A Roadmap for Scientific Ballooning

2020-2030

Carolyn Kierans, Goddard Space Flight Center

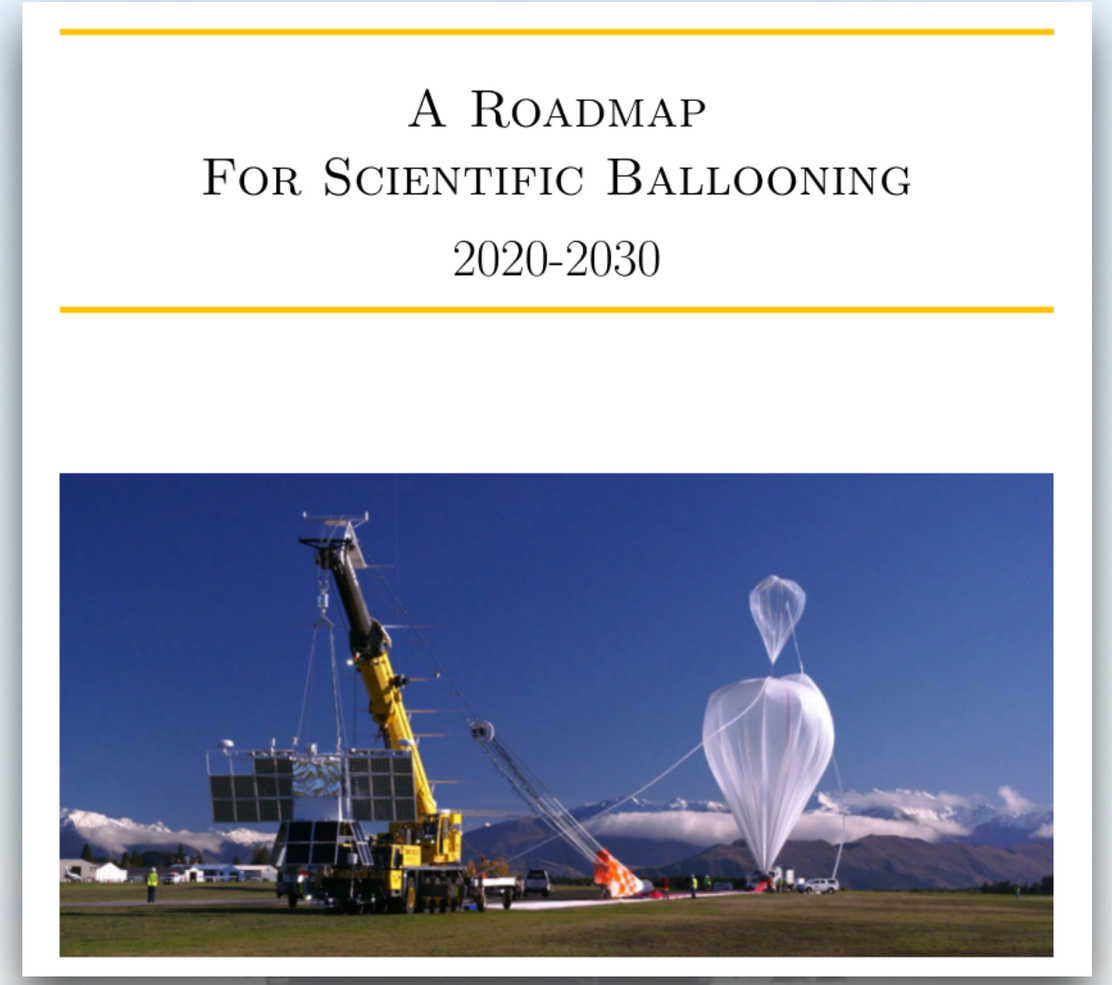
speaking on behalf of

the NASA Balloon Roadmap Program Analysis Group

Outline

- The Roadmap EC and Terms of Reference
- The Roadmap process and community input
- Synthesis of science drivers and Roadmap Findings and Recommendations
- Response to APAC Recommendations from Fall 2020 Meeting
  - Inclusion of Biological & Physical Sciences
  - General guest-observer science
  - Piggyback payloads
  - Opportunities for traditionally under-represented communities

https://sites.wff.nasa.gov/code820/roadmap_pag.html



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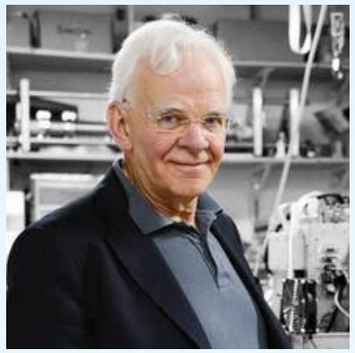
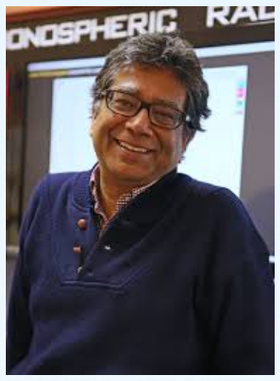





The full Balloon Roadmap PAG consists of all members of the community who participate in the open meetings.

Terms and Reference

- Articulate and prioritize the key scientific drivers and needed capabilities for NASA's Balloon Program - Chapter 5

- Evaluate the expected capabilities of potential balloon-borne missions for achieving the science goals and maturing important and strategic technologies of SMD - Chapter 2

- Evaluate Balloon Program goals, objectives, investigations, and required measurements on the basis of the widest possible community outreach - Chapter 4

- Articulate and prioritize focus areas for needed balloon mission technologies - Chapters 3 and 5

- Summarize and asses balloon launch opportunities and mission capabilities provided by emerging commercial providers - Section 3.6

Roadmap Process for Community Input

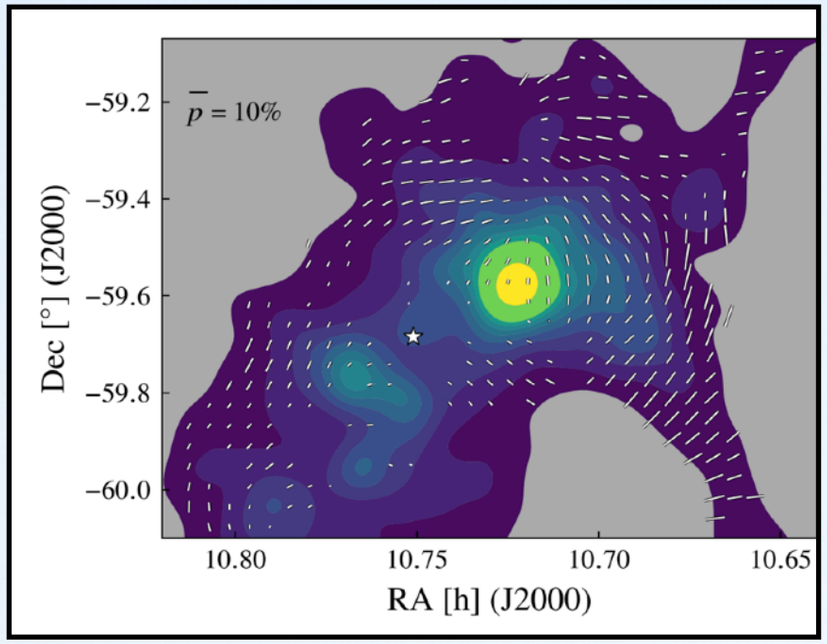
- Initial call for Roadmap White Papers in 2018
- Town halls at large conferences in 2018-2019
  - AAS, COSPAR, AGU, APS, Scientific Ballooning Technologies Workshop
  - invited and solicited talks
- Initial recommendations prepared for Astro2020 Decadal Survey
  - delivered in Fall 2019 White Paper
- Summer 2020, PAG-EC regrouped to finalize Roadmap document
  - more complete than early ASTRO 2020 version

Science Drivers, Challenges, and Key Outcomes

Scientific Ballooning

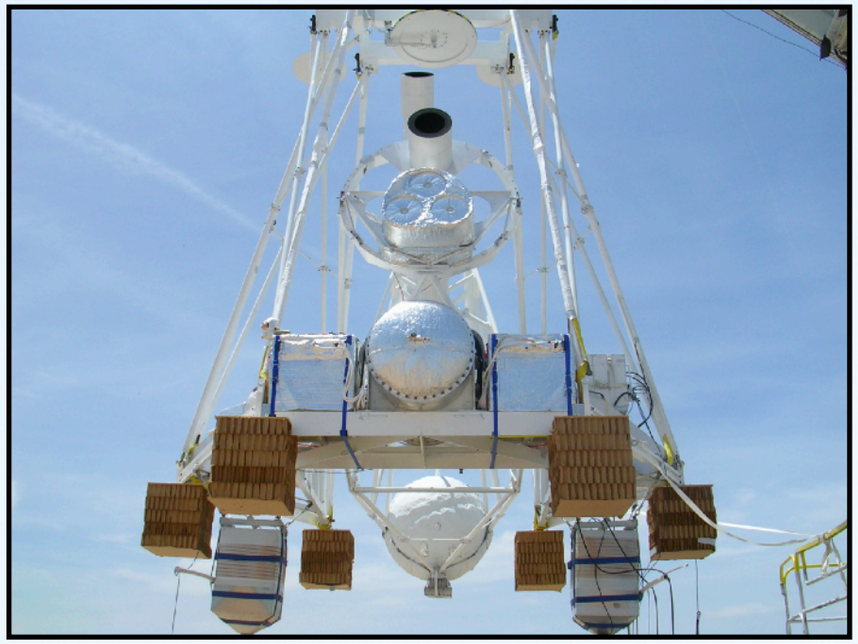
The instruments launched with balloons are as varied as the accessible science, but all benefit from the 3 main advantages of scientific ballooning:

Groundbreaking science



BLASTPol measures sub millimeter polarization of Carina Nebula: Shariff et al., *ApJ* 872 (2019)

Innovative technology development



HEFT leads the way for NuSTAR optics
Harrison et al., *Experimental Astronomy* 20 (2005)

Complete educational experience

HASP students preparing for flight
T. G. Guzik, *IEEE Aerospace Conference* (2015)

Science Drivers

Astrophysics

- Astroparticle and High Energy Astrophysics
- Exoplanet & Stellar Astrophysics
- Observational Cosmology

Earth Science

- Climate Change
- Stratospheric Ozone Losses
- Solar Radiation Management
- Geophysical & Planetary Acoustics
- High Energy Atmospheric Physics

Planetary Science

- Atmospheric Dynamics
- Comets
- Asteroid and Trans-Neptunian Object Satellites

Solar and Space Physics

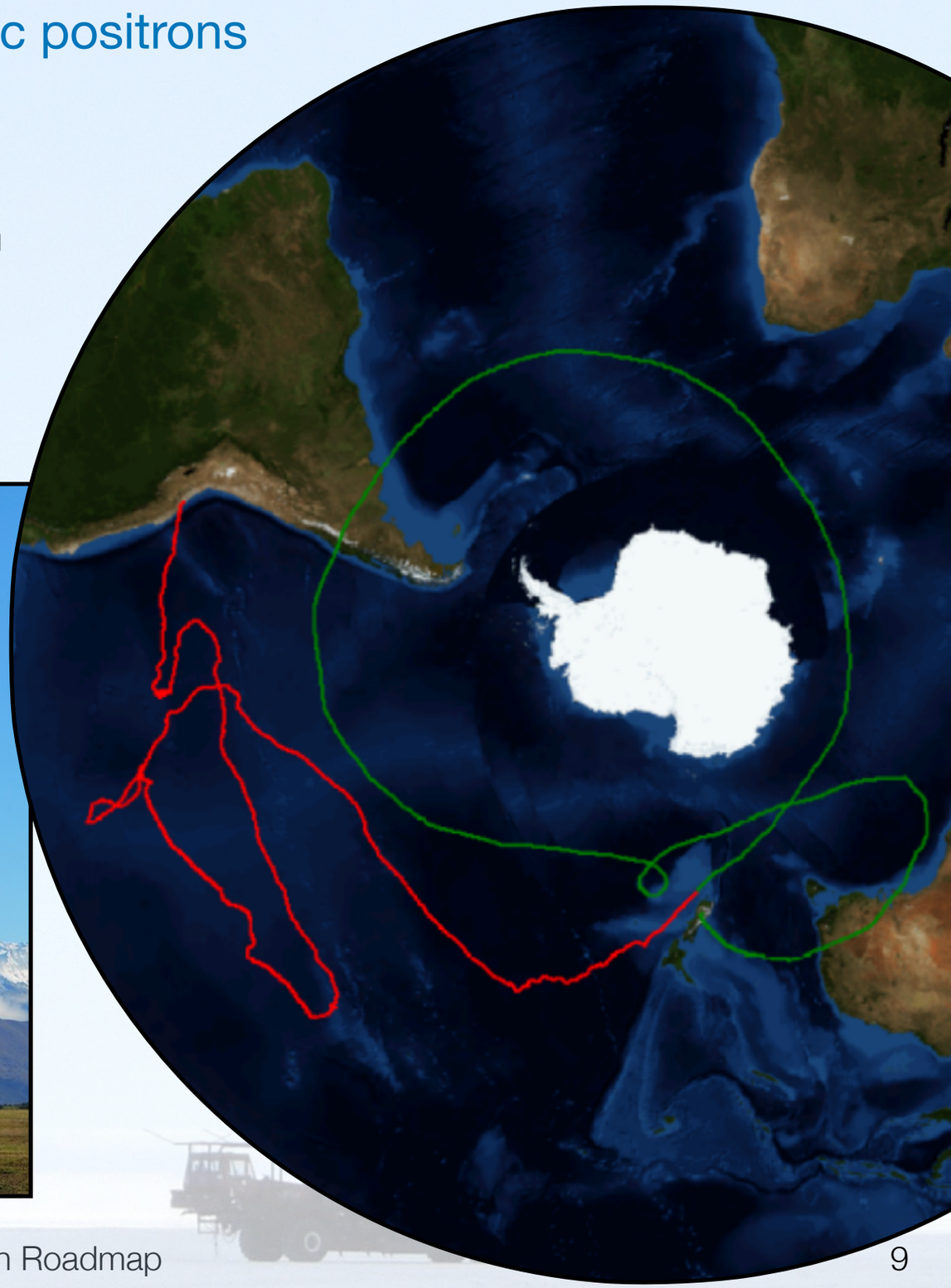
- Solar Physics
- Particle Precipitation into Earth Atmosphere
- Thermosphere and Mesosphere Studies
- Large-scale Magnetospheric Electric Field

Science Drivers - COSI

Science goal: To understand the source of Galactic positrons

COSI: The Compton Spectrometer and Imager

- high resolution measurements of 511 keV
- mid-latitude flight to observe Galactic center region
- SPB ultra-long duration flight
- 2000 kgs lift capabilities
- real-time telemetry downlink of all science data



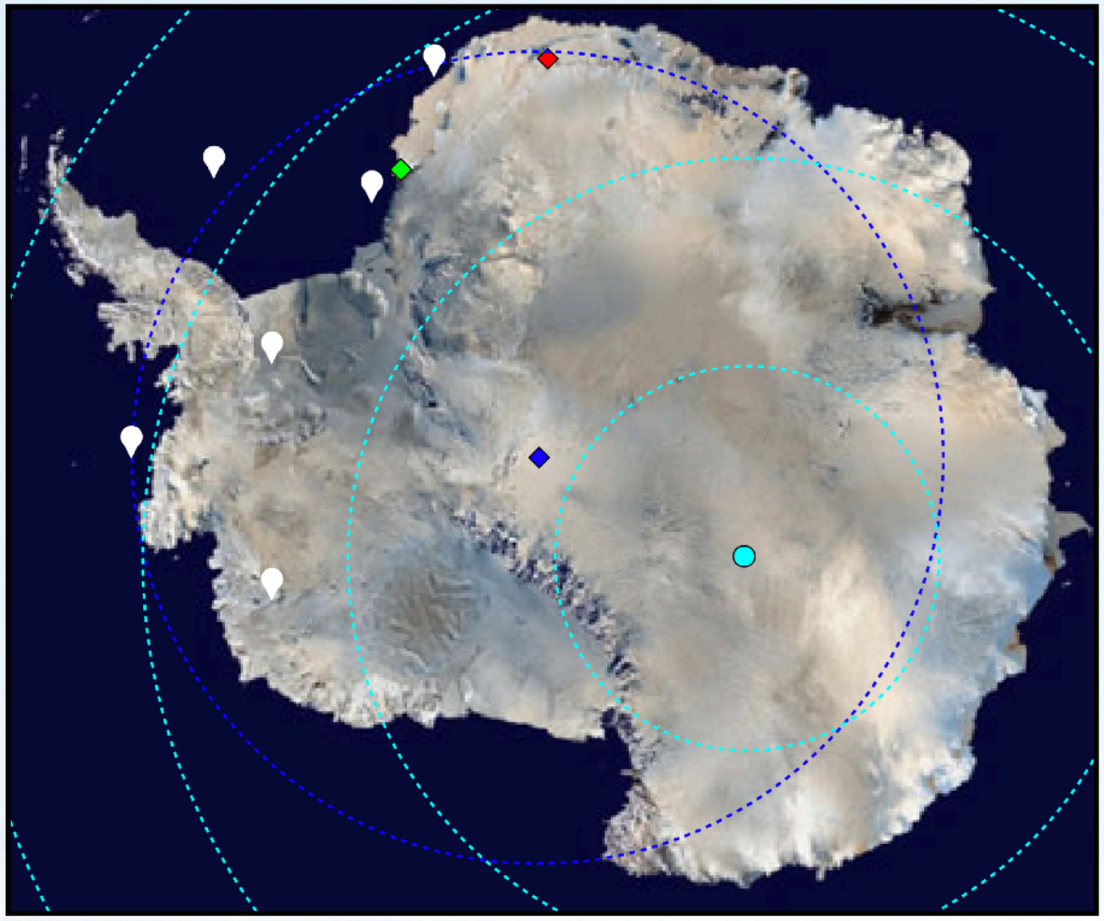
Science Drivers - BARREL

Science goal: To understand electron precipitation in Earth's atmosphere

BARREL: Balloon Array for Radiation belt Relativistic Electron Losses

- in-situ measurements of bremsstrahlung x-rays at different geomagnetic cutoffs
- multiple hand launched balloons ~25 kg payload
- SPB ultra-long duration flights
- work in tandem with NASA's twin Van Allen Probes

A. W. Breneman et al, *Nature* 523 (2015)



Science Drivers

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- Observational Cosmology

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Balloon Capabilities

Launch Sites & Facilities

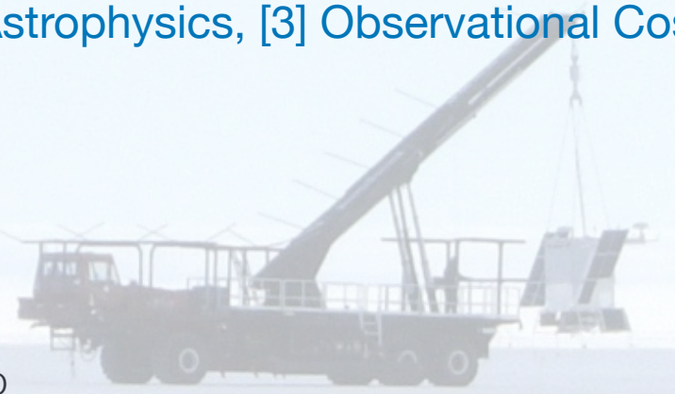
Funding Opportunities

Workforce Development, Education & Outreach

Balloon Capabilities “Science Traceability Matrix”

Science Driver	User Community	Required Capability
Ultra-long observing times	1, 2, 3, 4, 5, 6	**Superpressure Balloons**
Night and day observations	1, 2, 3, 5	
Mid-latitudes flights for Galactic observations	1, 3	
Real-time, high-throughput telemetry	1, 2, 3, 4, 5, 6	**Payload Telemetry**
Reduced atmospheric overburden	1, 2, 3, 5, 6	**Lift Capabilities**
Large collecting area for low fluxes	1, 3, 6	
Sub-arcsecond precision pointing knowledge and stability	1, 2, 5, 6	**Pointing Systems**
Increased sensitivity at UV, IR, and optical	2, 3, 4, 5, 6	**Large aperture telescopes**
Novel technology development	1, 2, 3, 4, 5, 6	**Opportunities for Small Payloads**
Small dedicated instruments	1, 2, 3, 4, 5, 6	
In situ atmosphere measurements	4, 6	**Commercial Opportunities and Aerostats**
Measurements at a range of altitude	4, 6	

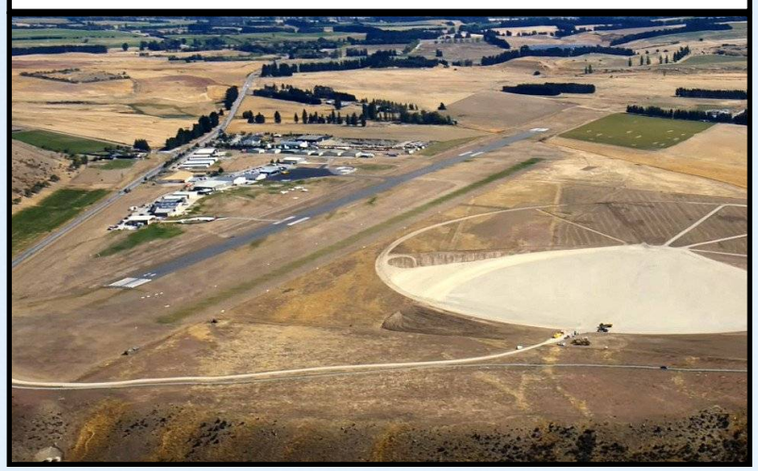
User Community Key: [1] Astroparticle Physics, [2] Exoplanet and Stellar Astrophysics, [3] Observational Cosmology, [4] Earth Science, [5] Planetary Science, [6] Solar and Heliophysics



Launch Sites & Facilities

More opportunities, more support, and more diversity

NZ launch site



Launch crews & facilities

LDB Antarctic program

Mission safety protocols

North American launch sites

Diversity of launch sites

Funding Opportunities

Earth & Planetary Science

- no funding opportunities in Planetary science
- very limited opportunities in Earth Science

➡ Recommends SMD implement funding opportunities for Earth and Planetary

Pioneers, and Explorers Missions of Opportunity

- new class of investigation for highly meritorious and high-impact missions
- MoO for exceptionally compelling science investigations beyond the standard APRA and Pioneers opportunities

➡ Recommends continued support of Pioneers and MoO calls

Guest Investigators programs

- trend towards balloon payloads following an observatory-class model

➡ Recommends NASA provides funding opportunity for Guest Observer/ Investigator missions

Workforce Development, Education & Outreach

Scientific ballooning uniquely enables and supports students and early-career scientists and engineers specifically through its short project timescales and hands-on training.

HASP Graduates

West Ferris Secondary School Grade 11 Students

- Recommends that NASA:
  - i) engage with nationwide entities supporting transdisciplinary learning
  - ii) improve accessibility to flight options
  - iii) develop safety and performance standards at appropriate level
  - iv) support technical workshops for entry level scientists

- Recommends additional effort to engage more female and minority scientists and engineers in the program at all levels.

Comments from APAC - Fall 2020

Findings

Consolidation and integration of astrophysics balloon experiment data within other NASA Astrophysics Division archives is desirable.

High-altitude ballooning supports astrophysics, earth science, solar science and space physics, and planetary science missions. However, there was **no inclusion** within the current draft formulation of the Balloon Roadmap **of the Biological & Physical Sciences** (BPS), which is now part of the NASA Science Mission Directorate.

Recommendations

The APAC requests updates on advances in **aerostat technologies** and other long-duration balloon projects that might **enable general guest-observer science** using large aperture telescopes with **arc-second pointing precisions** across the electromagnetic spectrum.

The APAC recommends that the Astrophysics Division consider adding a **formal process for proposing piggyback payloads**, potentially across disciplines.

The APAC request a detailed presentation describing the Balloon Roadmap at its next meeting as appropriate.

The APAC is also interested in how this initiative would incorporate **opportunities for traditionally under-represented communities** and **broaden the workforce capabilities** and PI/CoI opportunities beyond the core groups that have historically participated in the ballooning program.

Biological & Physical Sciences

High-altitude ballooning supports astrophysics, earth science, solar science and space physics, and planetary science missions. However, there was **no inclusion** within the current draft formulation of the Balloon Roadmap of the **Biological & Physical Sciences** (BPS), which is now part of the NASA Science Mission Directorate.

Biological & Physical Sciences

*Not included in final Roadmap report since BPS was transitioned to SMD after Roadmap was initiated

Effects of radiation exposure to on biological systems

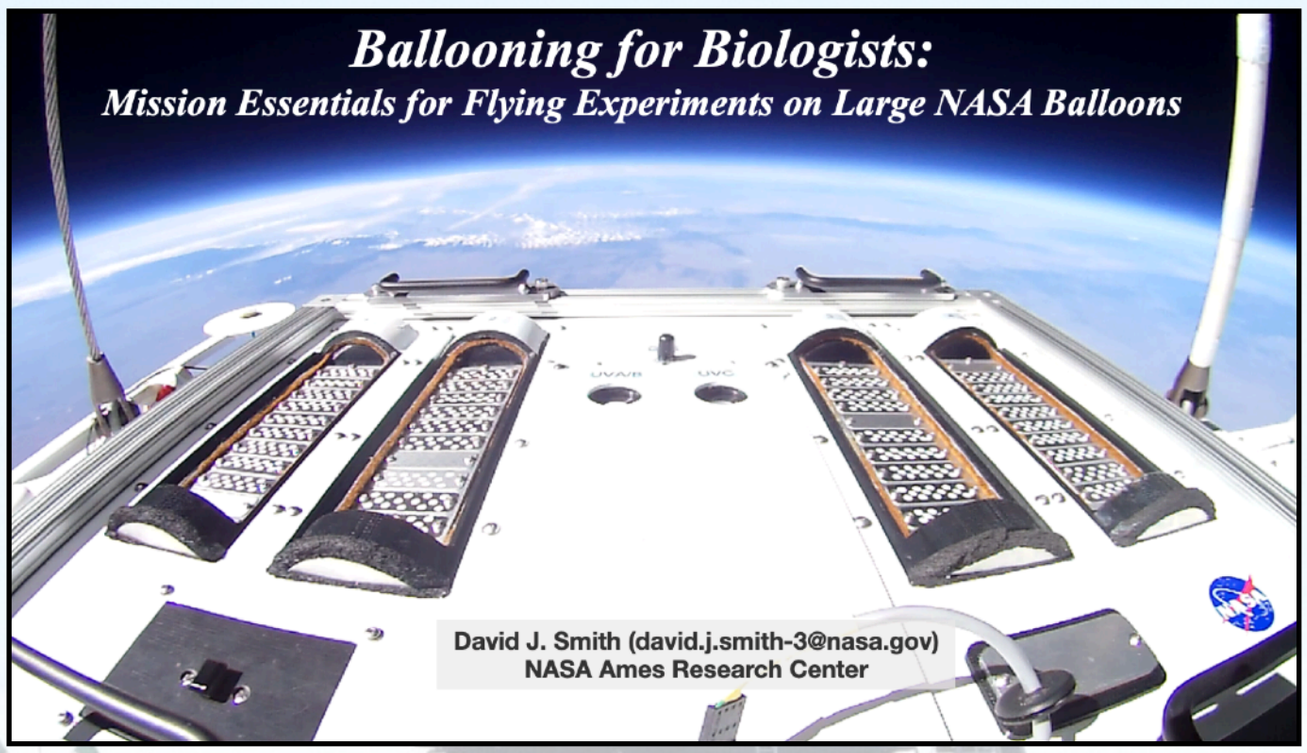
- balloons provide environments unattainable in ground facilities or at ISS
- polar flights give dose equivalent higher than ISS
- small payloads, such as piggybacks, are cheap with a quick turn-around

Solicitation for Space Biology piggyback opportunities in 2016 (NNH16ZTT001N-AB)

- 8 proposals submitted, 1 selected
  "Accumulated Doses and Microbial Mutagenesis from Ionizing Radiation Exposures (ADMMIRE) over Antarctica"
  PIs: Dr. Smith/Dr. Venkateswaran

E-MIST piggyback flights in 2014, 2015, and 2019

http://www.nasa.gov/ames/research/space-biosciences/e-mist-2015



Guest Observer Opportunities

The APAC requests updates on advances in aerostat technologies and other long-duration balloon projects that might enable **general guest-observer science** using large aperture telescopes with **arc-second pointing precisions** across the electromagnetic spectrum.

Guest Observer Opportunities

Balloon instruments are traditionally purpose-built for a dedicated cost-effective science investigation

- common technology (pointing, power systems, etc) designs are shared (biennial Scientific Balloon Technologies Workshop)

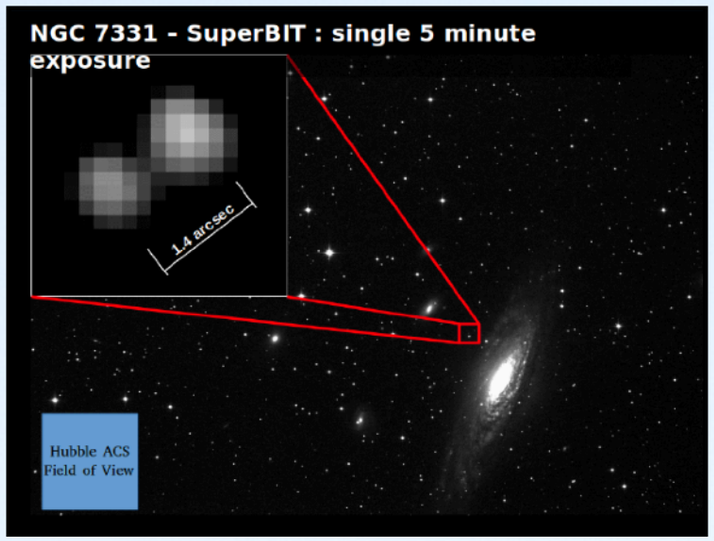
Many science questions can be answered with similar telescope designs

- exoplanet & stellar astrophysics, observational cosmology, planetary science, solar and heliophysics
- UV, IR, submillimeter, visible

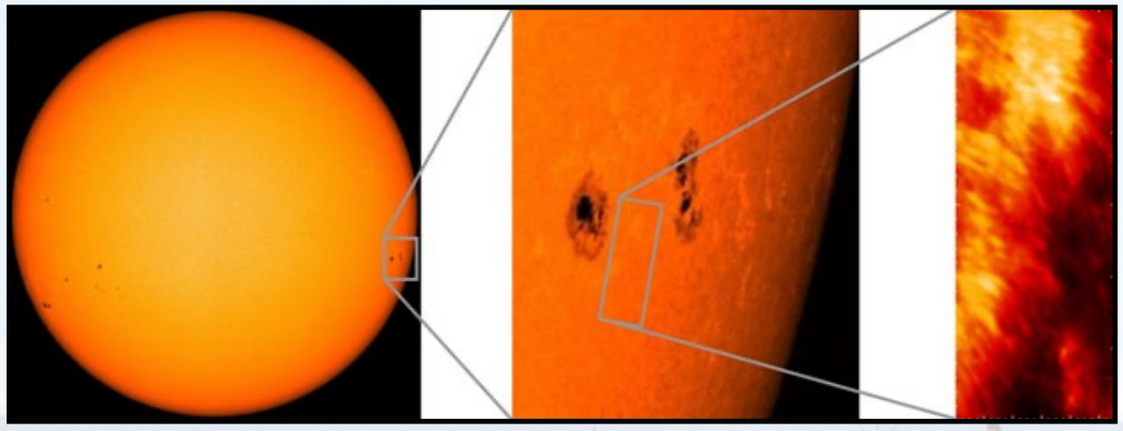
With increase in scientific capability in the coming decade from ultra-long duration flights there is an **expected trend** towards balloon payloads following an **observatory-class model**

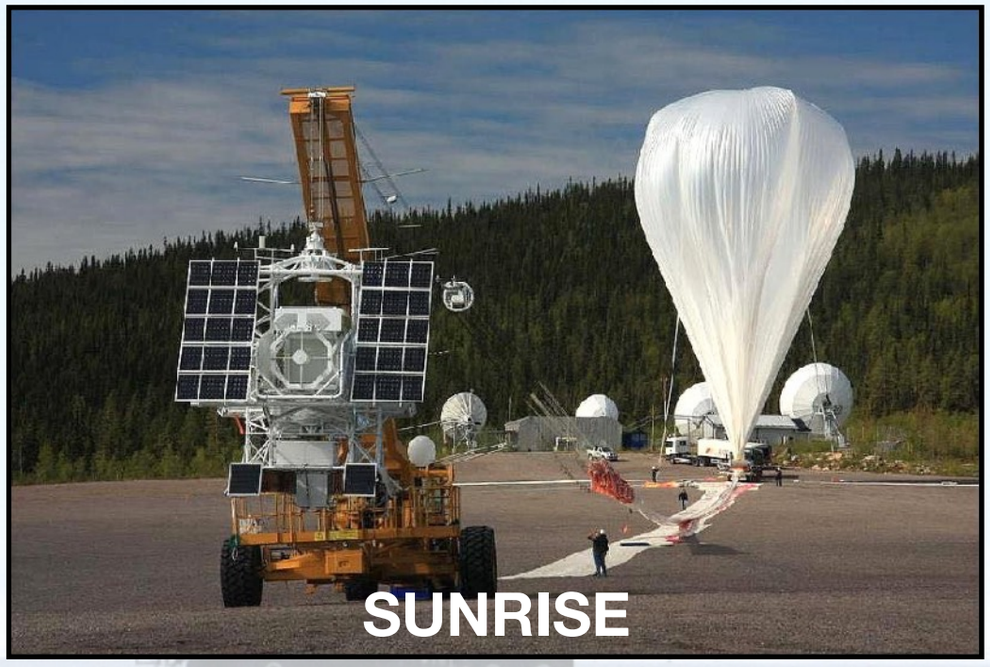
Large Aperture and Arc-second Pointing

Diffraction limited imaging in near-UV to near-IR achieved with **SuperBit** (0.5 m)

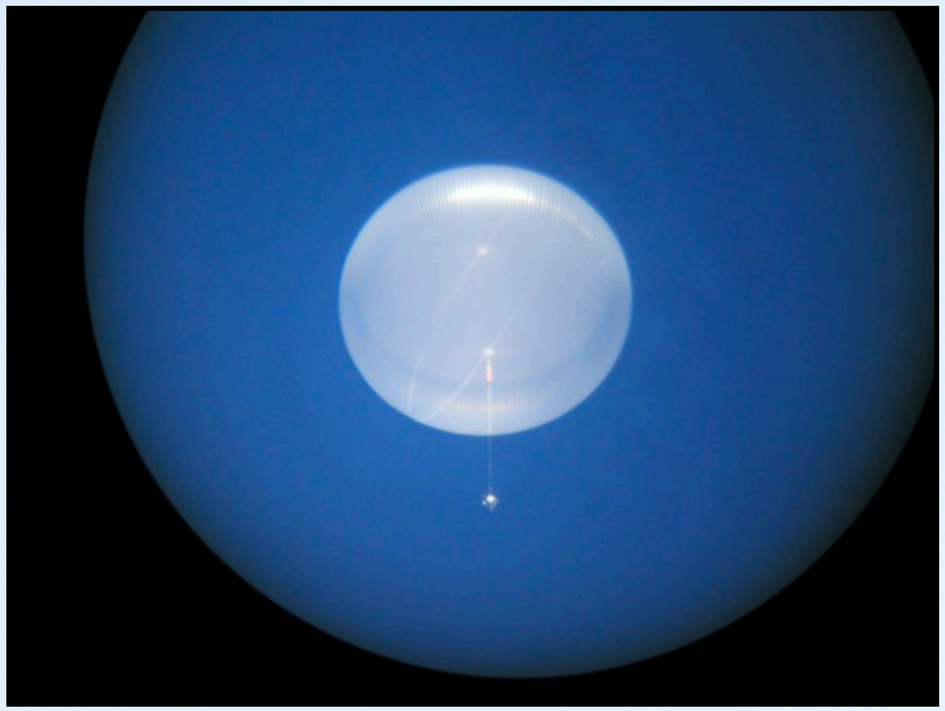


Near diffraction-limited imaging in UV and IR achieved with **SUNRISE** (1 m)





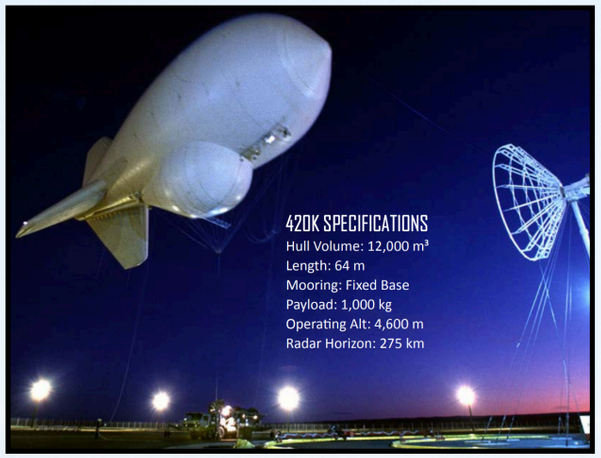
Balloon technologies to enable observations



Superpressure balloon

- enable mid-latitude flights
- ultra-long duration observations (50-100 days)
- day/night cycles
- offering science flights, but still in development

➡ Recommendation for continued advancement



Tethered Aerostats

- Low altitude (5-10 km)
- Short duration (5-10 days)

Commercial capabilities

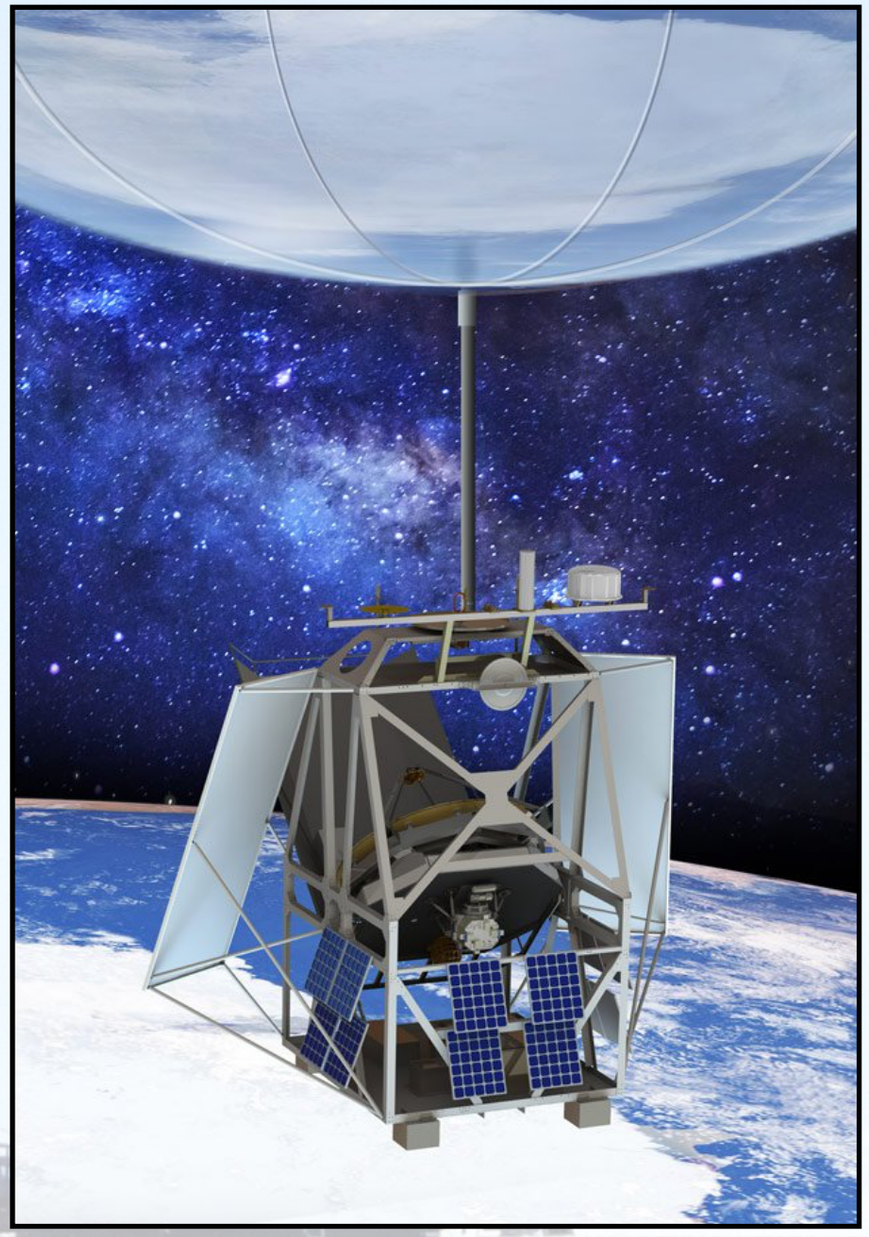
- Light weight payloads
- Limited altitudes for heavy-lift capabilities

Guest Observer Opportunities - ASTHROS

ASTHROS

Astrophysics Stratospheric Telescope for High Spectral Resolution Observations at Submillimeter

- far-infrared to submillimeter
- 2.5 m-aperture telescope
- planned launch from Antarctica December 2023



➡ envisioned to become a facility for the astrophysics community

- complementing SOFIA with southern hemisphere observations, access to longer wavelengths

T. Hams will address the programatic aspect

Piggyback Payloads

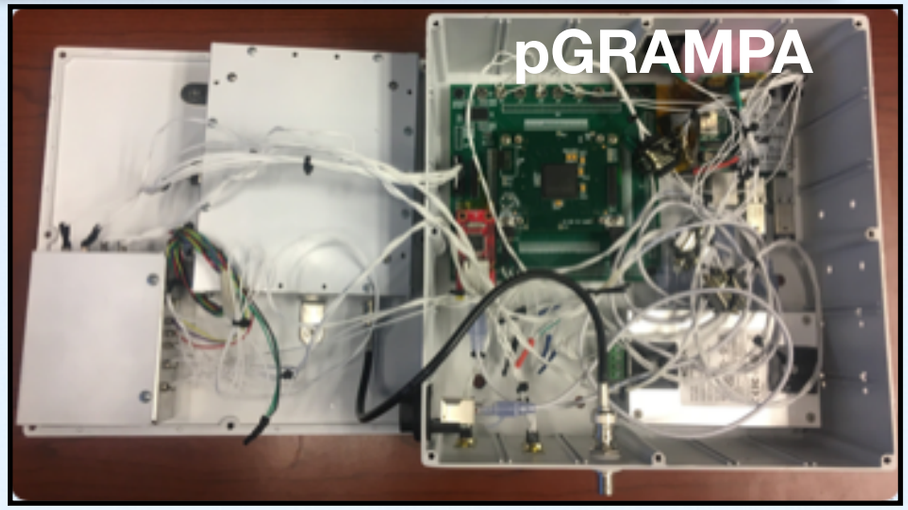
The APAC recommends that the Astrophysics Division consider adding a **formal process for proposing piggyback payloads**, potentially across disciplines.

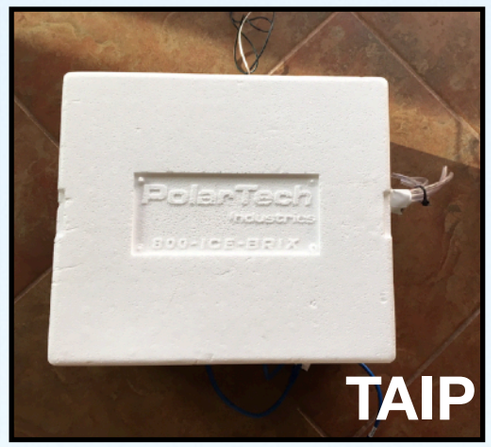
Piggybacks Payloads

Mission of opportunity “Piggyback” flights

- cutting-edge technology development
- small-scale novel science
- no burden of a full gondola
- e.g. single detectors, power systems, radiation monitors

16 Piggyback payloads flown
2019 Fort Sumner Campaign





Accessible testbed for new researchers

- not well known outside off the balloon community
- more involvement can increase diversity in balloon program

Opportunities for Under-represented Communities

How would this initiative incorporate **opportunities for traditionally under-represented communities** and **broaden the workforce capabilities** and PI/CoI opportunities beyond the core groups that have historically participated in the ballooning program.

Diversity in the Balloon Program

- **Diversity can mean:** science, institution, gender/race/background of scientists, trained skill set, PI's experience/age…

With information from 1/3 of the Astrophysics payloads, the percentage of female grad student involvement is 40-50%.

Diversity of science payloads and institutions

	Total
Astrophysics	**51**
CMB IR/Sub mm	**13**
HE	**8**
Particle Astro	**21**
UV-VIS	**9**
Earth Science	**5**
Planetary	**3**
Heliophysics	**29**
Programmatic	**8**
Student	**15**
Test	**37**
Abort	**5**
Total	**153**

In Astrophysics:

- 51 launches
- 32 different projects
- 22 different PI-institutions
- 5 payloads from NASA centers
- 4 Minority Serving Institutions

Balloon payloads, especially piggybacks, provide opportunities to institutions/groups that don't traditionally have access to hardware.

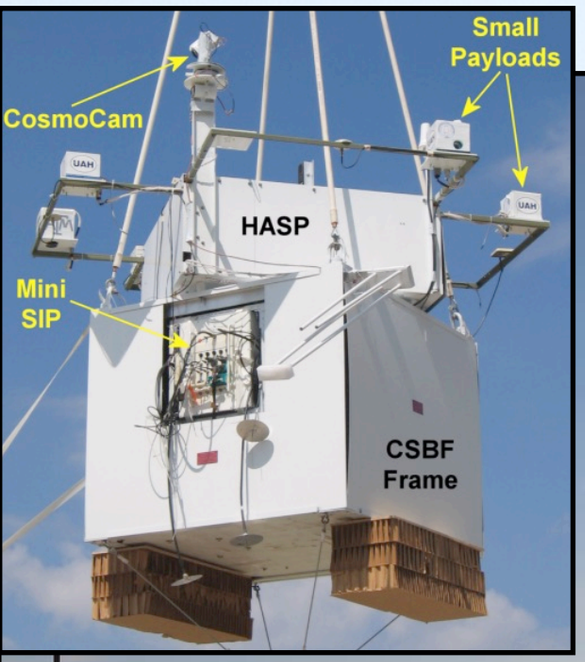
- 1/3 of current flight applications are new payloads

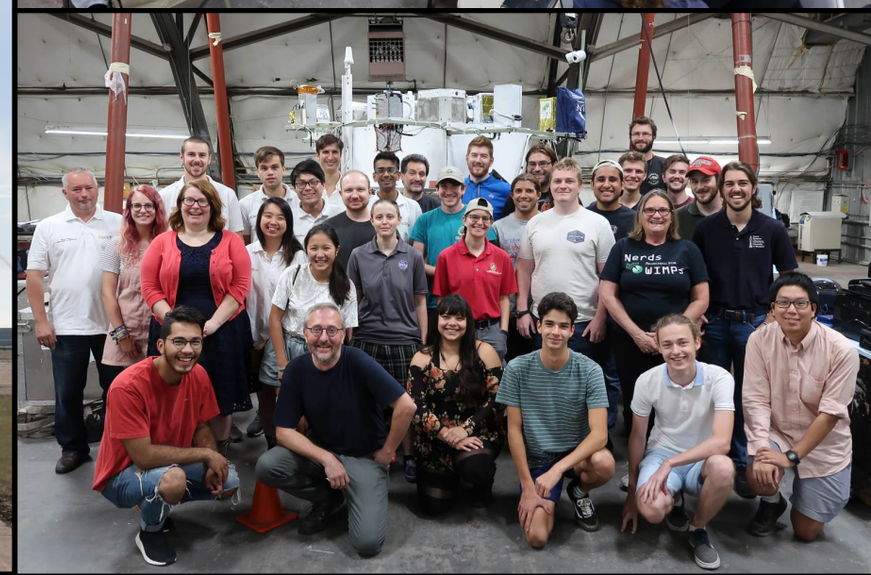
HASP - High Altitude Student Payload

Operates as a partnership between the NASA Balloon Program Office and Louisiana Space Consortium (LaSPACE)

Provides annual flight opportunities for student groups

- developed in 2005 to address a looming crisis in training the next generation of scientists and engineers.





846 undergrads and 136 grad students

Scientific Ballooning in the Next Decade

A Roadmap
For Scientific Ballooning
2020-2030

https://sites.wff.nasa.gov/code820/roadmap_pag.html

Following the recommendations given for

- balloon capabilities
- launch sites & facilities
- funding opportunities
- workforce development, education & outreach,

the NASA Balloon Program will continue to enable groundbreaking science in all disciplines of the SMD.

Backup Slides

Roadmap Findings and Recommendations

Balloon Capabilities

(A) Super-pressure balloons The PAG recommends that the NASA super-pressure balloon program continue to pursue the goal of 100-day flights including at mid-latitudes. NASA should strive to advance the lift capability and float altitude to the point where SPBs are commensurate with current zero-pressure balloon capabilities.

(B) Payload Telemetry The PAG commends NASA for efforts to improve balloon payload downlink bandwidth. The science return of any mission can be significantly enhanced by higher data downlink capability, avoiding the possibility of data vault loss as a mission failure mode. By the end of the decade, payloads will be capable of producing hundreds of Terabytes or even Exabytes of science data in a 30-day flight. The PAG recommends that NASA pursue an ambitious communication downlink goal of 100 Mbit/s average through a balloon flight (32 TB in 30 days) by the end of the decade, enabling a higher science return at much lower mission risk. The PAG also recommends that NASA pursue an increase in allocations of existing telemetry links such as TDRSS and Iridium to balloon payloads to help in the near term.

(C) Lift Capabilities The PAG commends NASA for the range of qualified balloons which satisfy the lift capabilities requested by the majority of the science community. Atmospheric transmission increases exponentially with altitude and, in the same manner, so does scientific return. This motivates the development of larger balloons capable of taking payloads closer to the edge of space. The PAG recommends expeditious flight qualification of the 60 Mcf balloon and the development of a larger class of zero pressure balloons capable of flying payloads of >1 ton to altitudes of >160,000 ft.

Balloon Capabilities

(D) Pointing Systems The PAG commends the Balloon Program for the development of the Wallops Arcsecond Pointing System, and recommends building on this success to provide even better pointing knowledge and stabilization for potential observatory-class (>1m) balloon-borne telescopes. The PAG also recommends commencing development on a second generation WASP that is lighter, more compact, and with improved pointing knowledge.

(E) Large-aperture telescopes The PAG finds that several areas of scientific research would be greatly augmented with the development of one or more diffraction-limited near-UV, visible, near-IR, and/or thermal IR telescopes of up to 3 m on a balloon-borne platform. The PAG recommends that the NASA Science Mission Directorate consider development of an observatory-class telescope of this magnitude, to be managed by the balloon program for user instruments.

(F) Opportunities for Small Payloads The PAG finds that there is significant interest in the use of small (<75 kg) payloads for scientific research in a range of disciplines. The PAG recommends that the balloon program continue to develop support systems for small balloons and continue to facilitate flight opportunities for piggyback payloads. The PAG also recommends that the process for finding piggyback opportunities should be advertised more broadly to the balloon user community.

(G) Commercial Opportunities: Aerostats The PAG finds that commercial offerings of tethered aerostats, and possibly untethered station-keeping airships, may provide scientific opportunities that could be compelling, and may also engender new ideas for investigations. The PAG finds that these vehicles appear to be developing an economy of scale for both military and non-military applications. The PAG recommends that NASA study these vehicles, engage the community on potential science applications, and study the practicalities of how they might be integrated with the existing Balloon Program.

Launch Sites and Facilities

(A) Multiple-Payload building in Wanaka The PAG commends the NASA Astrophysics Division and Balloon Program for developing and maturing the 18 Mcf super-pressure balloon, and the new launch facility in Wanaka, New Zealand, which supports SPB launches. These developments will enable new science investigations from Wanaka with science returns
comparable to significantly more costly space flight missions, and complementing to NASA flagship missions. The PAG recommends continued support for the growth of this facility, including a new payload integration building that could accommodate multiple payloads.

(B) Launch crews & Facilities The PAG recommends that NASA follow through as soon as possible with the approved increases in the capacity of launch facilities and the number of ground crews that can support them. Ground crews and their associated facilities can only support a limited number of launches within a given launch window (as determined by prevailing weather conditions), which can result in missed launch opportunities and avoidable fatigue to all concerned. Additionally, the ground crew capabilities must be commensurate to the multiple locations and duration of the campaigns that are currently in place. Therefore, The PAG recommends that completion of the approved increase in ground crews and launch facilities should be given a high priority.

(C) LDB Antarctic Program & Three-payload support The PAG commends the Balloon Program for the continuing success and scientific impact of the Antarctic Long Duration Balloon (LDB) program flown out of McMurdo Station. Antarctica represents a unique resource and environment for investigations across several disciplines and the opportunities afforded by the LDB merit such support. The PAG recommends unwavering NASA support for this flagship program and its associated facilities near Williams Field, Antarctica. The PAG recommends that NASA authorize a deploy a third payload building at the earliest opportunity and commit to the resources necessary to sustain a three-large-payload per season launch rate. The PAG recommends that NASA strive to acquire the aircraft resources necessary to ensure timely recovery of payloads.

Launch Sites and Facilities

(D) Mission Safety Protocols The PAG recommends that NASA consider appointing a panel consisting of both scientific balloon community and NASA to engage each other in a review of current mission safely protocols within the Balloon Program, to address the issue of burgeoning and confusing standards, which have reduced efficiency and productivity in recent years, without necessarily improving the safety of the program.

(E) North American launch sites and infrastructure investment The PAG finds that a North American launch site that can provide reliable night-time launch opportunities is a high priority not only for Astrophysics balloon payloads, but other disciplines as well. The PAG recommends that NASA identify and develop alternative launch sites in addition to Palestine, TX, and Ft. Sumner, NM, and possible Pacific Northwest sites under consideration. The PAG finds also that current infrastructure in Palestine and Ft. Sumner has aged to the point that is having a negative impact on the productivity and safety of the program, and the PAG recommends that NASA invest substantially in repairs, maintenance, and upgrades on these important facilities.

(F) Diversity of Launch sites and scope The PAG finds abundant evidence that expansion, not contraction, of the present portfolio of balloon flight options for both launch location and duration is important to the continued health of NASA astrophysics research, and the training of new investigators at every level. The PAG recommends that NASA give high priority To continuing operations from locations that support research in auroral and radiation belt physics, and high latitude magnetosphere-, ionosphere-, and thermosphere-coupling, which are compelling scientific drivers in heliophysics and require flights at magnetic latitudes ranging from 55-70 degrees (e.g., Kiruna, Sweden).

Funding Opportunities

(A) Earth & Planetary Science The PAG notes that currently NASA scientific ballooning offers no funding opportunities in Planetary science, and very limited opportunities in Earth Science. As we have detailed in previous chapters, there are many different scientifically compelling investigations in both Earth and Planetary Sciences, and significant opportunities for workforce development that are missed due to the lack of funding. The PAG strongly recommends that the NASA Science Mission Directorate implement consistent funding opportunities for Earth and Planetary Science balloon payloads.

(B) Pioneers, and Explorers Missions of Opportunity The PAG commends NASA for including balloon investigations in the new Pioneers mission class in the Astrophysics Research and Analysis Program (APRA) within Research Opportunities in Space and Earth Sciences (ROSES). This class of investigation (up to $20M over 5 years) for highly meritorious and high-impact missions is of particular importance for long-duration and ultra-long duration payloads that launch from Antarctica, Sweden, and Wanaka, NZ. The PAG recommends That NASA continue this program as a regular part of the APRA investigations with the ROSES program. The PAG also recommends that NASA continue to periodically include balloon-borne payloads within its Missions of Opportunity for the Explorer class investigations, to provide the possibility for exceptionally compelling science investigations that may require a level of commitment beyond the standard APRA and Pioneers opportunities.

(C) Guest Investigators programs As balloon-borne instruments continue to increase in scientific capability in the coming decade, especially in light of the new Pioneers mission class and ultra-long duration flights achieved through the superpressure balloon, there is an expected trend towards balloon payloads following an observatory-class model. The PAG recommends that NASA provide a funding opportunity for Guest Observers/Investigators for balloon missions, in addition to accommodating data analysis from balloon-borne instruments in relevant solicitations, such as the Astrophysics Data Analysis Program (ADAP).

Workforce Development, Education & Outreach

(A) Workforce development The PAG recommends that the community and Balloon Program Office work to foster high altitude ballooning as a key element in NASA's workforce development pipeline from pre-college to new scientists. The PAG recommends specifically that NASA:
(i) Engage with nationwide entities that are already supporting transdisciplinary learning.
(ii) Improve accessibility to flight options for groups involved with experiential projects.
(iii) Develop safety and performance standards for balloon projects at a level significantly below spacecraft standards.

(B) Diversity The PAG commends NASA Balloon Program efforts to balloon to support diversity and inclusion, but recommends that additional effort is warranted to engage more female and minority scientists and engineers in the program at all levels: from students, postdoctoral researchers, and investigators within the scientific community, up to the Balloon Program Office and the Columbia Scientific Balloon Facility. The PAG also recommends that NASA, the BPO, and CSBF develop quantitative assessments of their progress in addressing these issues.

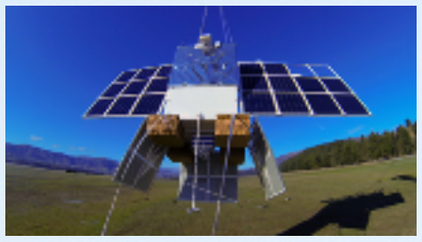
(C) National Space Grant College and Fellowship program engagement The PAG recommends that NASA should engage with the National Space Grant College and Fellowship program to continue and expand strong support for student training ballooning programs that support the workforce development pipeline at all levels including K-12, university students, and in-service teachers.

(D) 2024 Solar eclipse The PAG recommends that NASA engage with stakeholders interested in the April 8, 2024 North American total solar eclipse as early as possible to assess scientific, workforce development, and public engagement projects, as well as payload weight classes including heavy payloads, and potential launch sites.

Groundbreaking Science in the Past Decade

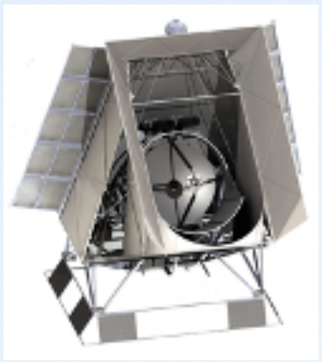
X-Calibur

- reports observations of X-ray pulsar GX 301-2 with first constraints on linear polarization in the 15-35 keV X-ray regime



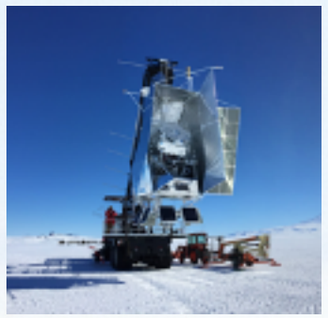
COSI

- reports detection and imaging analysis of the 511 keV Galactic positron annihilation line
- constraining upper limit on the polarization of GRB160530A



BLAST-Pol

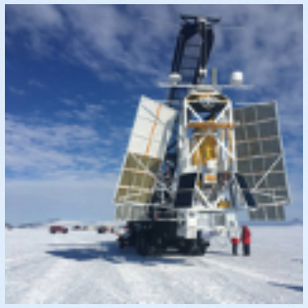
- flat submillimeter polarization spectrum of the Carina Nebula
- first observation of the Submillimeter Polarization Spectrum in a Translucent Molecular Cloud
- finds evidence of relations between density and magnetic field orientation in Vela C molecular complex



SPIDER

- reports a new limit on CMB circular polarization

Groundbreaking Science in the Past Decade

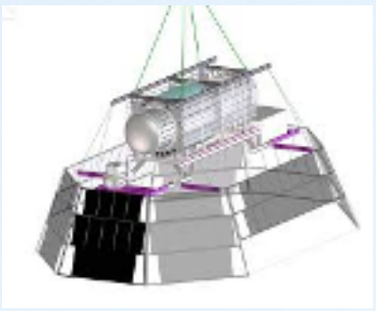


STO-2

- reports velocity-resolved spectral observations of extreme star formation regions in Carina, via CII

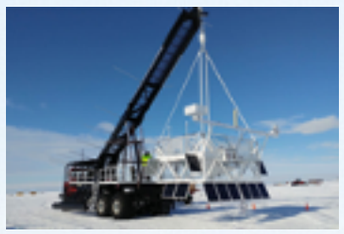
ANITA

- reports stringent ultra-high energy neutrino limits from flights in 2013 & 2016, and anomalous cosmic-ray like events from 2013 & 2007 that could signal beyond standard model physics
- observed four anomalous cosmic-ray-like events in 2016 that are consistent with tau neutrino signals



BESS-Polar II

- provided most stringent constraints on the possible abundance of antihelium
- reports measurements the cosmic-ray antiproton spectrum at solar minimum



SuperTIGER

- reports that abundances of elements from Iron to Zircon show a 20% contribution from massive stars.

Technology Development

Mission of opportunity "Piggyback" flights

- small-scale tests
- cutting-edge technology development
- no burden of a full gondola

Hand launch payloads

- small-scale tests
- long-duration flights for small science payloads

Conventional flights in Fort Sumner or Palestine

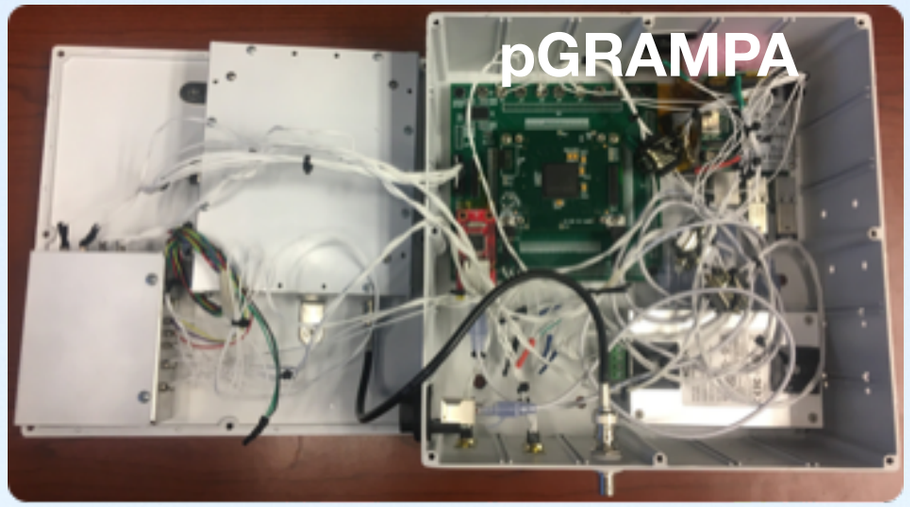
- test flights of full systems
- incremental improvements of technology

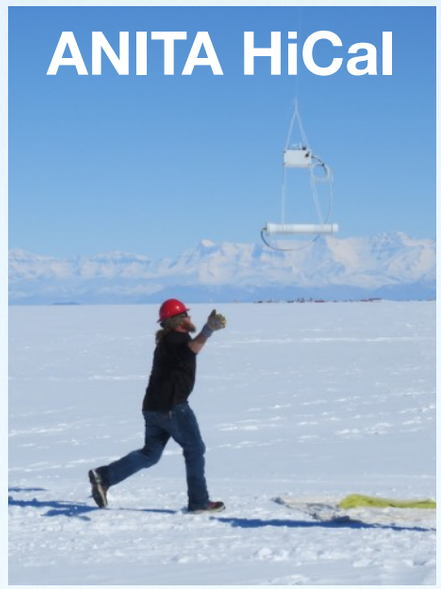
Long duration balloon (LDB) flights

- test flights of full systems
- demonstration of scientific goals
- flight operations with real-time monitoring and telemetered data

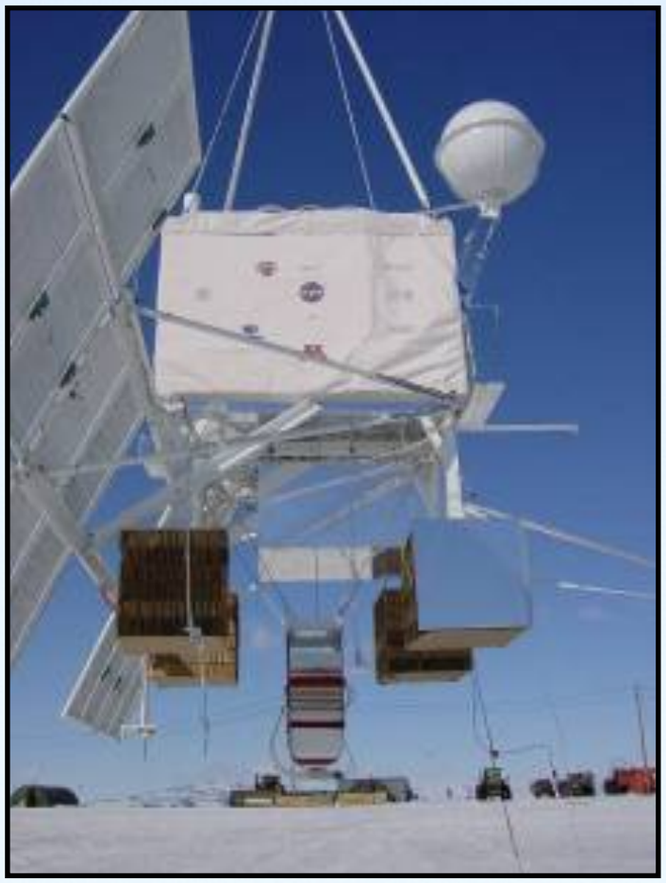
Ultra long duration (ULDB) flights

- Superpressure Balloon technology
- test flights with night observations





Technology Development



Balloons are a necessary platform for technology development

- small and large scale tests of new technologies
- cheap access to space-like environment
- accessible to a variety of institutions
- recovery allows for incremental improvements
- raises TRL

Balloon technology lead to space missions

- **Past:** COBE, WMAP, RHESSI, ACE, GLAST, EOS-Aura, Swift, NuStar…
- **Future missions:** COSI-SMEX, X-Calibur, POEMMA, AMEGO…