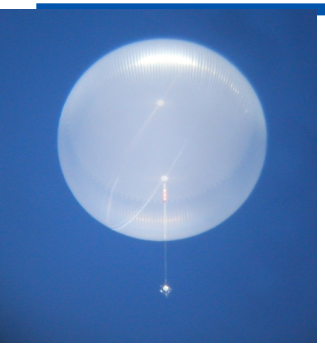
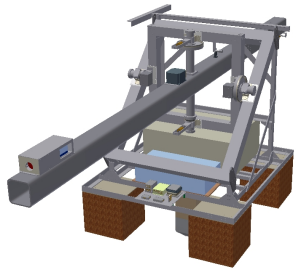
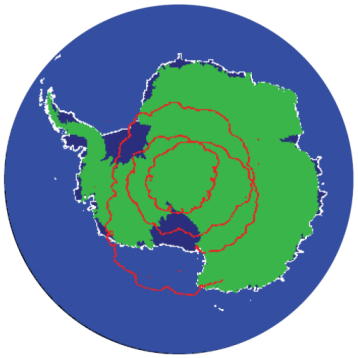


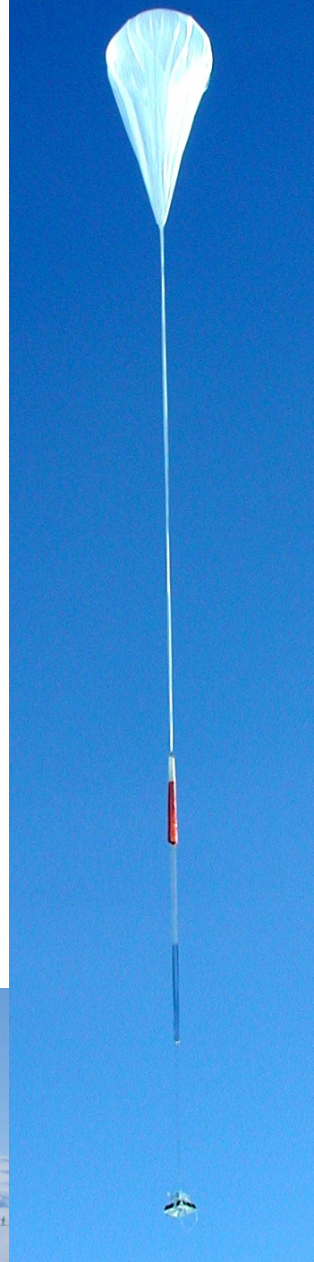
NASA Long Duration Balloon Program

Peter Gorham
Univ. of Hawaii at Manoa

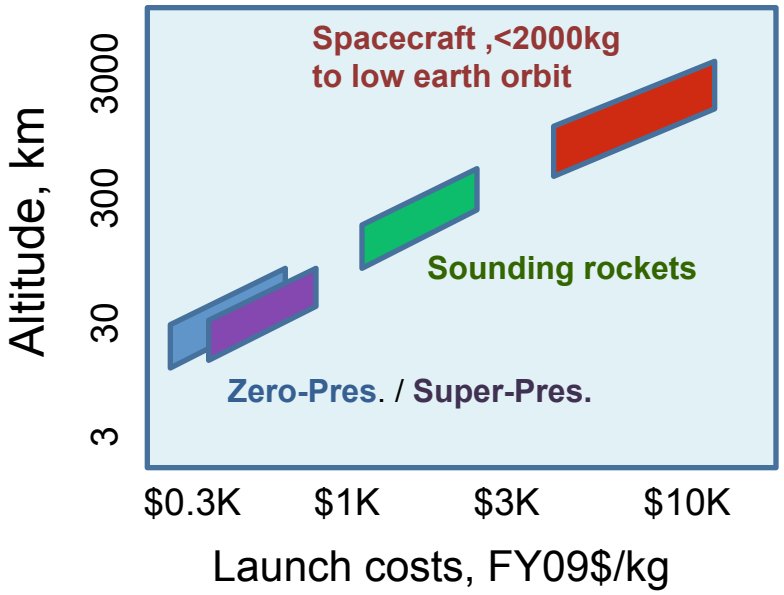


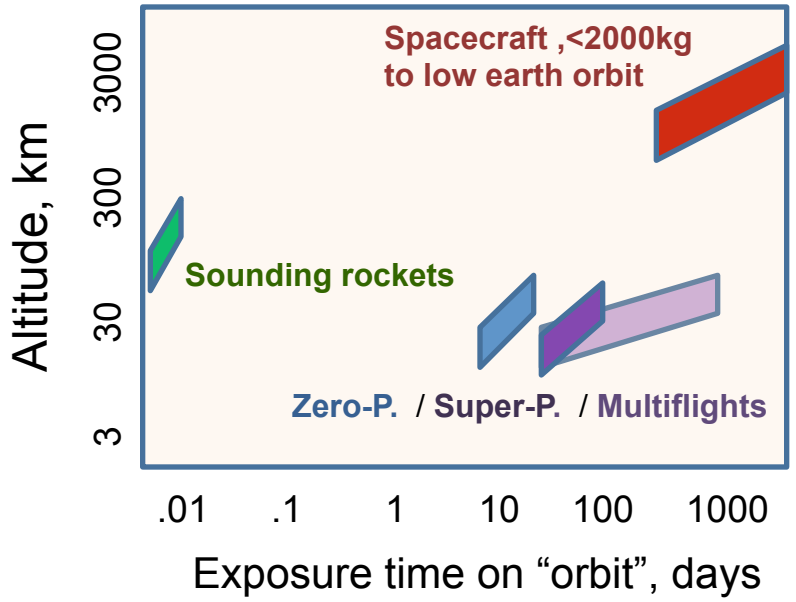
standing in for Dr. W. Vernon Jones
Senior Scientist for Suborbital Research
Astrophysics Division, DH000
Science Mission Directorate
NASA Headquarters
w.vernon.jones@nasa.gov
1-202-358-0885





Long and Ultra-Long-Duration Ballooning (ULDB)





- LDB/ULDB: NASA’s lowest cost access to space (>= stratosphere)
  - -- spacecraft-scale payloads (1000-2000 kg)
  - -- exposures comparable to short-duration spacecraft
  - -- **recoverable & re-usable payloads: increased exposure at low cost**
- Rapid response to new phenomena
- Some astrophysics is best done in the stratosphere
- Test-bed for spacecraft instruments
- Training ground for next generation of scientists

History of NASA Long-Duration Balloon Flights

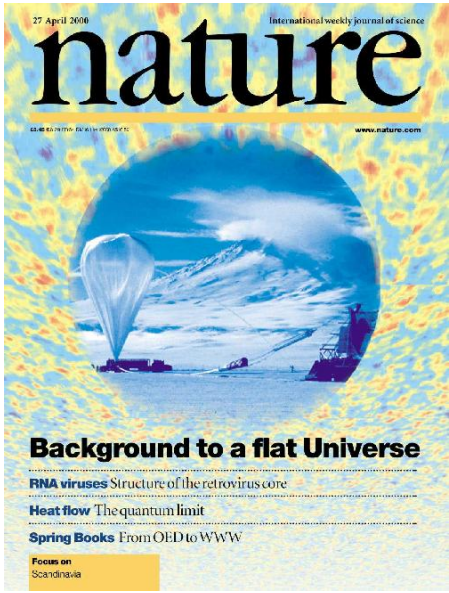
- 52 “polar” Long-Duration Balloon (LDB) flights have been conducted since the first successful launch in 1991 by the NASA - NSF Office of Polar Programs partnership.
- 41 Antarctic flights (*)
  - 29 single circumpolar flights with durations of 8 - 20 days.
  - 6 double circumpolar flights with durations of 20 - 32 days.
  - 4 triple circumpolar flights with durations of 35 - 42 days.
  - 2 super-pressure balloon (SPB) test flights: 54 days; 22 days.
- 2 flights from Fairbanks, Alaska to Canada over Russia with durations of 13 days.
- 9 Flights from Kiruna, Sweden to Canada with durations of 4 - 6 days.

(*) At least 3-5 payloads/yr want Antarctic Flights FY 2013 - FY 2015

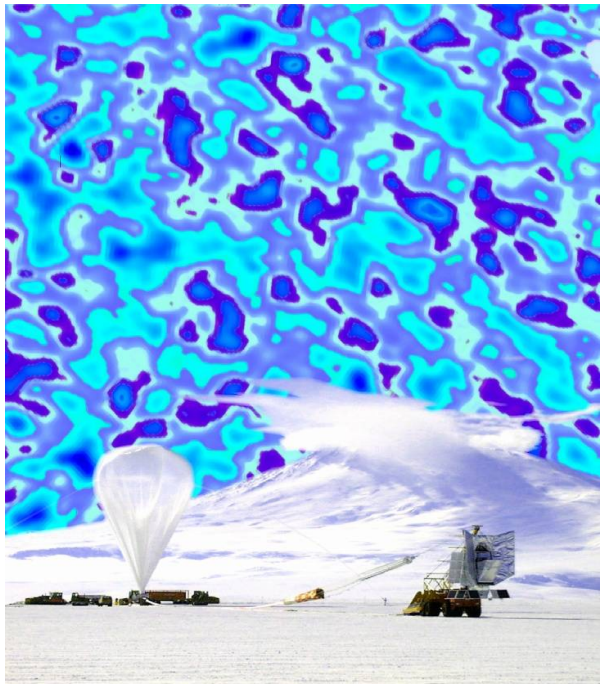
Important Science Results from Ballooning

- 2006 Balzan Prize for Astronomy and Astrophysics was awarded to:
  - Paolo de Bernardis, Università di Roma "La Sapienza" & Andrew Lange (d. 2010, formerly at Caltech)

"For their contributions to cosmology, in particular the Boomerang Antarctic balloon experiment."

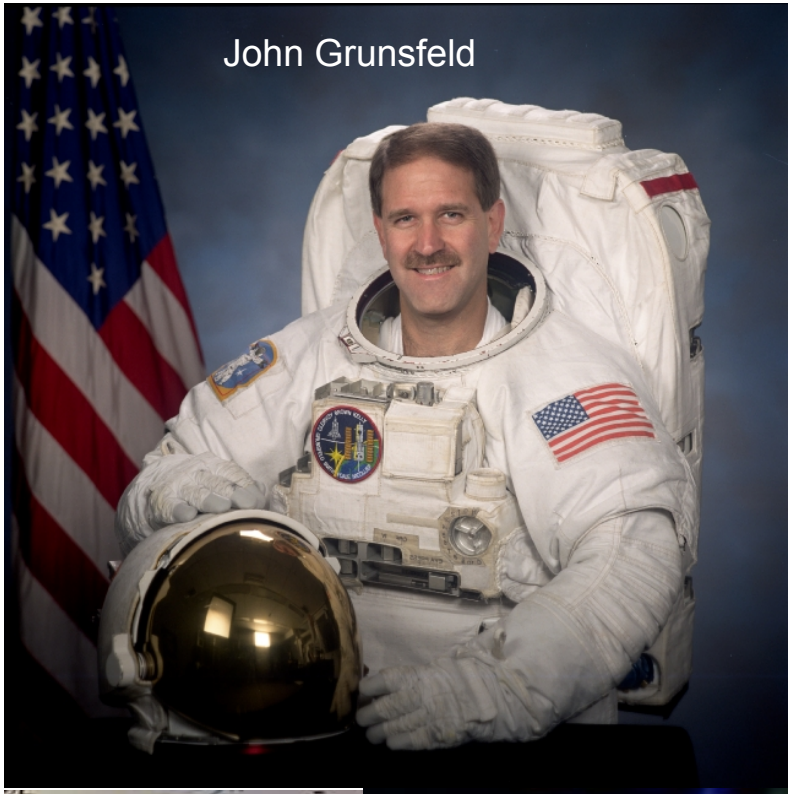


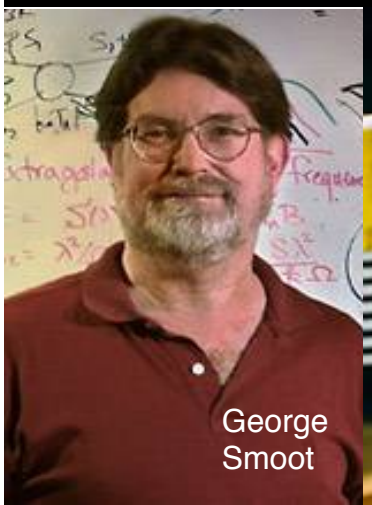
- The Balzan Prize is "One of the highest awards for science, culture and humanitarian achievement, ranking close to the Nobel Prize"
  - Awarded only occasionally for Observational Astronomy and Astrophysics
    - Reinhard Genzel (2003)
    - Fred Hoyle and Martin Schwarzchild (1994)
    - Martin Rees (1989)
    - Jan Oort (1984)



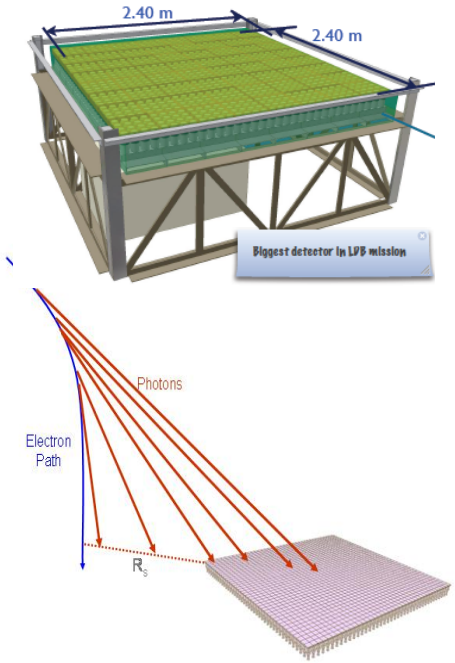
Many Scientists With Leading Roles in NASA
Were Trained in the Balloon Program*

- John Grunsfeld
  - NASA/SMD Associate Administrator
  - NASA Astronaut
  - Hubble Space Telescope Repairs
  - **Worked on GRIP at Caltech*
- John Mather
  - NASA/GSFC Senior Scientist
  - Nobel Prize 2006 for COBE
  - Senior Project Scientist for JWST
  - **UC Berkeley dissertation on CMBR balloon payload , led directly to COBE work*
- George Smoot
  - UC-Berkeley Professor
  - Nobel Prize 2006 for COBE
  - Director, Institute for Early Universe @ Ewha Woman's University, South Korea
  - **MAXIMA CMBR balloon payload*





FY-12 Antarctic Campaign: 2011-12 Season



CREST (Cosmic Ray Electron Synchrotron Telescope) PI: Musser/U. Indiana; 10.6 days

Observes characteristic linear trail of synchrotron photons generated as an ultra high energy electron passes through the Earth's magnetic field.

Detector is 2 x 2 m^2 array of 1600 1" diameter BF_2 crystals.

STO (Stratospheric Terahertz Observatory) PI: Chris Walker/U. Arizona); 13.4 days

Utilizes the Flare Genesis platform for THz surveys to probe the life cycle of the Interstellar Medium.

C+, N+ galactic plane survey using a 0.8 m telescope with two cryogenic 4-pixel THz arrays.

Upcoming FY-13 Antarctic Campaign: 2012-13 Season

Three balloon payloads are being given the opportunity to launch in Dec - 2012:

Super-TIGER (PI: Binns/Washington U. St Louis):

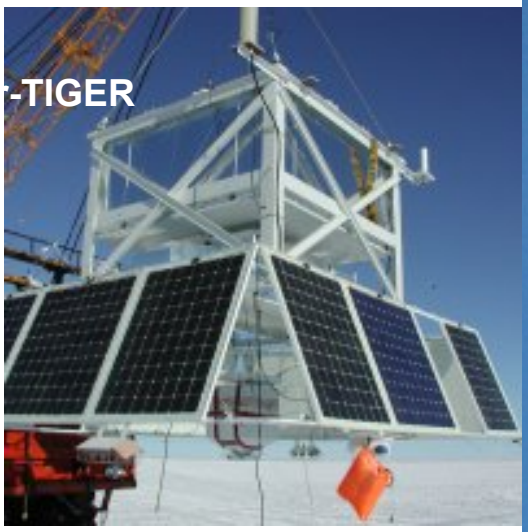
Studying the origin of cosmic rays via heavy elemental abundance measurements.

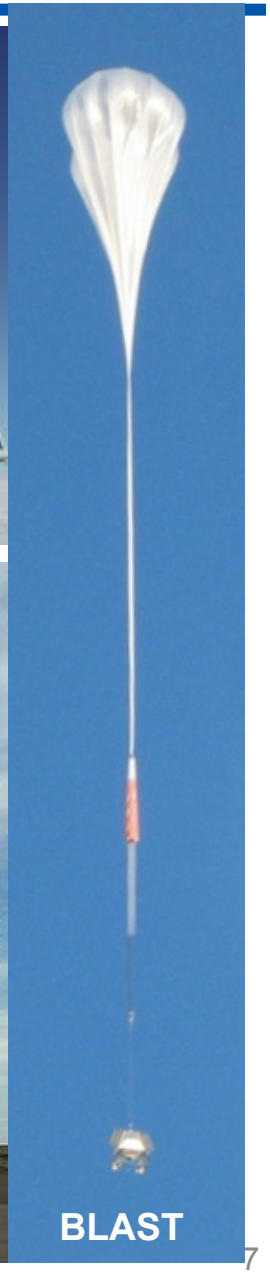
EBEX (PI: Hanany/Minnesota):

E- and B-mode Explorer; CMB polarization as a probe of cosmic inflation and gravitational lensing.

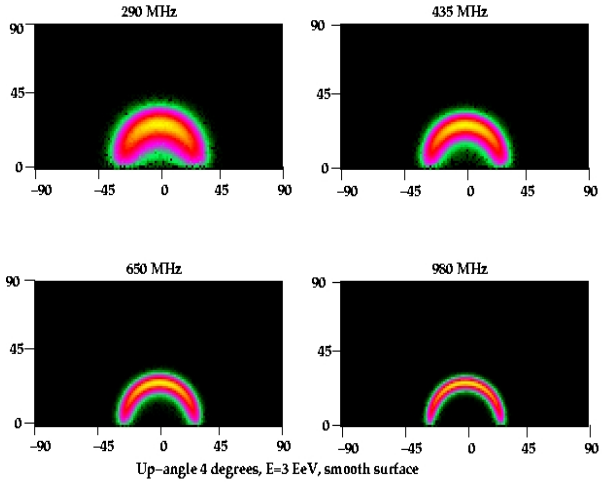
BLAST-pol (PI: Devlin/U. Penn):

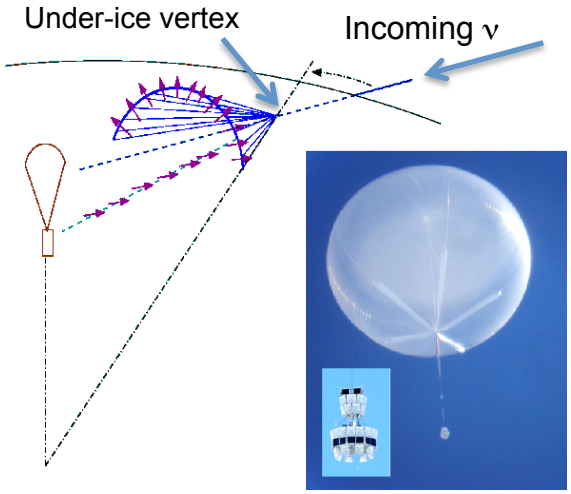
Mapping of polarized dust emission along the Galactic Plane; influence of magnetic fields on star formation.

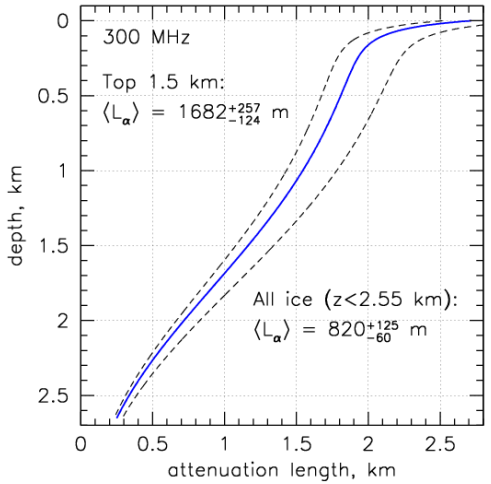




Antarctic Impulsive Transient Antenna (ANITA)

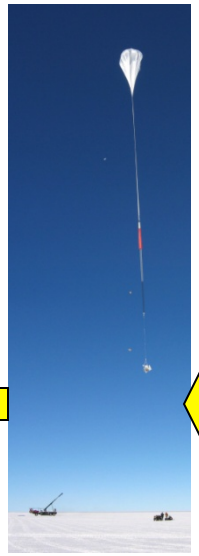


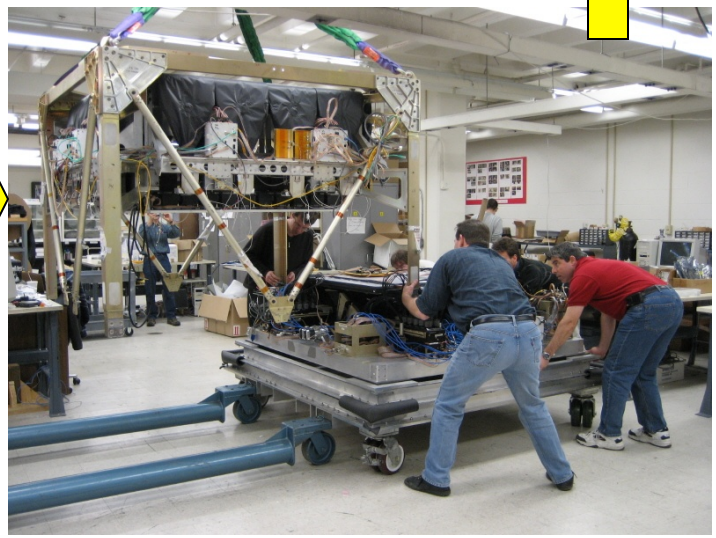




- ANITA: a ring-imaging RADIO Cherenkov detector for EeV cosmogenic neutrinos
  - **NASA's 1st & only neutrino expt?**
- `Beam Target': all of Antarctica
  - ~1M km^3 volume synoptic view
- Sensitivity is actually best from balloon
  - spacecraft altitudes too high
- 2 flights complete, 3rd flight next year

The Story of a Balloon Flight Starts Here
Students play key roles!



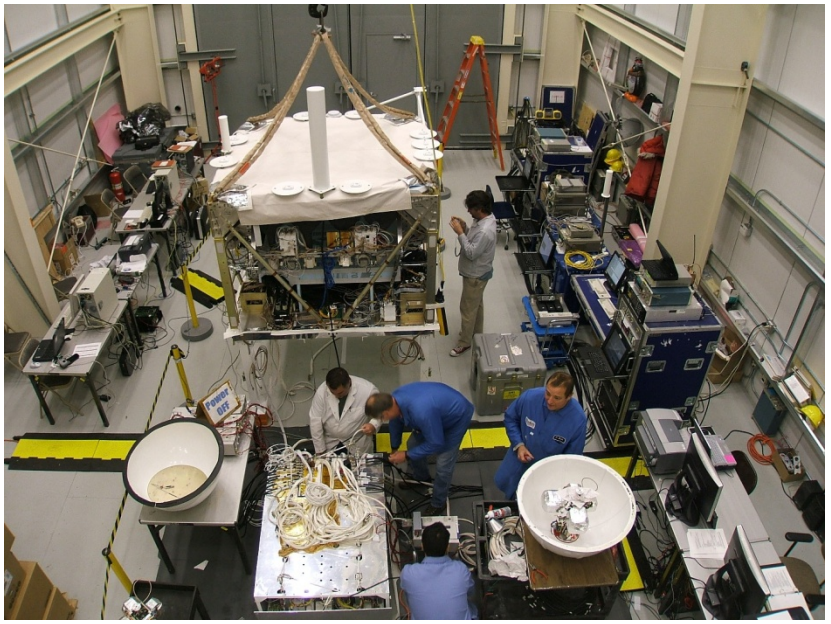


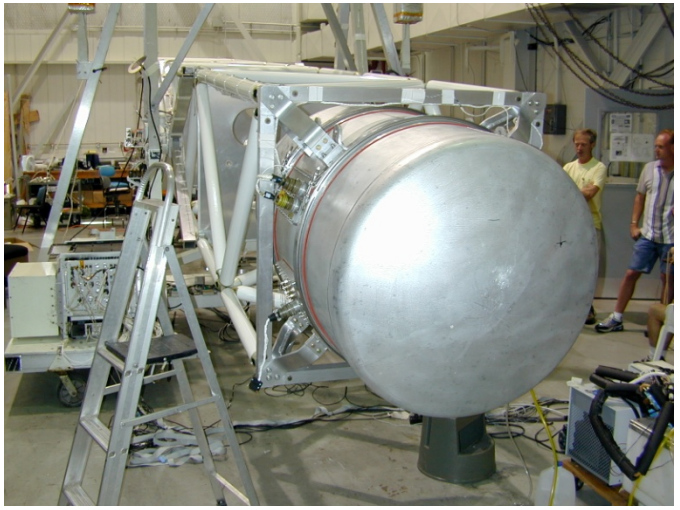
Next Stop: CSBF Palestine, Texas

- Columbia Scientific Balloon Facility
  - Works with the Science Teams to plan Campaigns and carry out Engineering support.
  - Supports Integration and Test

Payload Integration and Test

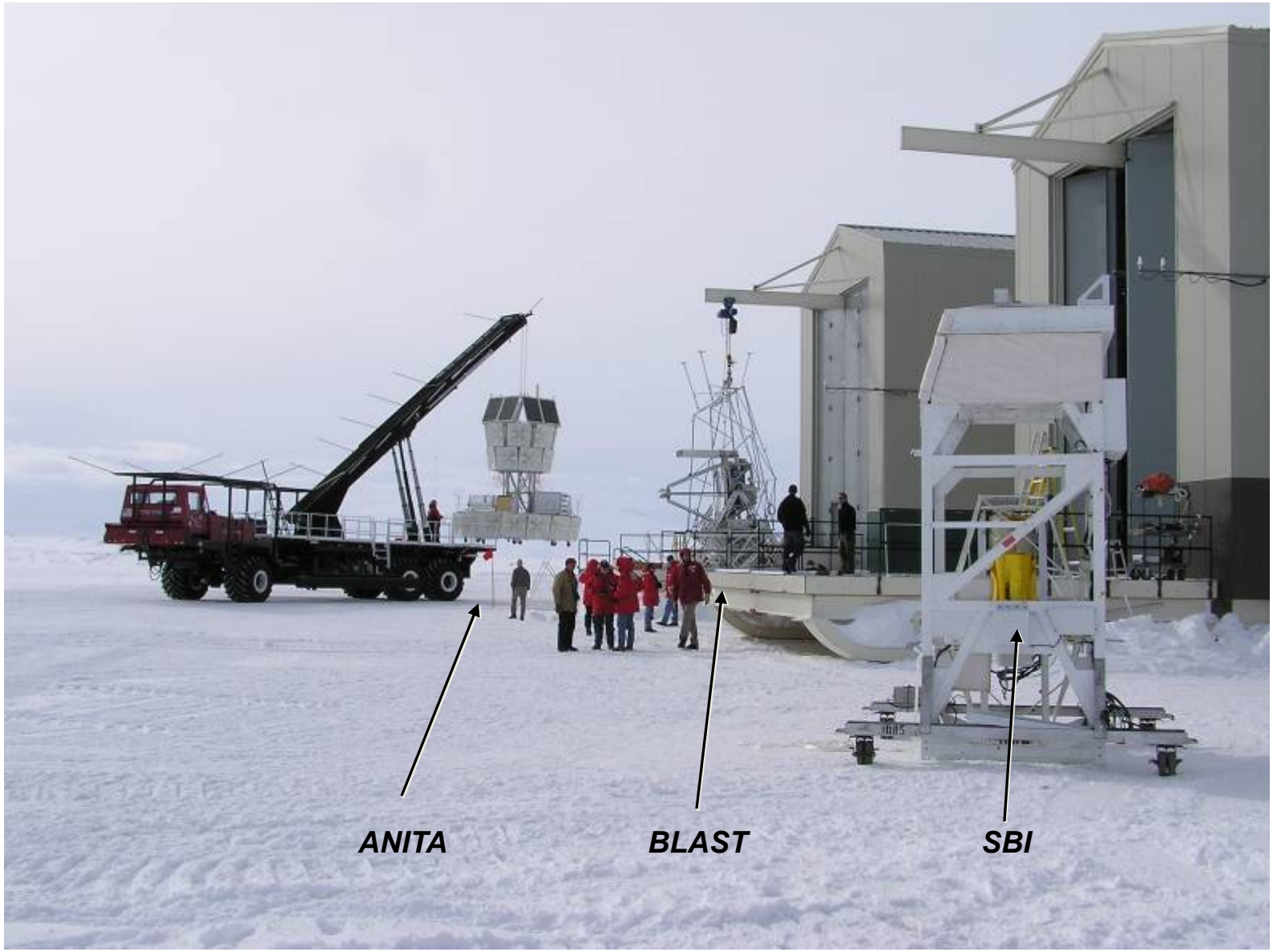
- Payload Integration & Test
  - Science teams arrive Palestine for integration and testing.
  - Solar array assembly completed
  - Hang Test /end to end testing
  - Payloads are shipped to campaign site





Arrival at the Williams Field Launch site

Processing Payloads for Launch



LDB/ULDB Operational Control Center

- Located at CSBF in Palestine, Texas
- Can support 3 LDB payloads in flight simultaneously
- Receipt and processing of telemetry
- Flight management
- Transferring experiment data to users
- Communications
- FAA Airspace coordination

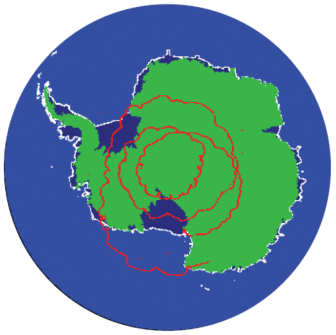
Antarctica is the Centerpiece of NASA Ballooning

•The Balloon Program has focused on expanding the highly successful LDB flights **OVER / AROUND** Antarctica.
  – Flight durations of up to 4-6 weeks.
  – Flight support to 3 payload flights every year.

• Frontier Astrophysics on Super-Pressure Balloons (SPB) will justify Ultra-Long Duration Balloon (ULDB) flights **FROM** Antarctica in the coming decade.

• ULDB flights from Antarctica yield long exposure: 60 days possible now; 100 days on the horizon.

• NASA is working with NSF/OPP to enable **flights to leave Antarctica** for recovery in South America, New Zealand, Australia, etc.



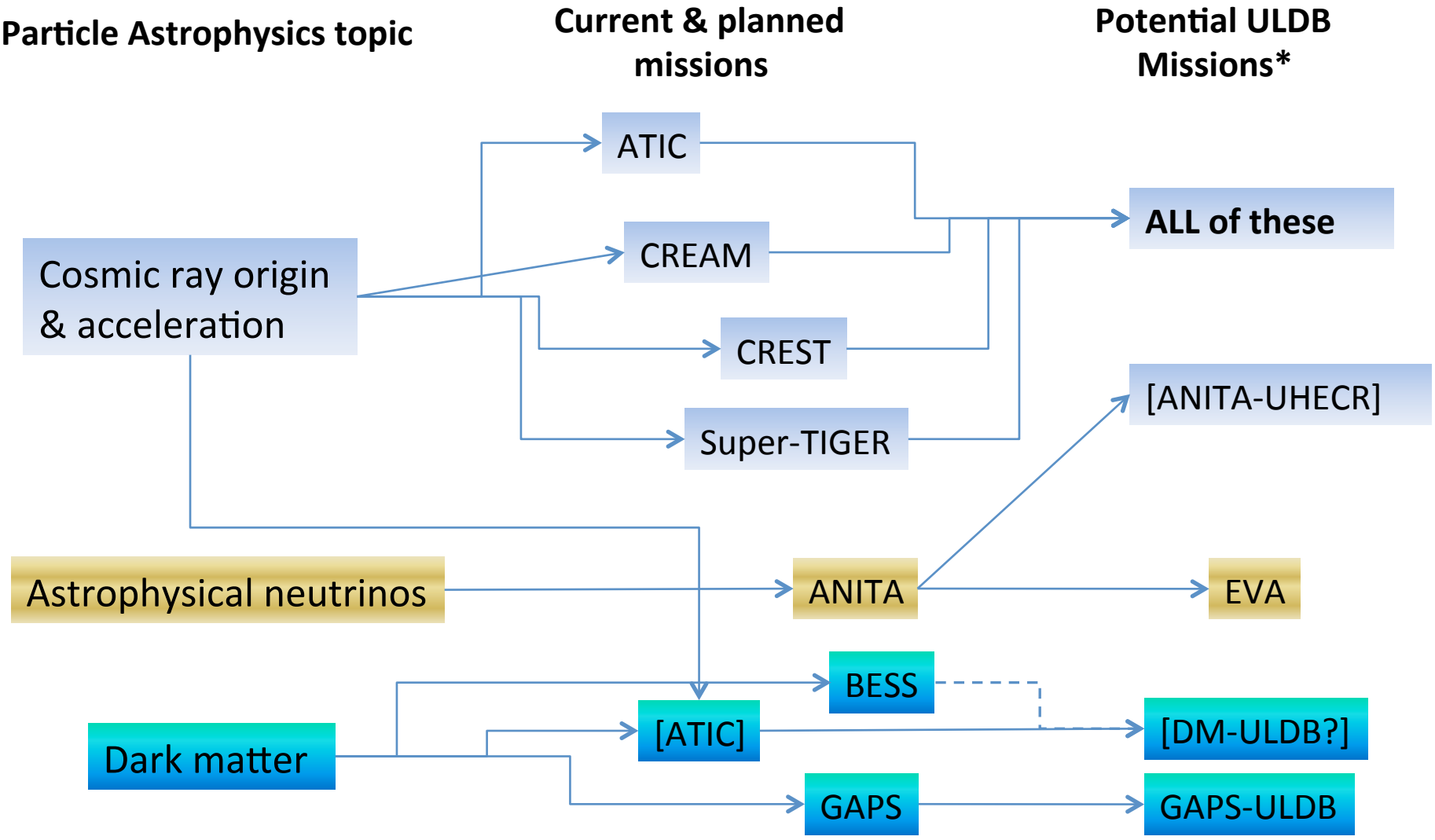
42-day CREAM flight
Dec - Jan 2004-05

Record 54-day SPB
flight Dec - Feb 2008-09

Evolution to Super Pressure Ballooning

- Long Duration Balloon (LDB) flights employing conventional zero-pressure balloons have a proven history of scientific discovery, with many cited achievements.
  - Most High Priority projects are proposing multiple LDB missions.
- Super-pressure balloons are a major technological advance.
  - They offer an order of magnitude increase in flight capability.
  - They enable Ultra Long Duration Balloon (ULDB) flights (60-100 days).
  - They open areas of exploration closed to zero-pressure balloons, e.g. LDB flights at mid-latitudes.
- Costs to convert LDB payloads for ULDB flights are modest.
  - Most LDB payloads can be upgraded for ULDB flights.
  - LDB and ULDB together form a science opportunity continuum.
- ULDB missions can be adapted quickly to new challenges.
  - They are ideally suited as a Small Explorer (SMEX) mission alternative.
  - They offer significant science at fraction of the cost of a space mission.

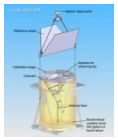
Particle Astrophysics & LDB/ULDB



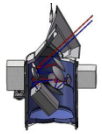
*ULDB defined as: Super-pressure balloon, >110,000ft, >60 days aloft, any latitude, up to 2000kg suspended mass

LDB/ULDB (non-Particle) Astrophysics Missions

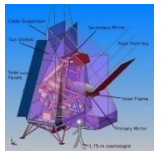
Science topic | **Science focus area** | **Potential ULDB Missions**



ARCADE → PIPER

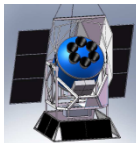


EBEX



Cosmic microwave BR

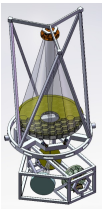
SPIDER



Big Bang Cosmology

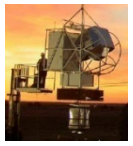
CMBR foreground sources → BLAST

Dark Energy → HALO

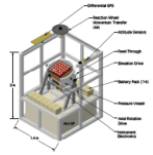


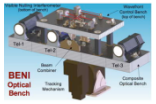
X-ray & γ-ray sources

Polarized emission, Nuclear lines → NCT



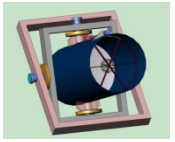
GRAPE



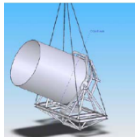


Astrobiology → **Exoplanets** → BENI

BEST

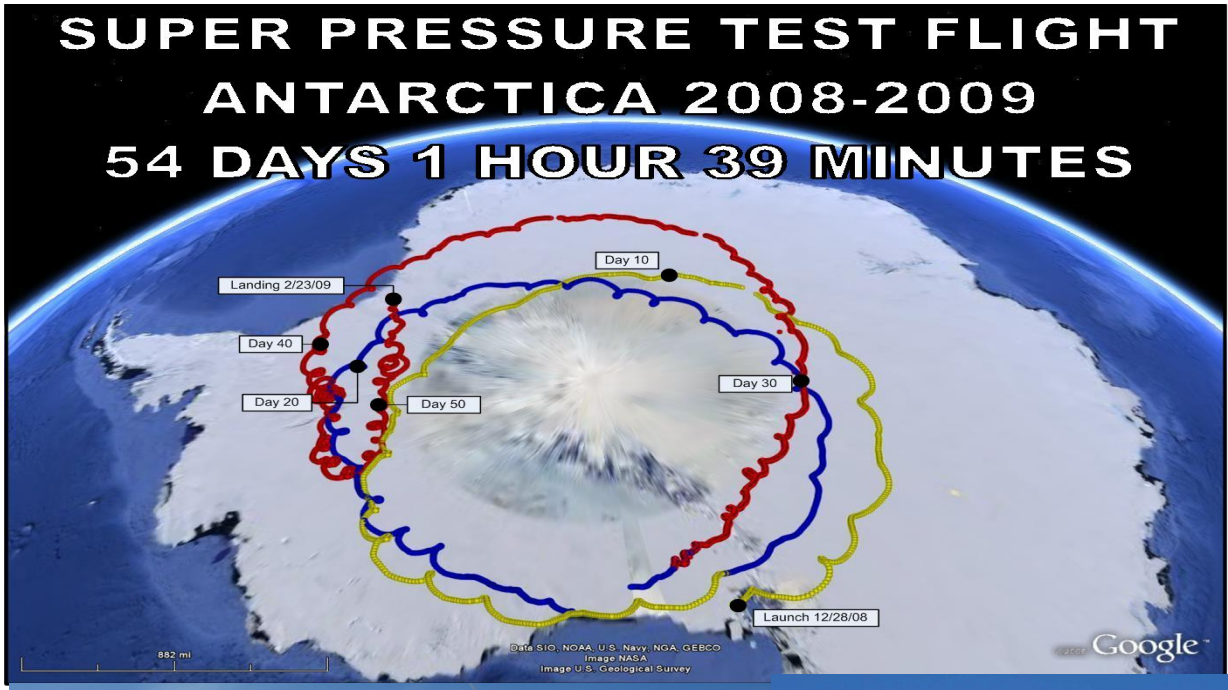


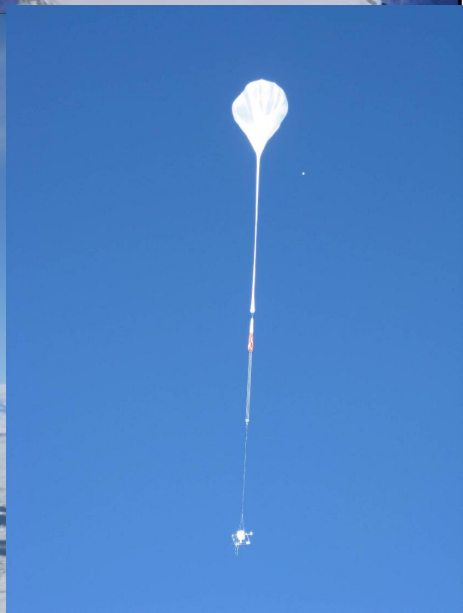
Planet Scope



2008-09 Super Pressure Balloon Test Flight

- 54 days of flight: Longest large NASA balloon flight ever.
- Balloon remained pressurized- no apparent gas loss: <u>It could have flown much longer...</u>
- At that time, it was the largest (7 MCF) super pressure balloon flown successfully.



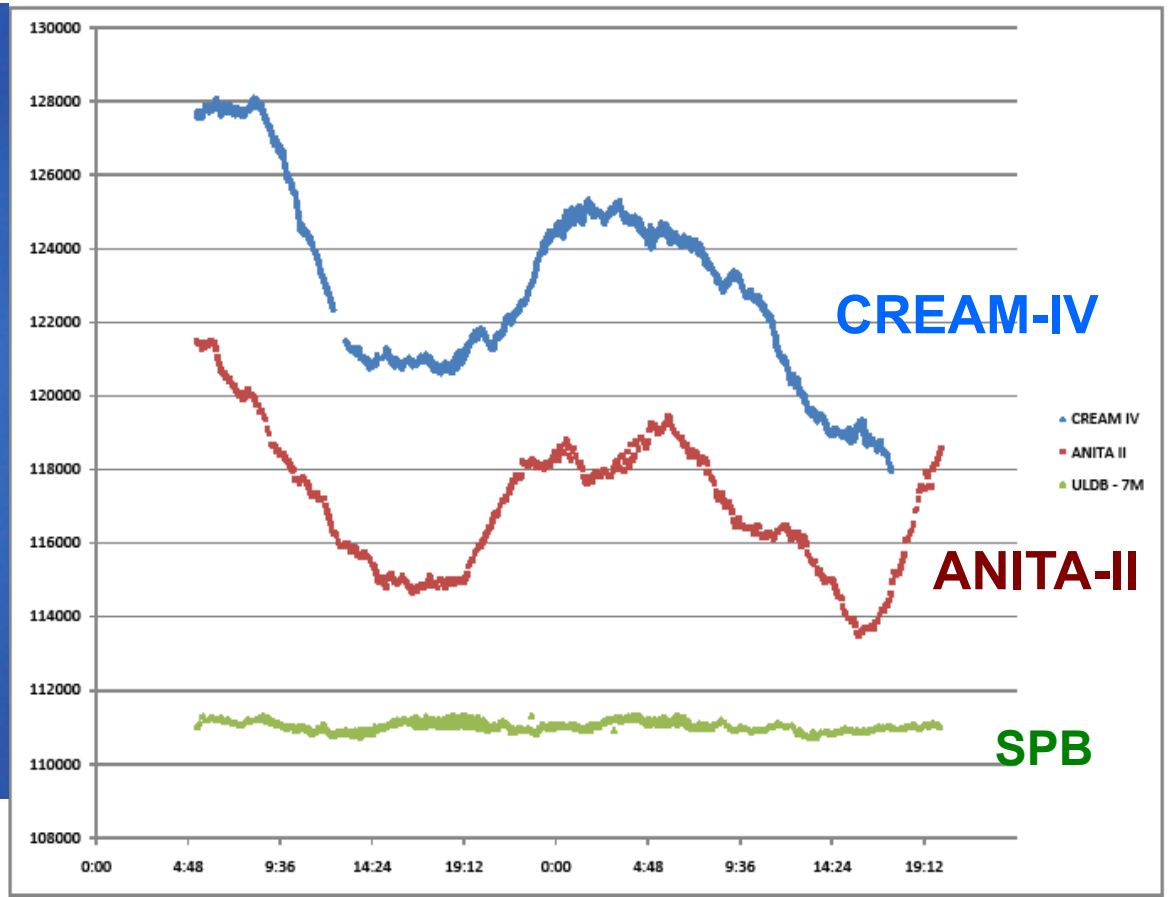


Super Pressure Balloon Development

Ultra-Long-Duration Balloon (ULDB) flights

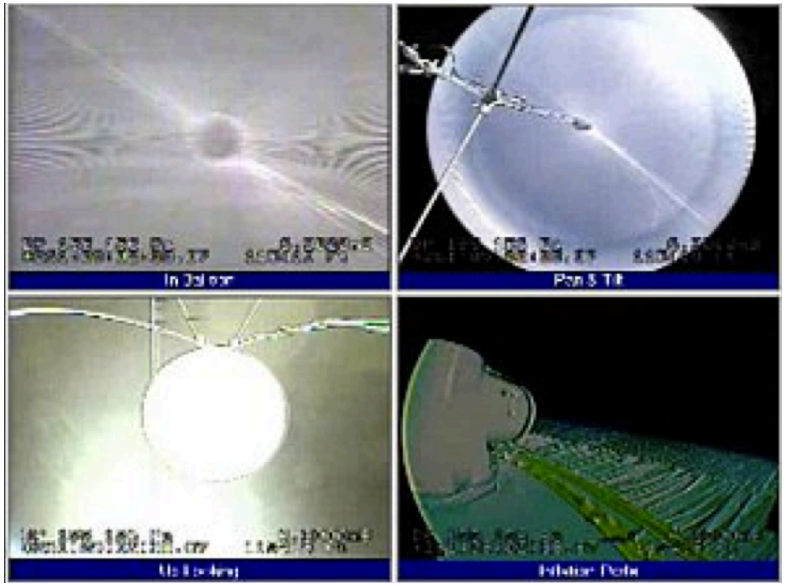
- Vented "Zero Pressure" balloons used in Antarctica are in equilibrium with the atmosphere, so the altitude changes with air temperature/pressure.
- Super pressure "Constant Volume" balloons maintain altitude stability, so they enable long-duration flights, even at mid-latitudes.

Photograph of the ANITA Vented Balloon at Float Altitude

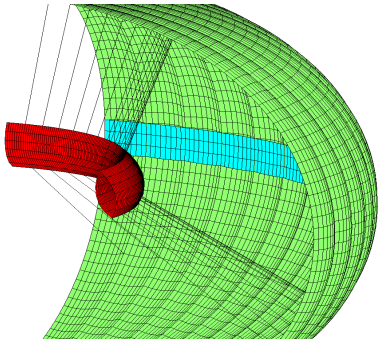


SPB Flight 631NT, 2012 August

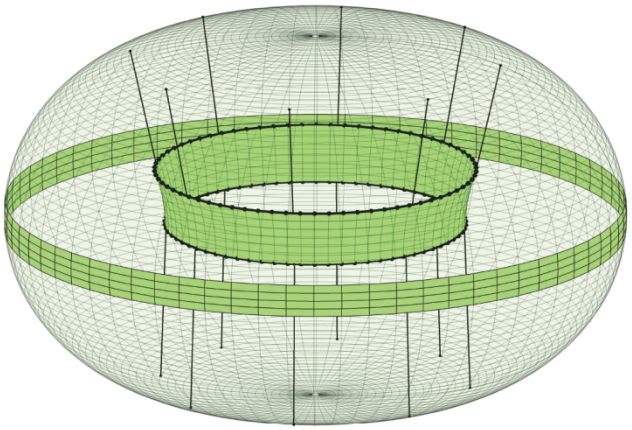
- 18M cubic feet (0.5M m^3) SPB
- Launched as Esrange, Sweden
- Successfully deployed at float, no clefting or other issues
- Short flight (for non-balloon reasons)
- This balloon is now considered part of available NASA inventory
- Explorer-class balloon missions of opportunity possible <u>now</u> for Antarctica
- Can carry a metric ton payload to ~ 5-6 mBar (~110-115Kft)

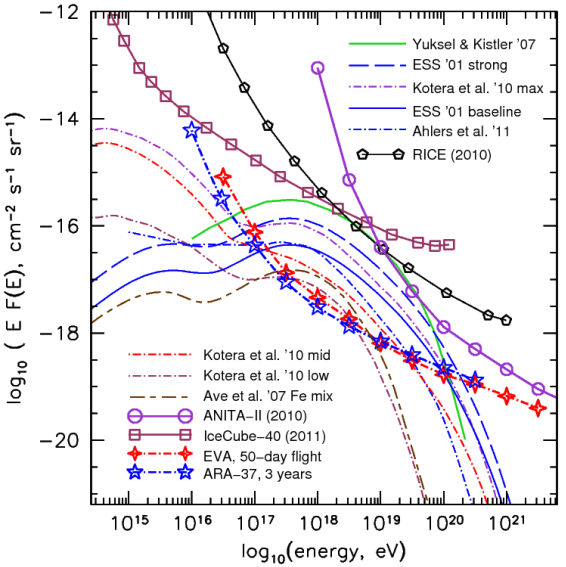


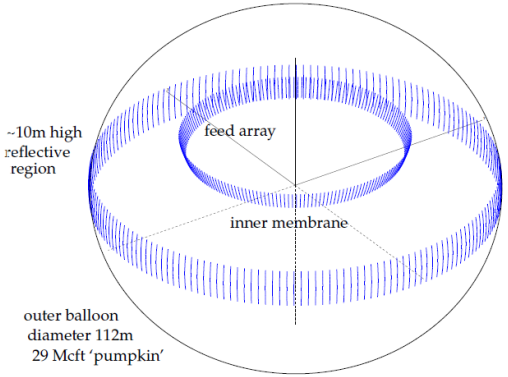
ExaVolt Antenna (EVA) SPB Mission

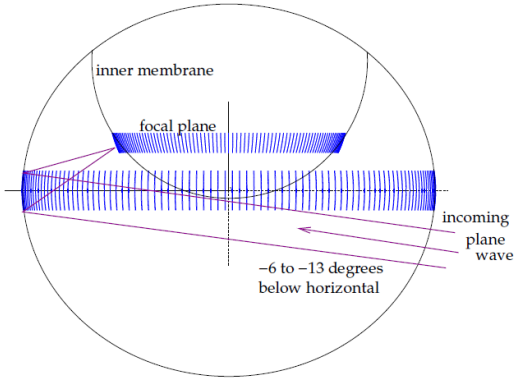


Finite Element models









Concept sketch

- **GOAL: UHE Neutrinos and cosmic rays via radio**
  - Relies on NASA super-pressure balloon technology
  - Gives balloon with stable shape and altitude
- Reflective band near equator = toroidal radio dish
  - Dish focal region is in balloon interior, requires an inner membrane for patch antenna feed array
- Gain simulations give 25-30 dBi even with fairly strong aberrations **(100x ANITA)**
  - This meets requirements for a large radio "light bucket"
  - 2π acceptance in azimuth
- **Current status: NASA technology development funding**

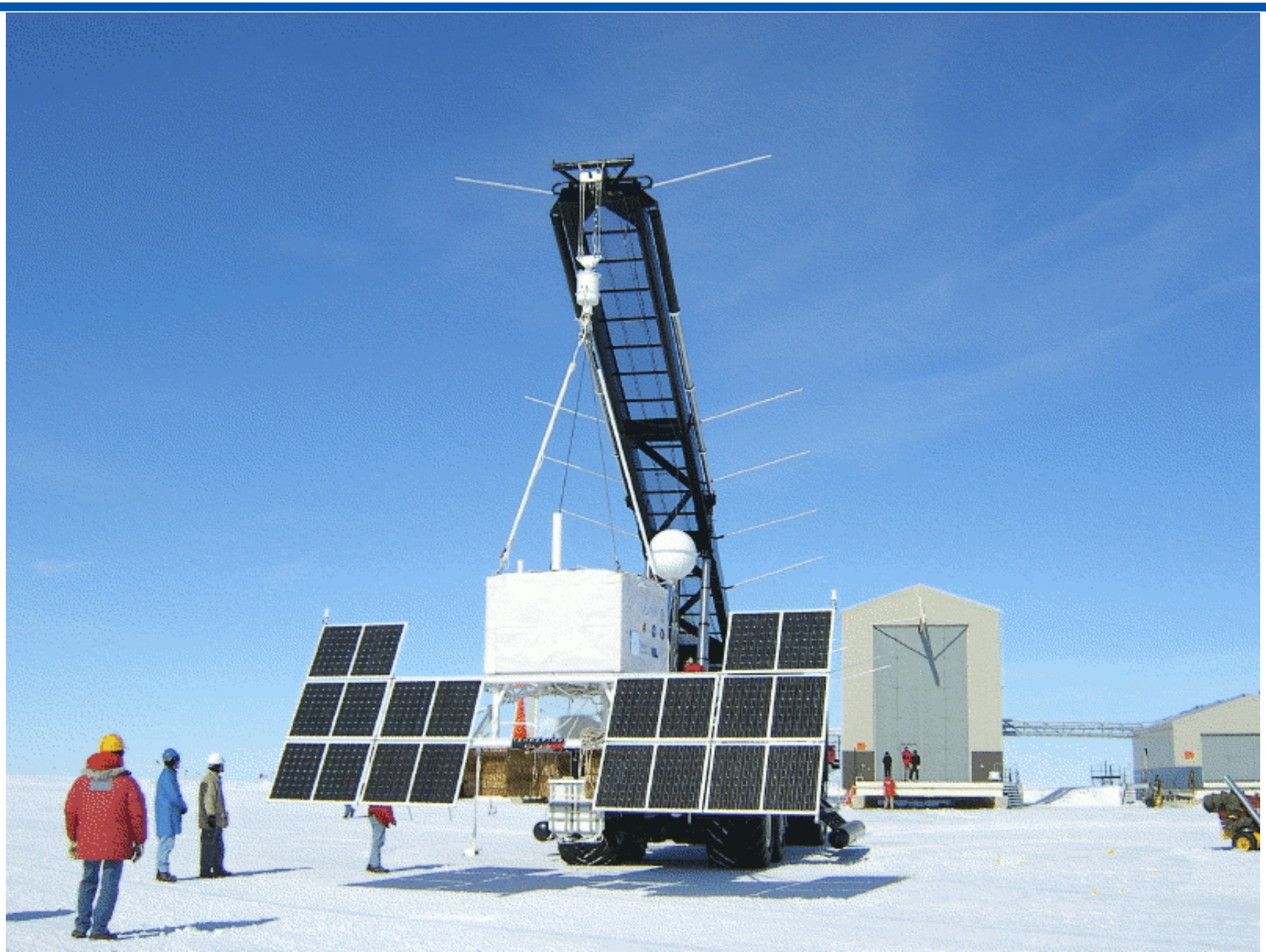
Concluding Remarks

- Balloons offer flight opportunities for unique science investigations that require, or can be done in, near-space.
  - Quick access to space at much less cost than orbital missions
- They play important roles in migrating bench top technologies to space flight readiness levels.
- They provide students with the hands-on hardware training crucial for developing the next generation of scientists and engineers.
  - Time from concept, to detector, to flight and data analysis is consistent with **pursuit of a graduate degree**
- Balloons and Sounding Rockets are the primary engines for generating scientists with the hardware and project management skills needed to lead new space missions.

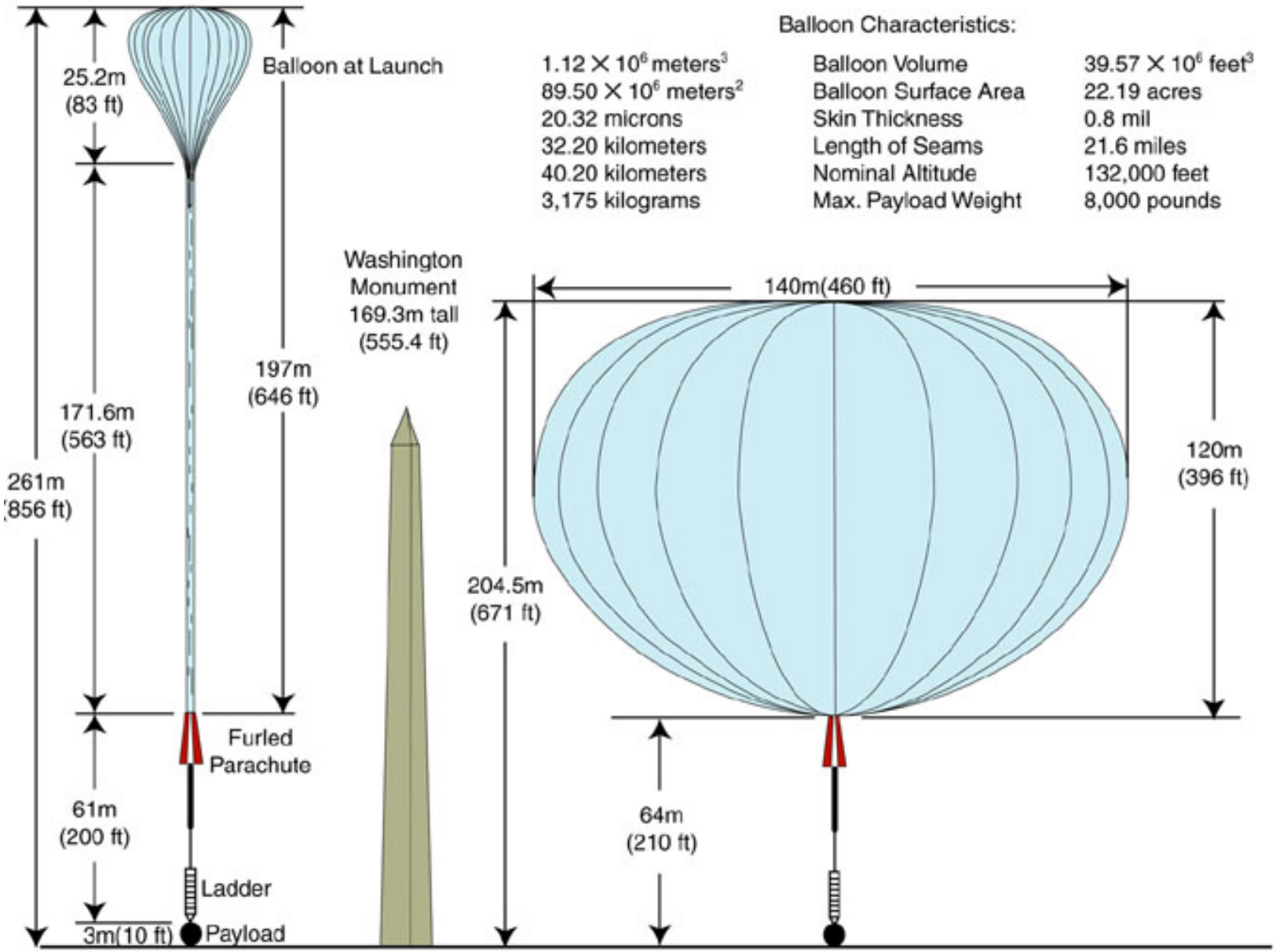
Acknowledgements
The NASA Balloon Program is a Partnership

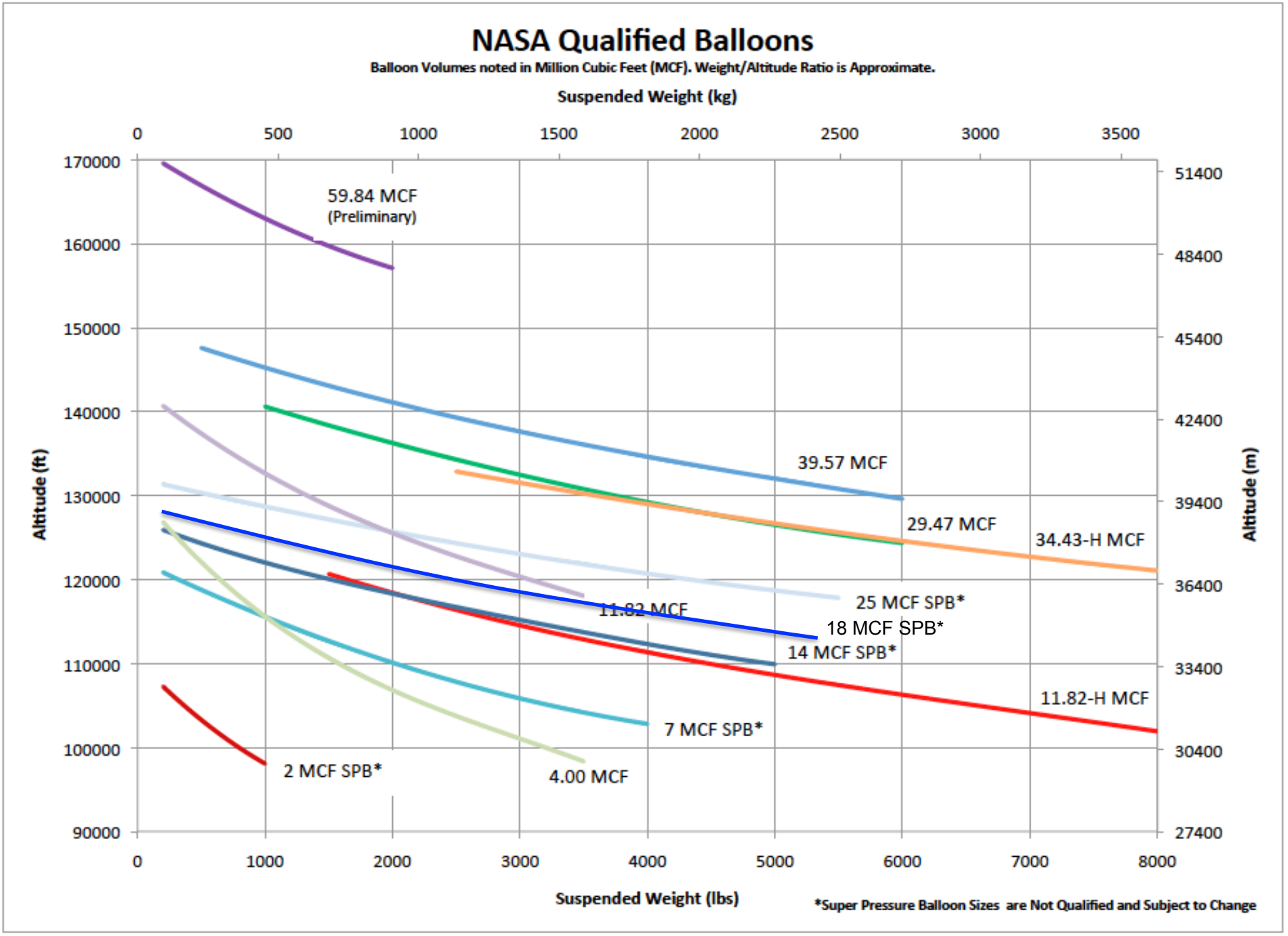
- Executive oversight of the NASA Balloon Program is provided by the Astrophysics Division, Science Mission Directorate, NASA Headquarters
- Implementation of the Balloon Program is delegated to the Goddard Space Flight Center Wallops Flight Facility (WFF) at Wallops Island, Virginia http://www.wff.nasa.gov/balloons
- Balloon flights are conducted by the Columbia Scientific Balloon Facility (CSBF) in Palestine, Texas http://www.csbf.nasa.gov/
- The CSBF is managed by the Physical Science Laboratory, New Mexico State University, under contract with WFF
- The balloons are manufactured by Raven Industries Aerostar Division in Sulfur Springs, Texas
- The Antarctic LDB program would not be possible without the crucial contribution of the U.S. National Science Foundation Office of Polar Programs and its support contractors in Antarctica

Key Events in a Balloon Launch Sequence

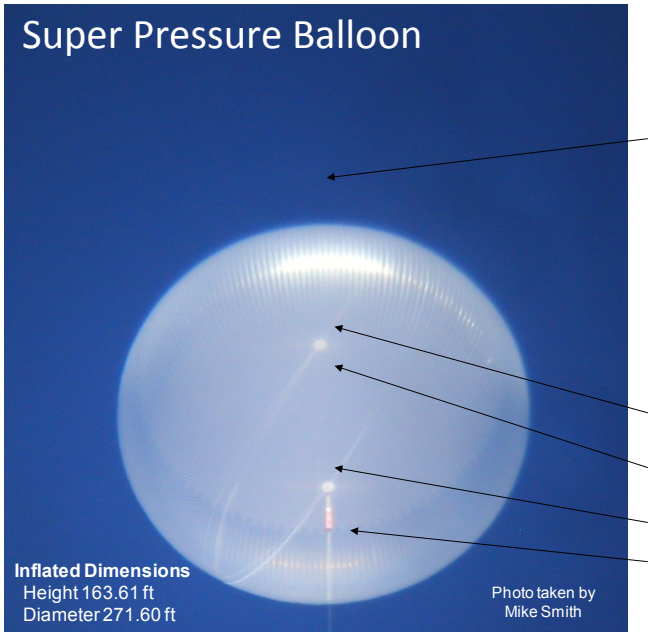


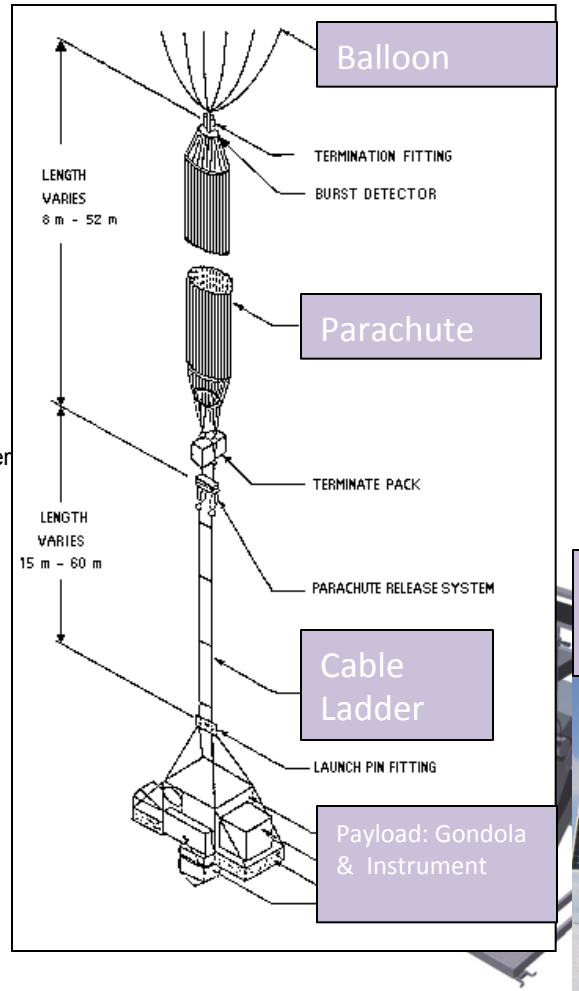
Scientific Research Balloons: How Big?

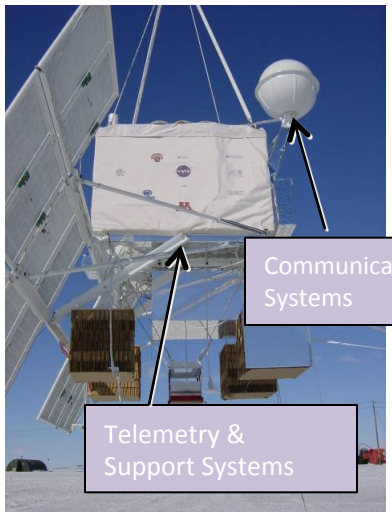


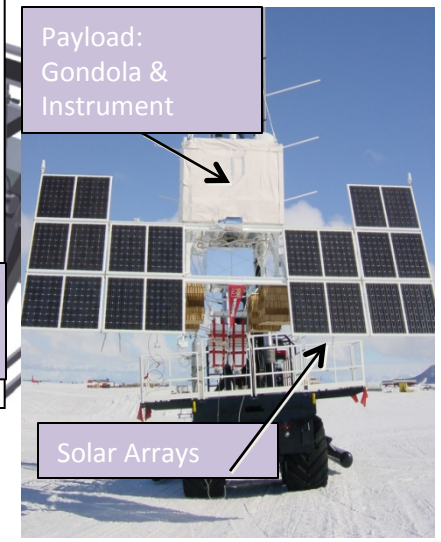

NASA Qualified Balloons
Balloon Volumes noted in Million Cubic Feet (MCF). Weight/Altitude Ratio is Approximate.
Suspended Weight (kg)
0
500
1000
1500
2000
2500
3000
3500
Altitude (ft)
170000
160000
150000
140000
130000
120000
110000
100000
90000
Altitude (m)
51400
48400
45400
42400
39400
36400
33400
30400
27400
59.84 MCF
(Preliminary)
39.57 MCF
29.47 MCF
34.43-H MCF
25 MCF SPB*
11.82 MCF
18 MCF SPB*
14 MCF SPB*
11.82-H MCF
7 MCF SPB*
2 MCF SPB*
4.00 MCF
0
1000
2000
3000
4000
5000
6000
7000
8000
Suspended Weight (lbs)
*Super Pressure Balloon Sizes are Not Qualified and Subject to Change

The ULDB & Wallops Arc-Second Pointer (WASP) System

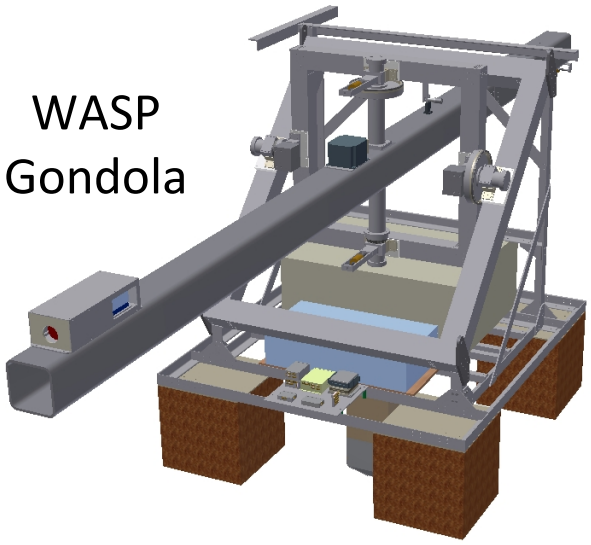




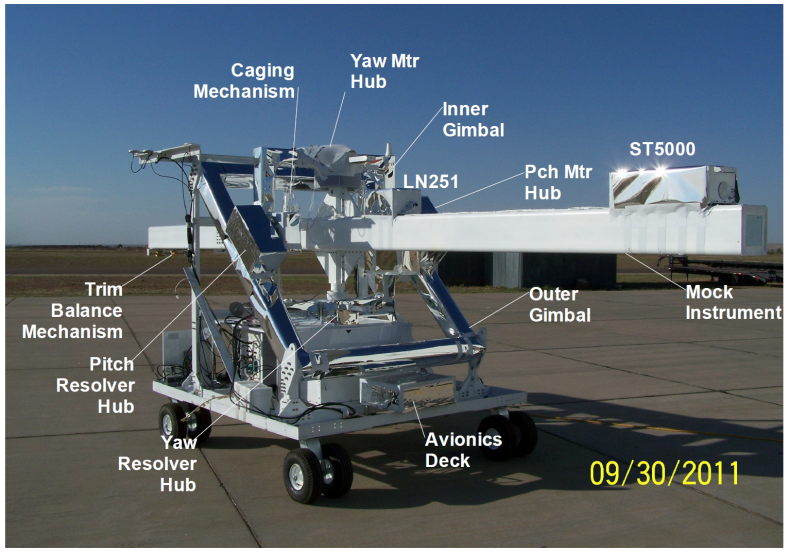
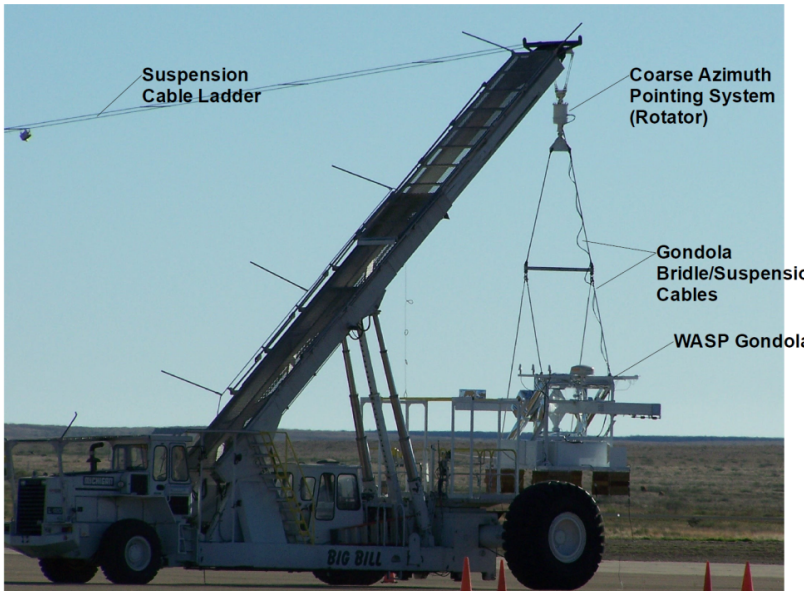




WASP
Gondola



NASA-provided ULDB flight systems are similar to current LDB flight systems

Wallops Arc Second Pointer (WASP) Project

- A WASP test flight was conducted from Ft. Sumner, N.M. on October 7, 2011. The flight duration was ~ 5 hours.
- The project team exercised the proto-type WASP system for ~ 2 hrs at float altitude of 102,000 ft (32 Km).
  - Demonstrated sub-arc second pointing stability with the mock telescope in a typical flight environment (Uncaged mock-instrument and pointed it inertially)
  - Inertial target offsets were issued from the ground to demonstrate science operations mode and target acquisition dynamics.
  - System was able to maintain arc-second pointing stability during discrete ground-commanded gondola azimuth adjustments.
  - Demonstrated operations concept for long-duration target observation