JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Dead Batteries In Antarctica

A Failure Cake Story!

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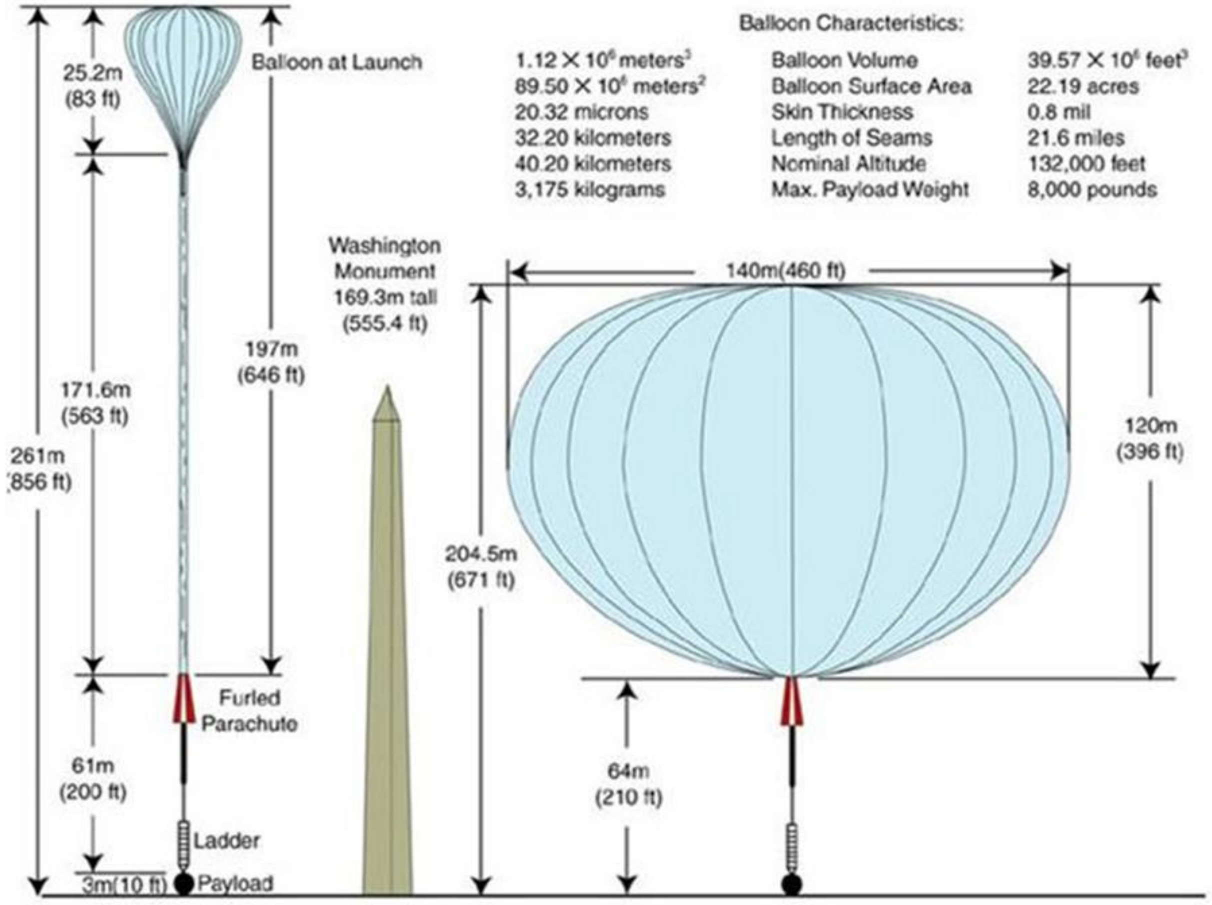
What is Scientific Ballooning?

- Science conducted in the Earth stratosphere using giant He filled balloons
- Science supported: Astrophysics, Heliophysics, Earth Sciences, Planetary Science
- APL and other institutions develop the scientific payloads and NASA provides the ride to the stratosphere

- NASA provided the balloons specification
  - 150 ft to 400 ft in diameter
  - 12 to 60 M feet3
  - Capable to carry up to 8000 lbs of payload
  - Fly between 100,000 and 130,000 ft altitude

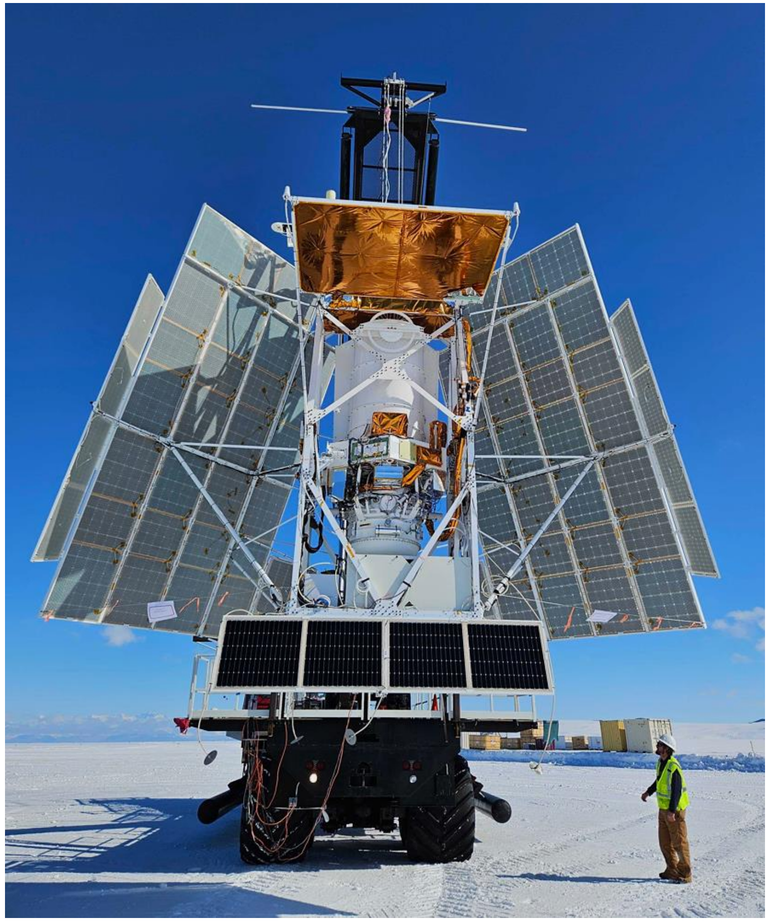
- NASA supported launch sites:
  - New Mexico for up to 1 day flights
  - Antarctica for 10 up to 50 days flights
  - Sweden: 4 to 7 days flights
  - New Zealand: 10 possibly up to 100 days flights



Courtesy NASA

Meet GUSTO!

- GUSTO: Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory
  - ULDB: Ultra Long Duration Balloon-borne



What is GUSTO?

- Far-infrared spectrometer in sub-orbital altitude to study the full life-cycle of the Interstellar medium
- End Product will be 3-dimensional maps of the Milky Way Galactic Plane and Large Magellanic cloud

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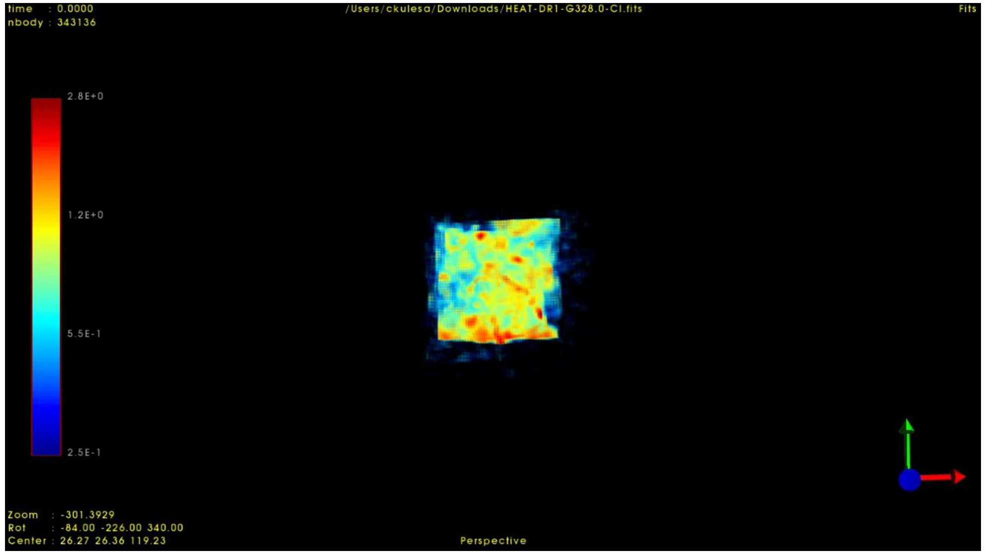
THE UNIVERSITY OF ARIZONA

NASA



GUSTO Mission Overview

Science Objectives

1. Determine the constituents and the life cycle of interstellar gas in the Milky Way
2. Witness the formation and destruction of star-forming clouds
3. Understand the dynamics and gas flow into and within the Galactic Center
4. Understand the interplay among star formation, stellar winds and radiation, and the structure of the interstellar medium in the Large Magellanic Cloud (LMC)
5. Construct Milky Way and LMC templates for comparison to distant galaxies.

GUSTO Highlights

Instrument

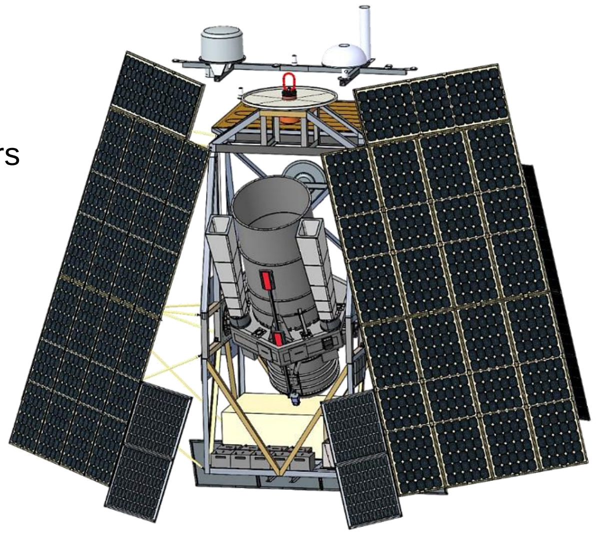
- 0.90-m telescope
- Terahertz heterodyne array receivers
- Cryostat cooled detectors

Gondola

- 2.5 axis stabilized pointing
- Active cooling system
- Solar powered

Launch site

- McMurdo Stn. Antarctica



Key Mission Requirements

Mission Design Life	**75 day Baseline, 55 day Threshold**
Altitude	**Sub-orbital, nominal 33.2 km**
Launch Vehicle	**Zero Pressure Balloon (ZPB)**
Observatory Mass	**1,600 kg maximum**
Power Usage	**850 W minimum average**
Data Downlink	**300 kbps minimum average**
Storage	**1.6 TB**

Mission Programmatics

$47.516M Cost Cap
Project Category 3, Risk Class D streamlined
31 December 2023, launch readiness date
Sponsored by NASA-GSFC Explorers Program Office

Instrument:	University of Arizona (UA)
Gondola:	Johns Hopkins Applied Physics Lab (APL)
Mission Operations:	APL
Science Operations:	UA

PI/DP:	Christopher Walker/Craig Kulesa, UA
Project Manager:	Kieran Hegarty, APL
Mission System Engr.:	Pietro Bernasconi, APL

GUSTO Block Diagram

Science Payload (Responsibility: UA)

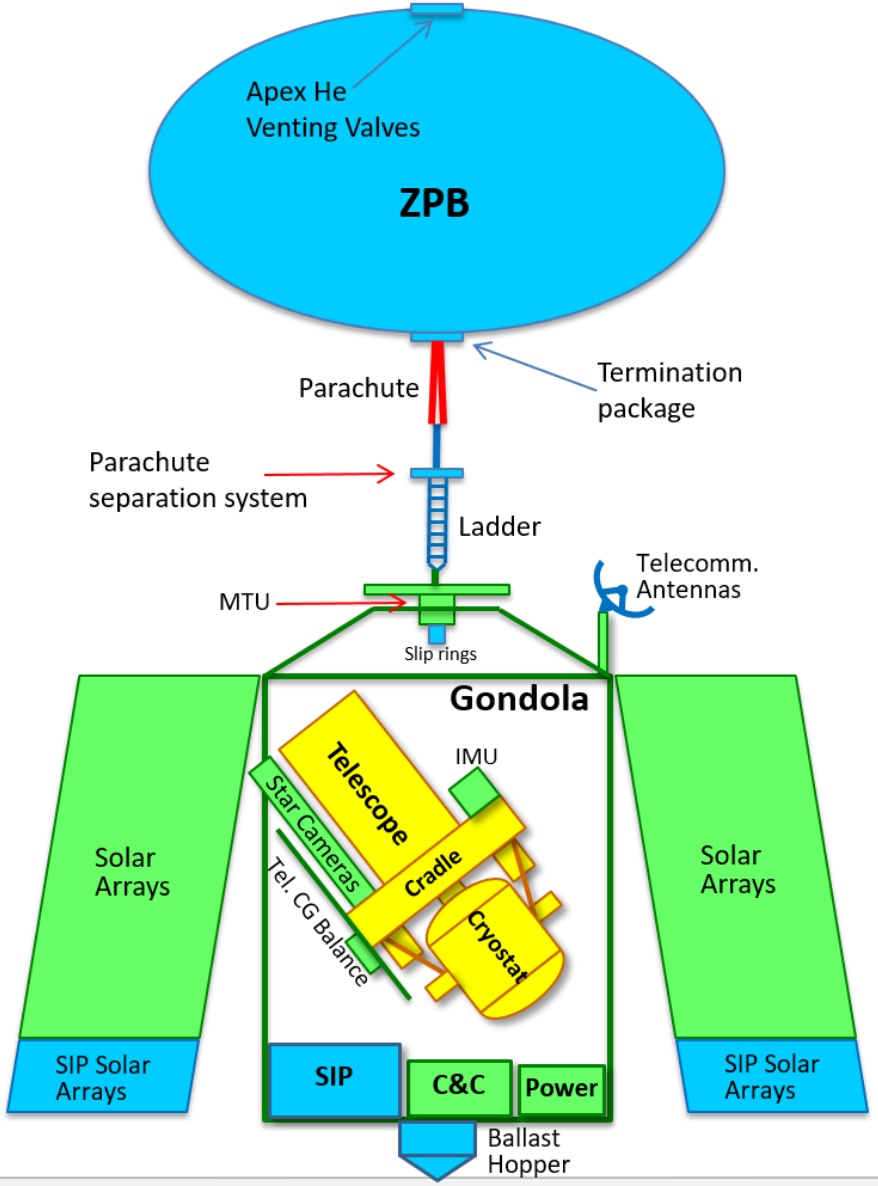
- Payload Development
- Telescope operations
- Cryostat operation
- Detector system & spectrometers
- Payload control & data processing
- Payload thermal management

Gondola (Responsibility: APL)

- Gondola Development
- Observatory I&T
- Command & Data Handling
- Pointing control
- Observatory Power
- Gondola thermal management
- Payload liquid cooling

ZPB (Responsibility: NASA-BPO/CSBF)

- Balloon and related Subsystems
- Launch
- Balloon Control & Monitoring
- Telecommunications System
- SIP System Power & Thermal Management
- Ballooncraft Navigation & Tracking
- Termination & Recovery

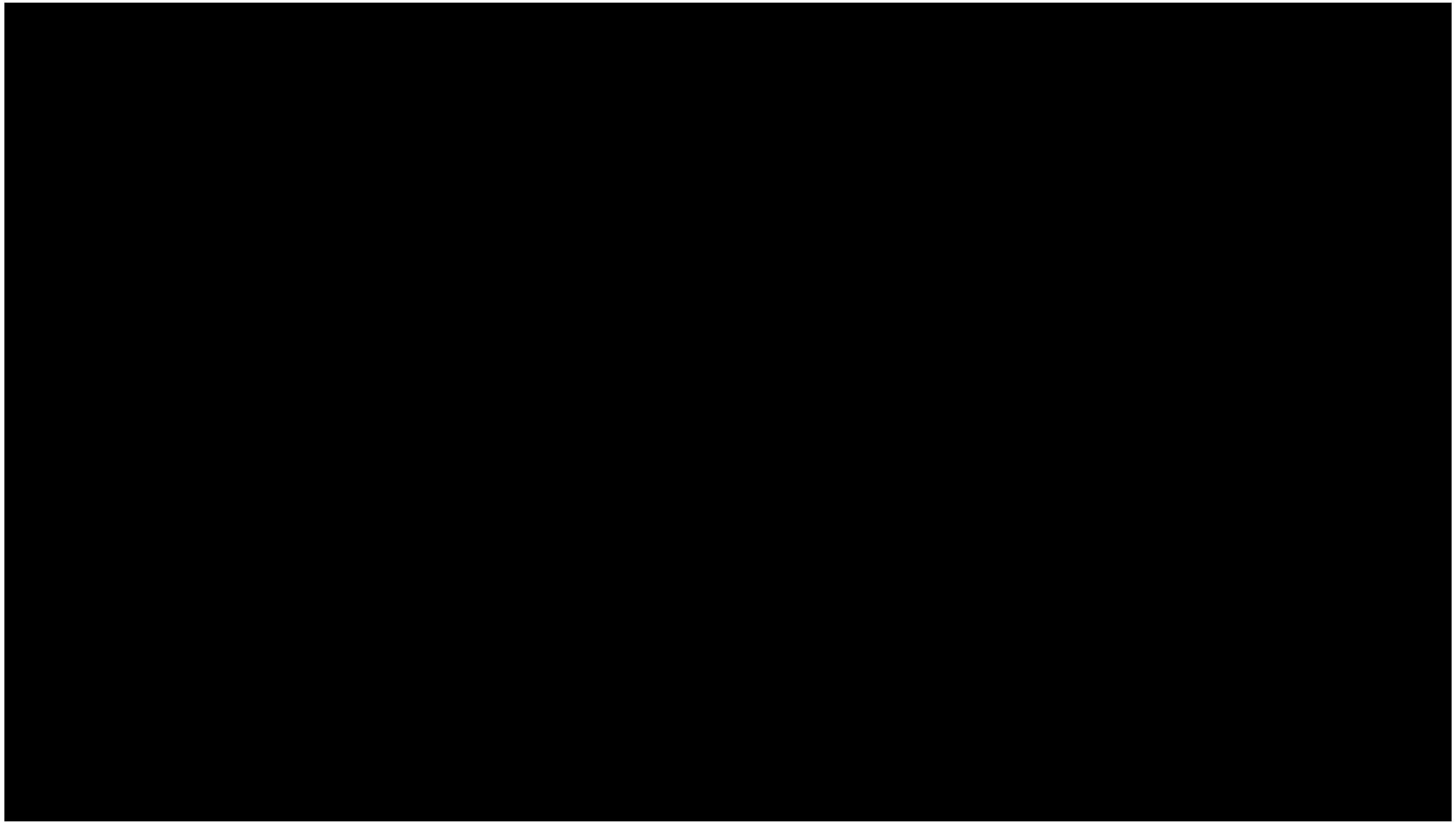


The Batteries

- GUSTO uses 8 X COTS Batteries
  - Nominal Capacity: 82 Ah each
  - Nominal Voltage: 25.5V each
  - Energy: 2.1 kWh each

Relevance To This Audience

- Class D
- Low Cost
- High Risk
- Novel Development



GUSTO I&T Flow

- Gondola I&T at JHU/APL
- Payload I&T at University of Arizona → ship to JHU/APL for integration with gondola
- Observatory functional and performance testing at JHU/APL
- Observatory shipped from JHU/APL to Columbia Scientific Ballooning Facility (CSBF) Palestine, Texas by truck
- Observatory shipped from CSBF to Fort Hood, Texas via truck; then via C-130 to Christchurch, New Zealand; then via C-130 to McMurdo, Antarctica
  - All goods imported into NZ between September 1st and April 30th must be fumigated for pests
  - >2 weeks to get from CSBF to Antarctica

- In preparation for travel from CSBF to Antarctica, the 9 flight batteries (+1 spare) were partially discharged…

- Requirement to discharge batteries driven by transportation safety requirement

CODE OF FEDERAL REGULATIONS

Title 49

Transportation

Parts 1 to 99

Revised as of October 1, 2023

Containing a codification of documents of general applicability and future effect

As of October 1, 2023

Published by the Office of the Federal Register National Archives and Records Administration as a Special Edition of the Federal Register

§ 172.102 49 CFR Ch. I (10–1–23 Edition)

acid, stabilized, classified as UN 3107 Organic peroxide type E, liquid or UN 3109 Organic peroxide type F, liquid may be fitted with a vent consisting of hydrophobic membrane, provided:

(1) Each inner packaging contains not more than 70 mL;

(2) The inner packaging is designed so that the vent is not immersed in liquid in any orientation;

(3) Each inner packaging is enclosed in an intermediate rigid plastic packaging with a small opening to permit release of gas and contains a buffer that neutralizes the contents of the inner packaging in the event of leakage;

(4) Intermediate packagings are packed in a fiberboard box (4G) outer packaging;

(5) Each outer packaging contains not more than 1.4 L of liquid; and

(6) The rate of oxygen release from the outer packaging does not exceed 15 mL per hour.

b. Such packages must be transported on cargo aircraft only. The requirements of §§ 173.24(g)(1) and 173.27(c) do not apply.

A82 The quantity limits in columns (9A) and (9B) do not apply to human or animal body parts, whole organs or whole bodies known to contain or suspected of containing an infectious substance.

A100 Lithium ion cells and batteries must be offered for transport at a state of charge not exceeding 30 percent of their rated capacity. Lithium ion cells and batteries at a state of charge greater than 30 percent of their rated capacity may only be transported under conditions approved by the Associate Administrator in accordance with the requirements in 49 CFR part 107, subpart H. Guidance and methodology for determining the rated capacity can be found in sub-section 38.3.2.3 of the UN Manual of Tests and Criteria (IBR, *see* § 171.7 of this subchapter).

A101 In addition to the applicable requirements of § 173.185, the quantity of lithium metal in the batteries contained in any piece of equipment must not exceed 12 g per cell and 500 g per battery.

A105 a. This entry applies to machinery or apparatus containing hazardous materials as a residue or as an integral element of the machinery or apparatus. It must not be used for machinery or apparatus for which a proper shipping name already exists in the § 172.101 Table.

b. Where the quantity of hazardous materials contained as an integral element in machinery or apparatus exceeds the limits permitted by § 173.222(c)(2), and the hazardous materials meet the provisions of § 173.222(c), the machinery or apparatus may be transported by aircraft only with the prior approval of the Associate Administrator.

A112 Notwithstanding the quantity limits shown in Column (9A) and (9B) for this entry, the following IBCs are authorized for transportation aboard passenger and cargo-only aircraft. Each IBC may not exceed a maximum net quantity of 1,000 kg:

a. Metal: 11A, 11B, 11N, 21A, 21B and 21N

b. Rigid plastics: 11H1, 11H2, 21H1 and 21H2

c. Composite with plastic inner receptacle: 11HZ1, 11HZ2, 21HZ1 and 21HZ2

d. Fiberboard: 11G

e. Wooden: 11C, 11D and 11F (with inner liners)

f. Flexible: 13H2, 13H3, 13H4, 13H5, 13L2, 13L3, 13L4, 13M1 and 13M2 (flexible IBCs must be sift-proof and water resistant or must be fitted with a sift-proof and water resistant liner).

A189 Except where the defining criteria of another class or division are met, concentrations of formaldehyde solution:

a. With less than 25 percent but not less than 10 percent formaldehyde, must be described as UN3334, Aviation regulated liquid, n.o.s.; and

b. With less than 10 percent formaldehyde, are not subject to this subchapter.

A191 Notwithstanding the Division 6.1 subsidiary risk for this description, the toxic subsidiary risk label and the requirement to indicate the subsidiary risk on the shipping paper are not required for manufactured articles containing less than 5 kg (11 pounds) of mercury.

A200 These articles must be transported as cargo and may not be carried aboard an aircraft by passengers or crewmembers in carry-on baggage, checked baggage, or on their person unless specifically authorized in § 175.10.

A210 This substance is forbidden for transport by air. It may be transported on cargo aircraft only with the prior approval of the Associate Administrator.

A212 ''UN 2031, Nitric acid, *other than red fuming, with more than 20% and less than 65% nitric acid*'' intended for use in sterilization devices only, may be transported on passenger aircraft irrespective of the indication of ''forbidden'' in columns (9A) of the § 172.101 table provided that:

a. Each inner packaging contains not more than 30 mL;

b. Each inner packaging is contained in a sealed leak-proof intermediate packaging with sufficient absorbent material capable of containing the contents of the inner packaging;

c. Intermediate packagings are securely packed in an outer packaging of a type permitted by § 173.158(g) of this subchapter which meet the requirements of part 178 of this subchapter at the Packing Group I performance level;

d. The maximum quantity of nitric acid in the package does not exceed 300 mL; and

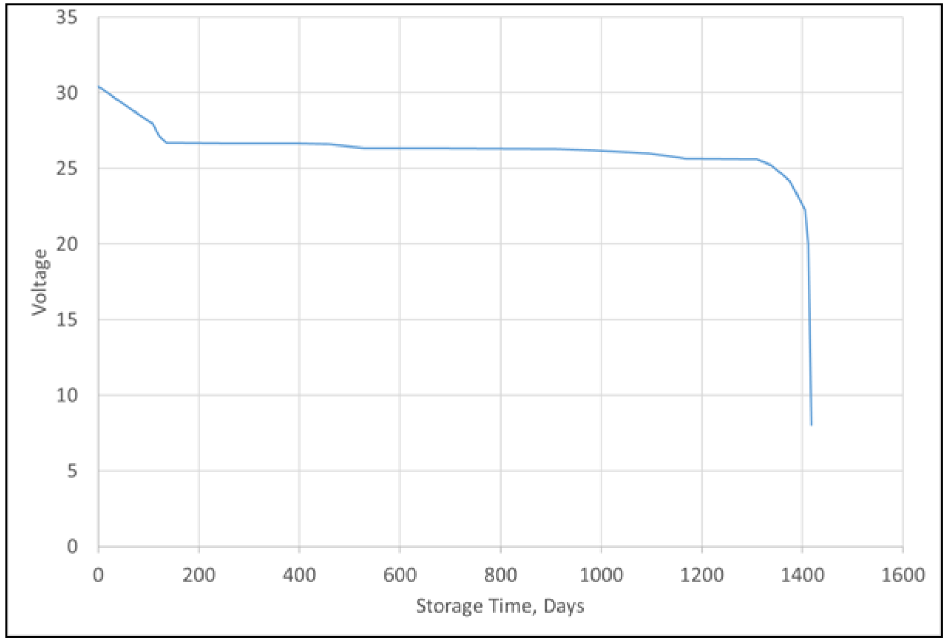
Flight Batteries Were Discharged During Preparation to Ship To Antarctica

- Battery supplier's recommendations at the time:
  - "Ensure the battery is at the proper state of charge (SOC) per the U.S. Department of Transportation (DOT) approval form."

- As a precaution, when discharged for transport, the batteries were discharged to about 20% SOC since the battery user's manual did not specify a minimum SOC and does not discuss what happens to the battery SOC when in storage
  - Team thought that a 20% SOC was a very safe state to discharge the batteries as it complies with the DOT requirements and does not conflict with the instructions in the battery supplier's user manual
  - **20% SOC = 22V**
  - Same approach was used before shipment from APL to CSBF (much shorter transit time)
  - This configuration, at this state of charge for the time duration of the trip from CSBF to Antarctica was not tested or verified on the ground

What Happened And Why Is This A Failure Story

- Upon arrival in Antarctica, flight batteries would not enable
- Battery supplier advised that they ship their product below 30% state of charge at ~26V
  - They advised us that our depletion to 22V was ~1% SOC; insufficient to power the internal battery management system
  - Following curve provided after the batteries would not enable in Antarctica (had it been provided earlier, the issue would have likely never occurred):

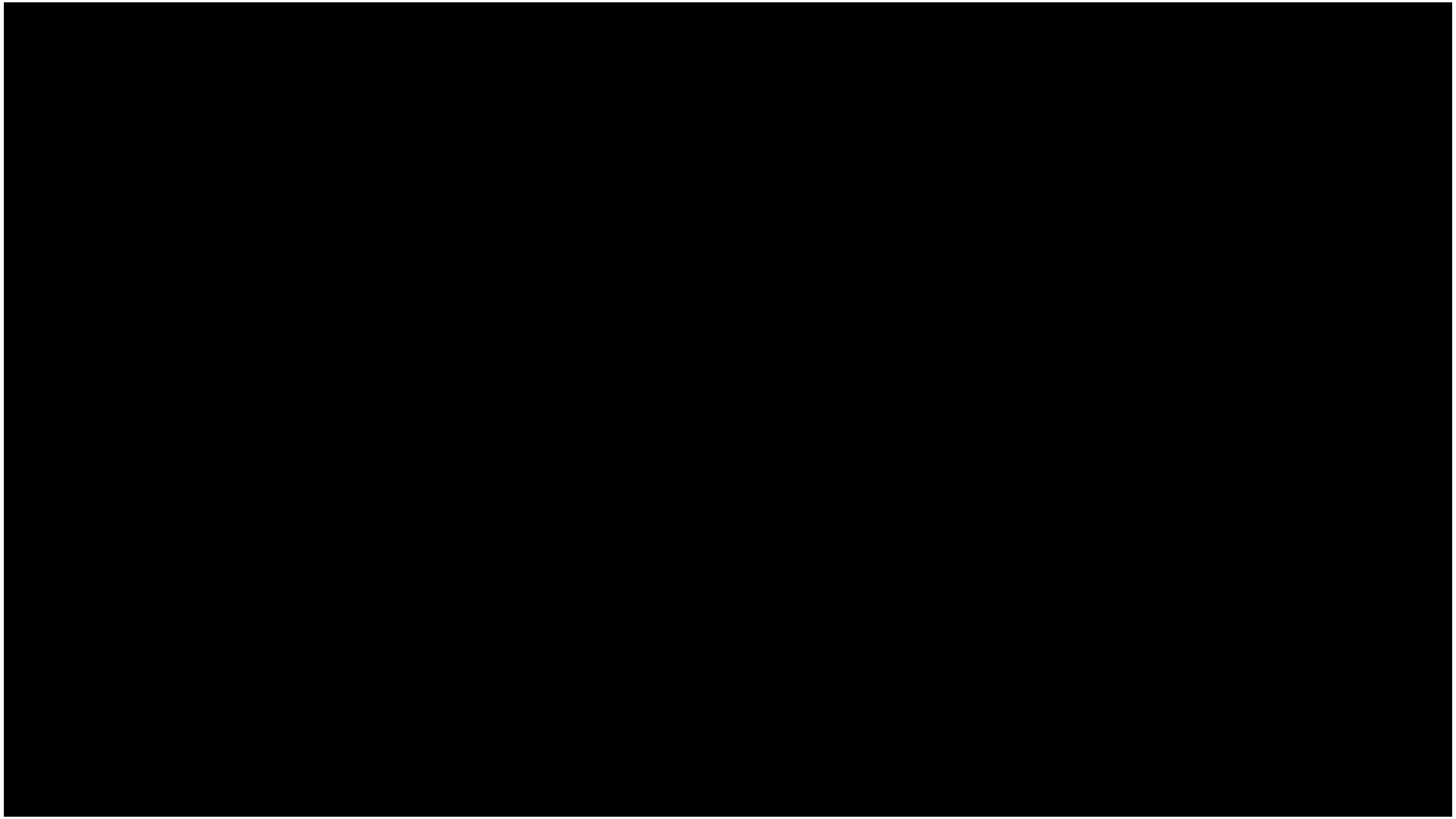


- Interesting note: While trying to understand the behavior of our flight batteries, we learned that a PI at a different institution had a similar experience during COVID, where batteries became unrecoverable after a long period of storage…

The Recovery…

- New flight batteries ordered from OEM…(they had needed quantity in stock!)…
- Shipped at 30% state of charge…
- Transported to Antarctica by NASA aircraft…(at a significant expense)…
- Provided to team…
- Integrated onto gondola…
- Launch occurred just after midnight on 31-Dec-2023…

GUSTO Launch!



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