BioSentinel: Enabling CubeSat-Scale Biological Research Beyond Low Earth Orbit

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Outline

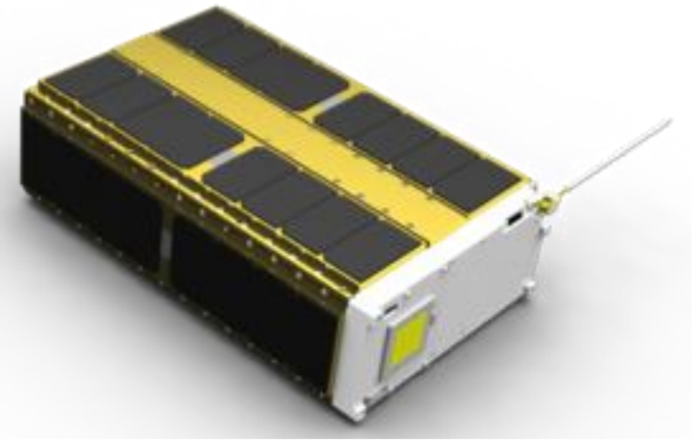
- Introduction
- Mission Overview
- Spacecraft Concept
- Design Challenges and Future Work

INTRODUCTION

A Unique Launch Opportunity

- NASA Advanced Exploration Systems (AES) is sponsoring 3 secondary payload slots on the first flight of the Space Launch System
- Secondaries will be deployed into a heliocentric orbit after separation of Orion CEV
- Baseline design constraints allow for 6-cube volume and 14 kg mass

Artist's rendering of the Space Launch System



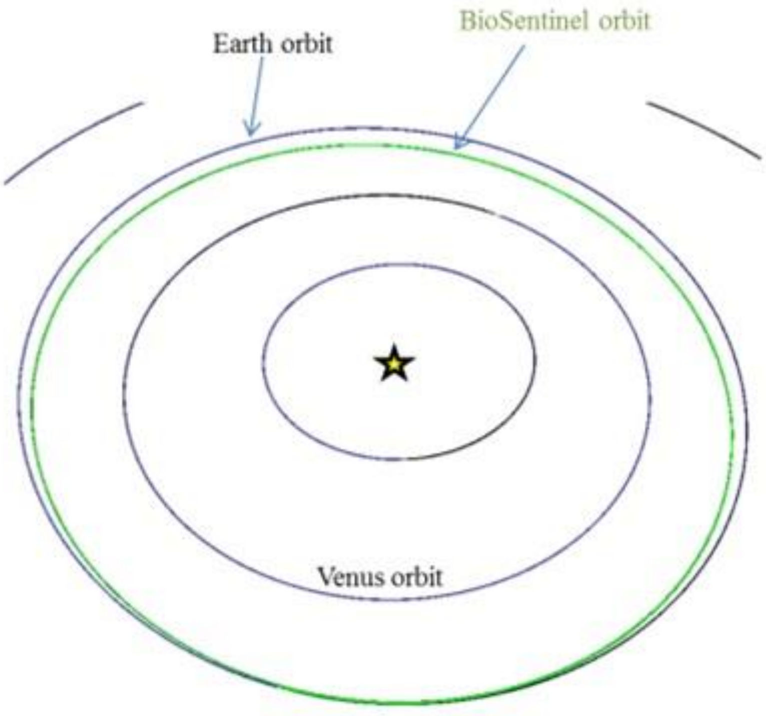
A visualization of one possible formulation of a 6U spacecraft to be used for the BioSentinel mission

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

Where CubeSats Haven't Gone Before

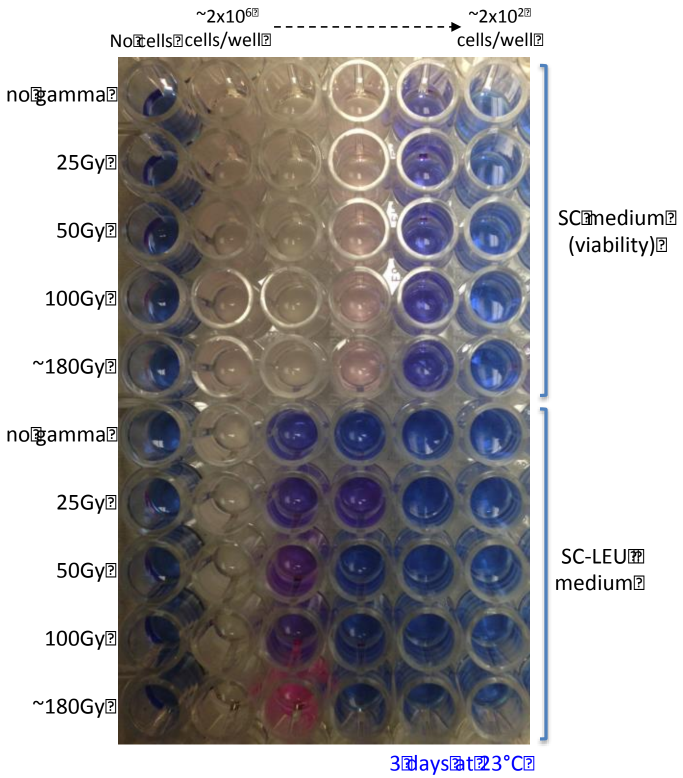
- Exact deployment orbit of secondaries still being characterized
  - Possible requirement for ΔV maneuver
- Will likely be Earth-trailing, heliocentric orbit
- Far outside the orbits typically occupied by CubeSats



A representative orbit that the BioSentinel spacecraft could occupy

MISSION OVERVIEW

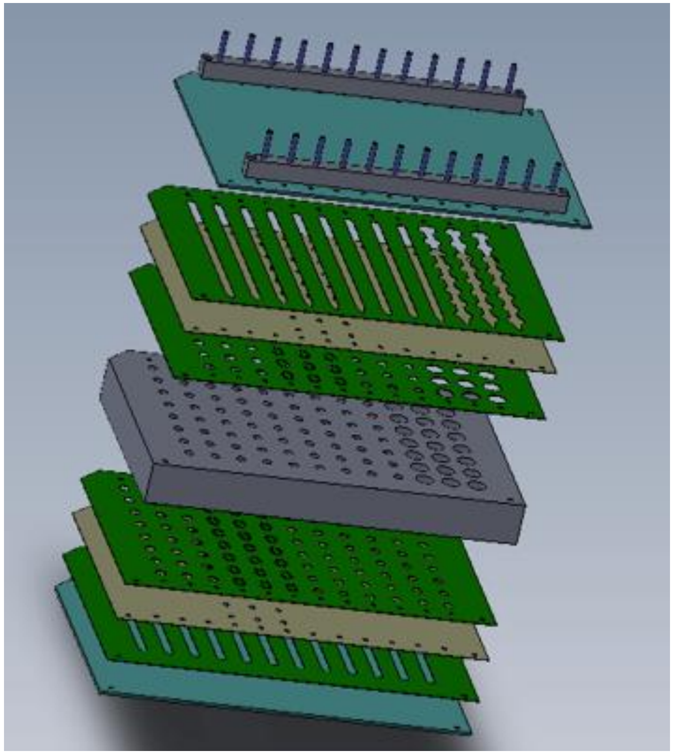
Valuable Access to the Space Environment



Representative yeast growth cells similar to those that will be used in BioSentinel

- The space radiation environment cannot be duplicated on Earth, making research into its effects challenging
- BioSentinel will measure a specific type of DNA damage resulting from exposure to this environment
- Laboratory-engineered yeast cells will sense and repair direct damage to their DNA (in the form of double-strand breaks)
  - Gene repair will initiate cell growth in microwells within payload volume

Foundational Research for Future Missions

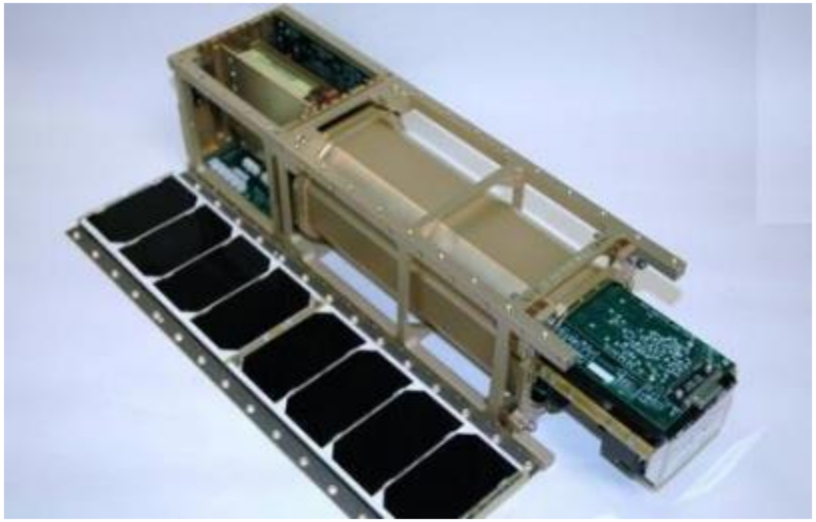


Visualization of the BioSentinel biology microwell stack-up

- Ionizing radiation presents a major challenge to human exploration of deep space
  - Specific deleterious effects of long-term exposure are unknown
- Challenging to replicate deep space radiation environment on Earth, particularly with SPEs
- Eukaryotic yeast cells are a valuable analogy for future manned missions
- BioSentinel will provide insight into shielding strategies and radiation countermeasure development

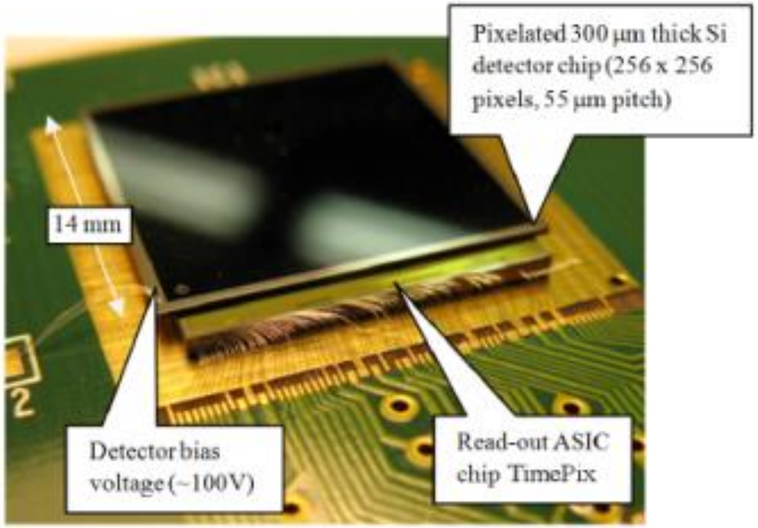
Building on Ames Heritage

- 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

Bonus Payload: Radiation Sensor

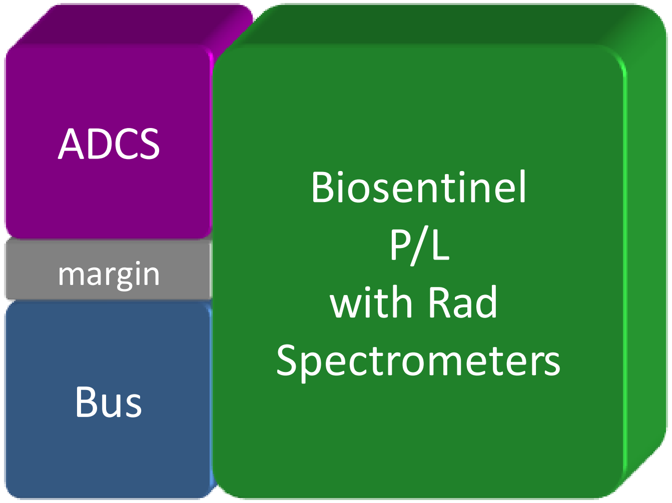


The TimePIX linear energy transfer detector chip

- In addition to biology payload BioSentinel will fly a stand-alone radiation sensor to provide direction measurement of galactic cosmic radiation
- Requires linear energy transfer detection and integrating dosimetry (TID) capability
- Future design work related to type of sensor and implementation, integration with spacecraft bus
- Collaboration with JSC RadWorks group

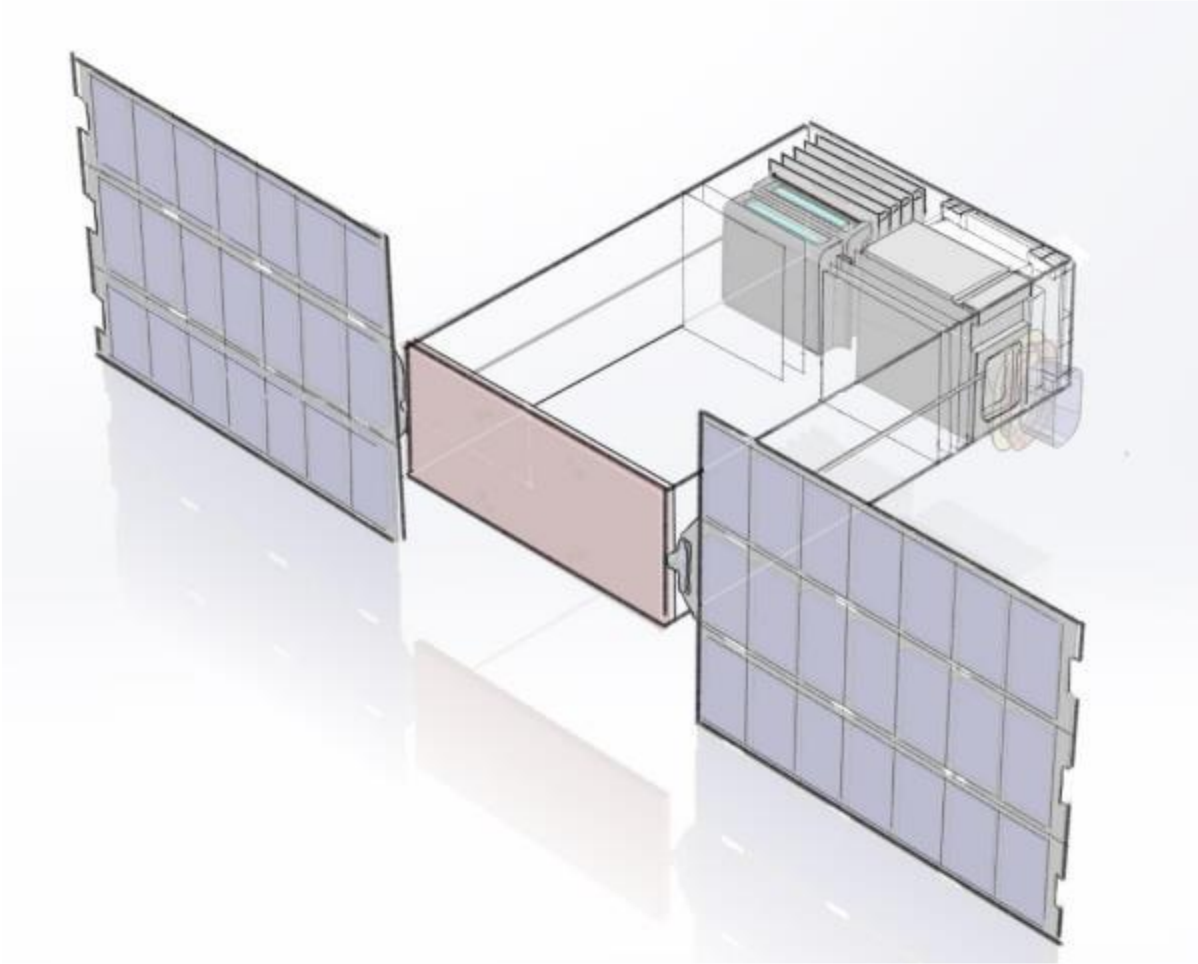
A Wide Range of 6U “Firsts” for Ames

- First 6U CubeSat to fly beyond LEO
- First CubeSat to combine both active attitude control and a biology science payload
- First CubeSat to combine both active attitude control and propulsion subsystems
- First CubeSat to integrate a third-party deployable solar array



Major BioSentinel subsystems shown with rough order-of-magnitude volume budgets

SPACECRAFT CONCEPT



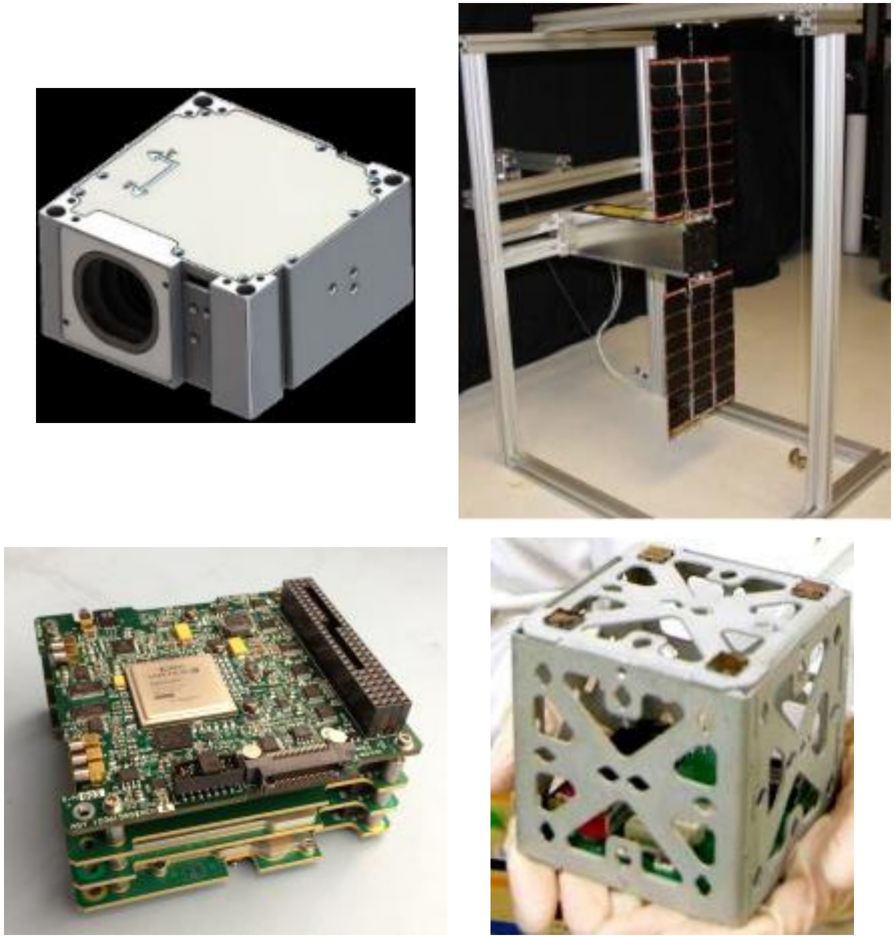
Current design concept for the BioSentinel Spacecraft

Environmental Considerations

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

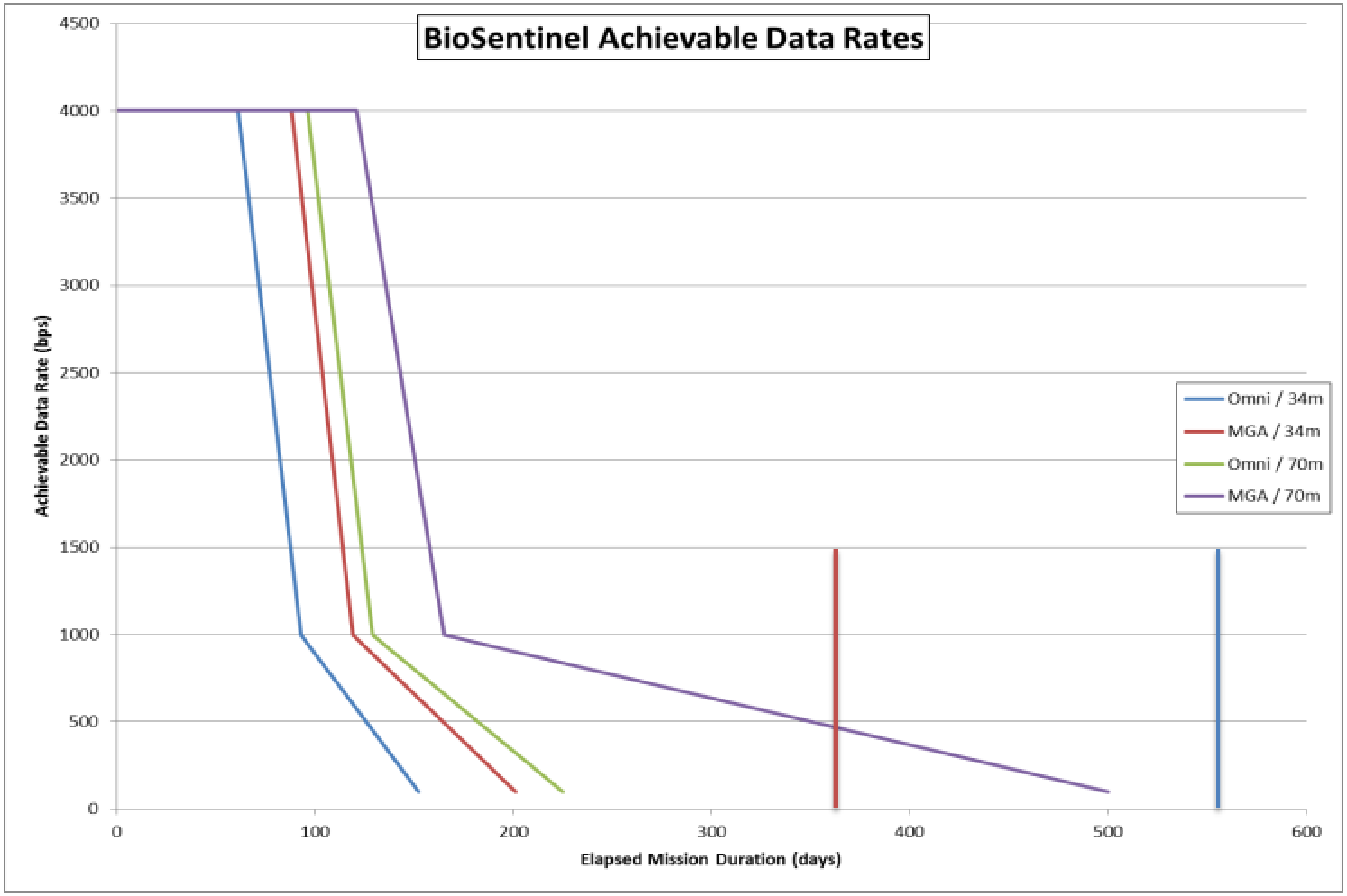
Subsystem Considerations

- Deployable solar panels required to generate sufficient power for all subsystems
- Traditional CubeSat S-band/UHF radios insufficient at mission operating orbit
  - X is preferred band (up and down) for deep space missions
- Propulsion required for both detumble and momentum management
- Biology must be maintained at a specific temperature and acceleration range



Candidate components under consideration for the BioSentinel mission

Data Rates Achievable

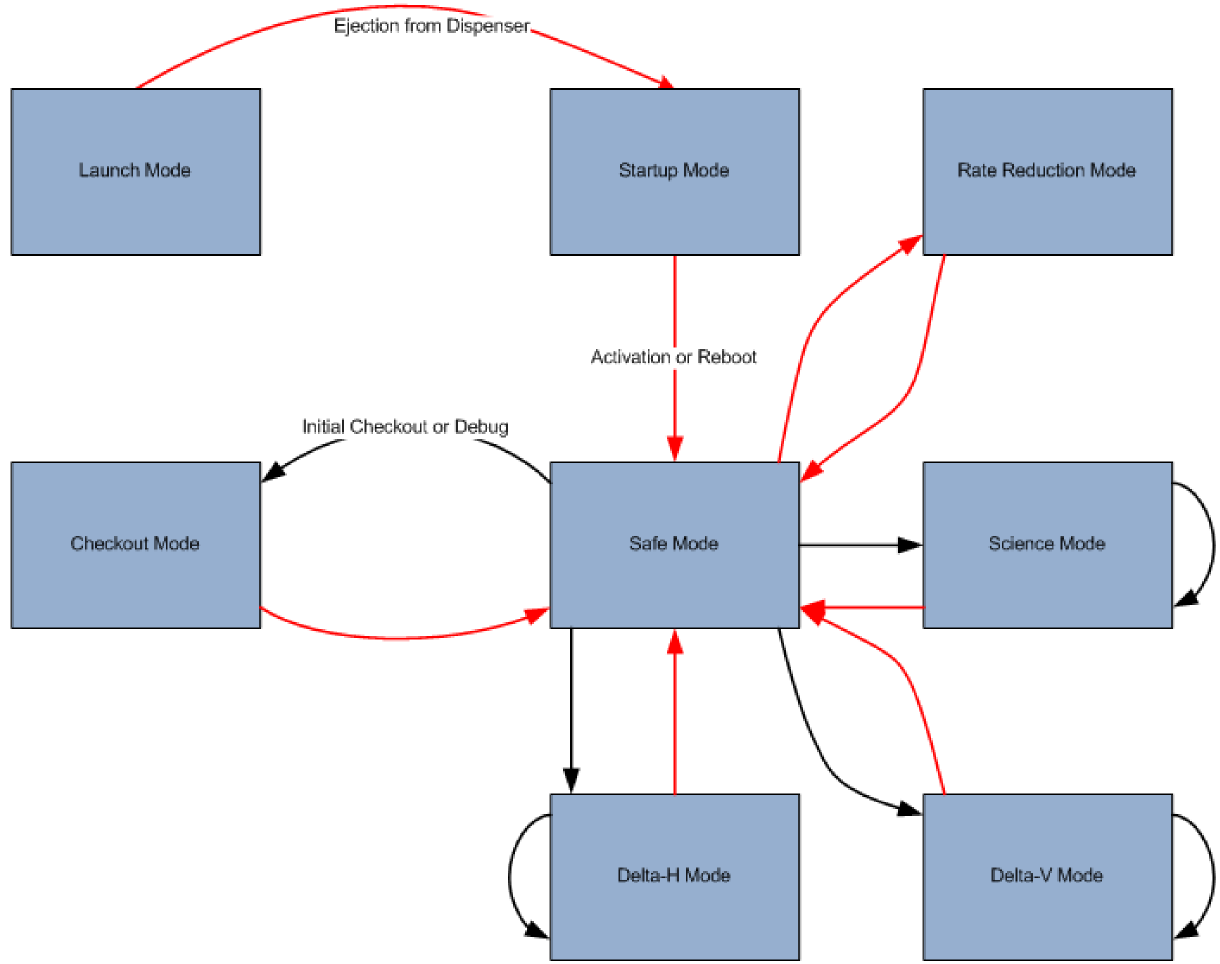


Rate at nominal mission end (0.43 AU)

Rate at extended mission end (0.7 AU)

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



A representative mode transition diagram for the BioSentinel mission

DESIGN CHALLENGES/ FUTURE WORK

- 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

QUESTIONS?

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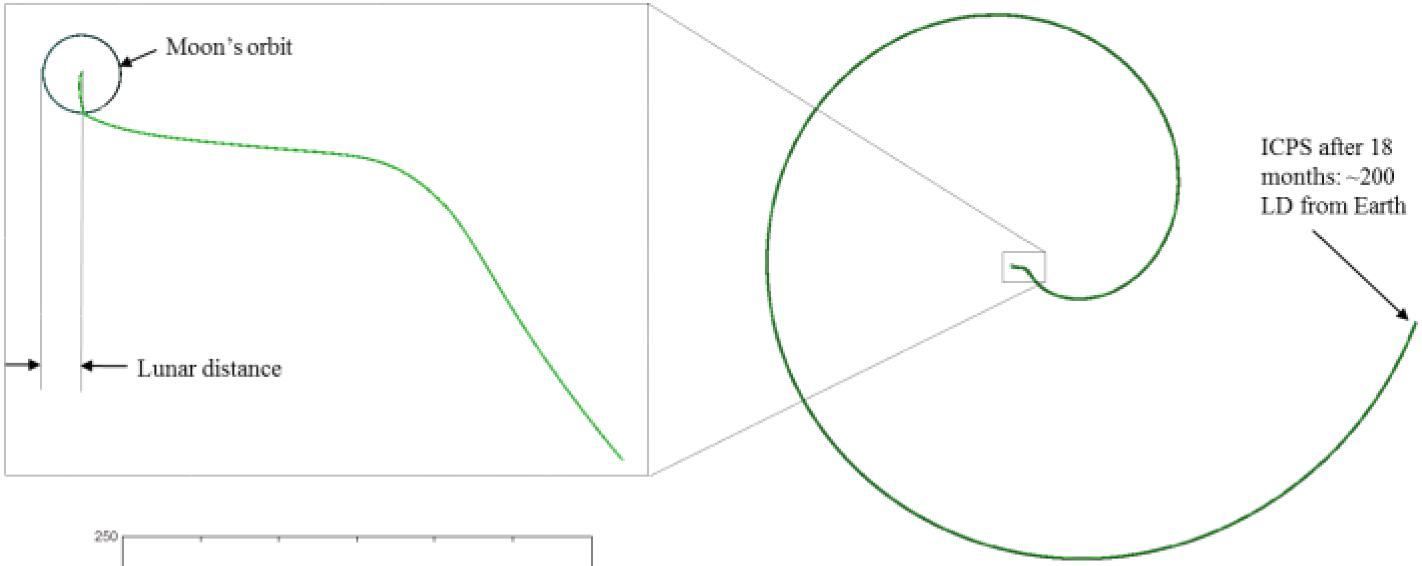
BACK-UP SLIDES

Location in Lunar Centered Space

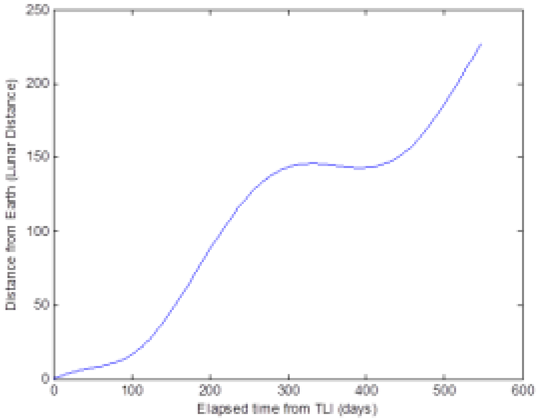
Now that ICPS trajectory has been recreated, propagate forward in time:



Moon's orbit

Lunar distance

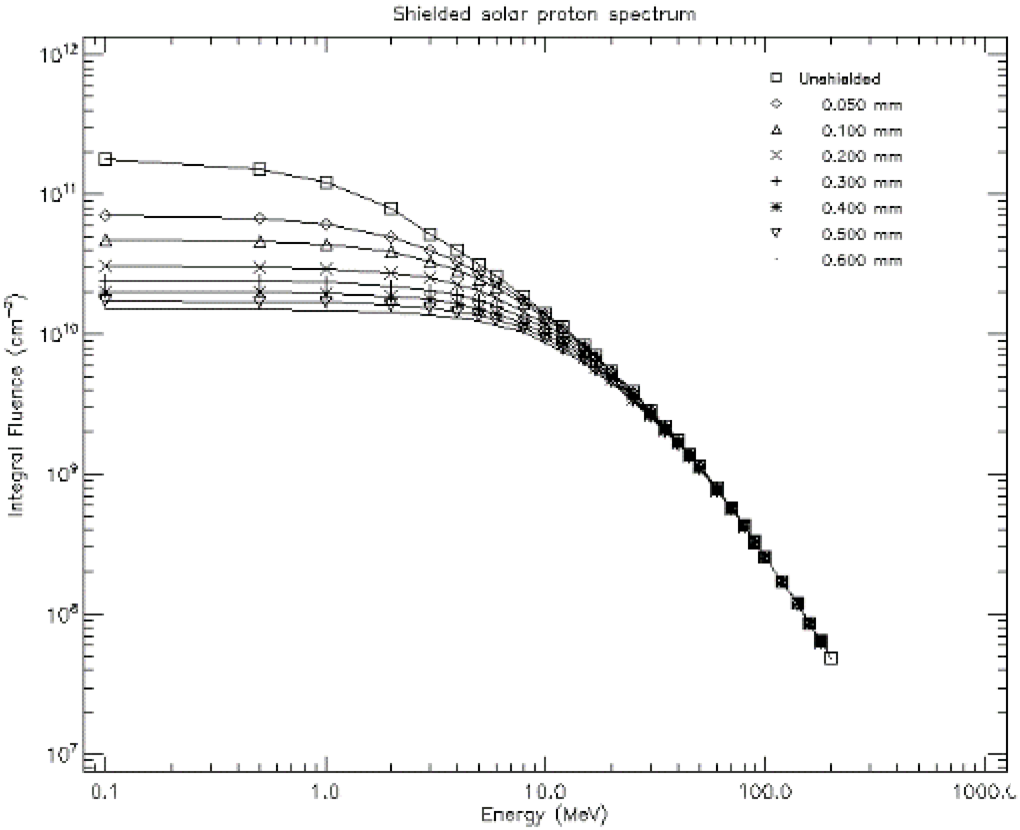
ICPS after 18 months: ~200 LD from Earth



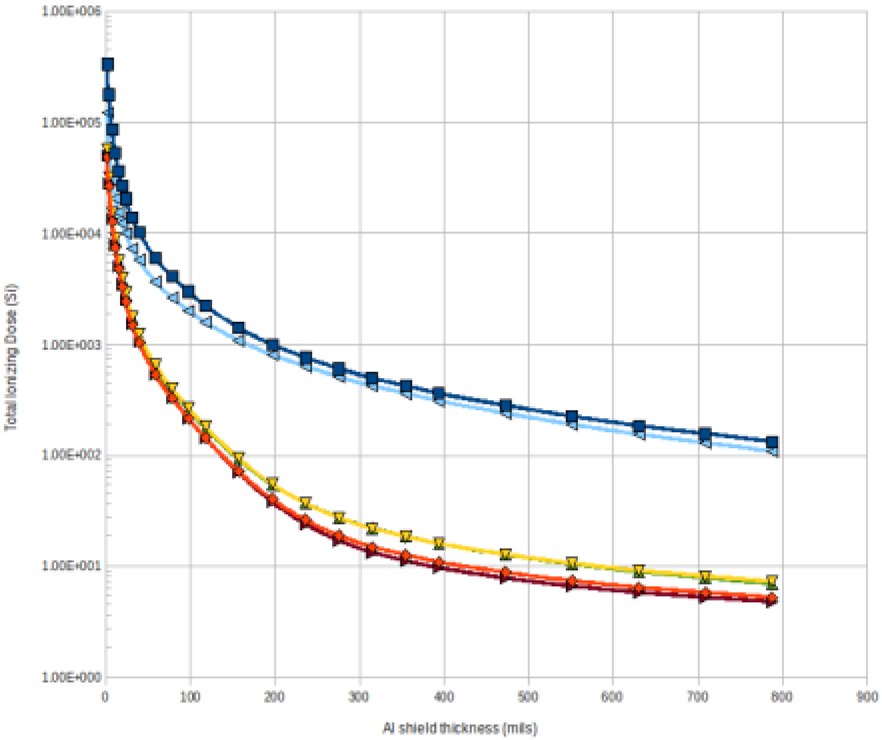
→ICPS appears to coast out into interplanetary space following its lunar flyby

→ 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



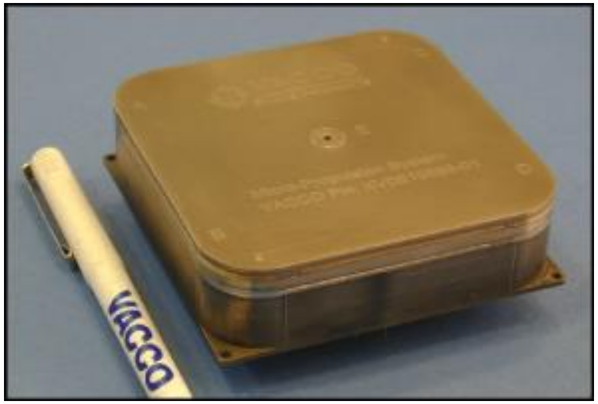
Transponder Options

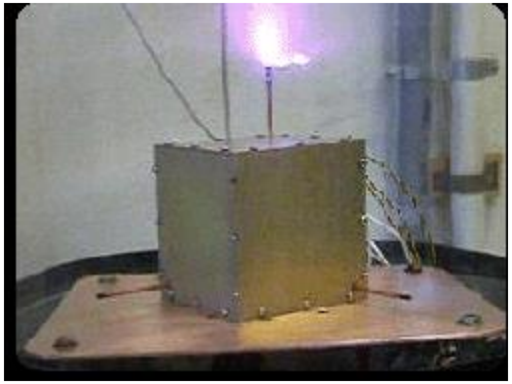
Radio	Mfr.	Band	Tx Power	D/L Modulation and FEC	D/L Rates*	Ranging	UL Modulation	U/L Rate**	U/L Receive Sensitivity	TRL (Est.)	Heritage
IRIS	JPL	X/X	0.4 (2) W	BPSK, QPSK; RS&CC or Turbo	62.5 bps – 4 kbps	PRN	BPSK, FSK	1 kbps	-120 dBm	5	INSPIRE (NASA)
DESCREET / SM100	Innoflight	S/X or X/X	1 W	BPSK, QPSK; 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

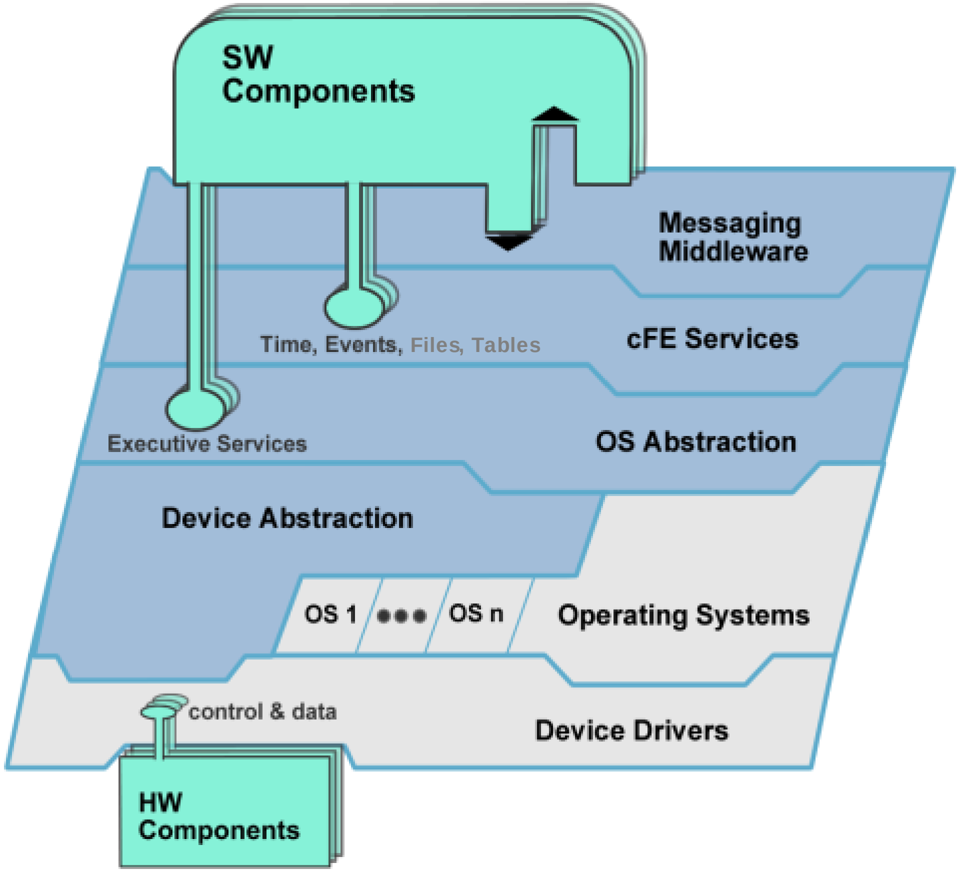
Product	Company	Fuel	Perf	Thrust	Isp
PETA	Espace / MIT	Ionic Salt	~500 m/s	50 uN	3500 s
ChEMS	VACCO	Butane	34 Ns	55 mN	~70 s
BEVO-2	UT Austin	Butane	TBD	TBD	~70 s
MP-110	Aerojet	R-134a	~10 Ns	~30 mN	~70 s
u-PPT	Busek	Teflon	~250 – 500 m/s	25 – 40 uN	440 s



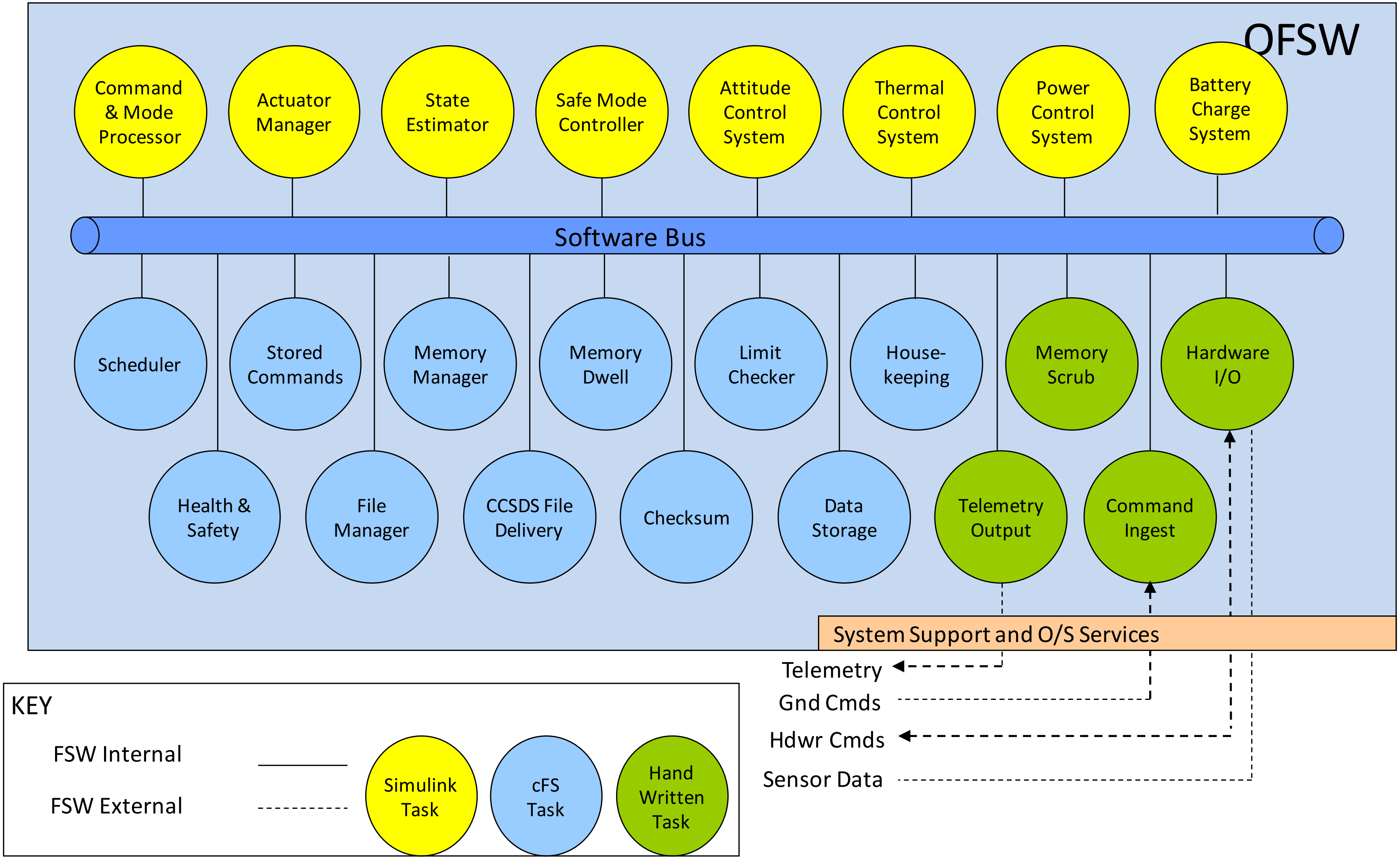


CFE/CFS Layered Architecture

- **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



OFSW

Command & Mode Processor

Actuator Manager

State Estimator

Safe Mode Controller

Attitude Control System

Thermal Control System

Power Control System

Battery Charge System

Software Bus

Scheduler

Stored Commands

Memory Manager

Memory Dwell

Limit Checker

House-keeping

Memory Scrub

Hardware I/O

Health & Safety

File Manager

CCSDS File Delivery

Checksum

Data Storage

Telemetry Output

Command Ingest

System Support and O/S Services

Telemetry

Gnd Cmds

Hdwr Cmds

Sensor Data

KEY

FSW Internal

FSW External

Simulink Task

cFS Task

Hand Written Task