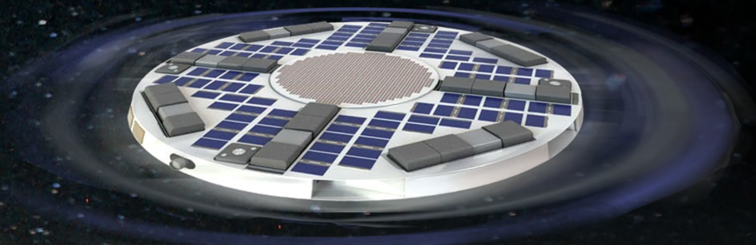
AMES RESEARCH CENTER

with The Aerospace Corp.

SpinSat:



A Novel Variable-Gravity-and-Radiation-Exposure Platform for Deep-Space Science: Payload Development and Science Opportunities

Tony Ricco, Jessica Lee, Jay Bookbinder – NASA ARC

Mark Looper – The Aerospace Corp.

SpinSat Ideation and Implementation Teams

Driving Science & Tech Gaps, Challenges

Fundamental Science

Biological and physical scientists need access to combined deep-space radiation + planetary gravitation…

- …to study basic processes and measure effects and impacts on biological and physical systems.

Human Health & Performance

Human health and accompanying biome **effects are poorly understood** for long-duration exposure to deep-space radiation & reduced gravity

- beyond-LEO experiments needed to understand/manage/mitigate effects on health and performance, including impacts on/from relevant biomes.

Technology Development for Deep Space Missions

Environmental control & life support, food production, other systems must perform in novel, challenging environments

- technology development and validation benefit from frequent access to relevant environments with controls

NASA needs access to deep-space radiation environments, those regions above the Van Allen Belts:
https://www.nasa.gov/directorates/esdmd/hhp/space-radiation/

SpinSat Deep-Space Platform Concept

SPINSAT

Develop innovative, low-risk platform to address critical science gaps and technology maturation needs for deep-space exploration:

Emulate planetary radiation-plus-gravitation environments for experiments

Key Objectives & Approach

- Beyond-LEO deployment: **lunar, transit-to-Mars, and Mars-surface** radiation-plus-gravity environments
- Multi-payload platform: **science** experiments, **model validation, tech development, risk reduction**
- Technical approach (led by NASA/Ames, in cooperation with the Aerospace Corp.)
    - Platform: Inspired by Aerospace's (non-spinning) DiskSat, a rideshare-friendly cubesat alternative
    - Avionics: high-TRL / off-the-shelf components + avionics heritage from NASA Ames' *BioSentinel* spacecraft (deep space, now 63 Mkm from Earth, ~2.5 years operation to date)
    - Artificial gravitation: spinning platform → 0.17x**g** and 0.38x**g**, along with 1x**g** controls
    - Relevant radiation: tailored shielding → lunar or Mars-like environments, also deep space
    - Up to 64U of payloads

NASA needs access to deep space radiation environments, those regions above the Van Allen Belts.
https://www.nasa.gov/directorates/esdmd/hhp/space-radiation/

The Why of SpinSat

Current capabilities for combined radiation and gravity research are limited

- Terrestrial and ISS-based centrifuges do not operate in deep-space radiation environments
- ISS provides “noisy” microgravity and partial gravity, but durations and gravity levels may not meet many deep-space mission planning needs
- Terrestrial particle accelerators are 1x**g** and impractical for long-duration/chronic radiation exposure testing
    - *biological responses (and even some electronic component effects) are often dose-rate dependent, not just total dose*

National Academies Echoes the Need…

US National Academies:

"...The research opportunities that are envisioned to exist within ***cis-lunar space are expected to be severely limited in volume and frequency. This sets an interesting conundrum where some critical research cannot be met with the current deep space platforms***, yet they would richly inform human exploration beyond LEO during the Artemis missions."

… and SpinSat responds:

A range of combined partial gravity and deep-space radiation exposure experimentation in a low-cost platform with 1xg experimental controls can:

- **Increase relevant flight opportunities** at lower cost for key experiments relative to platforms/destinations such as Gateway, lunar surface, Mars surface, etc.
- Support both **new and existing experimental designs** and payload hardware
- Provide a complement and partial **successor to ISS**'s LEO capabilities

SpinSat's Responsive Design Objectives

O-1 **Simultaneous long-duration exposure** (weeks → > 1 yr) to combined deep-space/lunar/planetary **radiation** and **gravitation** (0 → 1xg)

- Spinning spacecraft provides artificial gravitation
- Custom shielding simulates lunar, Mars radiation environments

O-2 **Low cost per experiment**

- Many experiments can be hosted on each platform flight
- Multiple experiment al replicates → enhanced statistical significance

O-3 **Frequent space access**:

- Launch vehicle and orbit agnostic (beyond van Allen belts)

O-4 **Easy payload interfaces**: highly familiar "**Cubesat" type**

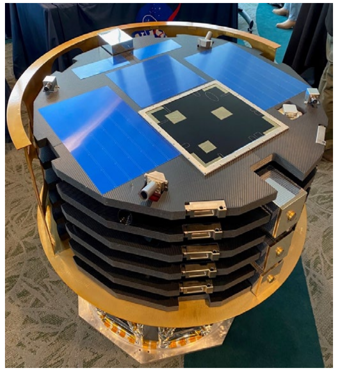
- Other configurations supportable, not a priori precluded
- Power, data, comms, gravity, radiation, benign thermal environment
- PIs can focus on the experiment, not the spacecraft

O-5 **Easy payload integration** and responsive access

- Stretch: "just-in time" loads for biology shortly prior to launch

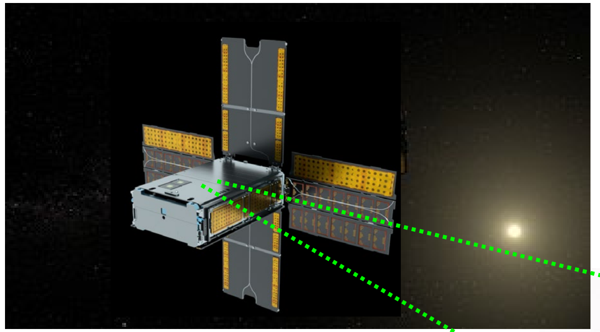
SpinSat Leverages NASA Investments

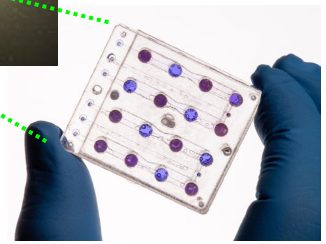
Platform architecture



DiskSat: A new spacecraft form factor *(NASA SSTP/ Aerospace Corp.)*

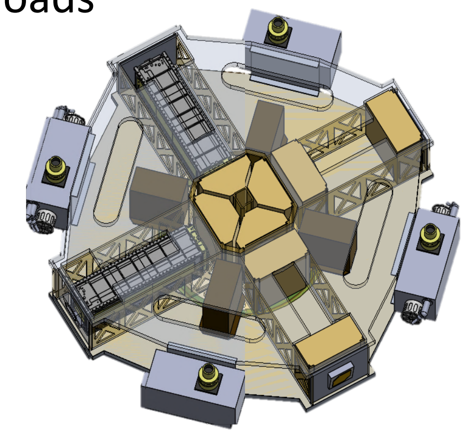
Avionics, bio payload components & design





BioSentinel: Proven design for deep-space biology missions: avionics, microfluidics, other science elements *(NASA/Ames)*

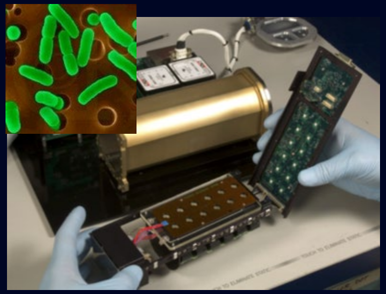
Platform enables more science per $



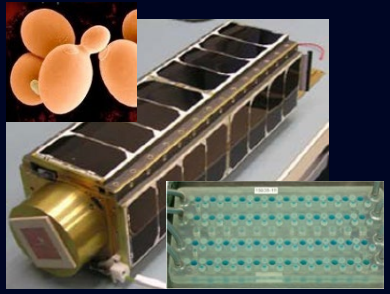
1 SpinSat = 16+ BioSentinel payloads
in a variety of orientations

SpinSat platform provides experiments with all necessary infrastructure: power, thermal environment, data storage, communications, acceleration and radiation monitoring, etc.

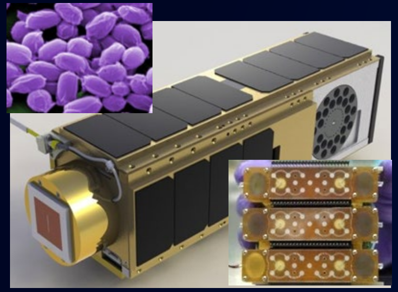
NASA/ARC Heritage and Precedents:
Smallsats & Biological Cubesats



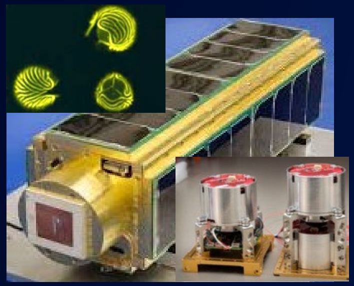
2006
- *E. coli* (bacterium)
- Microgravity effects on gene expression
- 12-well fluidic card
- LED-excited fluorescence for GFP expression, + LED light scattering for cell population
- 1st fully automated self-contained biological experiment on a cubesat



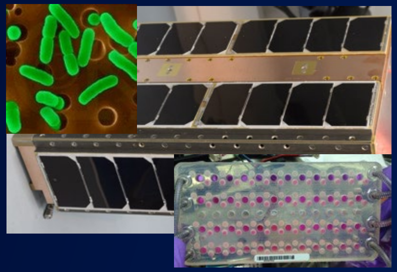
2009
- *S. cerevisiae* (yeast)
- Microgravity effects on antifungal response
- 48-well fluidic card
- In-situ preparation of multiple drug dose levels from concentrate
- 3-color LED optical detection system
- alamarBlue indicator dye



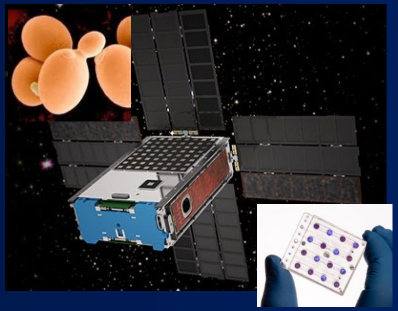
2010
- *B. subtilis* (bacterium)
- 1st demo of 2 distinct experiment payloads on one autonomous satellite
- Microgravity & LEO + radiation effects
- 3-LED optical detection; solar UV-vis spectrometer
- 1st time dried organisms rehydrated in orbit: enables multi-timepoint activation



2014
- *C. richardii* (aquatic fern spores)
- Variable gravity effects on spore germination *via* calcium ion transport
- 1st time artificial gravity capabilities in cubesat, 0 – 2x g
- 1st micro-centrifuges as well as Lab-on-Chip electrochemical sensors in a cubesat
- Deployed by re-supply mission *en route* to ISS

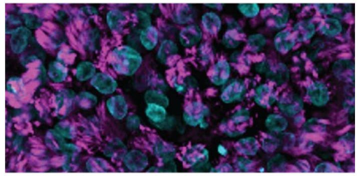
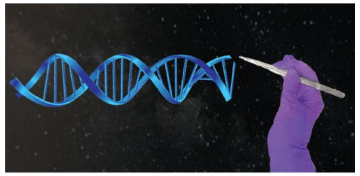
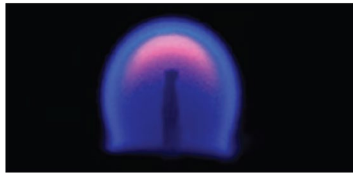
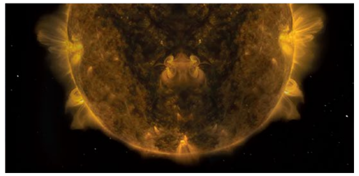


2017
- *E. coli* (uropathogenic bacterium)
- Microgravity effects on antibiotic response
- 48-well fluidic card
- 3-LED optical detection; variable-dose drug delivery
- 6U format for 50% more solar power
- 1st bio cubesat deployed from ISS



2022
- *S. cerevisiae* (yeast)
- Microgravity & deep-space radiation effects on DNA damage/repair
- 1st use of monolithic multilevel fused manifolds
- 18 x 16-well cards: 288 samples
- 1st deep-space bio cubesat: 2° payload on *Artemis-1*
- Onboard radiation spectrometer (LET)

Science Opportunities

		Samples		Measurands
Human Cells		Organoids Tissue cultures Stem cells Organ(s)-on-a-chip	Cancer cells Neurons/glia Intestinal cells Bone cells	Morphology Metabolism Gene/protein expression Evolutionary changes
Model Organisms		Bacteria, Fungi Spores Algae/cyanobacteria	*C. elegans* Tardigrades Small plants	Reproduction Germination, tropism, photosynthetic efficiency
Synthetic Biology		Pharmaceuticals Nutrients, vitamins Engineered materials		Yield, purity Process reliability Mat'ls. properties
Physical Science		Planetesimal accretion Regolith transfer Flame propagation		Size, kinetics, morphologies Process efficacy, reliability Kinetics, stability
Heliophysics		The Sun		Heliophysical phenomena

Assessments

- Microscopy
- Optical / electro-chemical assays
- Bioassays: proteins, genes, DNA damage, etc.
- Sequencing, sizing: molecules, particles
- Cytometry
- Biomass
- Behavior
- Mechanical / electrical / optical parameters

- Electric fields observed from a spinning platform

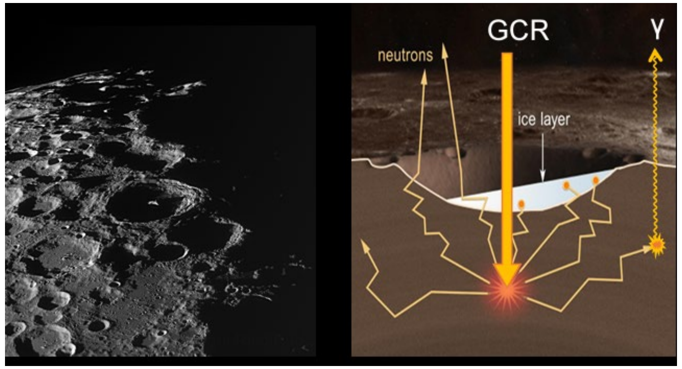
Biological Science Opportunities

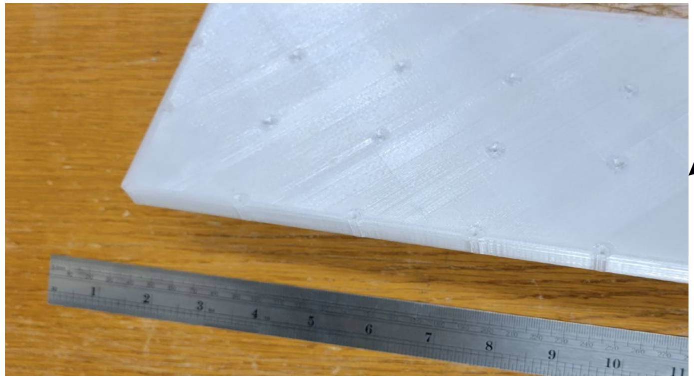
SpinSat Radiation Environments

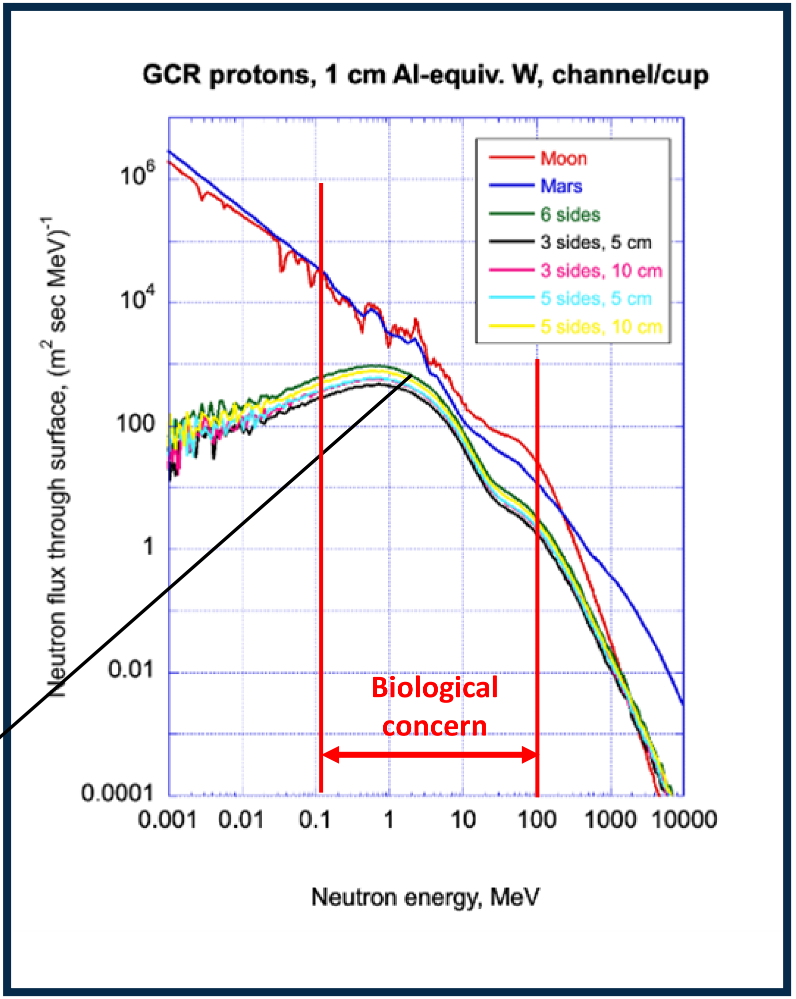
✓ Simultaneous Mars/lunar gravity to 1xg+ accelerations simultaneously with deep-space, lunar, and/or Mars radiation environments

Aerospace conducted a detailed study on simulating Moon and Mars surface radiation environments:

- Tungsten cube (6 mm) array in PETG matrix
- Provides close approximation to Moon & Mars surface radiation in range of interest
- ***Tailorable radiation flux via cube arrangement***
- Simple external mounting to payload housing
- ***LEO re-entry/breakup safe***

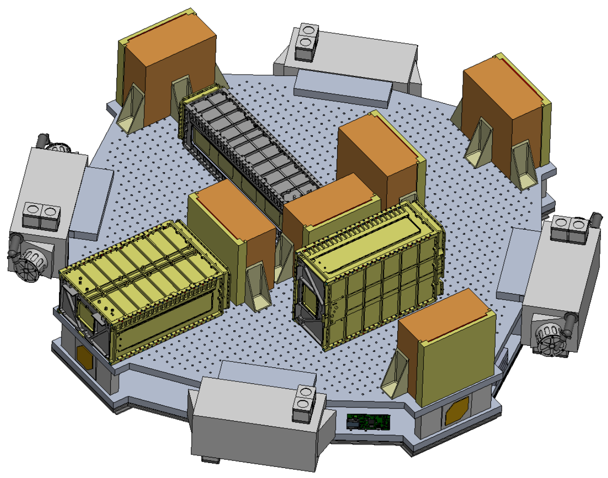




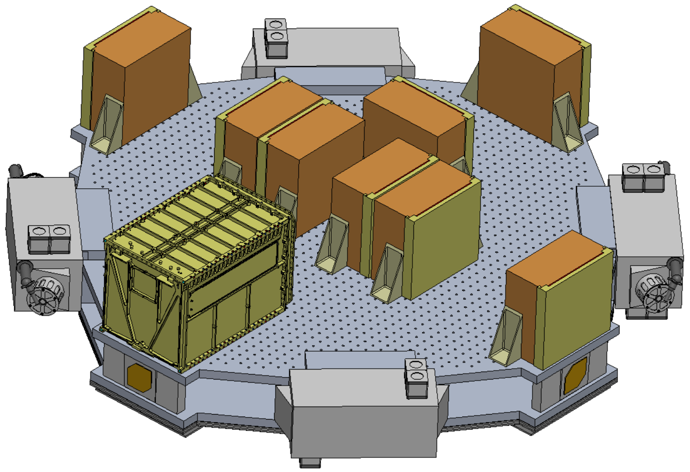


*PETG: Polyethylene terephthalate glycol – thermosetting polymer used for 3-D printing

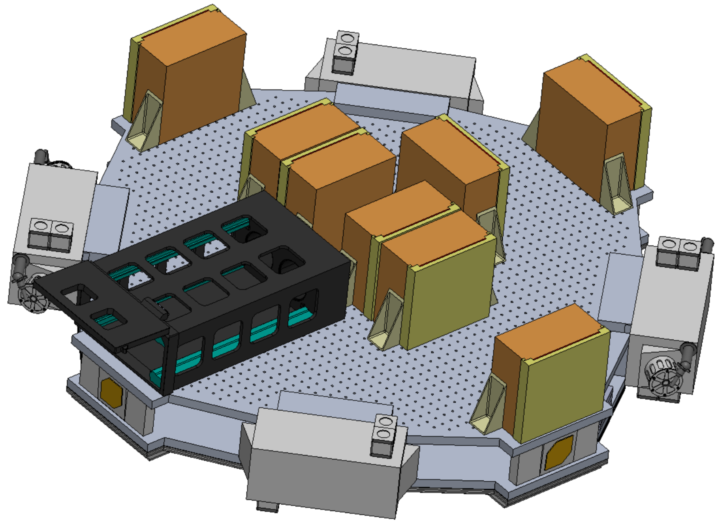
Flexible Payload Accommodations



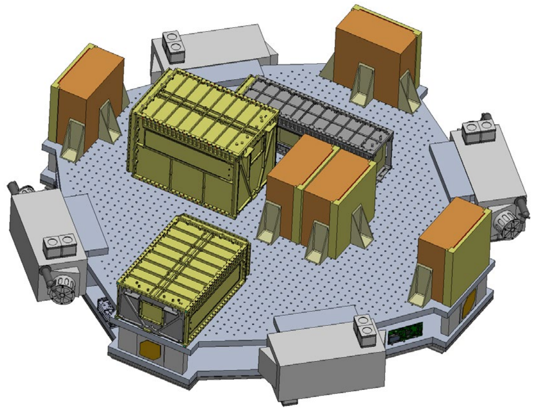
Rocket Lab 6U



Rocket Lab 12U



EXOpod 8U (deployed)



- Primary spacecraft structure composed of a dual deck sandwich design
  - Top deck hosts payloads
  - Bus avionics housed internally between decks
  - Minimizes design changes needed for payloads across missions
- Thermal management achieved by isolated sun-facing solar array structure
- Propulsion uses Hall-effect thrusters for spin-up and electrospray thrusters for attitude control
- Attitude-determination-and-control system based on flight-proven *BioSentinel* high-TRL components

SpinSat Path to Flight

Concept

DEFINE
- Initial science concepts
- Preliminary spacecraft req'ts.

REFINE
- Payload science workshop
- Spacecraft design study

DEVELOP
- Build demo. payloads
- Build proto-flight

DEMONSTRATE
- Deliver and integrate demo. payloads
- Launch/operate protoflight *SpinSat*

Payload dev. program

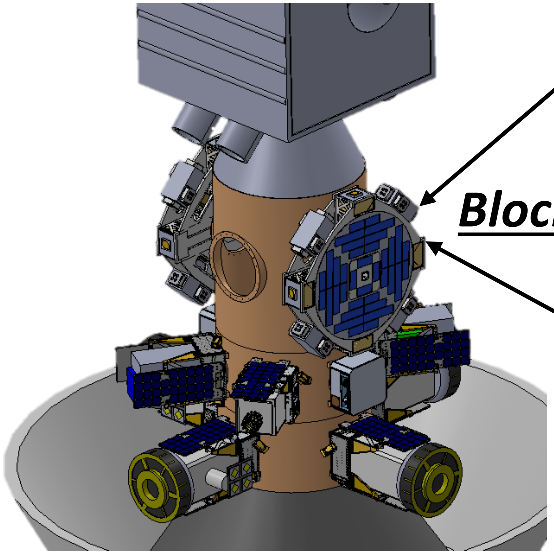
COMMERCIALIZE
- Commercial payload providers
- Qualified COTS spacecraft providers

Frequent Flyer SpinSat Science

2023 | 2024 | Today | 2026 | 2027 | 2028 | 2029 | 2030 | 2031

SpinSat Technical Approach

Technical Approach: Phased to enable rapid validation of overall strategy & execution of initial experiments, followed by refinement and larger platforms, while remaining cost effective:



Block 1

Operational Demo (LEO/sun-sync. orbit):

- **Simultaneous Lunar, Mars, & Earth Gravity**
- **Compatible with ESPA Grande Ring (610 mm ports)**
- **1.3 m Diameter; > 300W**
- **ESPA Port Mount: ~launch vehicle agnostic**
- **Common Simple Data Interface**
- **~12 month lifetime**

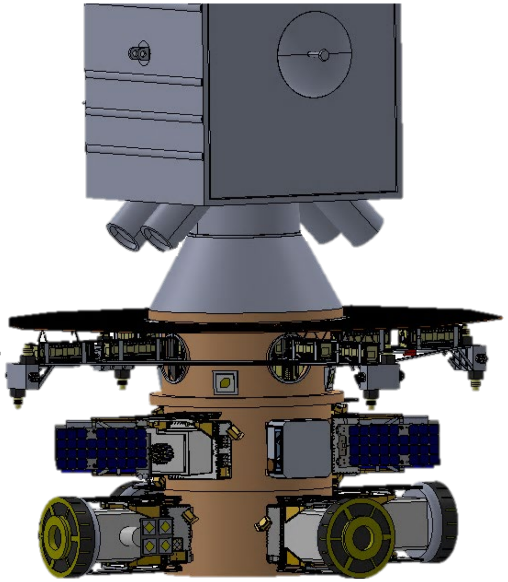
Block 1: Production Design (Deep Space)

- **Up 64 ‘U’ of payloads in various configurations**
- **Deep-space orbit or high-inclination sun-synchronous**
- **~1 – 3 year lifetime**

Block 2: Production Design (Deep Space)

- **3+m diameter, 2 kW, >300 ‘U’ payload volume**
- **Deep space orbit (agnostic)**

Block 2



As an ESPA-port secondary, SpinSat accommodates up to 64 ‘U’ of experimental payloads (16x BioSentinel)

As an ESPA-stack secondary > 300 ‘U’ (75x BioSentinel), allowing for a robust program of biological experiments

SpinSat as a Platform for Early Career Researchers

- ✓ SpinSat can provide researchers a user-friendly platform for frequent and inexpensive Class D opportunities to continue technical innovation and to train the next generation of principal investigators & leaders.

- ✓ Spinsat payloads are ideal for both NASA and international projects at a range of levels

Students from the 2023 Climate Change Research Initiative

SpinSat's Powerful Ideation Team

Jay Bookbinder	**PI / Capture Manager**	**Ames Research Ctr. (ARC)**
Pascale Ehrenfreund	**Science Lead (COSPAR President, former DLR Science Director)**	**GWU**
Scott Richey	**Project Manager, programmatics**	**ARC**
Tony Ricco	**Payload instrument manager, biology, microfluidics**	**ARC**
Rob Ferl	Science, programmatics (BPS Decadal Co-Chair)	Univ. of Florida
Anna-Lisa Paul	Science, plant molecular biology (NAS CBPSS)	Univ. of Florida
Christine Mehner	Human biology & Cancer	Premier research
Thomas Paige	Senior systems engineer	Aerospace Corp.
Richard Welle	Senior S/C systems engineer	Aerospace Corp.
Alberto Arredondo	S/C systems engineer	Aerospace Corp.
Mark Looper	Radiation scientist	Aerospace Corp.
Jessica Lee	Science, microbiology	ARC
Bruce Yost	Project management, programmatics	ARC
Randii Wessen	Capture Management	ARC
Code R MDC	**Engineering (Mission Design Center)**	**ARC**

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