High Altitude Balloon Science

CUUG GM

M. Patrick
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About Me

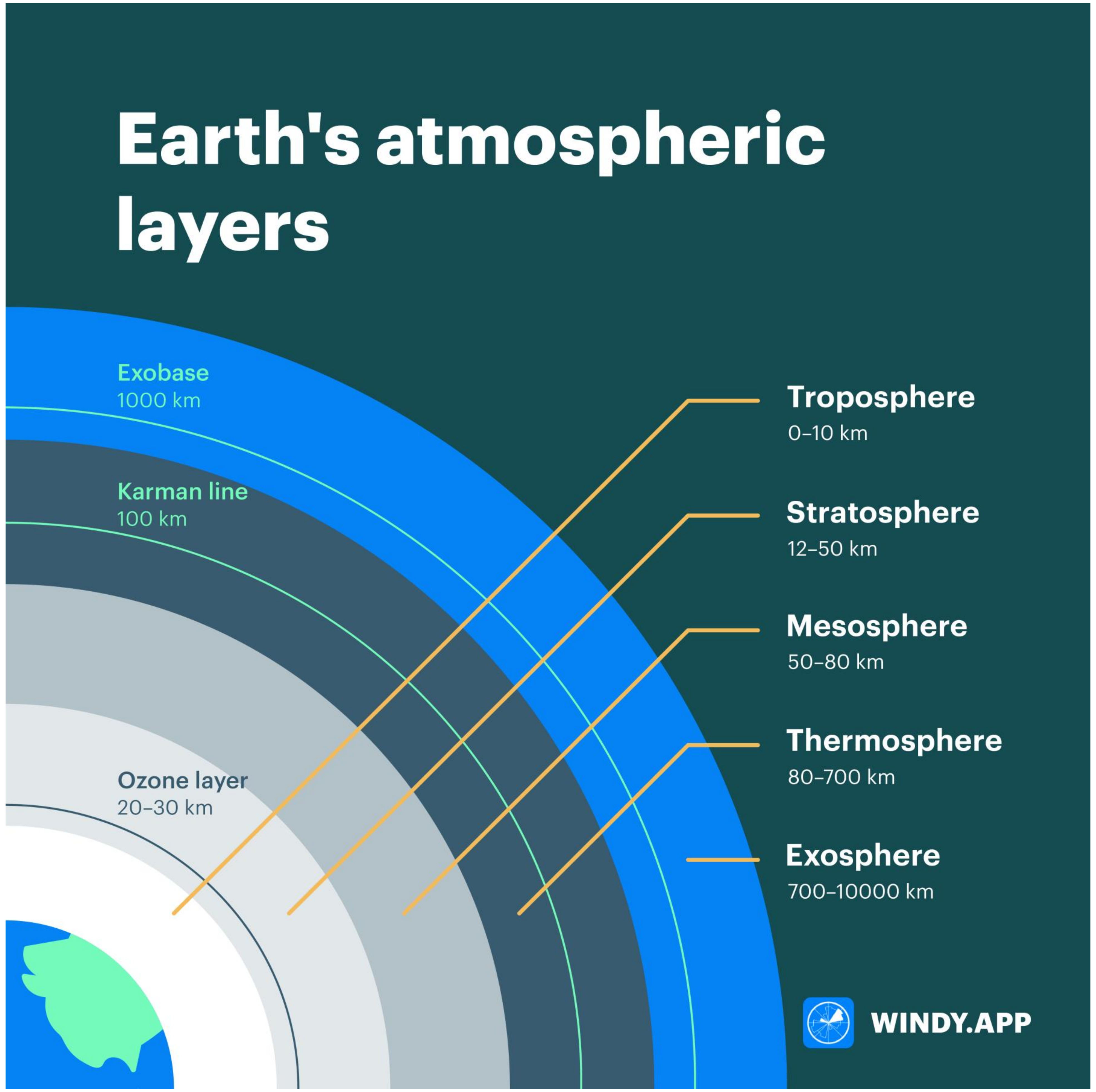
- Physicist, Data Scientist (CHEP Canada)
- Linux user since ~2007
- Research interests: space weather, radiation belts, high altitude balloons
- Work: IoT, radio, graph theory, machine learning
- Hobbies: packet radio, rocketry, teaching

Outline

- Balloons
    - types
    - applications (science, spying)
    - capabilities
- Stories
    - Things that worked (NASA and CSA flights)
    - Things that didn't (rockoons)
    - Things that (really) didn't: F22's, F18's and UFOs
- Lessons learned and project ideas
    - Cheap suborbital sounding rockets
    - Global mesh network

Balloons 101

- Giant membrane structures filled with hydrogen or helium
- Payload suspended beneath
- Sizes range from party balloon (pi-ball / pilot balloons), to stadium sized
- Key property: lift $payload really high (34 km+) for a long time
- Fly above most of the atmosphere (by mass)

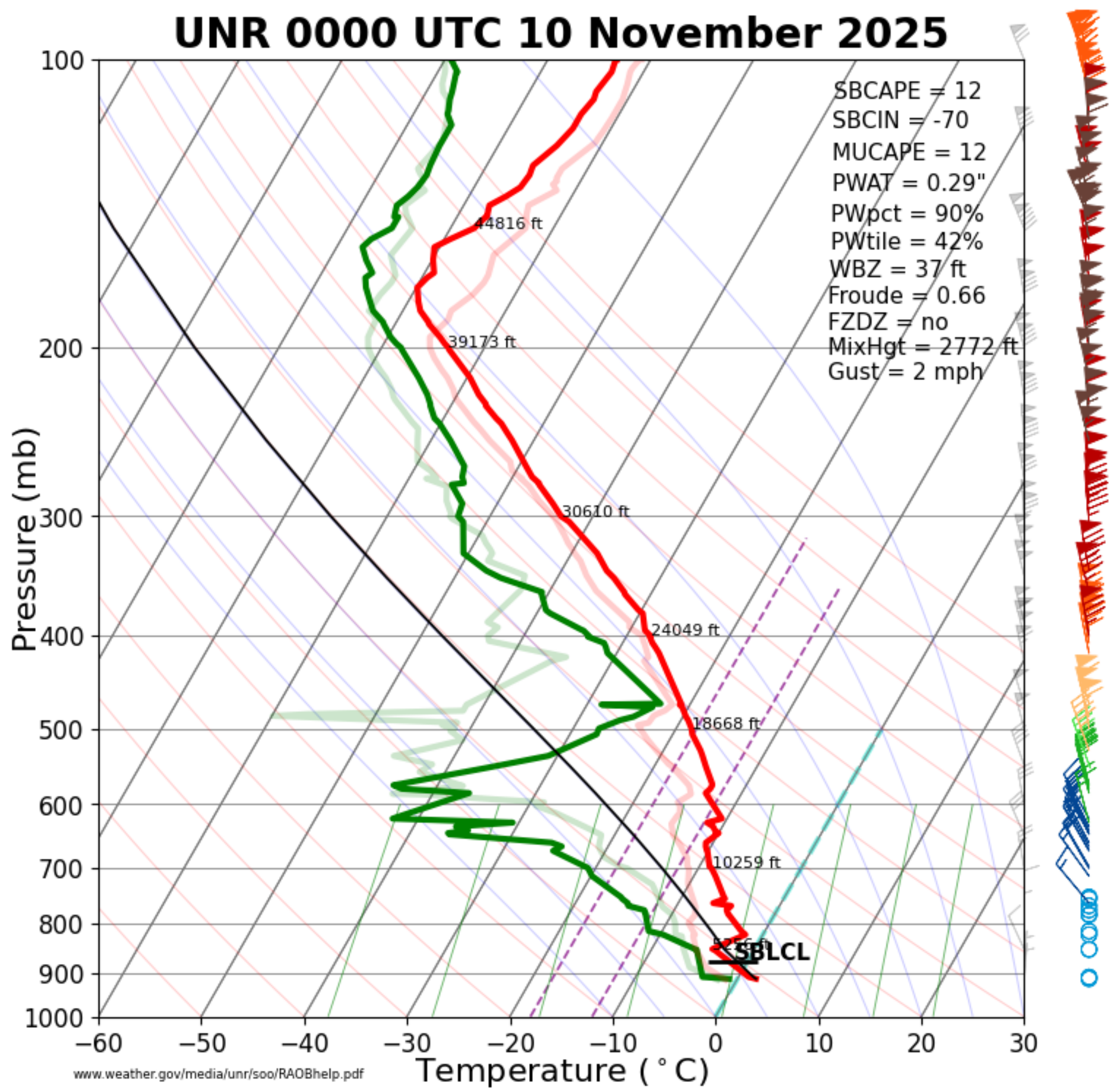


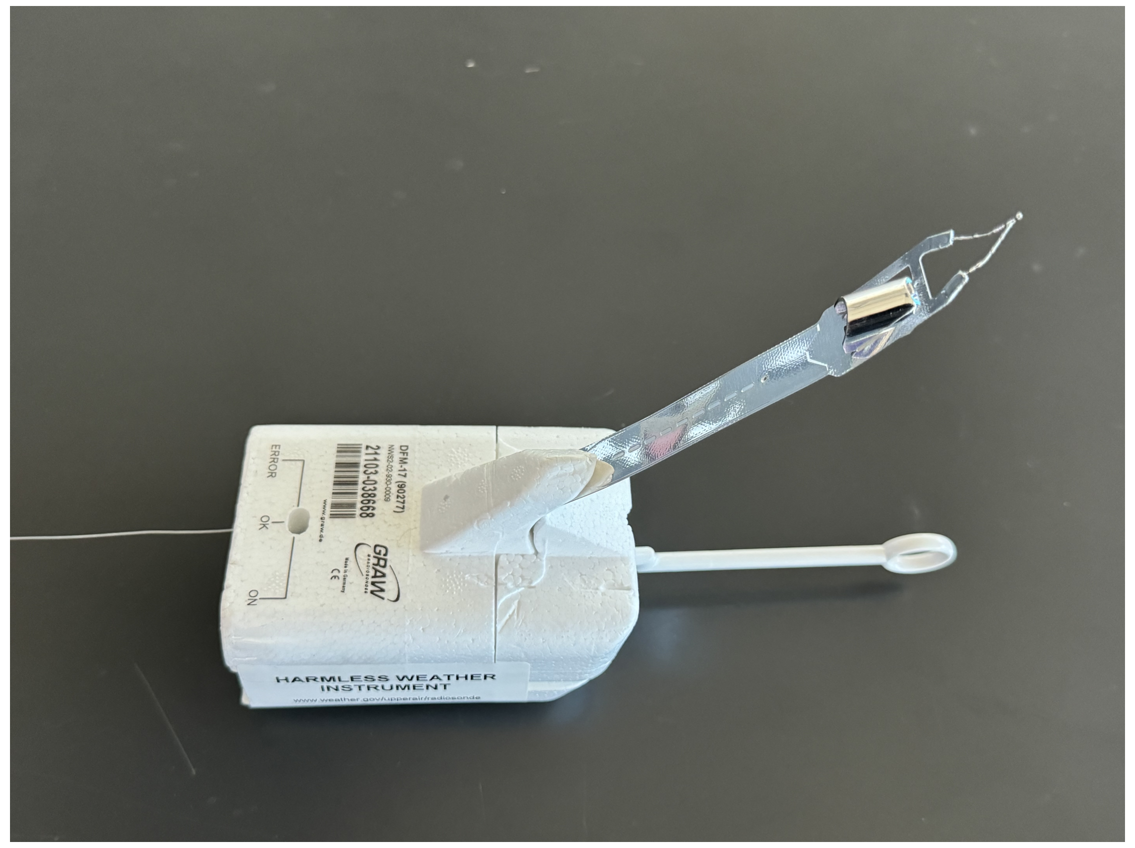
Type: Weather / Sounding

- Latex, 100 gram to 6 kg envelope mass
- Filled and sealed, released twice per day across the world
- Balloon rises, expands, and bursts (~2 hours)
- Attached radiosonde measures pressure, temperature, windspeed, humidity
- Used as input data for weather models

Type: Weather / Sounding

- Example of returned data
- Telemetry sent via radio, payloads are typically not recovered.
- Signals are clear-text, modulation and data format are known (~400 MHz FSK)
- Open-source package for receiving / decoding signals using RTL-SDR
- https://github.com/projecthorus/radiosonde_auto_rx





Type: Weather / Sounding

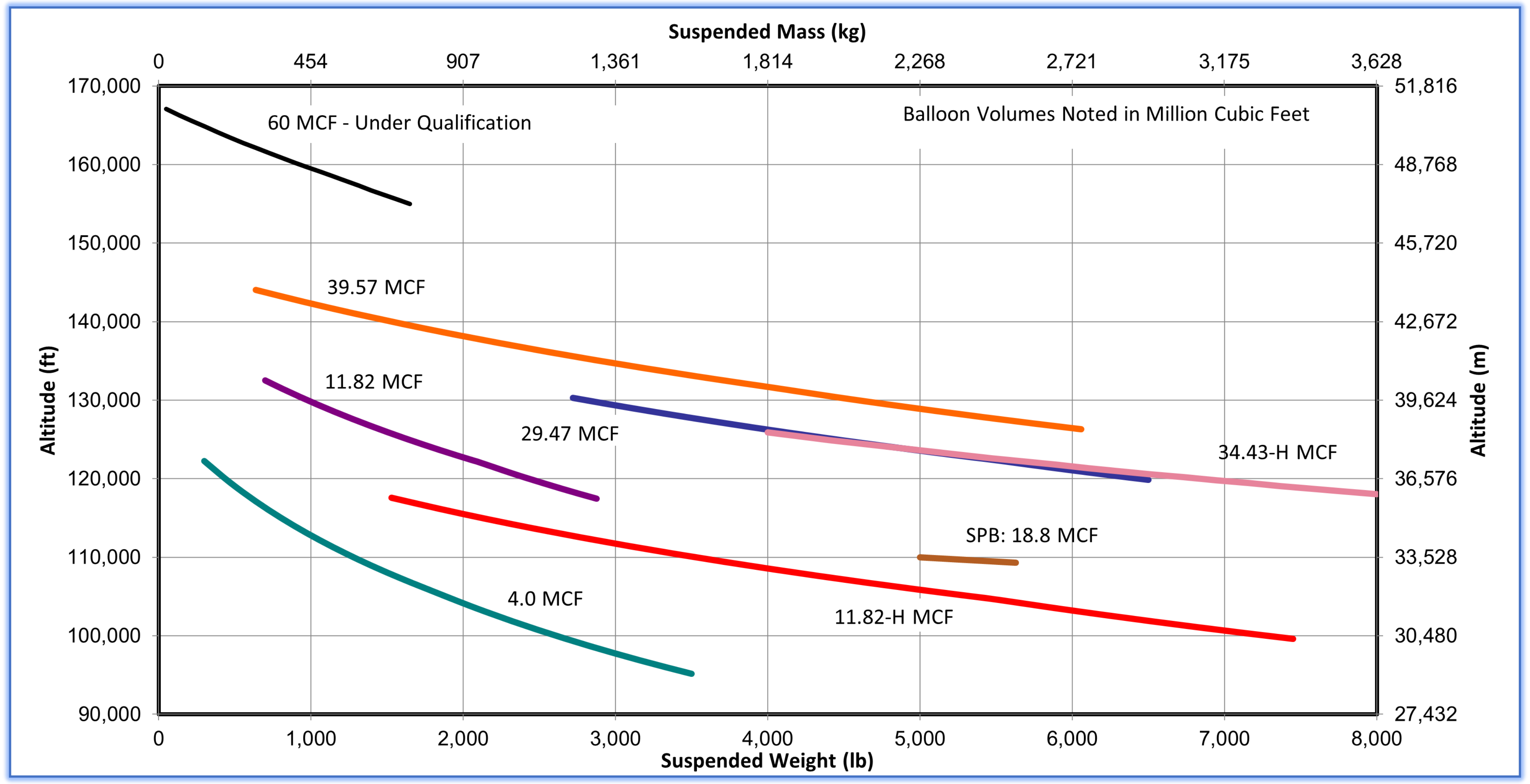
- Small, cheap, fast way to get to ~34 to 36 km altitude
- Only economical way to get in-situ data for weather models (wind velocity critical).
- Great for flying go-pros (Stanford students popularized this back in ~2012)
- Views are great!

Type: zero-pressure

- Some experiments need to carry heavy equipment (10's to 100's of kg) for longer durations (days).
- Examples: X-ray measurements, northern lights, extended weather observations
- Design is plastic sheeting (fragile, supports no internal pressure), vented to the atmosphere through an opening at the bottom
- Launched partially filled, expands as it rises, excess gas vents and reaches equilibrium
- Often requires a crane, special vehicle to launch due to immense size and li

Type: zero-pressure

- Expensive, labor intensive process to manufacture
- Cost -> 100x to 1000x (starts at 10k USD for a “small” one)
- Requires self-destruct mechanism to control flight duration
- Can survive day-night cycles but…



Type: zero-pressure

Sunset Effect

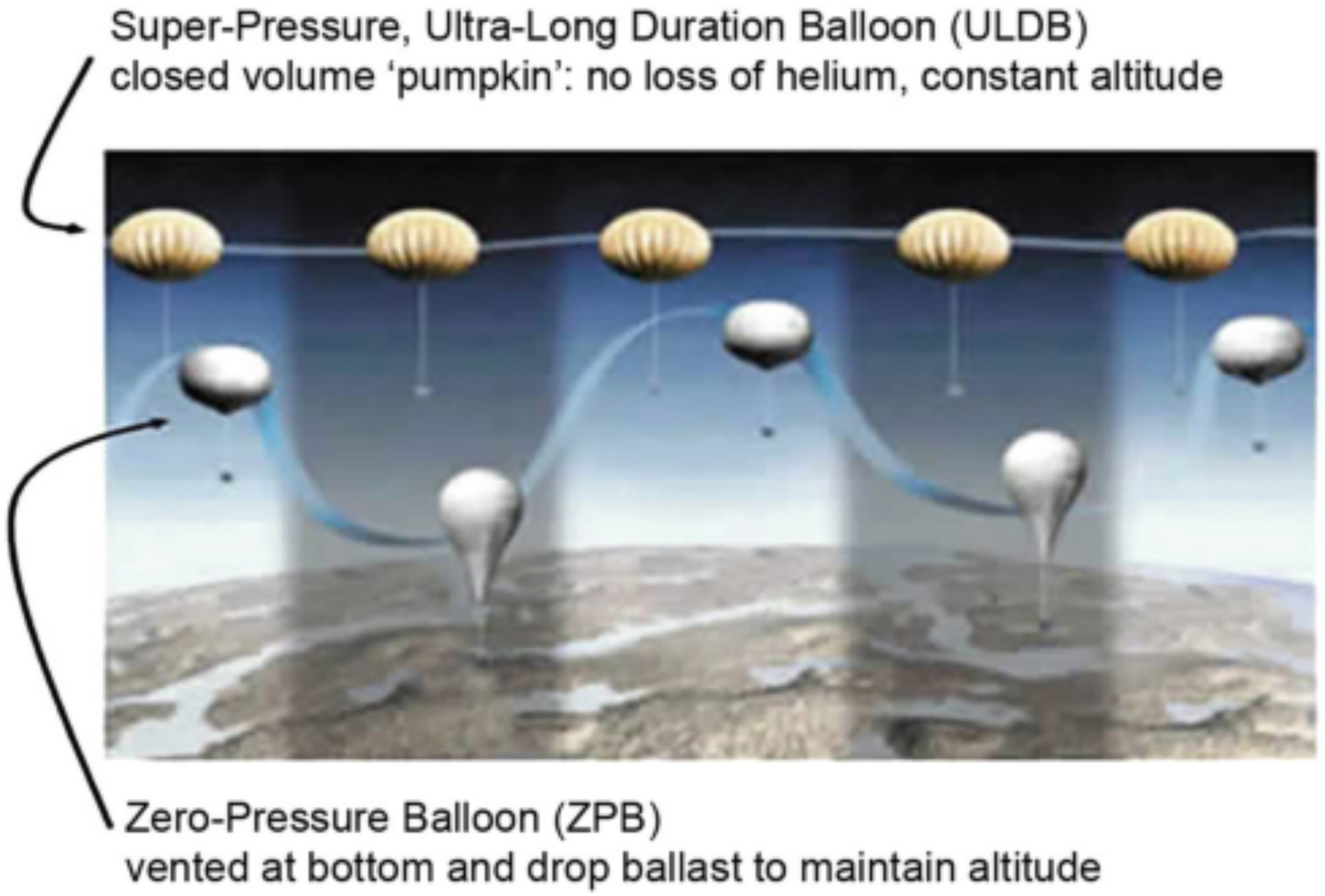
- Launched partially filled
- Excess lift is vented
- Sun sets -> temperature decreases
- Volume decreases -> descent begins
- Pressure surrounding increases -> compressed
- Descent accelerates…
- Feedback loop results. Mitigation: release ballast (sand)
- 6% to 10% per 24 hours must be released

Type: zero pressure

- #1 most common for scientific flights
- Good balance of duration, height, cost
- Only limiting factor is lifespan
- Exceptions exist: Antarctica flights during the summer (constant daylight, no sunset effect!)

Type: Superpressure

- Reinforced envelope, sealed from environment
- Must withstand pressure differential
- Equilibrium is maintained by balancing envelope strength with temperature, pressure of the lift gas
- Capable of withstanding day-night cycles indefinitely



Type: Superpressure

- Leads to some interesting possibilities
- Google loon (pre-starlink idea for airborne ISP)
- Ultimate limit on duration: UV degradation, gas diffusion through the envelope, logistics and airspace
- Extreme expense, generally made-to-order

Exceptions

- Use a latex balloon as a mini-superpressure?
- Requires valve controlled by active electronics
- Research project at U of C
- Works!
- However… the descent is problematic.
- https://www.youtube.com/watch?v=pJ9P4lzNr-k&t

Science

Why go through all this effort

- My research: using X-rays from energetic electron precipitation to study the radiation belts
- Van Allen: discovered bands of high energy charged particles in the near space environment (MeV or greater)
- There are conditions where they precipitate and hit the atmosphere
- Component of the northern lights
- Electrons are blocked ~80 km high, X-rays get down to around 32 km.
- Perfect target for extended observations from balloons

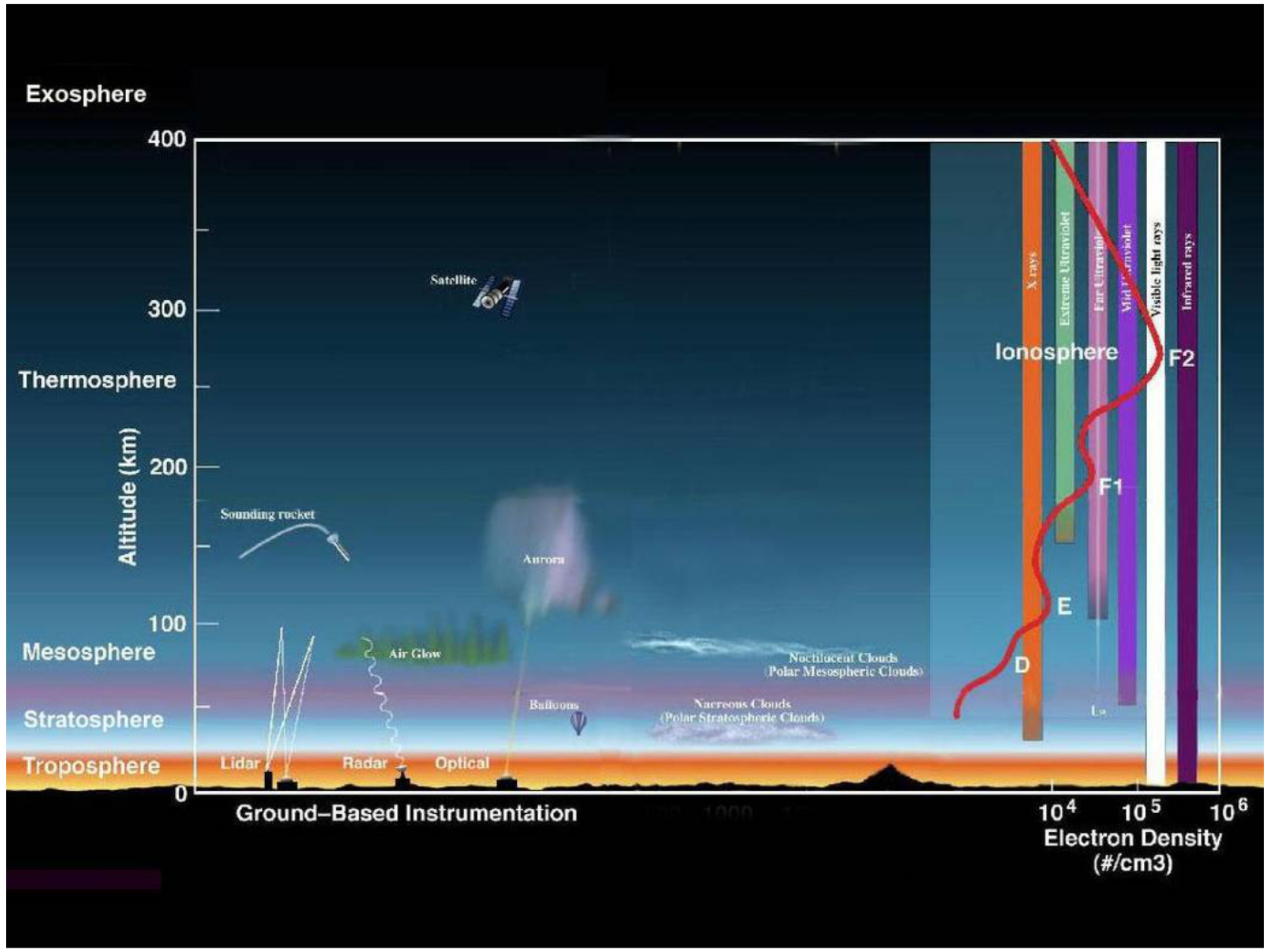


Figure 1.2: Schematic illustration showing the scale and structure of the atmosphere, with the overall trend in electron density with height. Image by NASA Goddard, from nasa.gov.

Energetic Electrons

- Charged particles driven by the Lorentz force
- Motion in space driven by the Earth's magnetic field
- Static and dynamic effects, coupled with the solar wind
- Space around earth has its own weather - additional complexity due to electromagnetic component

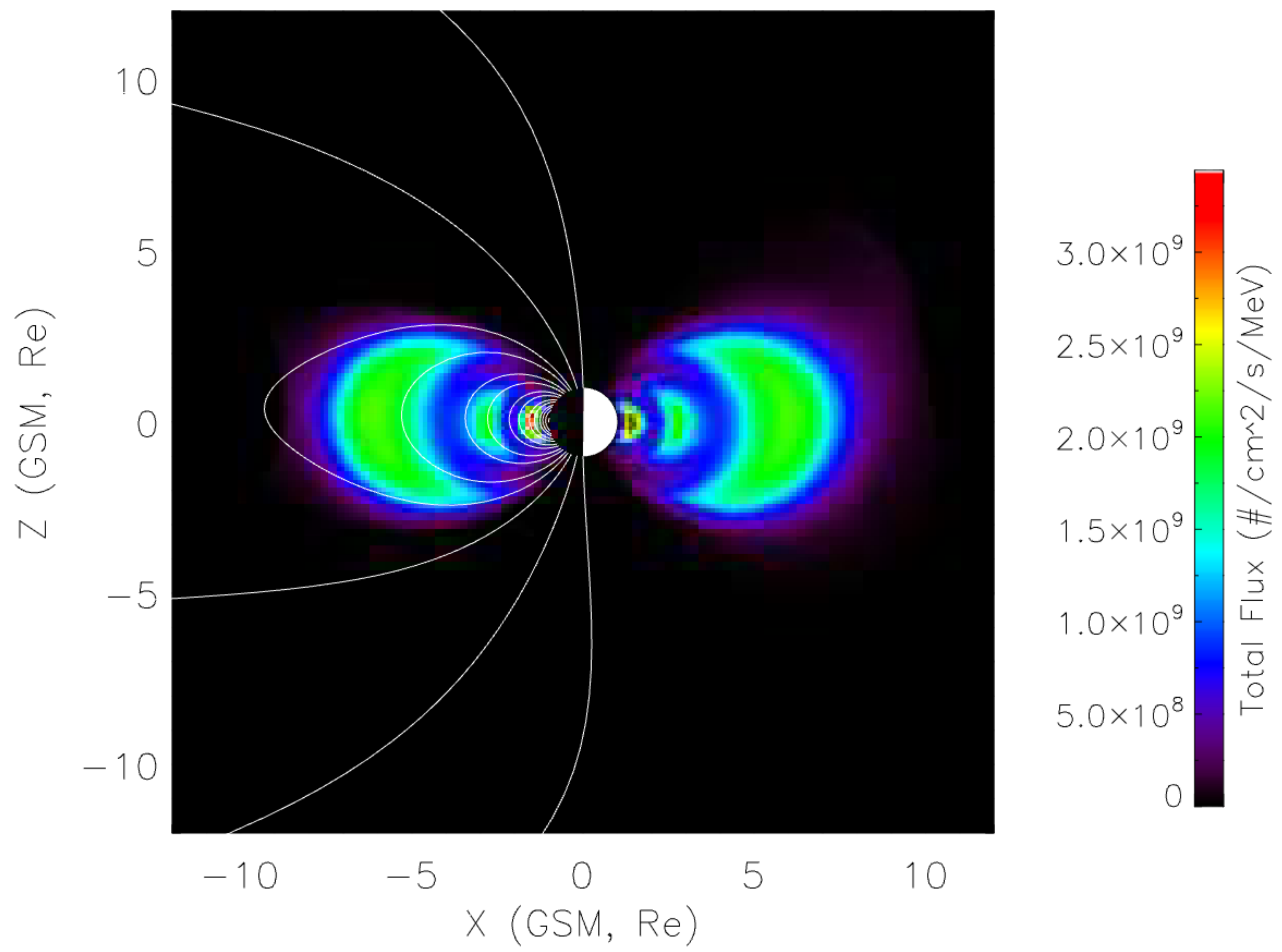


Figure 2.2: Cutaway view of AE9 model electron fluxes in the radiation belts, with some model magnetic field lines from Tsyganenko (1987) to show the overall geometry.

X-ray Spectroscopy

- X-ray spectra from monochromatic electron beams are simple to model
- Empirical and numerical simulations available.
- Can you go “backwards” and see what the original electrons were doing?
- Inverse problem. Not numerically well conditioned (many inputs lead to the same output)

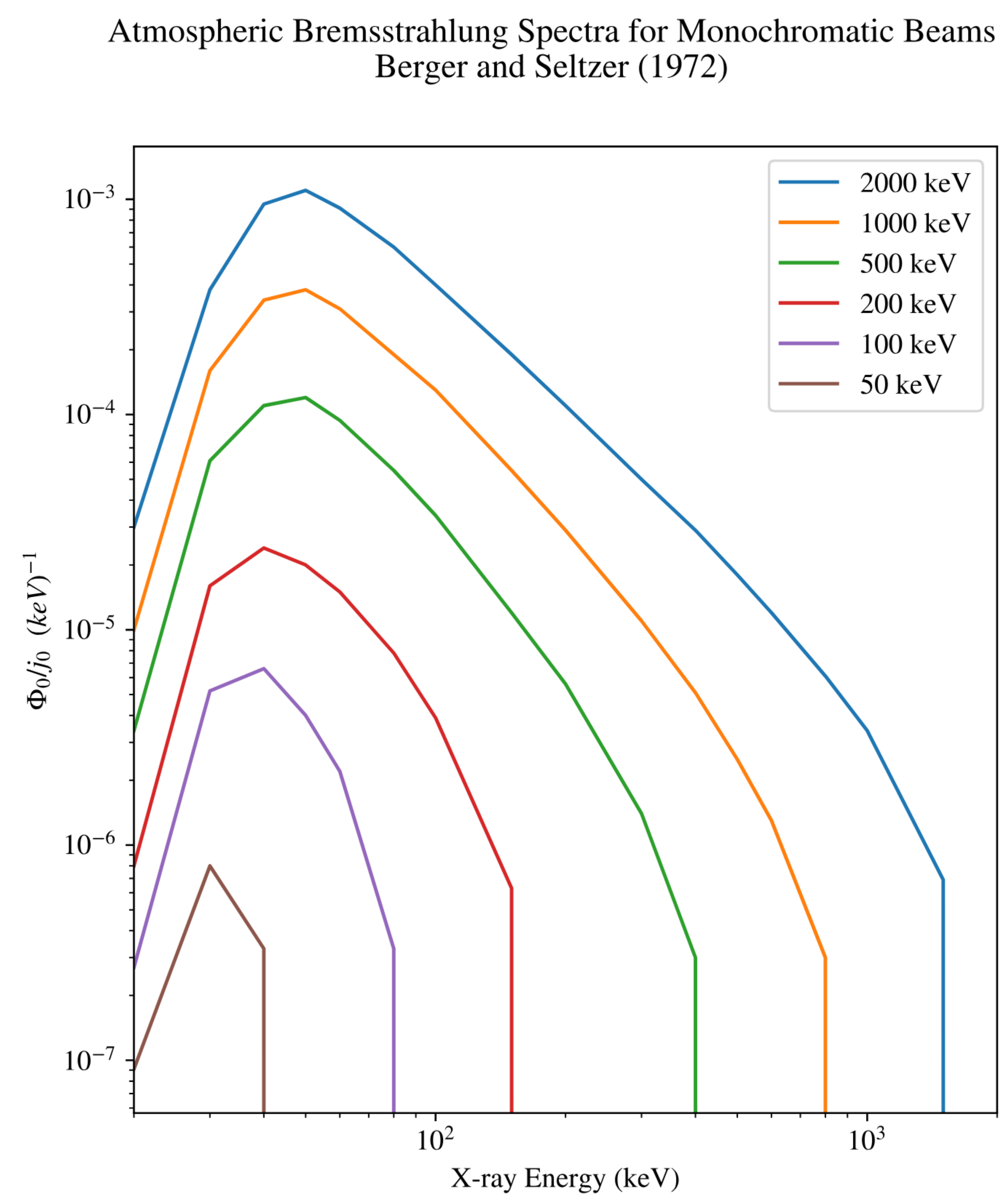


Figure 3.2: X-ray photon flux per incident electron flux for different incident electron beam energies, from Berger and Seltzer (1972) for an altitude of 34 km.

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X-ray Spectroscopy

- Requires many expensive simulations: impulse responses from monochromatic beams into a model atmosphere
- Model the atmosphere up to 500 km, including chemistry, average temperature, density
- Launch 1e9 simulated electrons
- GEANT4 / SLURM cluster of computers: monte-carlo simulation solves the “forward” problem.
- Combine with detailed model of the X-ray detector to simulate impacts.

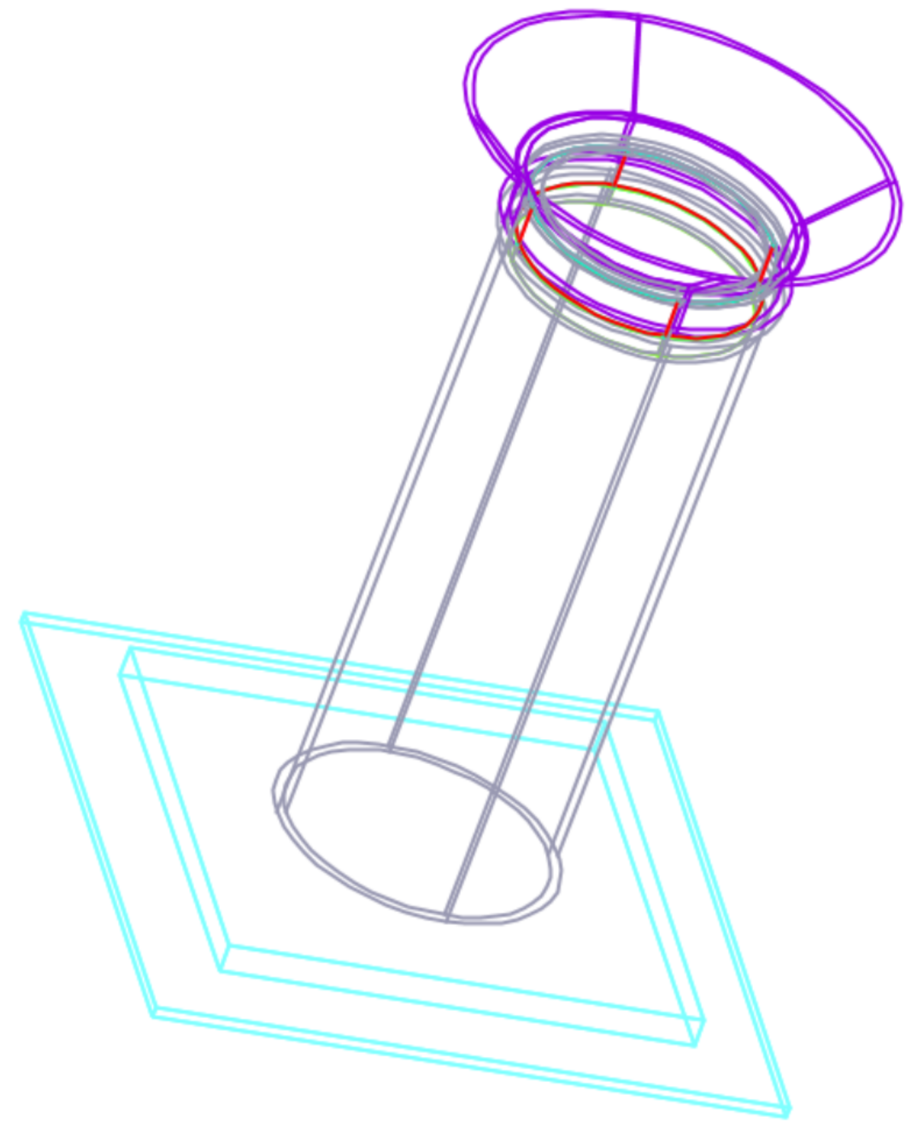

Figure 3.11: GEANT4 representation of the detector geometry. The lower plexiglass mount is shown in cyan, the aluminum body in grey, and the led collimator in purple. The height of the complete unit is approximately 30 cm.

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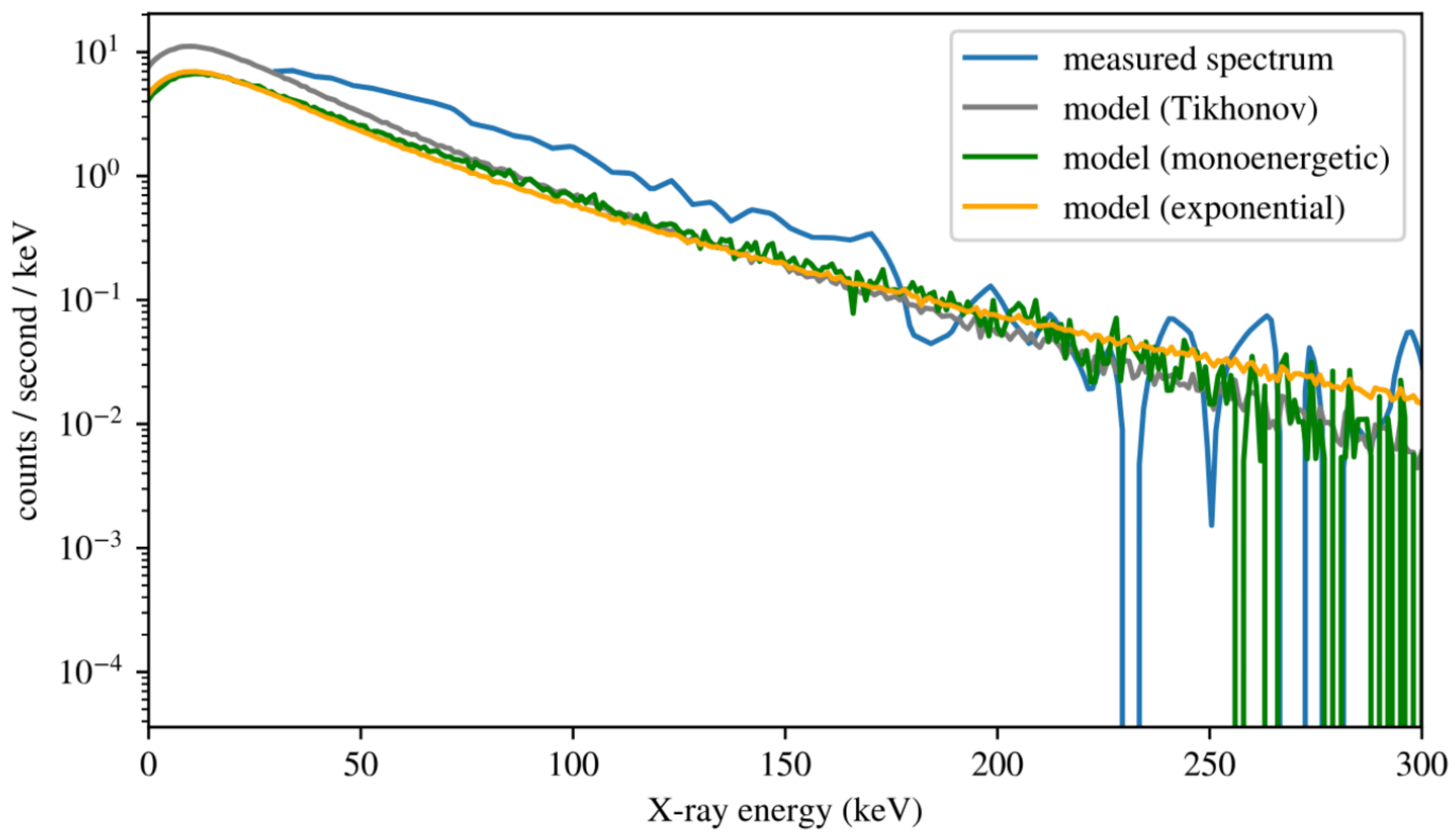
Experiment



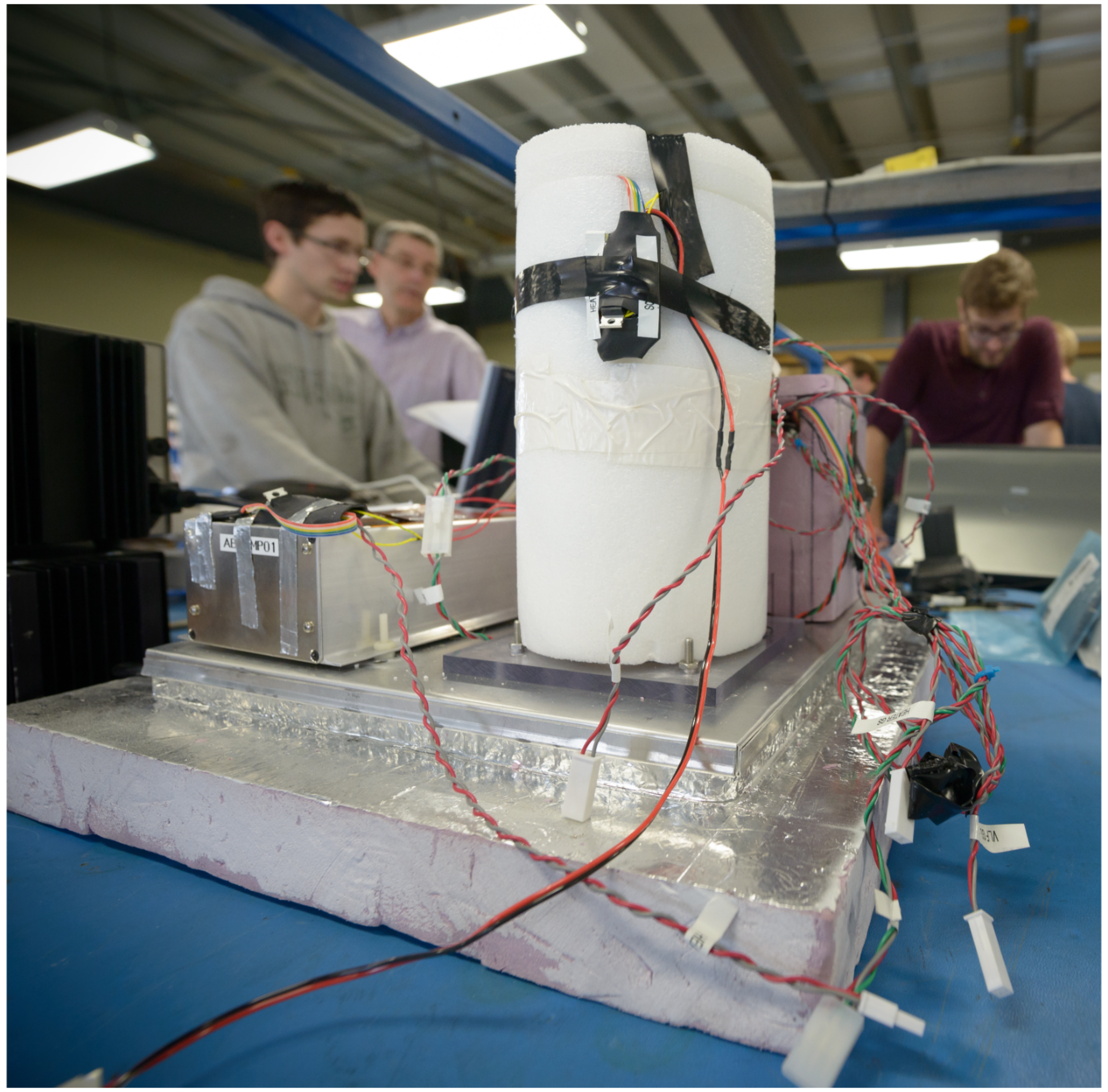


Figure 5.1: X-ray spectrometer (white cylinder) encased in insulation foam and installed with flight systems in balloon payload. The DPU (digital processing unit) is contained in the metal rectangular enclosure on the left. The lead collimator assembly is hidden under the white styrofoam insulation.

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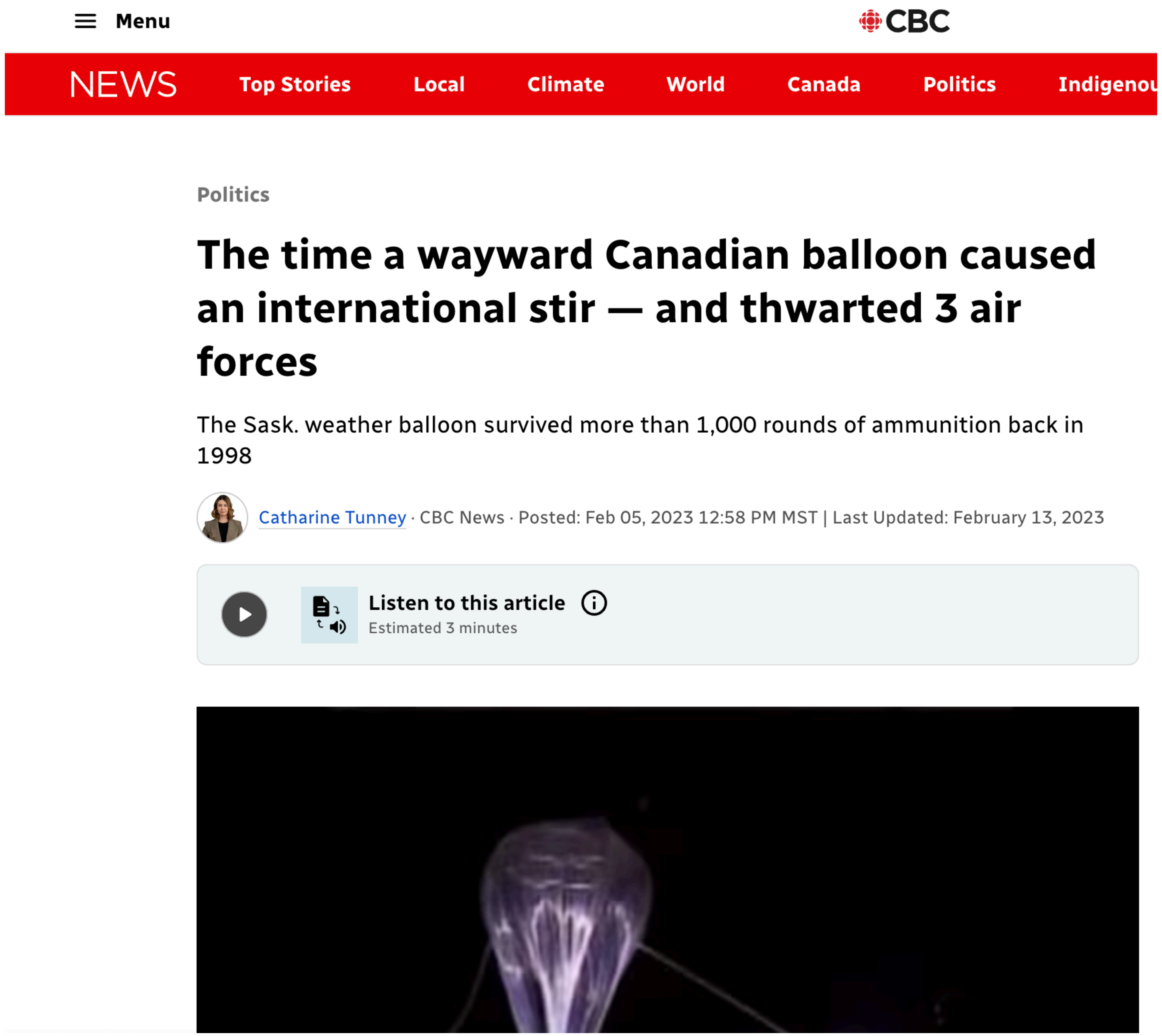
Results

- Balloons can infer the electron spectra from space using X-ray measurements
- Instead of assuming a model (monochromatic, exponential, gaussian) and fitting to the data, we can use numerical models to calculate the actual spectrum from the measurements
- This is important: space weather is generally under sampled (few measurements, large space).
- Removing unnecessary assumptions constrains the problem space - allows asking more complex questions.
- Moving towards a more predictive model of space weather

When things don't work…

- Zero-pressure balloon launched from Saskatchewan
- Destruct mechanism, backup, and secondary backup failed
- Jetstream carried it towards Europe
- F-18's sent to shoot it down
- Making a bunch of tiny holes causes it to leak, but takes surprisingly long to land



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Politics

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The Sask. weather balloon survived more than 1,000 rounds of ammunition back in 1998

Catharine Tunney · CBC News · Posted: Feb 05, 2023 12:58 PM MST | Last Updated: February 13, 2023

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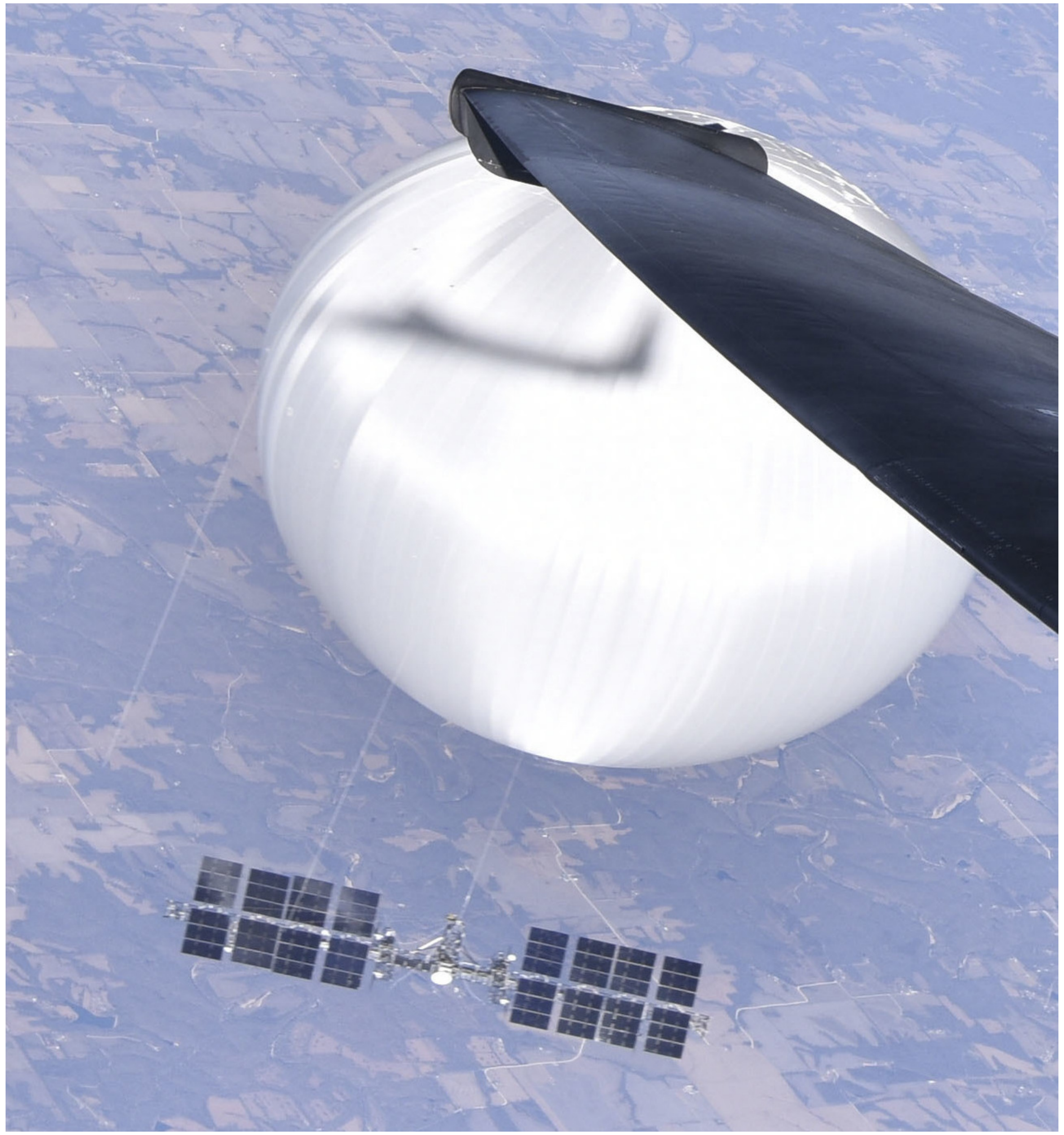
Estimated 3 minutes

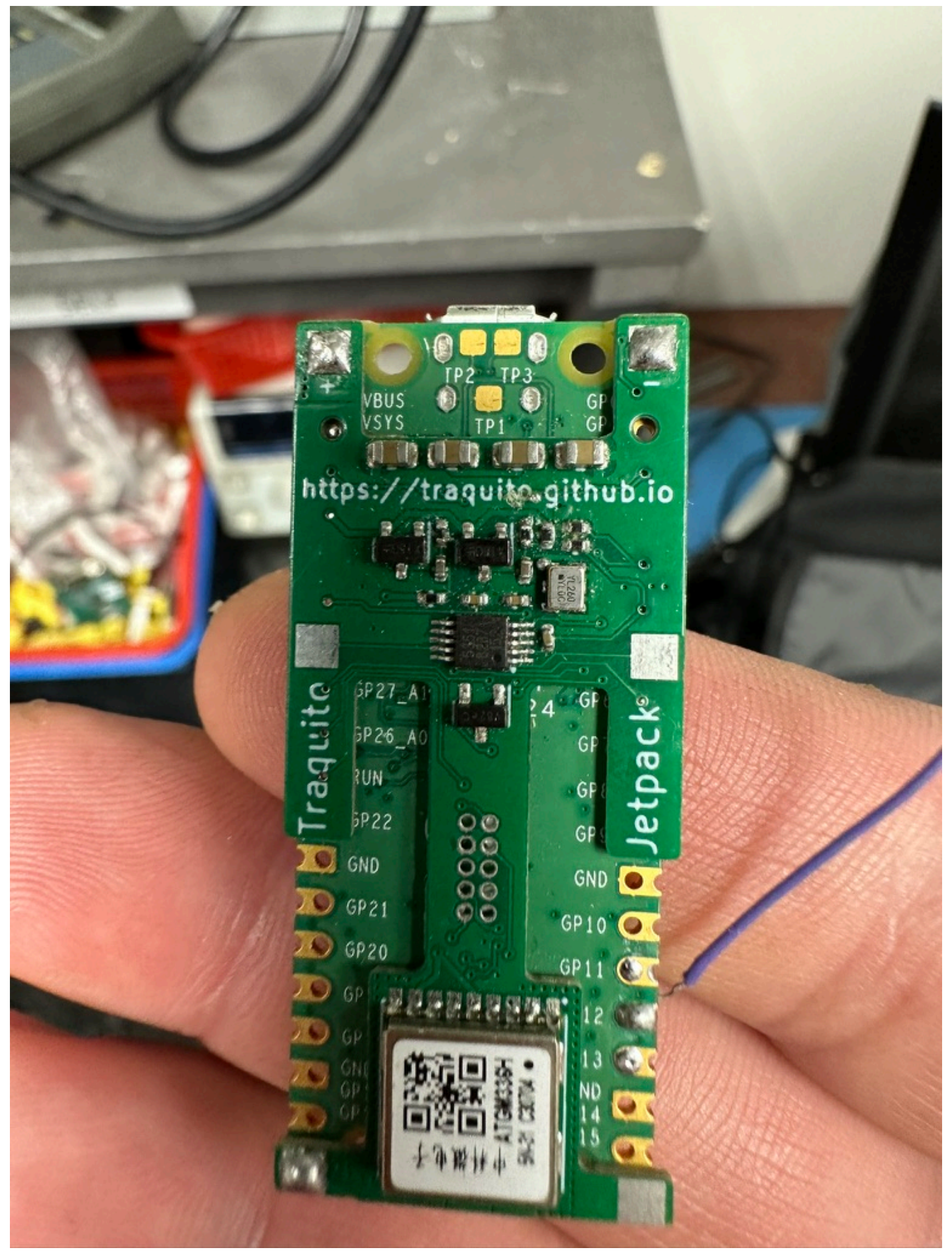
Spy Balloon

- Large, low (~20 km), slow
- Clear superpressure design
- Solar powered, long duration flight was clearly intended
- Somewhat obvious, leading to questions as to the original purpose
- Possible electronic surveillance (closer to signal, no ionosphere in the way).
- Great target for F22’s



Tiny Superpressure balloons

- Amateur radio “pico” balloons
- ~1m in diameter, commercial mylar balloons with ~15g payloads
- Float at ~12 to 14 km
- Can travel for months to years!
- Telemetry via HF radio (WSPR), bit-stuffed into FSK beacons and sent 1 bit per second for 2 minutes at a time.
- Solar powered, active only during the day



Tiny spy balloons?

- Mylar sphere, ~1m across, great radar cross-section
- Good target for sidewinder
- Unit cost of balloon: CAD $50
- AIM-9: US $381,069.74
- Ground personnel tried to find the wreckage, never recovered.
- K9YO pico balloon

2023 Yukon high-altitude object

2 languages

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From Wikipedia, the free encyclopedia

On February 11, 2023, NORAD, at the direction of the Canadian Minister of National Defence and Chief of the Defence Staff, downed an unidentified object over Yukon.[1][2]

After snowfall in the area made the debris difficult to find, the search was called off on February 17.[3][4]

2023 Yukon high-altitude object

Approximate location where the object was shot down.

Date	February 11, 2023
Location	Yukon, Canada
Type	Airspace violator
Outcome	Downed by an AIM-9 Sidewinder missile fired by a U.S. Air Force F-22 Raptor

Background [edit]

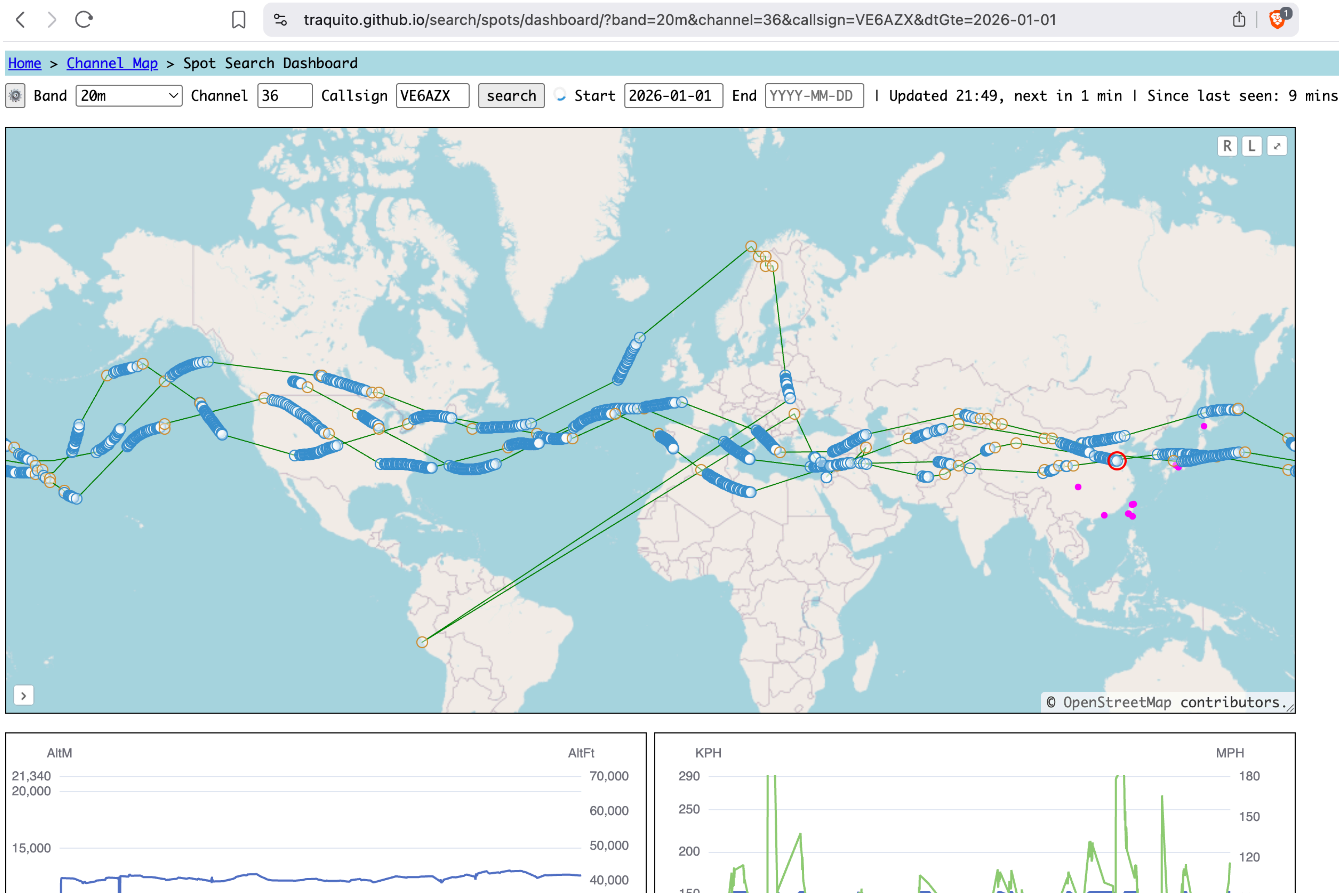
The object was downed a day after an Alaskan high-altitude object was shot down, and a week after the 2023 Chinese balloon incident.

Detection and flight path [edit]

The prime minister of Canada, Justin Trudeau, said NORAD monitored the object and deployed American and Canadian aircraft. Two U.S. Air Force F-22s from Joint Base Elmendorf–Richardson, assisted by refueling aircraft, monitored the object over U.S. airspace and continued to monitor it as it entered Canadian airspace. Royal Canadian Air Force CF-18 and CP-140 aircraft joined the formation monitoring the object after it passed into Canadian airspace.[5]

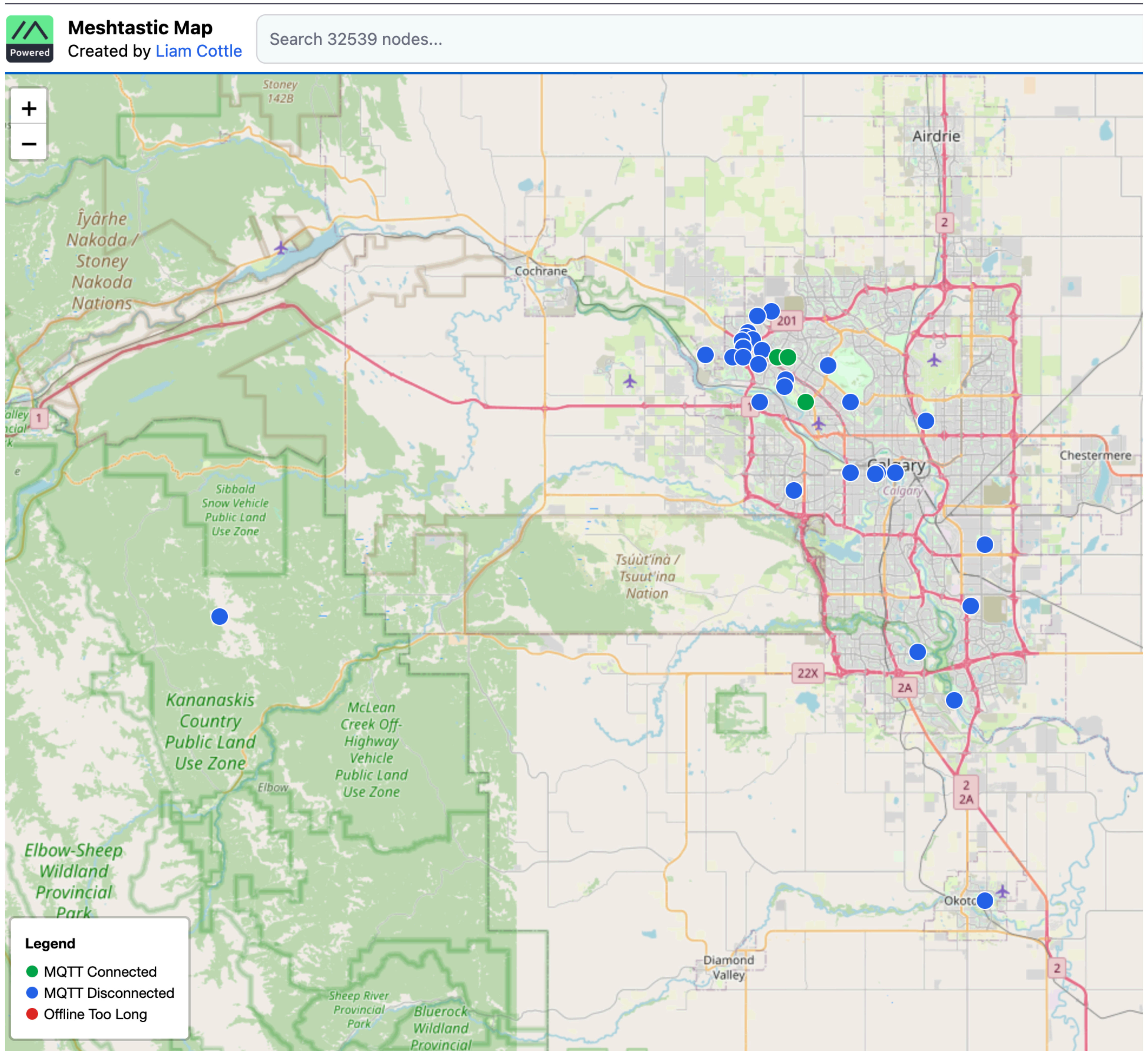
VE6AZX-14

- Launch: 2026-02-07
- Flying for 41 days (and counting!)
- 4 laps
- 146,000 km
- 12.6 km altitude
- No F22's yet…
- Lots of GPS spoofing, though



Project Ideas

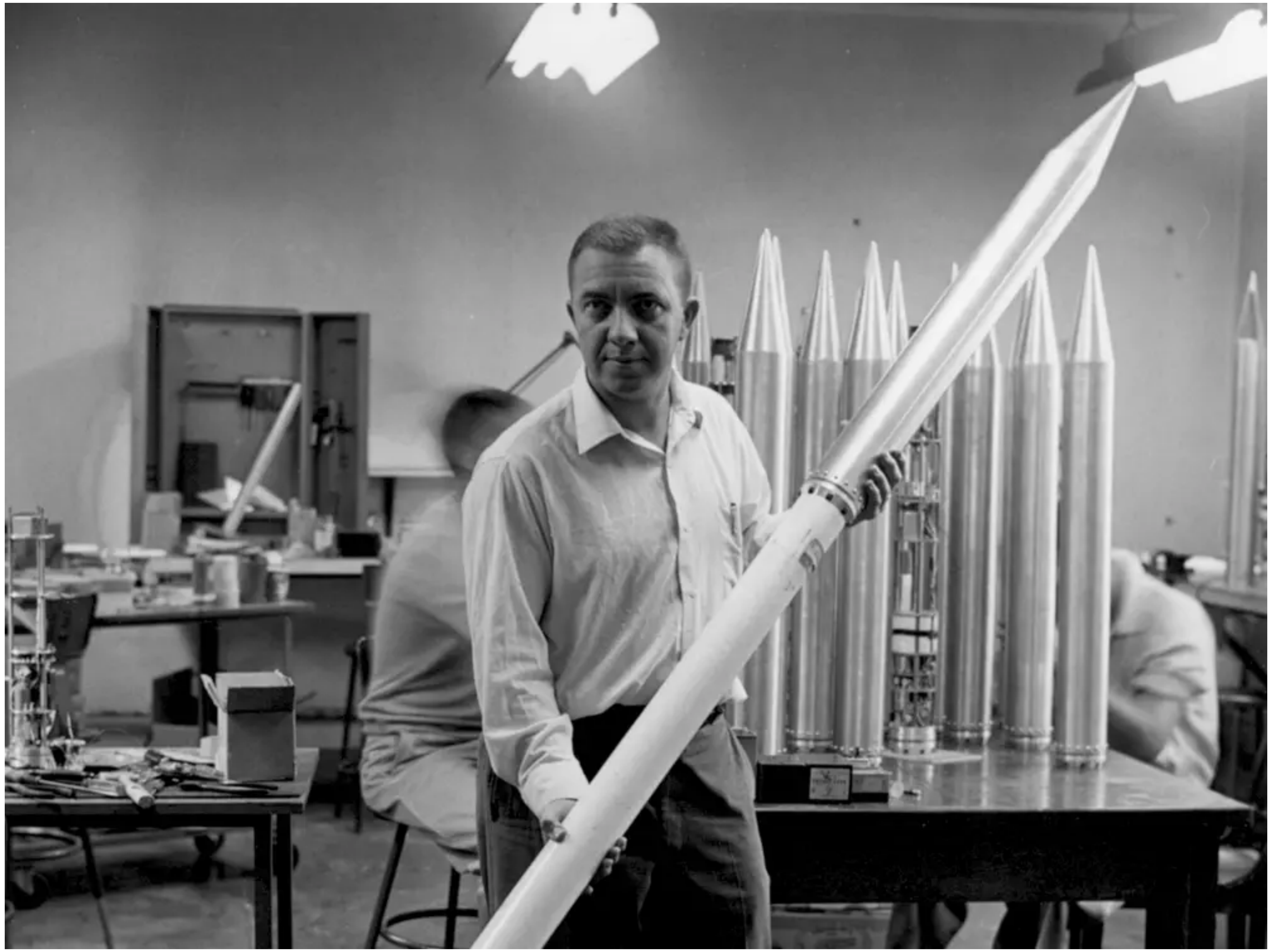
- Google loon / starlink knockoff?
- Combine pico balloons with LoRa radios (long range, low bitrate, ISM)
- A mesh network would only need N~100 units to cover the daylight side of the Earth
- May be essentially impossible to remove once deployed
- Footprint of one unit could exceed 500 km



Project Ideas

Rockoon

- Not a new idea (Van Allen DEACON rockets, 1960's)
- Possible to design one smaller, lighter, using a latex sounding balloon
- With a small tracker (GPS issues, ITAR)
- Simulations show 100 km sub-orbital flight possible with "J" rocket motor
- "G" hobby motor may go another 30 km above the balloon altitude.



Rockoon test

Didn't work, will try it again.

- Attempt to fly a "G" rocket from a suspended platform
- Collision with attachment point
- Debris field created, motor flew 200 ft downrange
- Next attempt: rocket suspended from a tethered balloon
- Distance ++, collision probability -- ?
- Raises some questions about regulations… no specific rule created yet.

Come join us!

- Semi-frequent HAB launches from near YYC
- Pico and regular balloons
- Flights organized at Calgary Protospace
- Go-pros, rockets, radio experiments
- New payload ideas welcome!