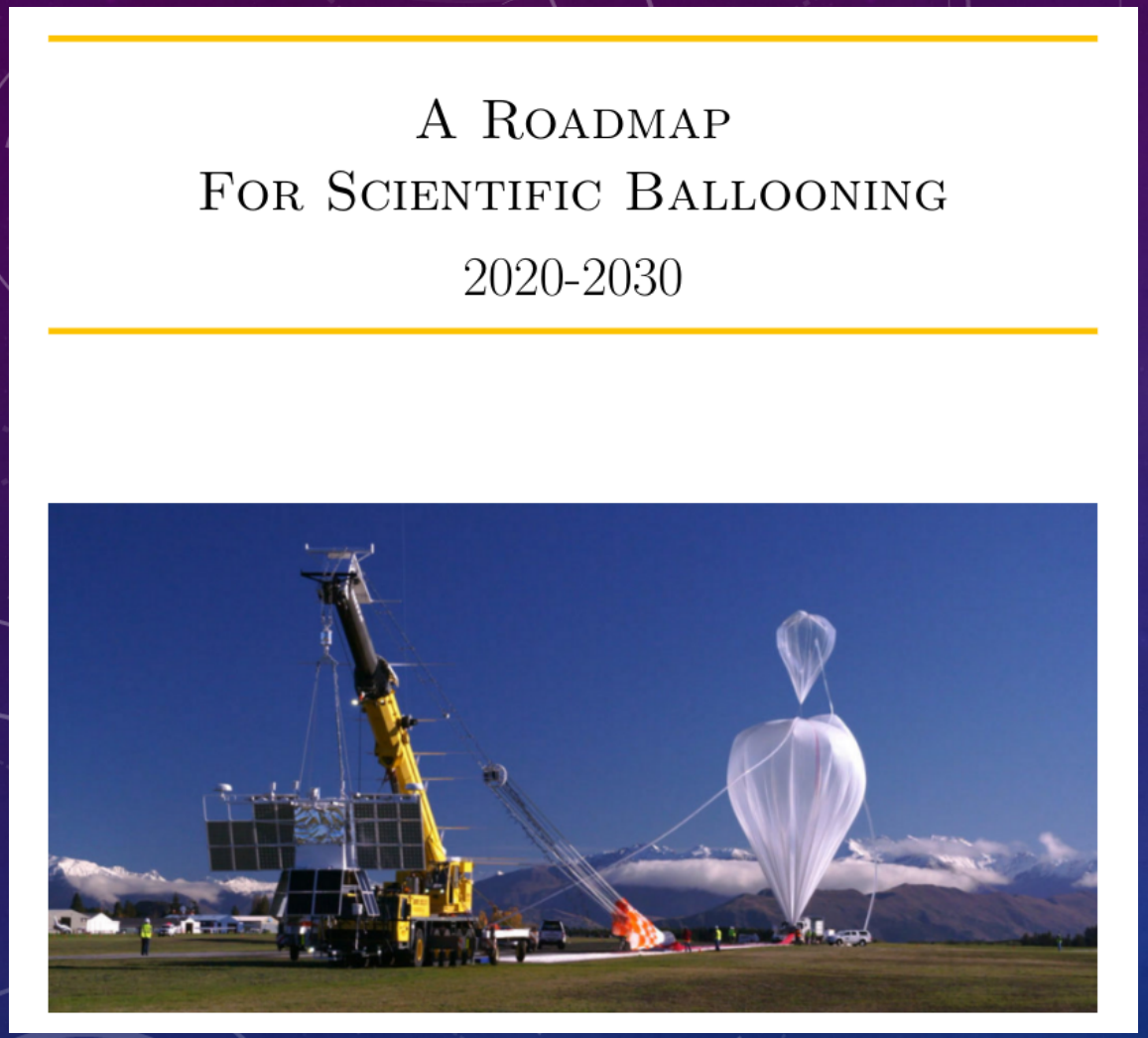

Report of the Balloon Program Analysis Group (PAG)

Compiled & Edited by the PAG executive committee

Presenter: Peter Gorham, PAG-EC chair

Outline of this presentation

- Introduce the Program Advisory Group Executive Committee (PAG-EC)
  - Describe our terms of reference
- Summarize the Balloon Roadmap Process and the organization of the report
- Summarize the advantages of balloons and report some science highlights
- Go through the complete set of Findings and Recommendations:
  - 20 distinct findings and recommendations in four focus areas

PAG Executive Committee Members

The NASA Program Analysis Group Executive Committee:

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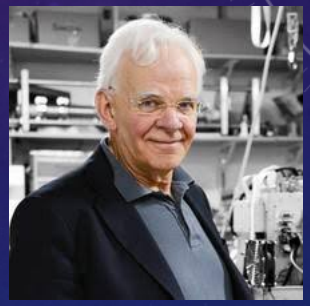
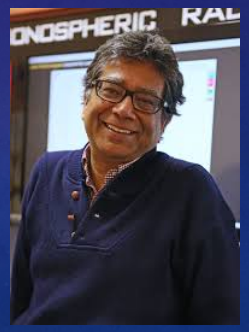
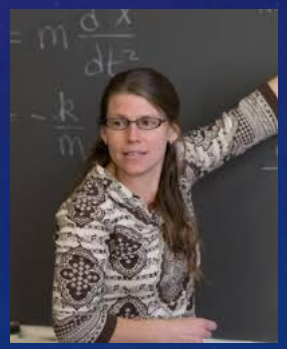


PAG Terms of Reference (our Charge)

- 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 assess balloon launch opportunities and mission capabilities provided by emerging commercial providers (section 3.6)

Balloon Roadmap Process

- Kicked off in early 2018 at AAS January meeting, Washington DC
  - Two hour mini-Townhall meeting, introduced the process and schedule
- July 2018: COSPAR Pasadena, CA: Townhall with many (O(20)) invited and contributed presentations
- December 2018: Townhall at December AGU meeting
- January 2019: Townhall at AAS coincided with Gov't shutdown
  - Informal but very useful meeting was still held
- Townhall at April APS meeting 2019, moderate attendance but very useful
- Townhall at May Balloon Technologies Workshop in Minnesota

Balloon Roadmap Process, continued

- Initial recommendations were prepared for ASTRO 2020
  - This was delivered in early Fall 2019 as a White Paper
- The goal was to then complete the report and deliver it to NASA in late 2019
- Delays pushed this into early 2020, and then COVID took over
  - My apologies to NASA & the APAC for the late delivery – it is on me as Chair.
- The PAG-EC finally was able to regroup the process during summer 2020
- The current report has had many changes since the early ASTRO 2020 version
  - Substantial new supporting material, revised and updated recommendations, and a completely new format.

Report Organization

- 1. Executive Summary
- 2. Science Drivers for the Balloon Program
  - 2.1 Astrophysics
  - 2.2 Earth Science
  - 2.3 Planetary Science
  - 2.4 Solar and Space Physics (Heliophysics)
- 3. Capabilities of the Balloon Program
- 4. The Workforce Pipeline and Education Through Scientific Ballooning
- 5. Findings and Recommendations

The Key Advantages of the Balloon Platform

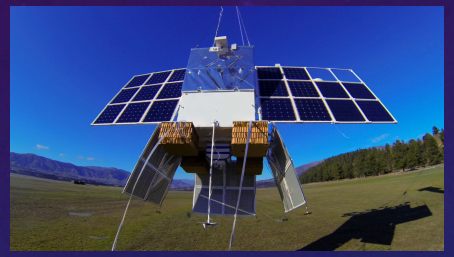
- Scientific balloons provide a unique platform for groundbreaking science
  - Achieve altitudes with negligible seeing and absorption compared to ground/aircraft
  - Low cost & rapid cycle → purpose-built instruments with highly focused science
  - Look-back at Earth → much closer than the lowest Earth orbit
- Balloon-borne missions provide a test bed for future space-flight instruments
  - Near-space environment at a small fraction of spacecraft & launch costs
  - Cost-effective way to raise TRL of instruments designed for space-based missions.
  - With the almost guaranteed recovery of the payload, improvements can be made on novel technologies and prototypes
- Balloon projects are a hands-on training ground
  - Unparalleled education experience for the next generation of scientists and engineers.
  - Project time-scales & risk profile commensurate with student involvement at all levels
  - High altitude hand-launch balloons provide an accessible platform for the education and outreach for younger students

Highlights of Ballooning in the Last Decade

- X-Calibur

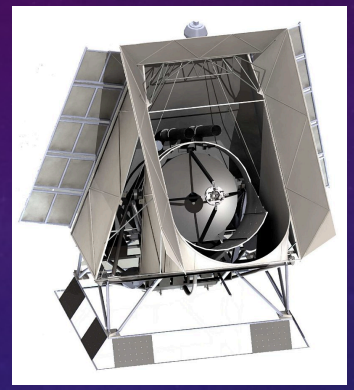
  - reports observations of X-ray pulsar GX 301-2 with first constraints on linear polarization in the 15-35 keV X-ray regime .

- COSI:



  - reports detection and imaging analysis of the 511 keV Galactic positron annihilation line.
  - Sets a constraining upper limit on the polarization of GRB160530A of 46%.

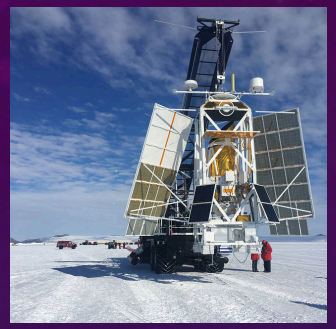
- BLAST-Pol:



  - Reports a flat submillimeter polarization spectrum of the Carina Nebula [9].
  - Reports 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.

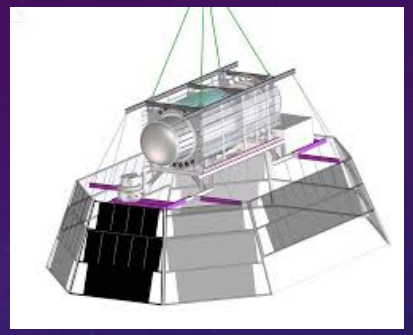
- SPIDER:
  - reports a new limit on CMB circular polarization.

Some Highlights of Ballooning in the Last Decade

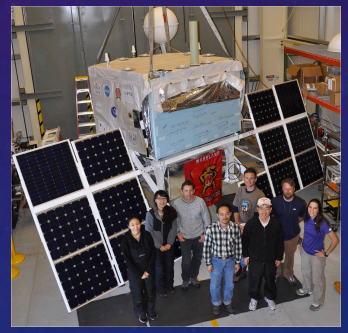


- STO-2:
  - reports velocity-resolved spectral observations of extreme star formation regions in Carina, via CII.

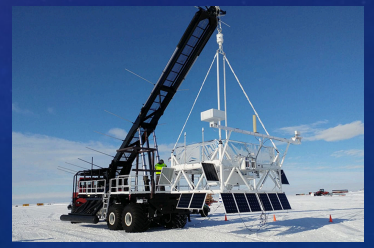
- ANITA:
  - Reports stringent ultra-high energy neutrino limits from flights in 2013 & 2016, and anomalous cosmic-ray like events from 2013 & 2007 that could signal beyond standard model physics
  - Observed four anomalous cosmic-ray-like events in 2016 that are consistent with tau neutrino signals



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



- CREAM:
  - reports measurements of protons to He in cosmic rays from 1 TeV/nucleon to 63 TeV/nucleon.



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

Findings & Recommendations: format

- We report findings and recommendations (chapter 5 in the report) in four general areas:
  - 5.1 Balloon Capabilities
  - 5.2 Launch Sites & Facilities
  - 5.3 Funding Opportunities
  - 5.4 Workforce Development, Education & Outreach
- In each area, recommendations are presented in priority order, with alphanumeric labels (A),(B), …

Findings & Recommendations: 5.1 Balloon Capabilities

(A) Superpressure 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. While data prioritization/decimation for telemetry may still be necessary, higher telemetry rates still reduce risk.
- 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.

Findings & Recommendations: 5.1 Balloon Capabilities

(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.

(D) Pointing Systems.

- The PAG commends the Balloon Program for the development of the Wallops Arcsecond Pointing System. The PAG 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.

Findings & Recommendations: 5.1 Balloon Capabilities

(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.

Findings & Recommendations: 5.1 Balloon Capabilities

(G) Commercial Opportunities: Aerostats

- The PAG finds that commercial offerings of tethered aerotats, 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, which may make them a cost-effective lighter-than-air vehicle for some scientific disciplines.
- 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.

Findings & Recommendations: 5.2 Launch Sites & 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.

Findings & Recommendations: 5.2 Launch Sites & Facilities

(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

(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.

Findings & Recommendations: 5.2 Launch Sites & Facilities

(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. The PAG recommends that NASA invest substantially in repairs, maintenance, and upgrades on these important facilities.

(F) Diversity of Launch sites and scope of program

- 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).

Findings & Recommendations: 5.3 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 workforce development occasions that go with them.
- 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.

Findings & Recommendations: 5.3 Funding 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)

Findings & Recommendations: 5.4 Workforce Development, Education & Outreach

(A) Workforce development

- The PAG recommends that the community and Balloon Pro-gram 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.
  iv. Support technical workshops for entry level scientists to provide a venue instrumentdesign sharing, lessons learned, and best practices

Findings & Recommendations: 5.4 Workforce Development, Education & Outreach

(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.

BALLOON CAPABILITIES, ATMOSPHERIC TRANSMISSION