Mark Ott, Sarah Castro, Greg Nelson, Troy Harkness
- Payload
  - Tony Ricco, Travis Boone, Ming Tan, Charlie Friedericks, Terry Lusby, Bobbie Gail Swan, Scott Wheeler, Susan Gavalas, Edward Semones
- Spacecraft and Bus
  - Brian Lewis, Matthew Sorgenfrei, Matthew Nehrenz, Marina Gandlin, Vanessa Kuroda, Ben Klamm, Craig Pires, Shang Wu, Abe Rademacher, Josh Benton

## Affiliations

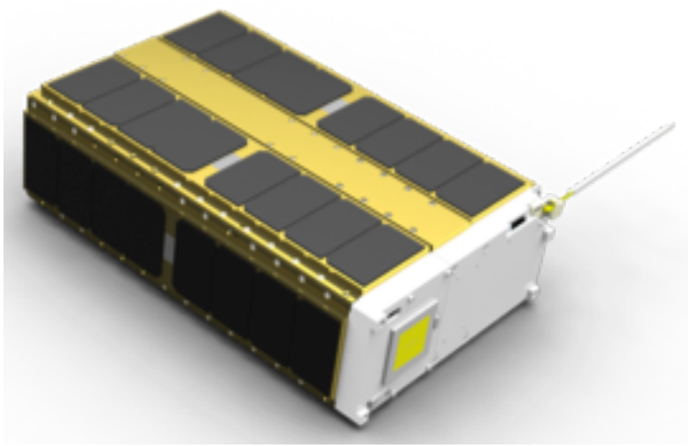
NASA Ames Research Center, NASA Johnson Space Center, Loma Linda Univ. Medical Center, University of Saskatchewan

## Support

NASA Human Exploration and Operations Mission Directorate (HEOMD)

Advanced Exploration Systems Division – Jitendra Joshi, Jason Crusan Program Execs.

# BACK-UP SLIDES



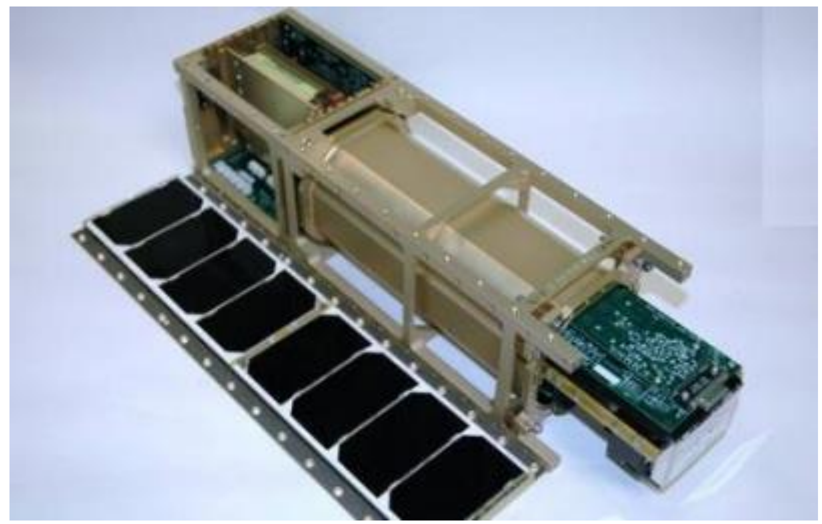
A visualization of one possible formulation of a 6U spacecraft to be used for the BioSentinel mission

## 3 Distinct Missions

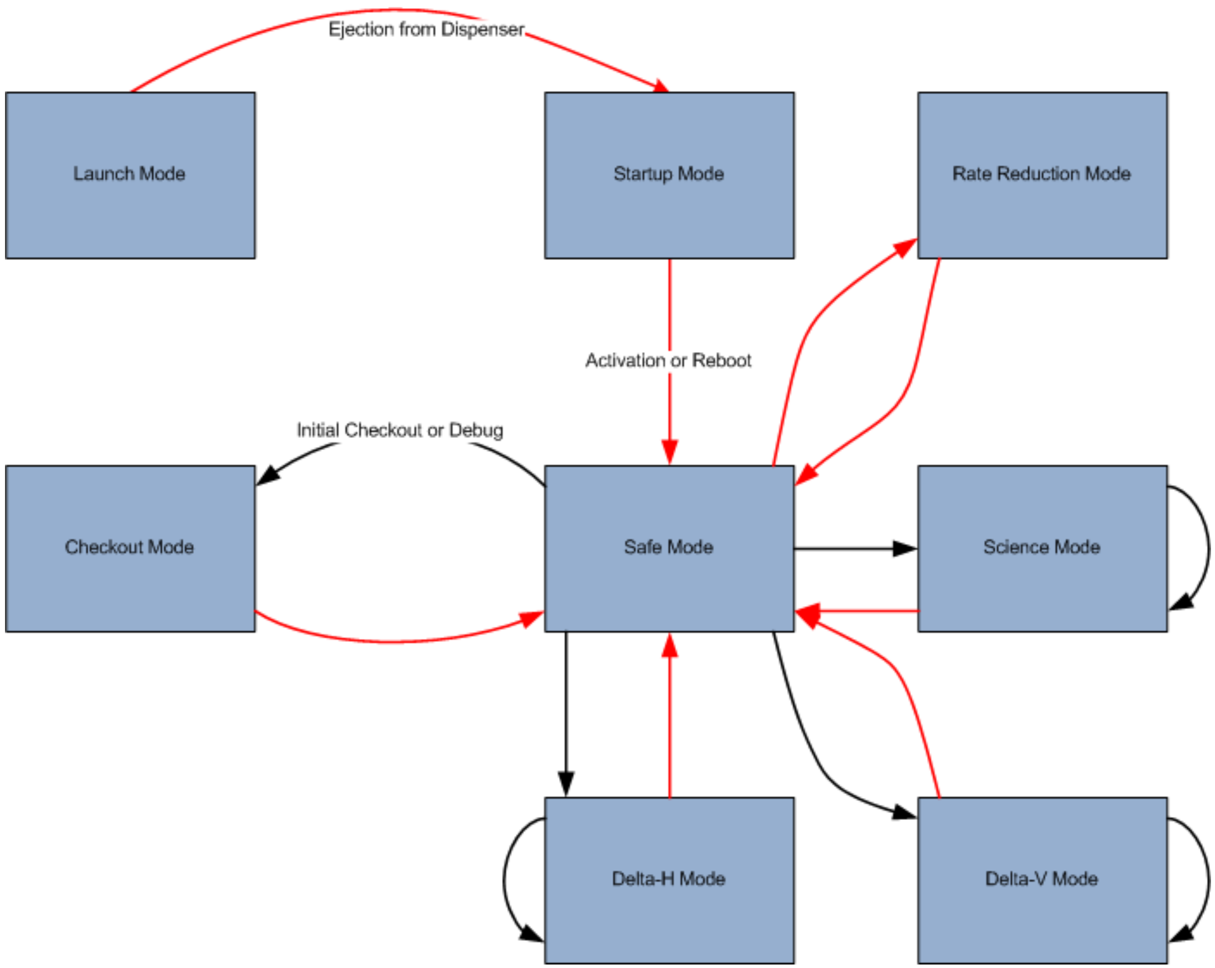
- Marshall Spaceflight Center, Jet Propulsion Laboratory, and Ames Research Center are supplying spacecraft
- MSFC NEOScout will inspect a NEO target, JPL LunarFlashlight will explore permanently shadowed craters on the moon, and Ames BioSentinel will characterize radiation environment

## Building on Ames Heritage

- Ames has previously flown biologically-focused CubeSats with the GeneSat, PharmaSat, and O/OREOS missions
- Spacecraft make use of miniaturized life support systems to allow for growth of cells in microgravity environment
- BioSentinel will leverage this heritage to build three separate payloads:
  - Flight payload, module that can be integrated on station, and ground control



The PharmaSat 3U spacecraft, which carried a mircrowell and fluidics system similar to that which will be used in BioSentinel



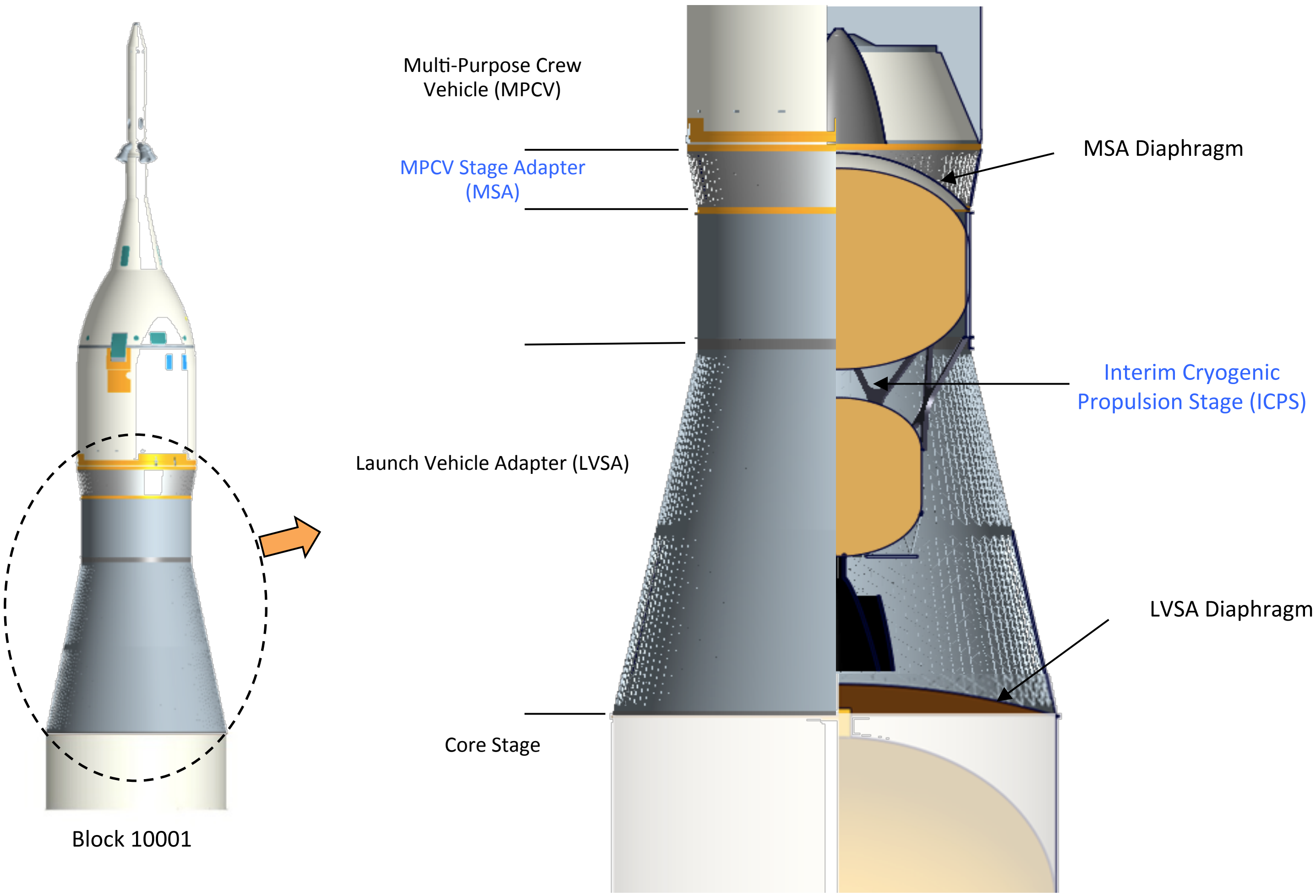

A representative mode transition diagram for the BioSentinel mission

# Avionics Challenges

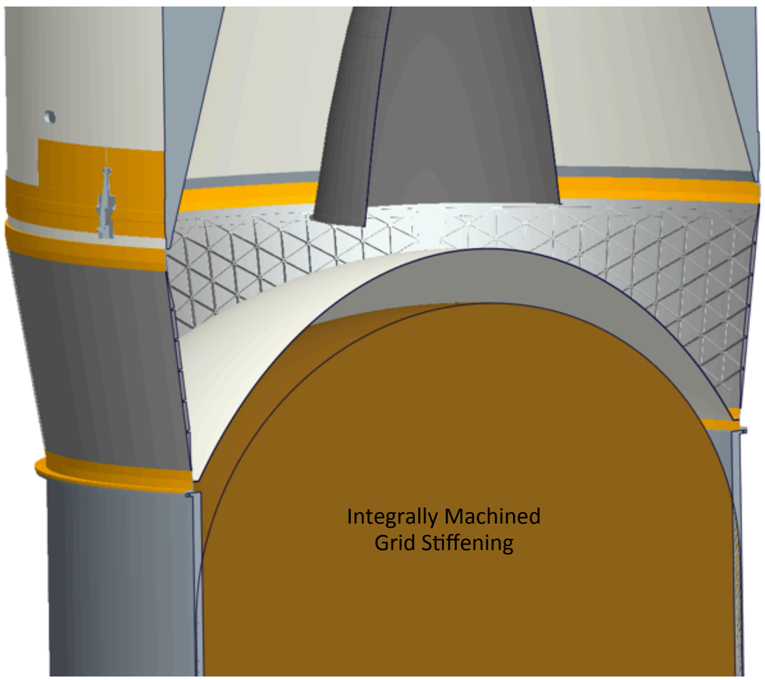
- BioSentinel will require a command and data handling (C&DH) system that is much more capable than previously flown in CubeSat-form factor spacecraft
- Simultaneously would like fairly inexpensive development boards for prototyping and testing campaigns
- Radiation tolerance of high importance
  - Radiation-hardened or phase-change memory, watchdogs, multiple or "golden" software loads, etc
- Implications for GNC development strategy: auto-coding vs. hand-coding filers, control schemes, schedulers, etc

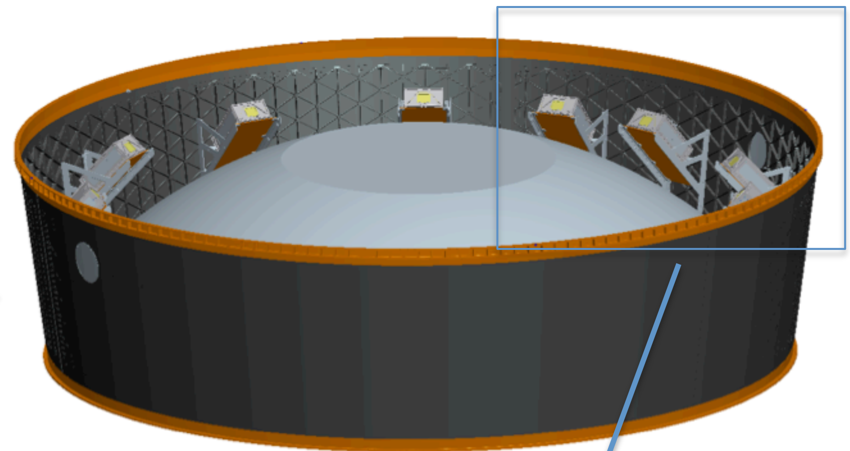
- Tip-off conditions from SLS are a major unknown
  - Initial body-fixed rates, potential need for a ΔV maneuver
- Tip-off conditions help to define GNC system needs, which will drive other subsystem budgets
- Detailed power budget assessment: ~30 W orbit-average power should allow for radio to be always on
  - As opposed to traditional CubeSat missions in which subsystem cycling sometimes required
- Need to define ground operations strategy
  - DSN likely the most feasible approach, issues with availability and cost
  - 34m likely acceptable for majority of mission life, larger array required at end of mission

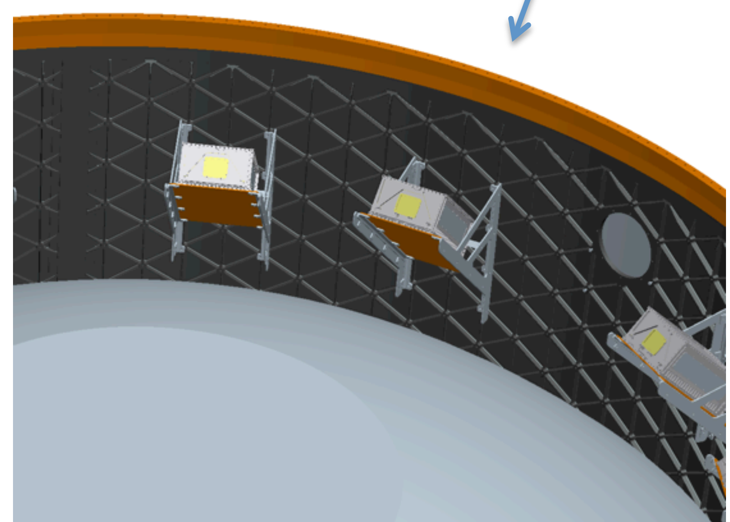
# SLS Exploration Mission (EM-1) Overview



# MPCV Stage Adapter (MSA)

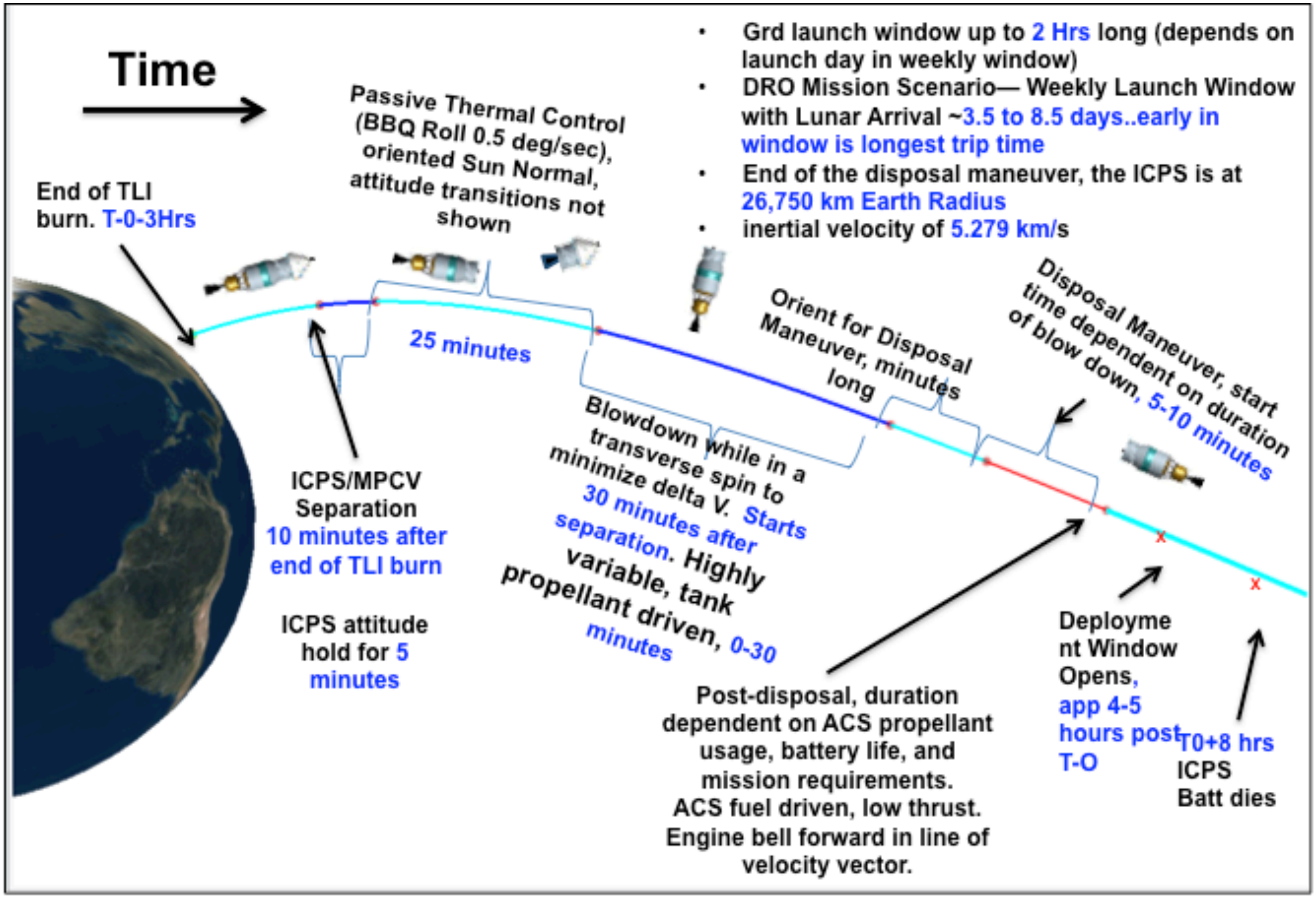




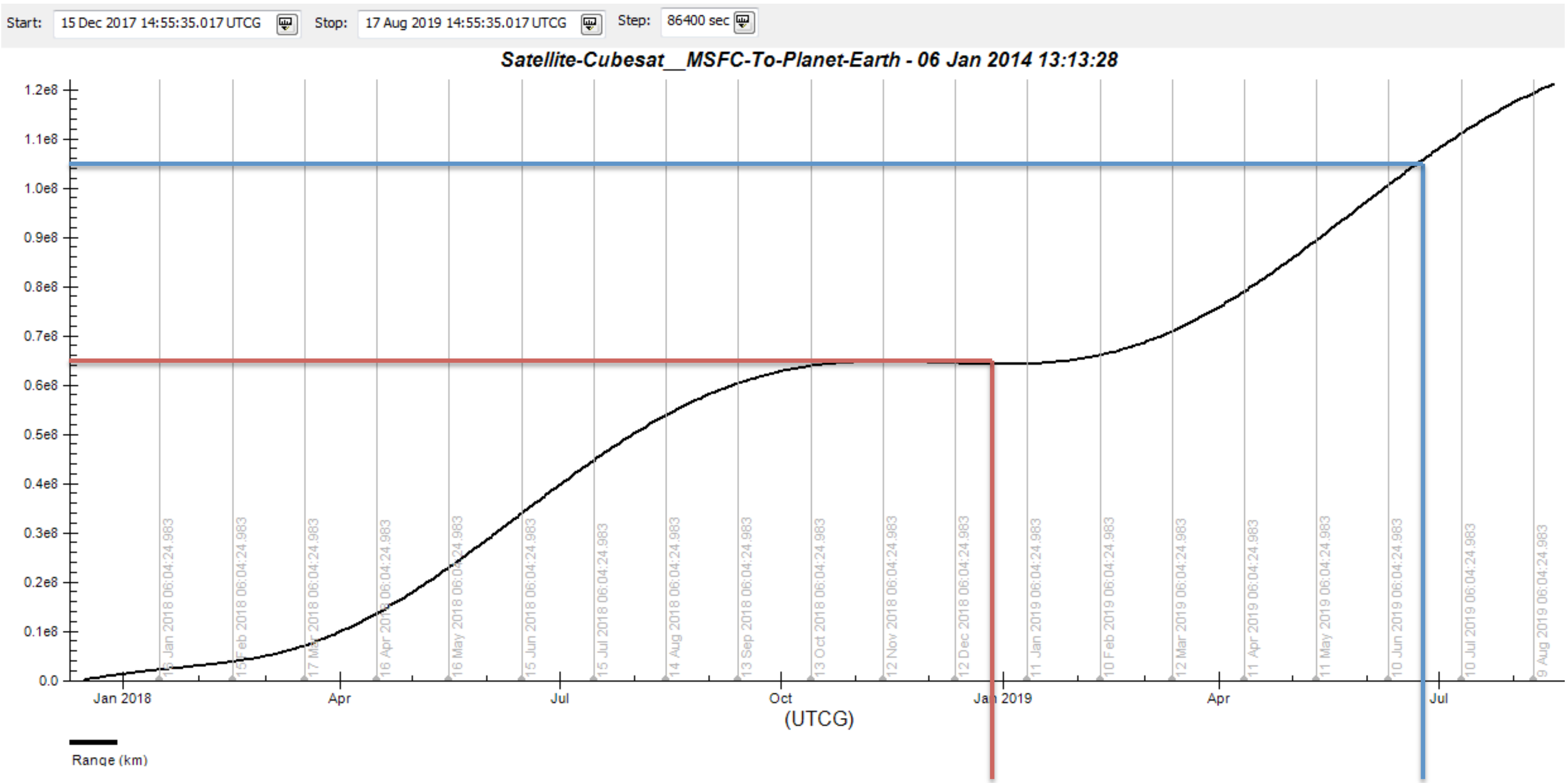
- Concept supports mass & volume for 12 bracket locations
- 11 locations support a dispenser & 6U (14 kg) Secondary Payload
- 1 Bracket location allocated to a sequencer

# Launch Through Secondary Payload Deployment



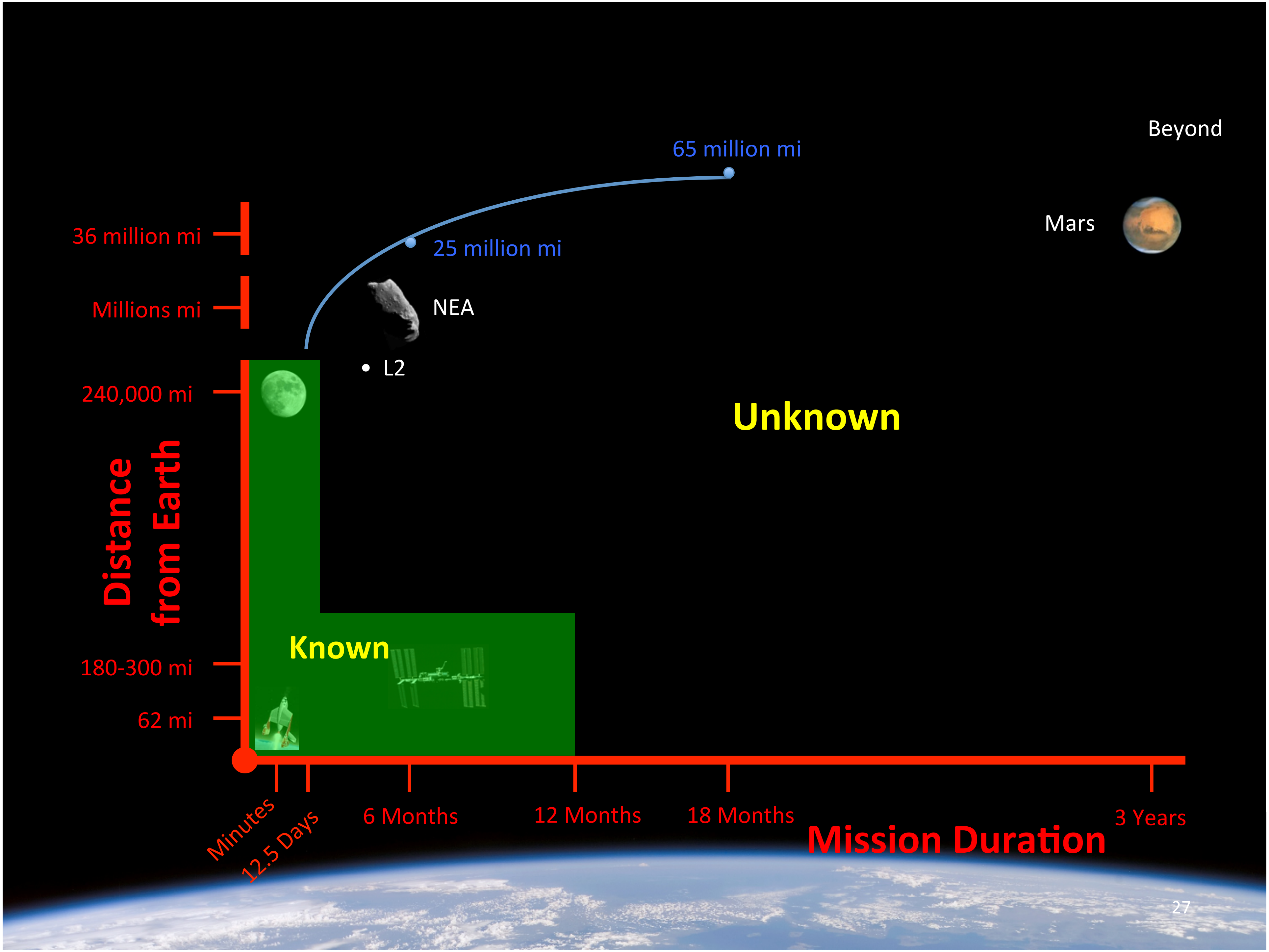

No BBQ roll after disposal maneuver complete.

# Communication Range to Earth



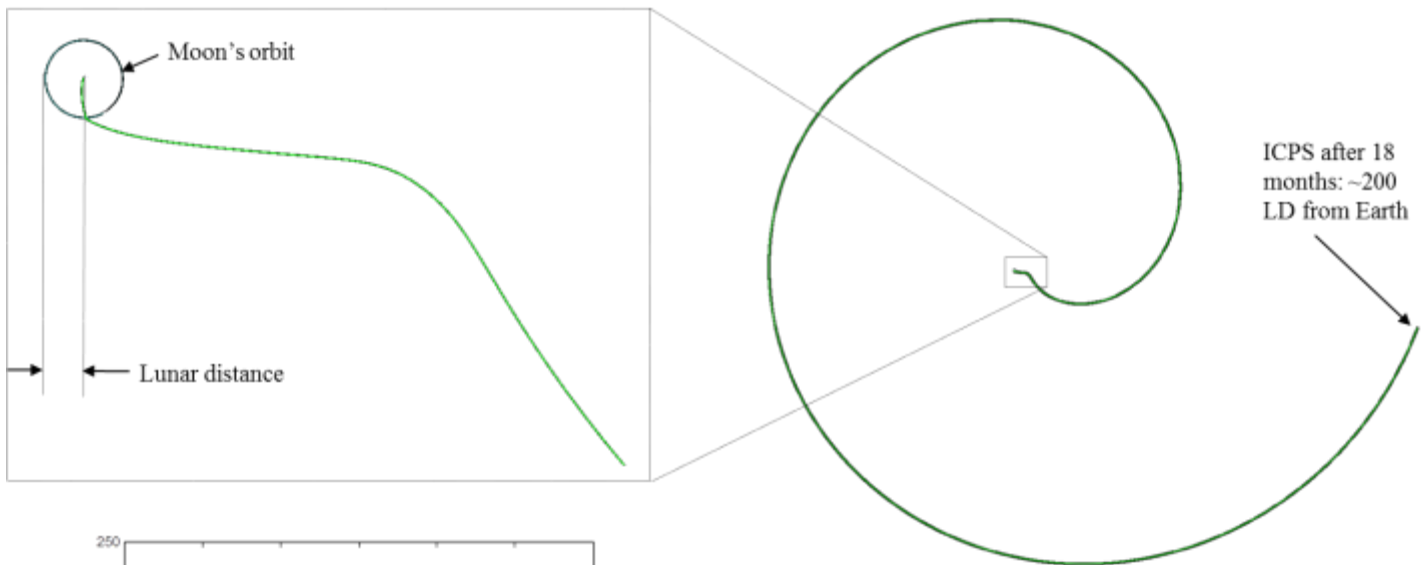

Range at nominal mission end

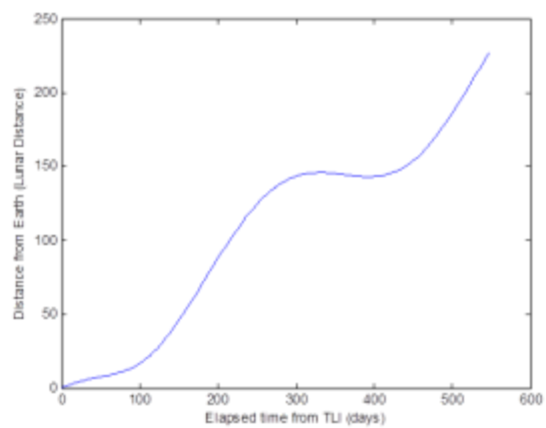
Range at extended mission end


Beyond
65 million mi
Mars
36 million mi
25 million mi
Millions mi
NEA
L2
240,000 mi
Unknown
Distance from Earth
Known
180-300 mi
62 mi
Minutes
12.5 Days
6 Months
12 Months
18 Months
3 Years
Mission Duration

# Location in Lunar Centered Space

**Now that ICPS trajectory has been recreated, propagate forward in time:**

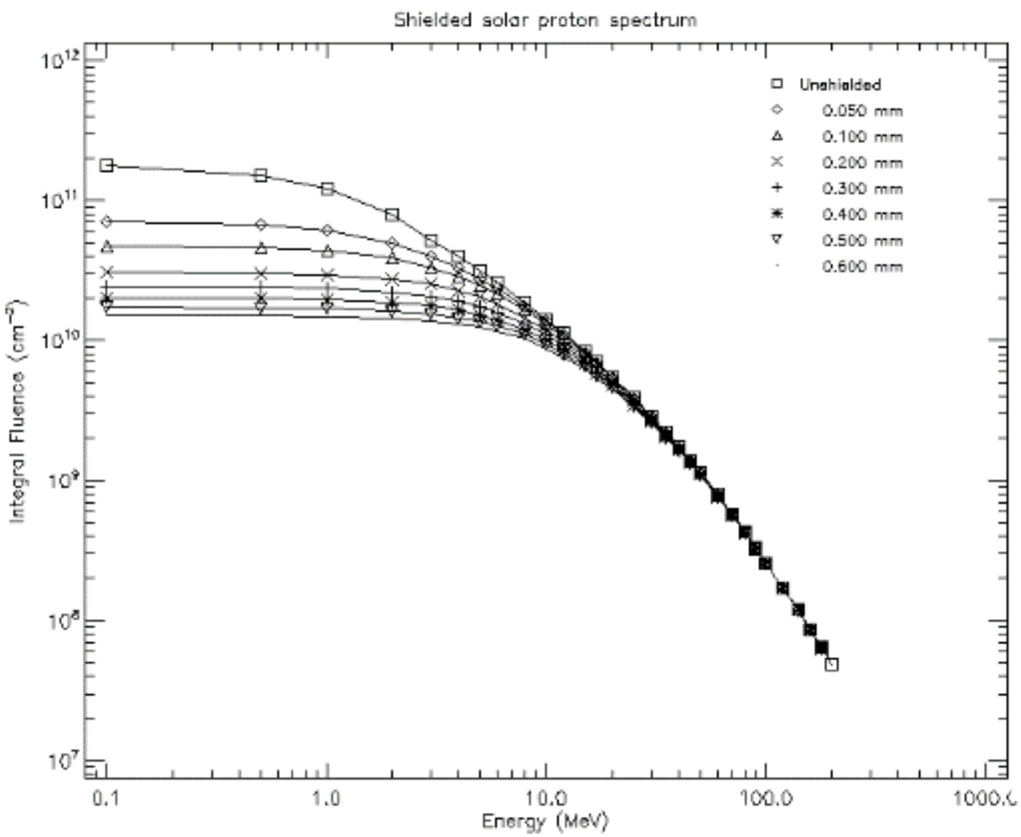


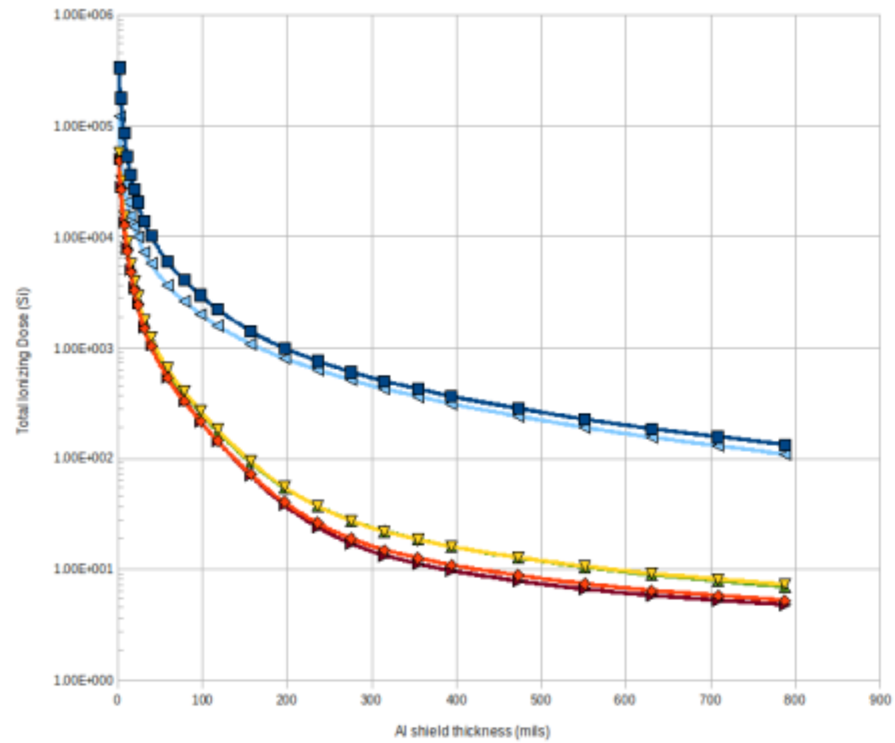

→ICPS appears to coast out into interplanetary space following its lunar flyby

→ A cubesat deployed with +/- 2 m/s ejection speed as early as 1 hr after TLI will also escape into interplanetary space but distance from Earth will vary

# Radiation Environment

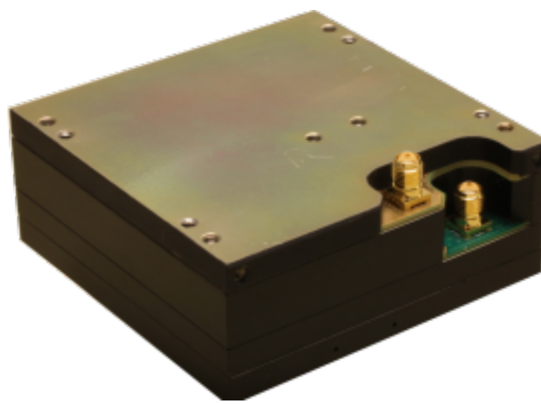



Total Ionizing Dose



# Transponder Options

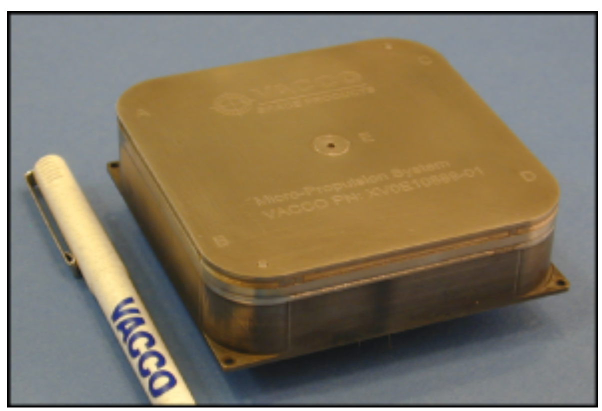
| Radio | Mfr. | Band | Tx Power | D/L Modulation and FEC | D/L Rates* | Ranging | UL Modulation | U/L Rate** | U/L Receive Sensitivity | TRL (Est.) | Heritage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IRIS | JPL | X/X | 0.4 (2) W | BPSK, QPSK; RS&CC or Turbo | 62.5 bps – 4 kbps | PRN | BPSK, FSK | 1 kbps | -120 dBm | 5 | INSPIRE (NASA) |
| DESCREET / SM100 | Inno-flight | S/X or X/X | 1 W | BPSK, QPSK; RS&CC or Turbo | 100 kbps – 4 kbps*** | PRN | GMSK, FSK | 1 kbps | -100 dBm | 3 | SENSE (USAF) |
| CSR_SDR-SS | Vulcan | S/S | 2.5 (4) W | BPSK, QPSK; RS&CC or Turbo | 100 bps – 4 kbps | PRN | BPSK, FSK | 1 kbps | -126 dBm | 5 | SunJammer (NASA) |

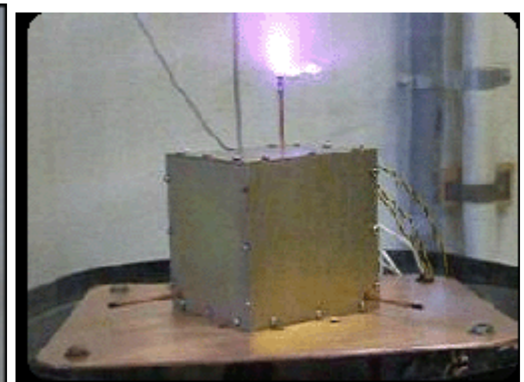


# Propulsion

- Momentum Management
  - No torque rods available
- Prop is typical solution
  - Tanks hard to accommodate
  - Hazardous fuels hard to accommodate
  - Need small impulse bits
  - Need low power for valve actuation
- Possible use of solar sailing
  - Alternate pointing direction to counter momentum buildup
- Almost all are fairly low TRL

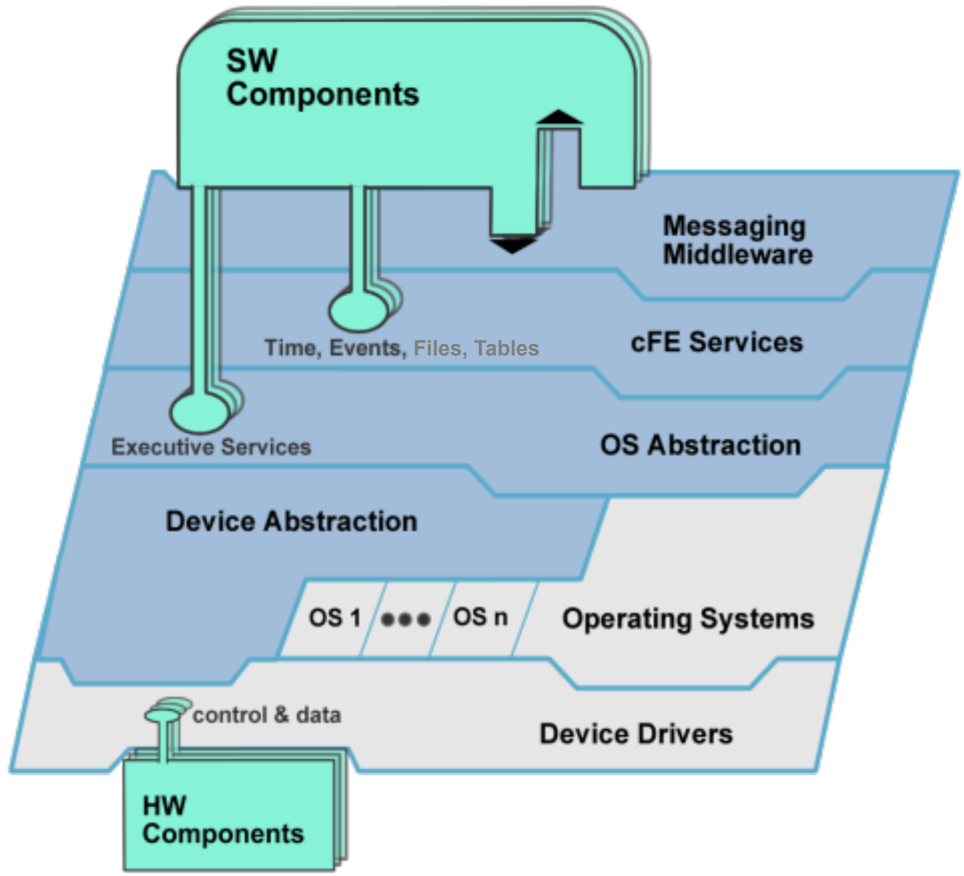
| Product | Company | Fuel | Perf | Thrust | Isp |
|---|---|---|---|---|---|
| PETA | Espace / MIT | Ionic Salt | ~500 m/s | 50 uN | 3500 s |
| ChEMS | VACCO | Butane | 34 Ns | 55 mN | ~70 s |
| BEVO-2 | UT Austin | Butane | TBD | TBD | ~70 s |
| MP-110 | Aerojet | R-134a | ~10 Ns | ~30 mN | ~70 s |
| u-PPT | Busek | Teflon | ~250 – 500 m/s | 25 – 40 uN | 440 s |



# CFE/CFS Layered Architecture

- **Each layer "hides" its implementation and technology details.**
- **Internals of a layer can be changed -- without affecting other layers' internals and components.**
- **Enables technology infusion and evolution.**
- **Doesn't dictate a product or vendor.**
- **Provides Middleware, OS and HW platform-independence.**



# FSW Architecture Overview