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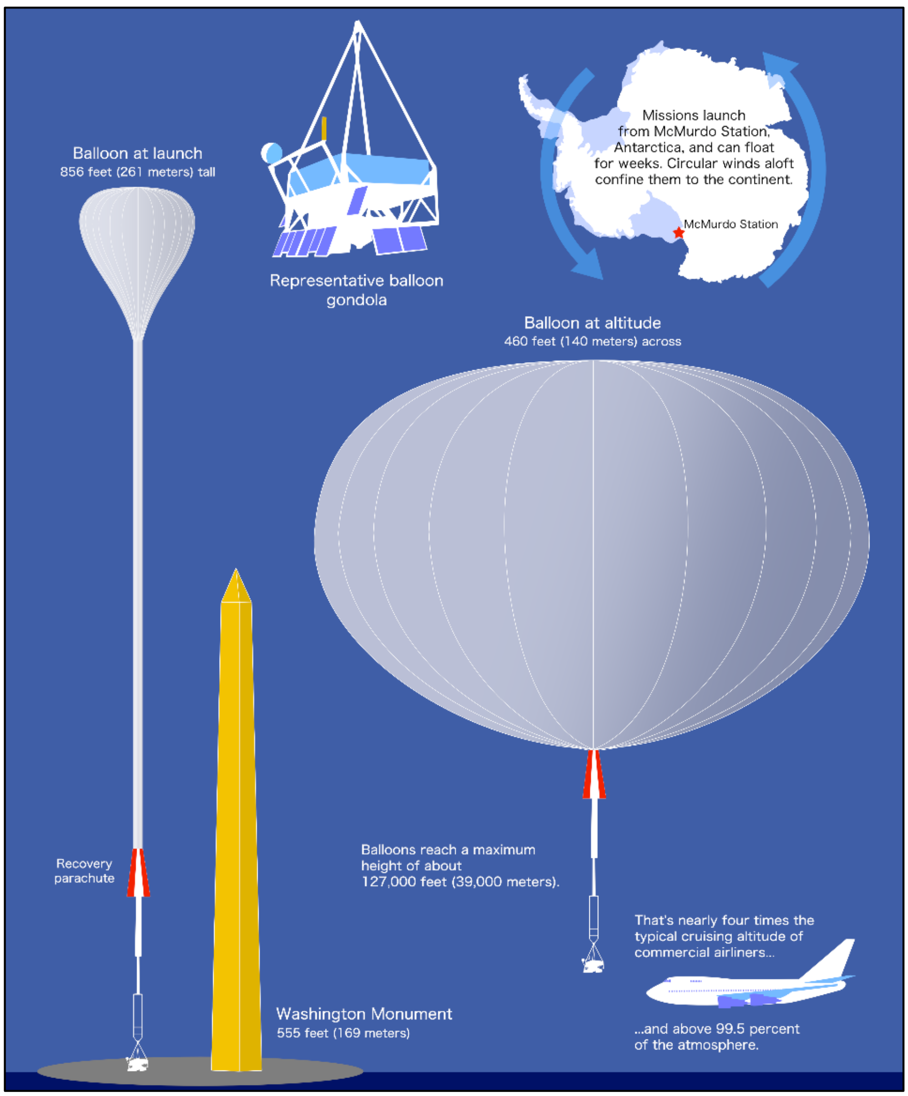
A Dedicated, Long Duration Balloon Mission from Antarctica to Measure the Effects of Low Dose Galactic Cosmic Radiation on Biology

Principal Author: David J. Smith, 650-279-0227, NASA Ames Research Center, david.j.smith-3@nasa.gov

Co-Authors: Thomas Berger (DLR), Amy Canfield (NASA WFF), Egle Cekanaviciute (NASA Ames), Jack Miller (LBNL), Seth Schisler (NASA Ames), Marianne B. Sowa (NASA Ames), Ye Zhang (NASA KSC), Brad Gersey (Space Environment Technologies), Eric Benton (Oklahoma State University)



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I. Summary

Antarctic long duration balloon missions flown by NASA's Science Mission Directorate (SMD) can be used as a surrogate for the deep space radiation environment, reducing the need to launch orbital experiments to assess the impact of galactic cosmic radiation (GCR) on biology. To date, over fifty NASA balloon missions flown from Antarctica have carried scientific payloads from Astrophysics (APD) and Heliophysics (HPD) in SMD. Only two life science experiments have been flown from Antarctica, and both were ride-along (piggyback) opportunities, limiting the sophistication and types of model organisms that can be incorporated into studies. Herein, we argue for ***establishing a large, dedicated Antarctic balloon mission for the Biological and Physical Sciences (BPS) Division in SMD to be launched in 2029/2030*, *with an "omnibus" gondola carrying dozens of independent Space Biology payloads that would receive a sustained exposure to low dose rate GCRs for 30+ days***. Our unprecedented, protracted radiation experiment cannot be done using ground-based simulation facilities or in space; it can only be achieved through an Antarctic balloon mission dedicated to BPS Division payloads. By providing more access to radiation research platforms through existing NASA SMD access to Antarctic balloon flight opportunities, the Space Biology community will be better positioned to address unknowns associated with low dose rate GCR exposures in long duration spaceflight.

II. Current Limitations on GCR Research

Traditionally, researchers seeking space radiation exposures for conducting life science investigations must launch experiments into space or attempt to simulate the conditions using ground-based facilities. Flight opportunities are infrequent, expensive, and constrained by volume, mass & power. Similarly, ground-based facilities like the NASA Space Radiation Laboratory (NSRL) at Brookhaven have high costs (~$6k/hr), small beam size (20 x 20 cm^2) for exposures, and a limited dose rate and radiation quality spectrum, constraining investigations [1].

III. The Scientific Case: Antarctic Balloon Flights Provide Deep Space GCR

Most cosmic radiation particles are deflected around the Earth by its magnetic field. But solar and deep space particles can penetrate through the magnetic north and south poles at latitudes above 70°. Thus, energetic particle radiation from space continuously bombards the Earth's upper atmosphere, particularly where polar balloon missions float. Antarctic-launched missions can remain aloft in this "near space" radiation-elevated environment for weeks or months, with circular stratospheric winds confining the balloon to the continent, while it carries up to 6,000 lbs of scientific payload, all of which can be continuously powered through solar arrays charged by a Sun that never sets below the horizon in the Antarctic summertime [1].

> Key Message:
>
> **Ionizing radiation exposures expected at human spaceflight destinations can be realized through suborbital, long duration Antarctic balloon missions, representing a major paradigm shift in how (and where) Space Biology experiments fly.**

With Si-based dosimeters, our team recently measured ionizing radiation dose rates in the Antarctic stratosphere on a 32-day NASA balloon mission (**Figure 1**) [2], showing the high altitude, high latitude environment as comparable to deep space not only in dose but in particle composition (**Figure 2**). Separately, our team also demonstrated a new balloon payload that can maintain active biological specimens in a pressurized hardware system [3], opening the door for "other than microbial" experiments in the near space environment. Taken together, these milestones make a clear and compelling case for additional Antarctic balloon flight opportunities in the BPS Division.

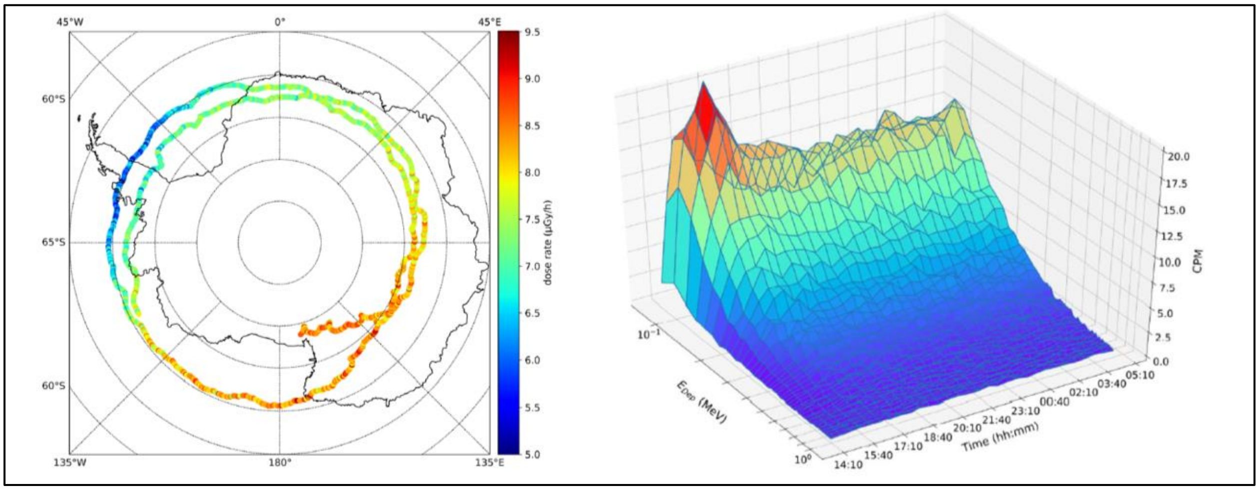

Figure 1. (*left*) The measured dose rate profile (μGy/h) for the E-MIST biological piggyback payload flown on a 32-day Antarctic mission in 2018-2019 [2]; (*right*) Energy deposition spectra for first 15 hours of E-MIST Antarctic flight for energy depositions *EDep* ≤ 1MeV in Si [2].

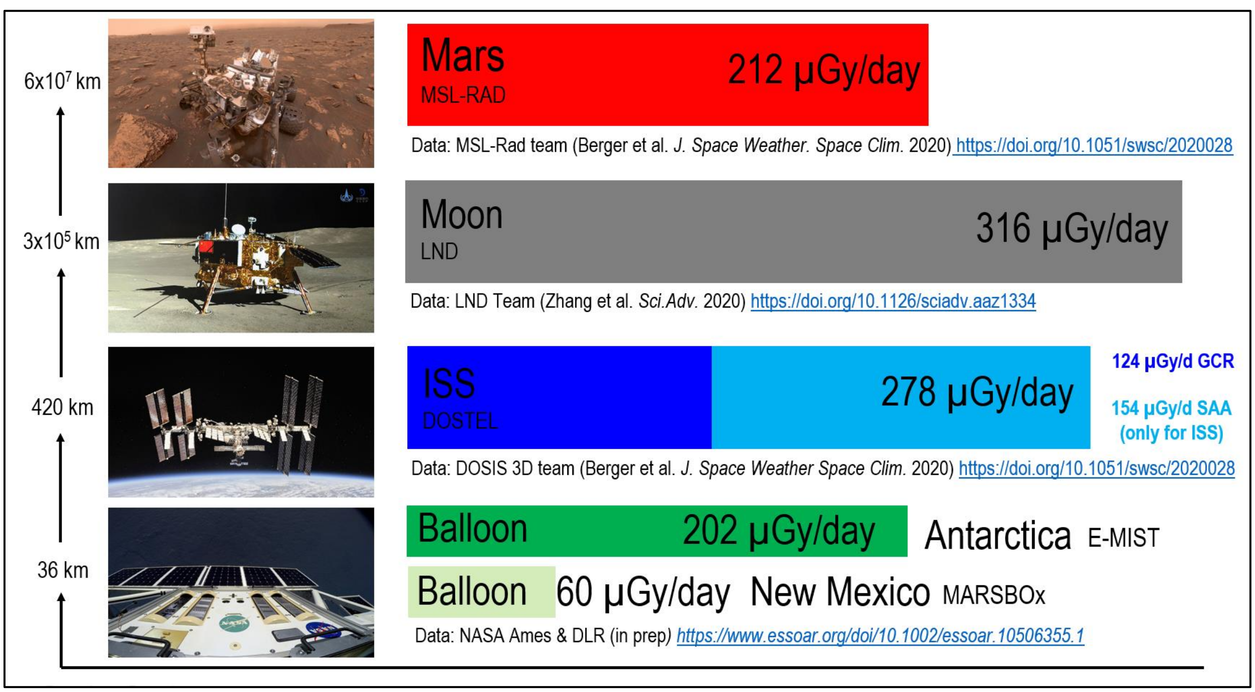

Figure 2. Antarctic balloon missions can provide deep space radiation conditions comparable to human spaceflight destinations, based on doses (*dark green bar*) reported by Berger et al. [2].

IV. Why is a Dedicated Antarctic Mission Needed?

The National Science Foundation (NSF) Office of Polar Programs manages the U.S. Antarctic Program and works alongside NASA's Balloon Program which provides logistic support for all scientific operations, including launch and recovery operations at Williams Field, near McMurdo Station. On average, NASA (with NSF oversight) will support 2 large (dedicated), long-duration launches per year on the ice. Thus, dedicated flight opportunities are competitive and highly coveted. The decision authority for which 1-2 NASA payloads(s) will received a dedicated flight opportunity is held by NASA SMD. Historically, only payloads from APD and HPD have been awarded dedicated Antarctic flights. But it is important to acknowledge NASA's Balloon Program is responsible for supporting all SMD-funded science. **Thus, with the BPS Division now in SMD (as of 2020), the Space Biology community has an unprecedented opportunity for a dedicated Antarctic balloon mission, if prioritized by SMD**.

Figure 3. The E-MIST payload ascending to the Antarctic stratosphere, flown as a piggyback payload on long duration NASA balloons from 2017-2019 (*ice shelf in view below*)**.**

As piggybacks, Space Biology has flown two biological payloads from Antarctica [2, 4], including investigations led by our team (**Figure 3**). ***So why is a larger, dedicated Antarctic mission needed?***

(1) Piggybacks must be simple and non-interfering with the primary (dedicated) payload.
(2) Piggyback payload teams cannot send scientists to Antarctica (because McMurdo Station resources are severely limited, including bed space, for scientific personnel).

Both aforementioned factors are "non-negotiable" for piggyback payloads, constraining the types of biological experiments that can fly. Consequently, a biological experiment from Antarctica (as a piggyback payload) requires specimens to be handed over ~6 months prior to launch for shipping. The timetable for returning the payload from Antarctica can also last ~6 months or more. Most Space Biology model organisms are not stable with prolonged stasis. **Thus, a dedicated Antarctic flight opportunity would allow for more diverse and sophisticated biological experiments, with on-ice research teams supporting late load and post-flight processing activities at McMurdo Station**. Instead of only flying plant seeds or microbes, Space Biology teams could instead plan experiments with *larger* and potentially *active* model organisms, for a variety of conceivable low dose, long duration GCR exposure investigations.

V. Plausible Path Forward

The fundamental pieces are already in place for supporting a dedicated Antarctic balloon mission for the BPS Division. Herein, we outline a plausible 7-year path (**Table 1**). **All costs for implementing Antarctic balloon missions are accounted for already by SMD**. The Space Biology budget in BPS would only need to account for (1) supporting research team science through competitively selected grants; and (2) the procurement of an "omnibus" gondola that could easily be designed by support contractors (~$1M) familiar with NASA ballooning.

Table 1 – Key Steps for Achieving a Dedicated Antarctic Balloon Mission for Space Biology

	2023	2024	2025	2026	2027	2028	2029
NRA ("Round 1": ~20 Space Biology teams selected through SMD ROSES solicitation)	■						
Payload prep and experiment maturation (with KSC & ARC support)		■	■				
Omnibus gondola build and payload integration			■	■			
Domestic balloon flight(s) in New Mexico, maturing all experiments and payloads				■			
NRA ("Round 2": ~10 Space Biology teams from Round1 down-selected to continue for Antarctica)					■		
Gondola (re)build and payload (re)integration					■	■	
Antarctic permitting and on-site logistics (NSF support)						■	
1st ever dedicated Antarctic balloon mission for Space Biology community (30+ day flight)							■

VI. Visualizing a Dedicated Mission for Space Biology

What is meant by an "omnibus" gondola? We envision a collection of 8-12, independent life science payloads (**Figure 4A**) on a gondola sharing common interfaces, for simple integration and telemetry. The "omnibus" approach already has proven success in the NASA Balloon Program, accelerating the path to flight. For instance, each autumn HASP [5] carries payloads from Ft. Sumner, New Mexico, with student research teams designing towards predesignated gondola positions (**Figure 4B**). An upfront, narrowly defined gondola system allows research teams to focus on the science (not the rest of the balloon system), while ensuring seamless integration and compatibility for a multi-payload "omnibus". We recommend the same approach for a dedicated Space Biology balloon mission from Antarctica, with all investigators working towards a universal interface built with support from contractors familiar with the NASA Balloon Program operations. The to-be-designed, dedicated gondola could feature shared environmental monitoring instruments (e.g. dosimeters), controls for biological experiments accommodating a wide range of model organisms (pressure, humidity, temperature, gas composition) & experimental designs, with an overall architecture (materials and configuration) that simplifies complementary radiation modeling (energy spectrum and flux for all major radiation types) based on the duration and atmospheric profile of the mission.

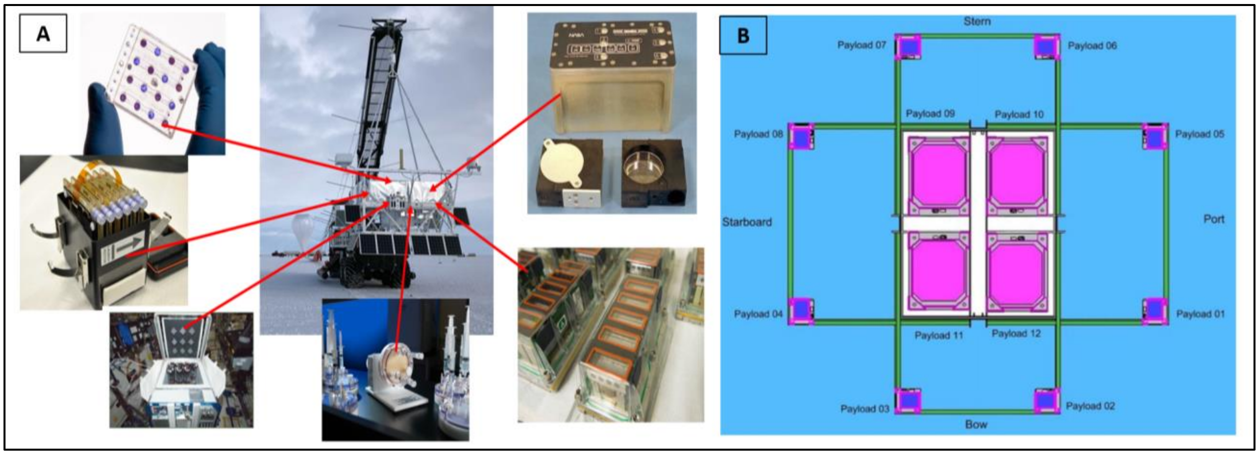

Figure 4. (A) A notional depiction of what an "omnibus" dedicated balloon mission for Space Biology, launched from Antarctica, with some representative hardware systems already used for ISS investigations; (B) Example from HASP [5] of a multi-payload balloon gondola (*top down* view of payload positions), with 4 large (*center*) and 8 small (*perimeter*) payloads.

As summarized in **Table 1**, for the proposed Antarctic balloon mission, solicited payloads could have balloon flight heritage [2-4, 6], ISS flight heritage, or be new systems developed by Space Biology-funded investigators over 3 years of development (2023-2026). Next, all candidate payloads would have proof-of-concept domestic flight opportunities on NASA Balloon Program missions launched from Ft. Sumner, New Mexico. Based on performance and experimental readiness from these precursor (USA-based) missions flown in 2026, Space Biology would then finalize the payloads awarded a position on the dedicated Antarctic balloon flight, with additional testing (2027), integration (2028), shipping & environmental permitting (2028), and, finally, field activities associated with launch & recovery in Antarctica (2029) on a mission to fly for 30+ days in the polar stratosphere.

VII. Conclusion

Carrying 6,000 lbs of biological experiments into space to study GCR effects is not yet realistic. Nor is evaluating how biology responds to simulated low dose GCR in a ground-based facility like NSRL for 30+ days of uninterrupted beam time. Those are the constraints on space bioscientists studying GCR radiation today, significantly diminishing the pace of progress.

In contrast, Antarctic balloon missions flown by NASA provide a unique opportunity for access to ~200 μGy/day, at doses & qualities comparable to deep space [2]. Biological balloon hardware systems have already been proven, albeit on a small and limited scale as piggyback payloads. To enable a more sophisticated set of biology experiments flown from Antarctica, a dedicated "omnibus" mission is needed, one that could conceivably carry 10-12 independent Space Biology payloads sharing a common gondola. With SMD prioritization and a stepwise, targeted series of ROSES NRAs by the BPS Division, this vision can be realistically achieved, yielding space radiation results that will help guide NASA's journey beyond low Earth orbit.

VIII. References

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