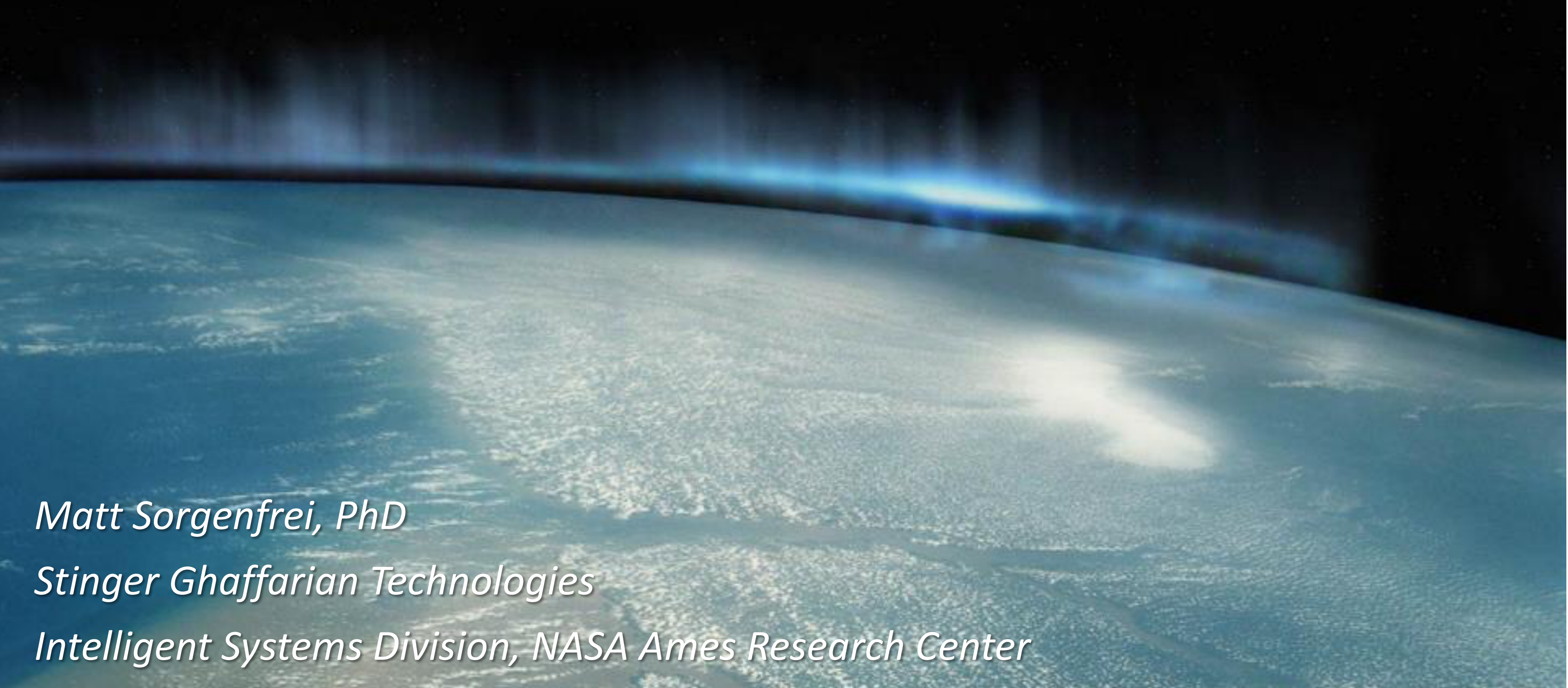
BioSentinel:

Enabling CubeSat-Scale Biological Research Beyond Low Earth Orbit



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Outline

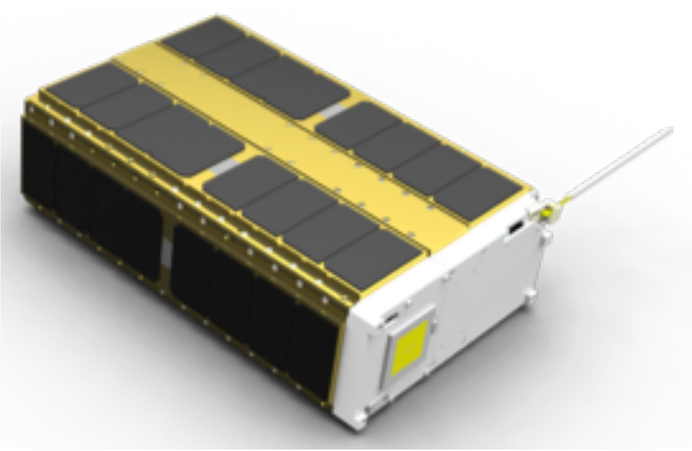
- Introduction
- Mission Overview
- Spacecraft Concept
- Design Challenges and Future Work

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 (SLS)
- 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



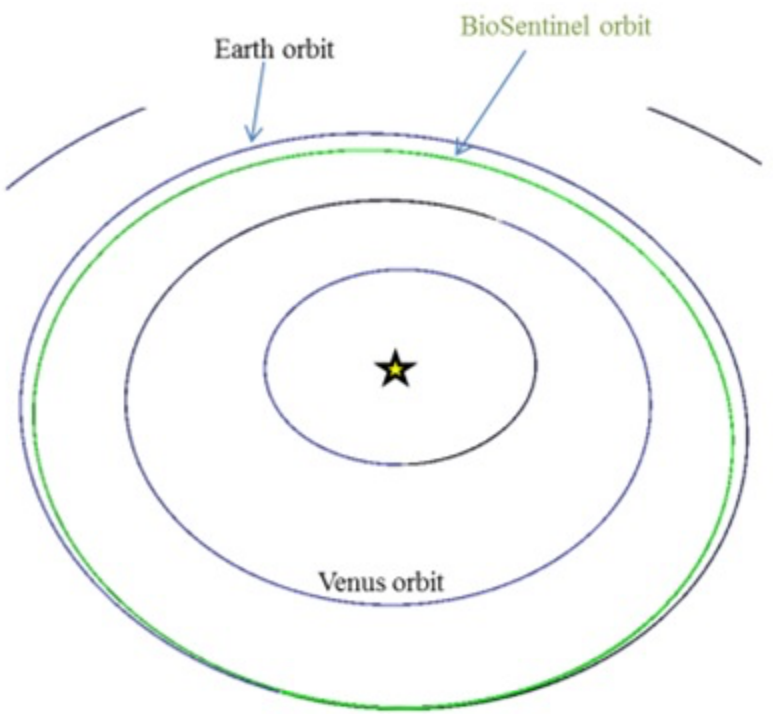
A visualization of one possible formulation of a 6U spacecraft to be used for the BioSentinel mission

3 Distinct Missions

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

Where CubeSats Haven't Gone Before

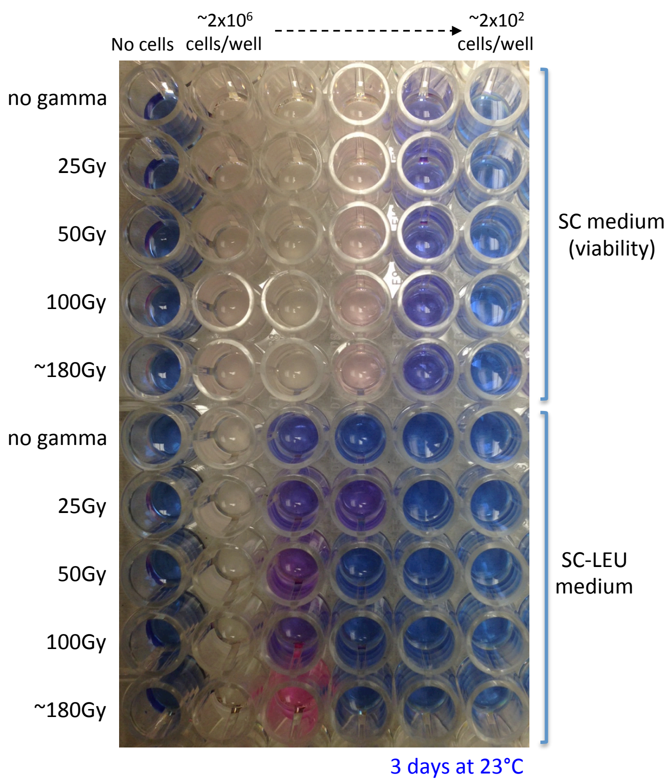
- Exact deployment orbit of secondaries still being characterized
  - Possible requirement for ΔV maneuver
- Will likely be Earth-trailing, heliocentric orbit
- Far outside the orbits typically occupied by CubeSats



A representative orbit that the BioSentinel spacecraft could occupy

MISSION OVERVIEW

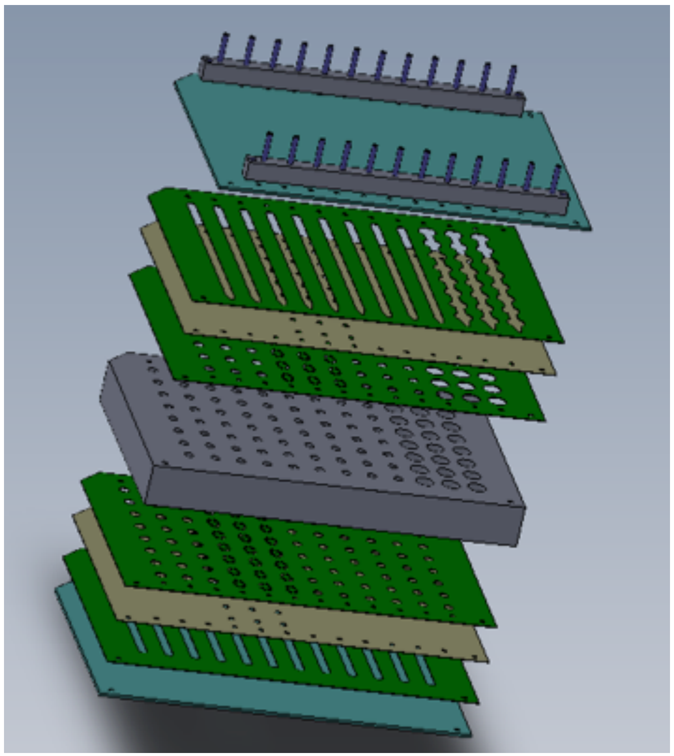
Valuable Access to the Space Environment



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
  - Specific damage is so-called double-strand breaks
  - Gene repair will initiate cell growth in microwells within payload volume

Foundational Research for Future Missions

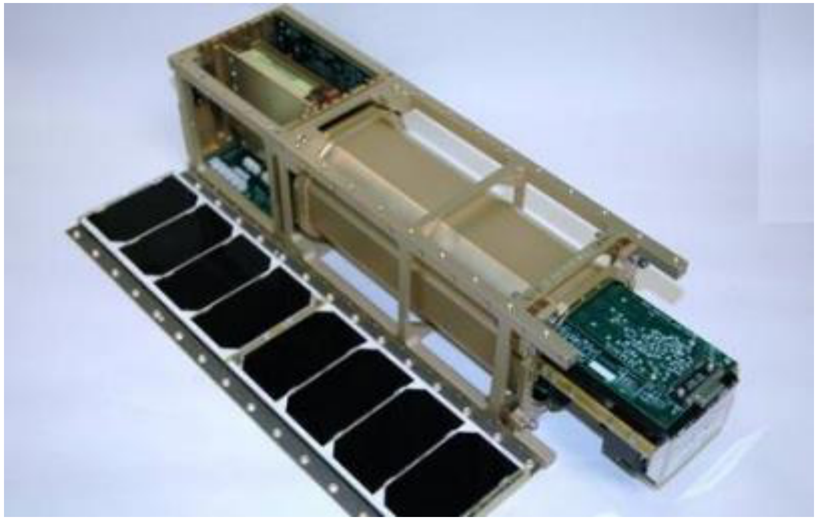


Visualization of the BioSentinel biology microwell stack-up

- 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

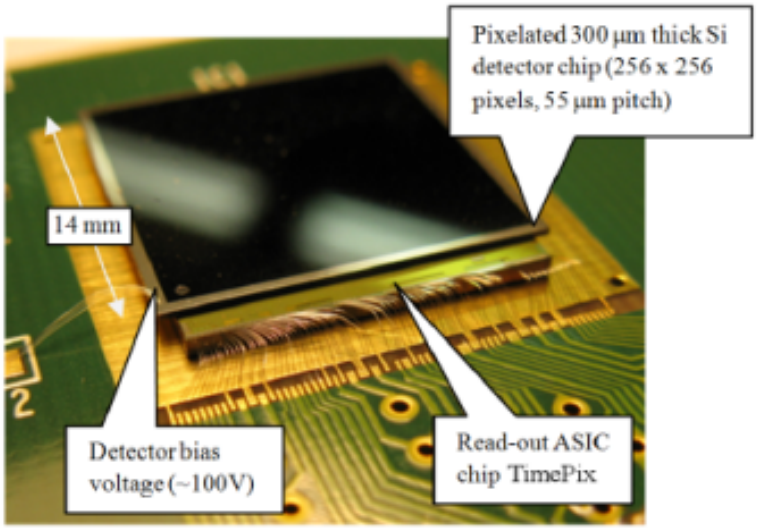
Building on Ames Heritage

- 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 with ISS, and ground control



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

Bonus Payload: Radiation Sensor

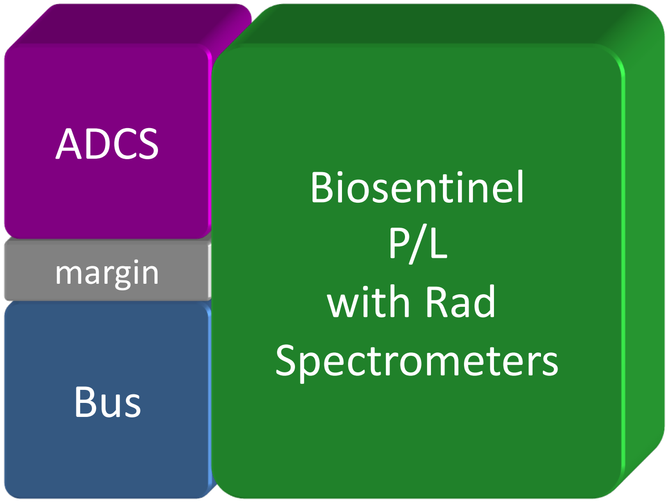


The TimePIX linear energy transfer detector chip

- 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

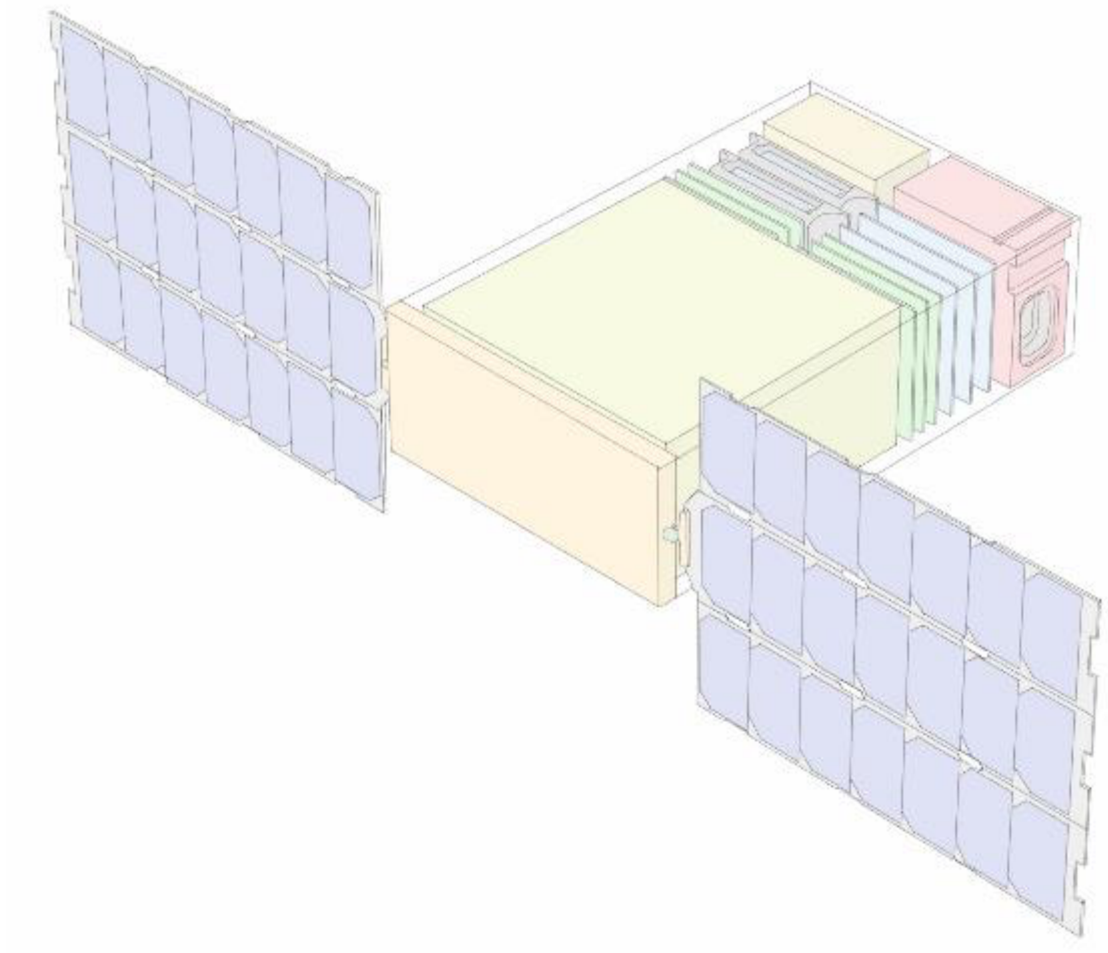
A Wide Range of 6U "Firsts" for Ames

- First 6U CubeSat to fly beyond LEO
- First CubeSat to combine both active attitude control and a biology science payload
- First CubeSat to integrate a propulsion subsystem for momentum management and (possibly) ΔV
- First CubeSat to integrate a third-party deployable solar array



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

SPACECRAFT CONCEPT



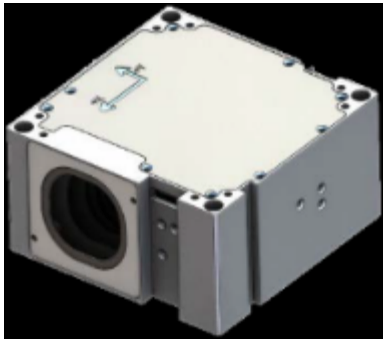
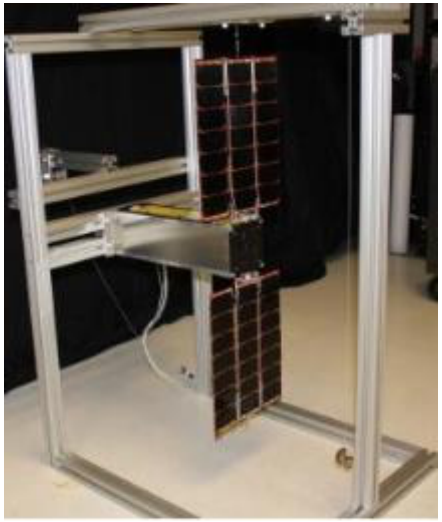
Current design concept for the BioSentinel Spacecraft

Environmental Considerations

- Higher exposure to radiation than experienced by previous CubeSats operating in LEO
  - Approximately 5 kRad 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, or torque coils/rods for attitude control
- Solar radiation pressure will be largest disturbance torque

Subsystem Considerations

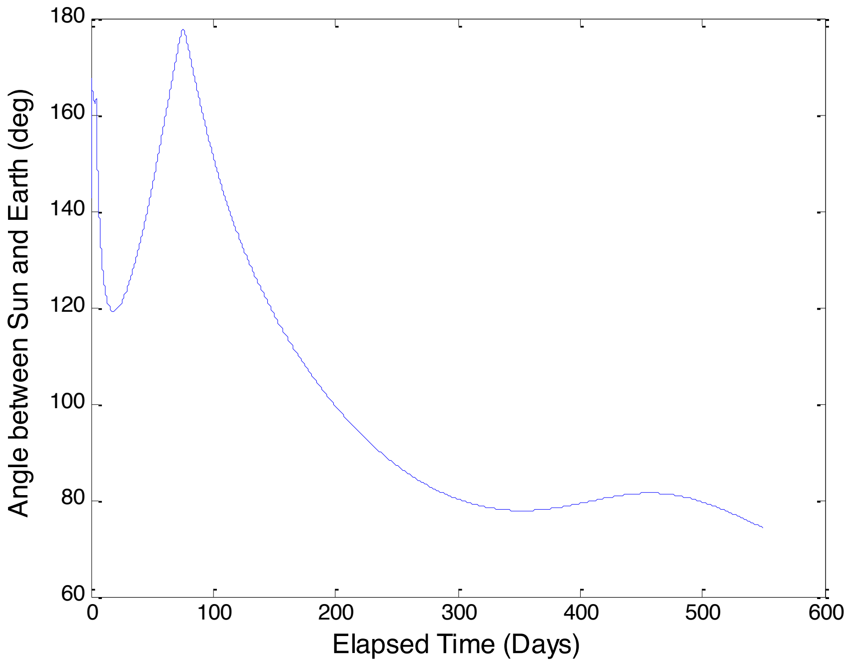
- Deployable solar panels required to generate sufficient power for all subsystems
- Traditional CubeSat S-band/UHF radios insufficient at mission operating orbit
  - X-band under consideration for up and down communications
  - Propulsion required for both detumble and momentum management
- Biology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

Candidate components under consideration for the BioSentinel mission

Communications Challenges

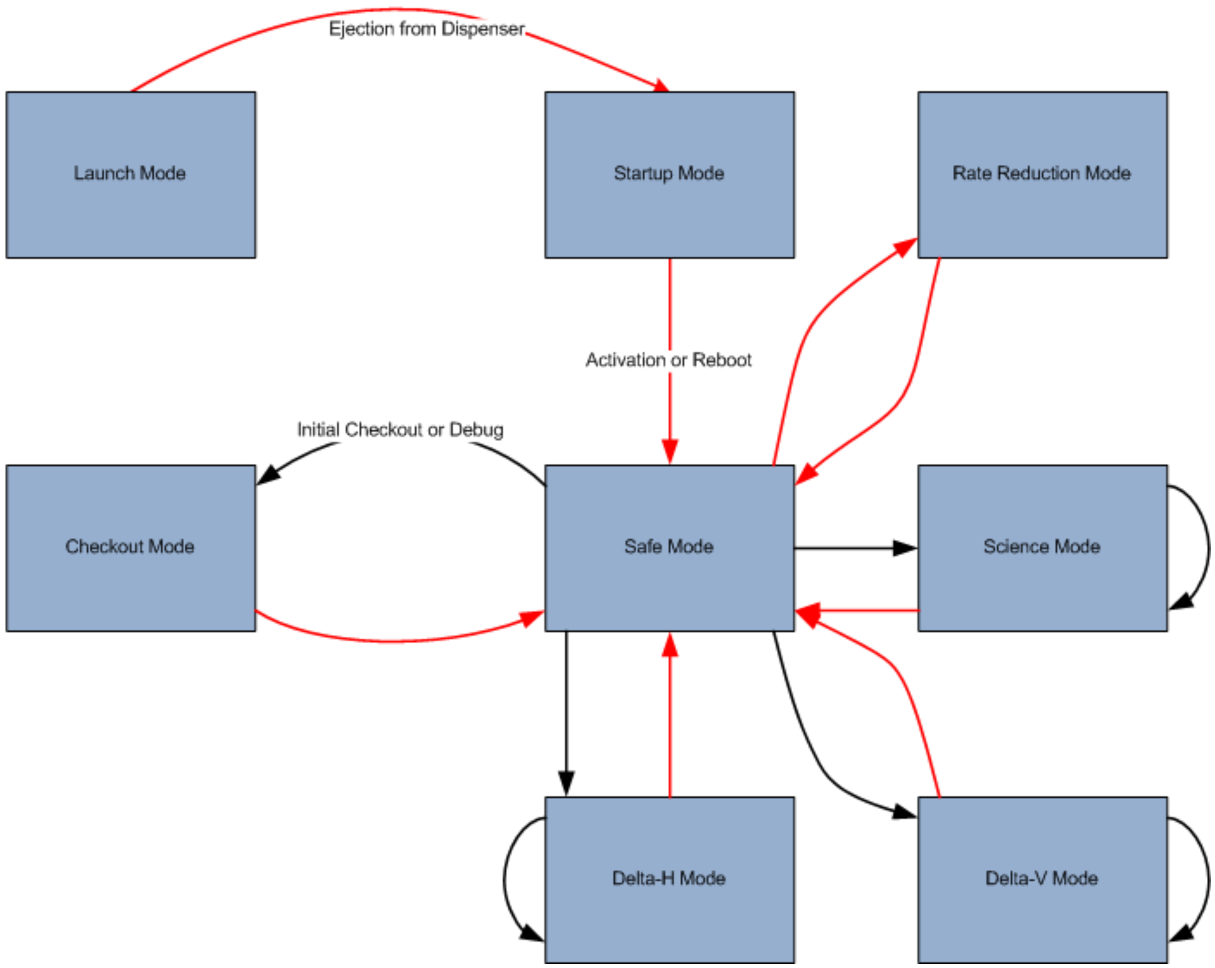
Data rate as a function of distance from Earth when using a 34m dish and an omni-directional or medium gain antenna



Angle between Sun and Earth as a function of mission day

Avionics Challenges

- BioSentinel will require a command and data handling (C&DH) system that is much more capable than previously flown in CubeSat-class 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 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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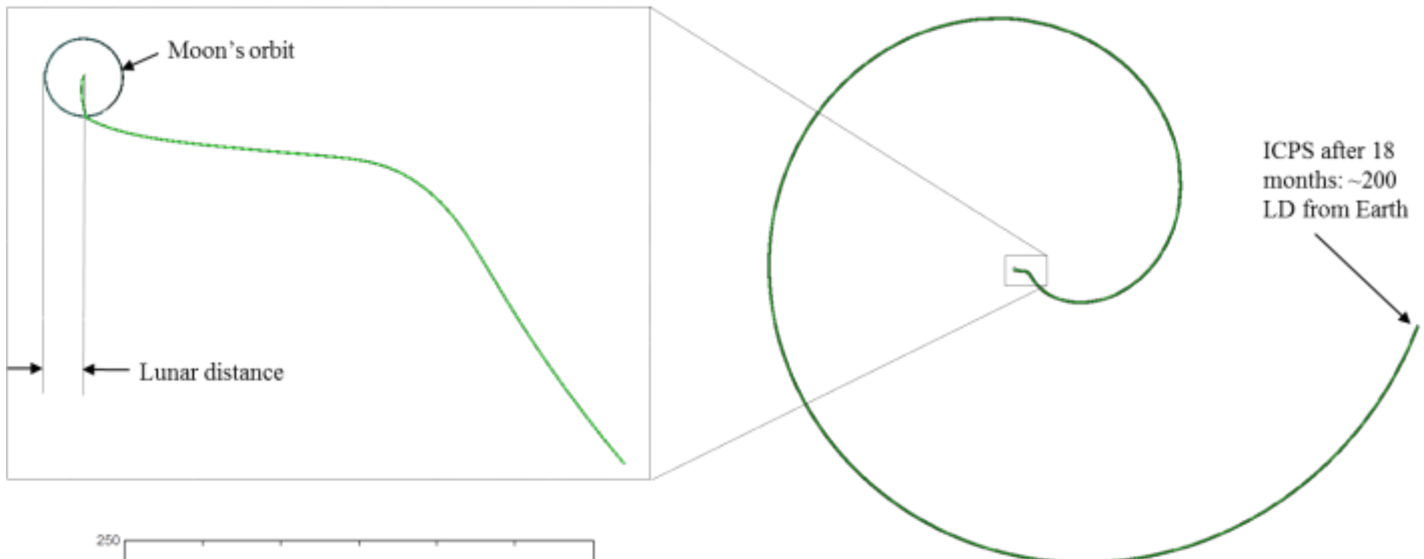
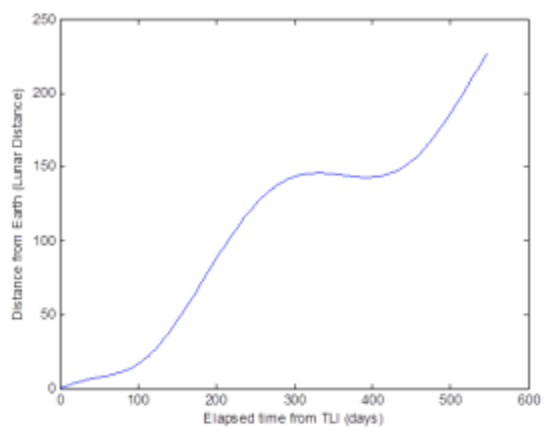
BACK-UP SLIDES

Location in Lunar Centered Space

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

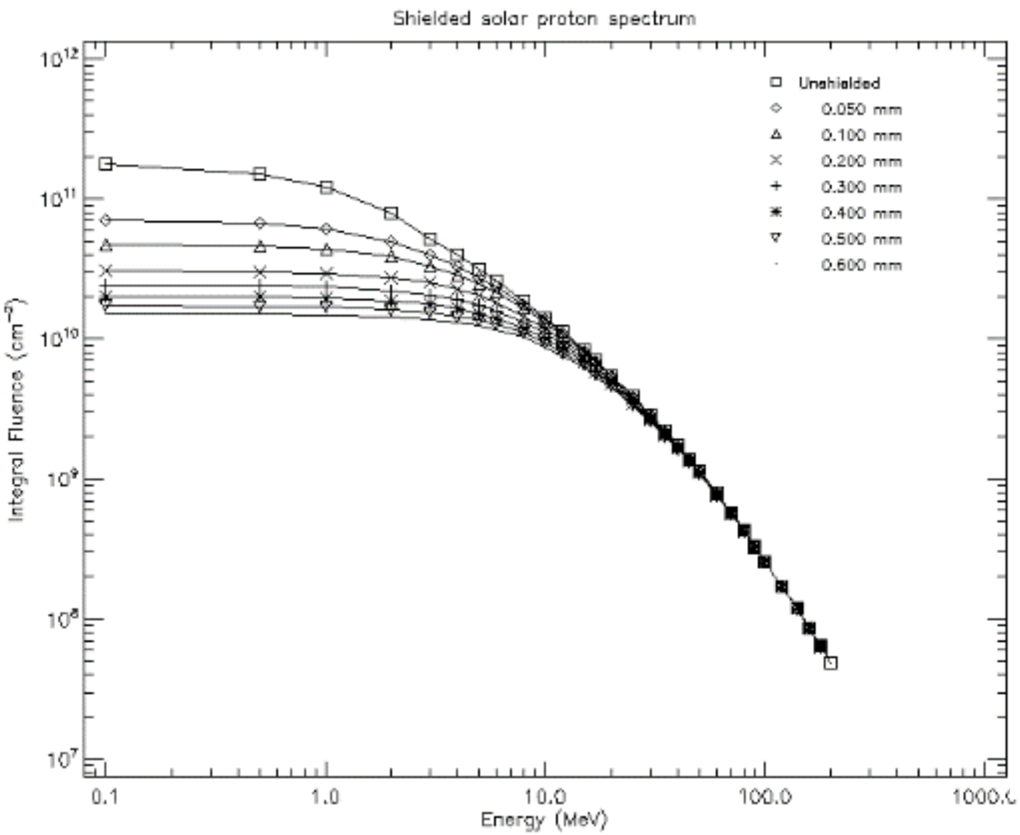




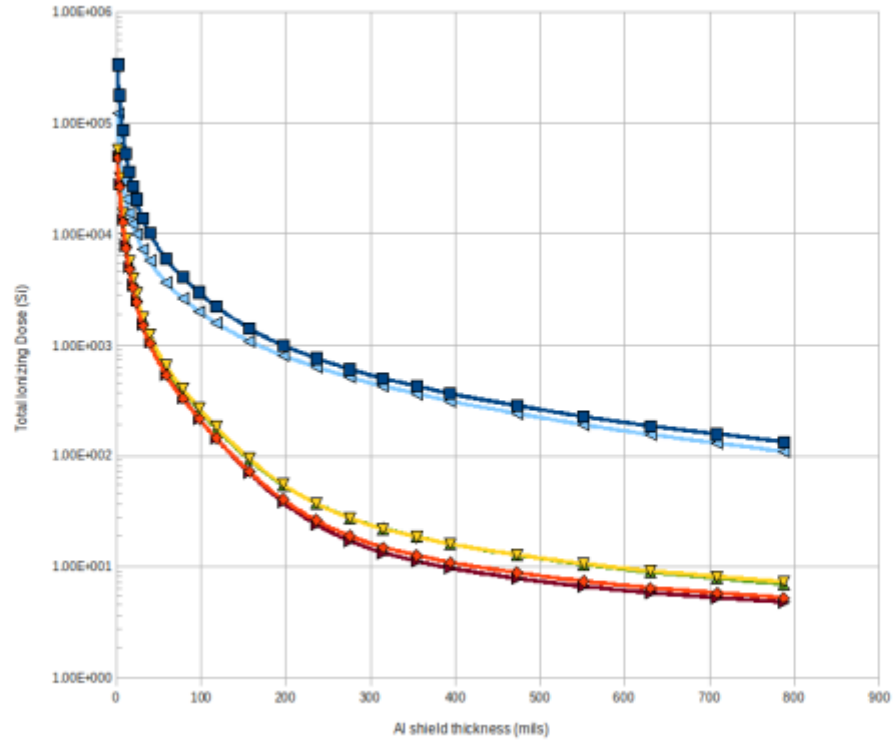
→ICPS appears to coast out into interplanetary space following its lunar flyby

→ 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



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.