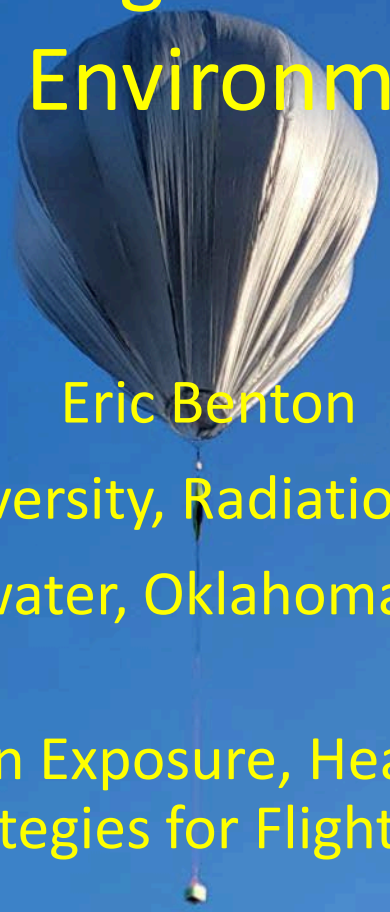
Radiation Monitoring in the Commercial Aviation Environment



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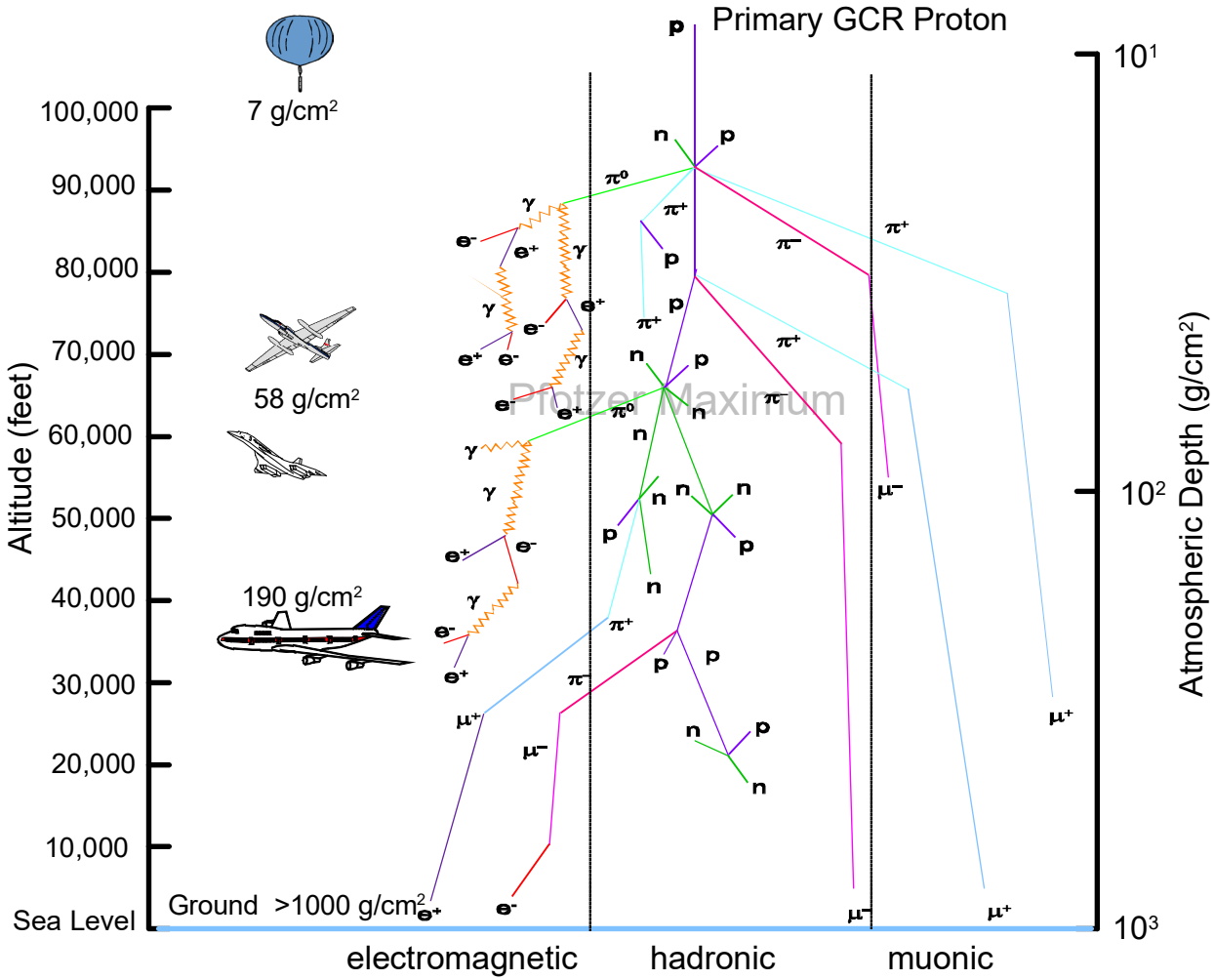
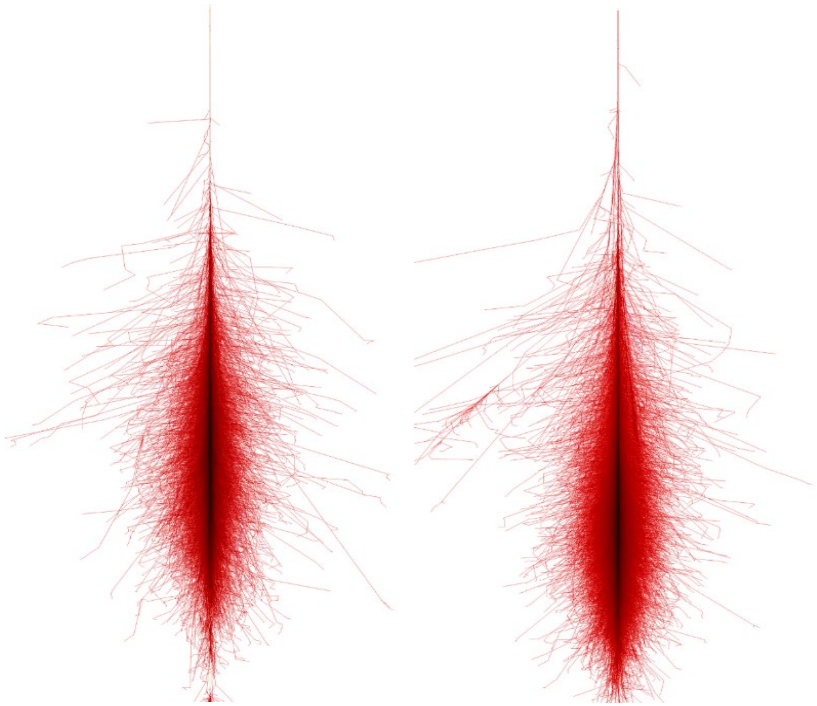
Assessing Radiation Exposure, Health Outcomes, and Mitigation Strategies for Flight Crewmembers

Committee Meeting #4: December 3, 2025

Cosmic Ray Air Showers



A diagram of a cosmic ray air shower illustrating the hadronic, electromagnetic and muonic cascades.

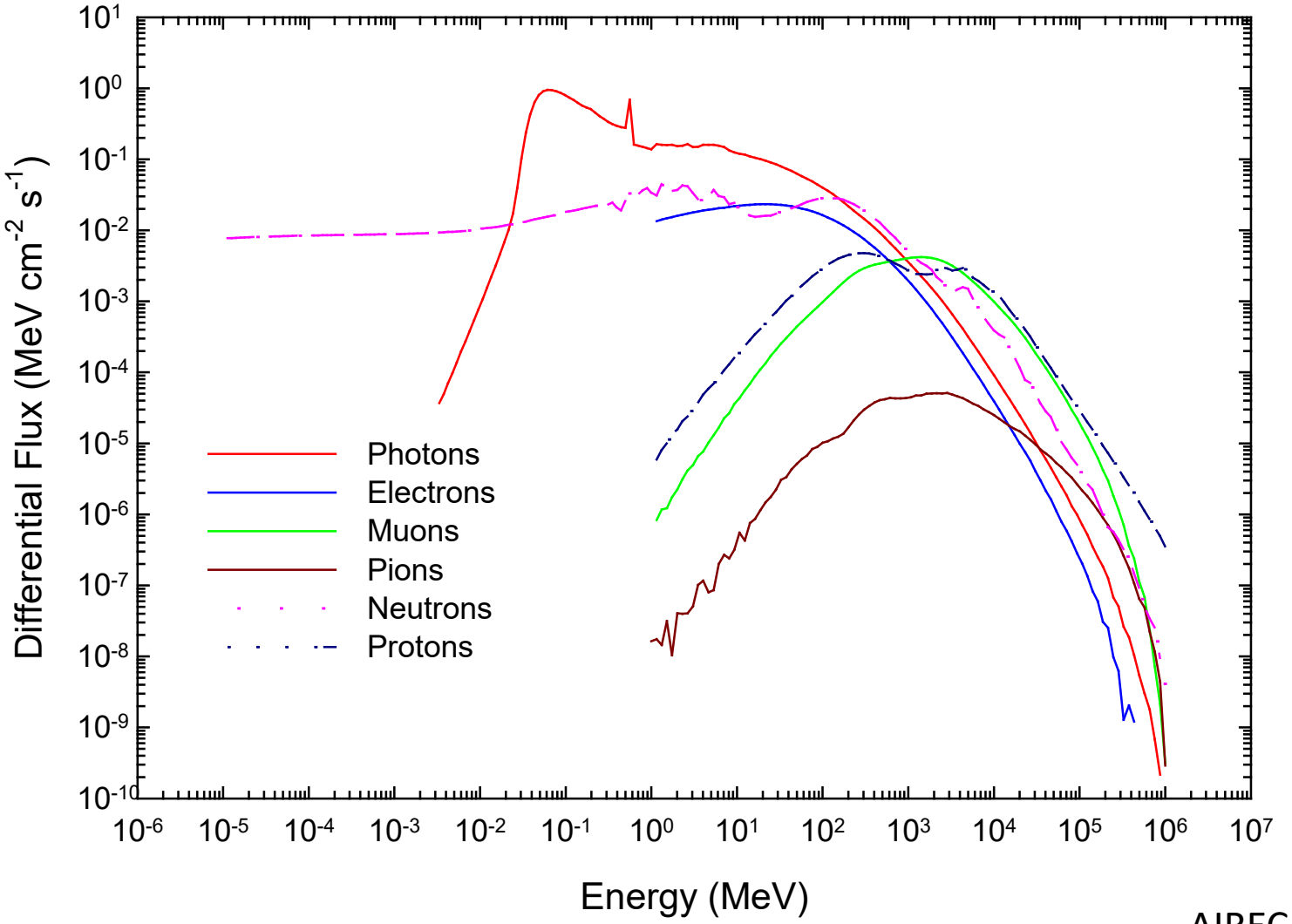


50 GeV proton

1 TeV proton

CORSIKA MC code simulations of proton-initiated air showers [CORSIKA website].

Energetic Particle Fluxes at 12 km altitude above Boulder, CO at Solar Maximum



AIREC calculation

Steady State Atmospheric Ionizing Radiation Environment (SSAIRE)

- SSAIRE consists of a superposition of particle air showers at various stages of development:
  - Most of (nearly all) the time the SSAIRE is the result of GCR,
  - (Very) rarely the SSAIRE will contain particles resulting from Solar Particle Events (SPE),
  - Only handful of SPEs measured at aviation altitudes (Czech NPI, Concorde),
  - Other atmospheric radiation phenomena, e.g. those associated with thunderstorms.
- In general, very few ionizing radiation measurements have been made in the atmosphere (especially when compared to similar measurements made in LEO).
  - Most measurements made at commercial aviation altitudes (e.g. DLR (Germany), Czech NPI measurement program). No formal program in US
  - Few measurements on high altitude aircraft (NASA ER-2, WB-57) and on high altitude balloons.
  - No measurements between ~35 and ~300 km.

- Numerous models for estimating air crew and passenger radiation exposure during flight (CARI-7, EPCARD, EXPACS), but few models (AIREC, PARMA, Pandoca) for estimating basic physics quantities (e.g. particle fluxes and energy spectra).
- Multiple reasons for lack of radiation measurements in the atmosphere:
  - lack of low-cost, easy to install/operate instrumentation that can be widely deployed on multiple platforms,
  - lack of cooperation with airlines (especially in USA),
  - little scientific interest, but hopefully changing with growing awareness of the importance of Space Weather.

Open Questions Regarding the SSAIRE

- Health effects on air crew and passengers,
- Effects in electronics/avionics,
- Particle fluxes and multiplicities as function of primary particle type and energy,
- Average height and altitude spread of primary particle first interaction,
- Lateral, as well as vertical structure of air showers, degree of shower overlap as functions of time, angle, altitude, geographic location, weather conditions, etc.,
- Empirical data with which to validate both dosimetric and physics models,
- Temporal variation on various different time scales,
- Effect of ion concentration in the atmosphere (effects on weather and climate),
- Role of major SPEs in modifying SSAIRE,
- “New” phenomena associated with thunderstorms (e.g. Terrestrial Ground Enhancements (TGE) and Terrestrial Gamma Flashes (TGF)),

Sensitivity of Detectors to Different Types of Ionizing Radiation

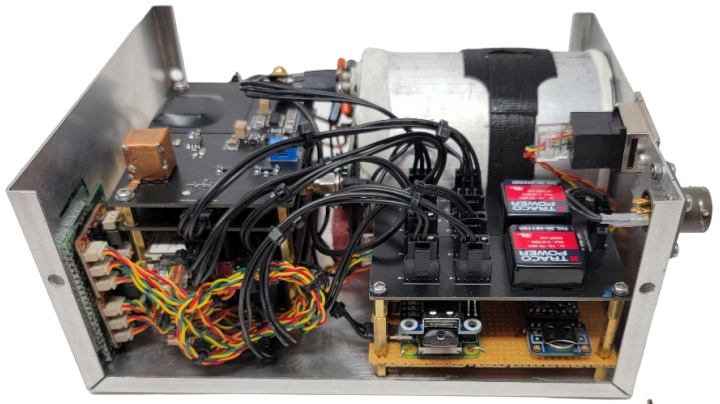
- Minimum Ionizing Radiation (dominates in terms of particle flux)
  - electrons/positrons,
  - x-/gamma-rays,
  - pions and muons,
  - relativistic protons
- Highly Ionizing Radiation (dominates in terms of RBE)
  - secondary charged particles produced by **Neutrons**
  - alpha particles and heavy ions
  - stopping protons
- No single detector is sufficiently sensitive to both types ionizing radiation
  - Si PIN photodiode for minimum ionizing radiation
  - Tissue Equivalent Proportional Counter (TEPC) for neutrons and highly ionizing radiation
  - Results from two detectors can be combined into total absorbed dose and dose equivalent measurements.

Constraints on Aviation Dosimetry Instrumentation

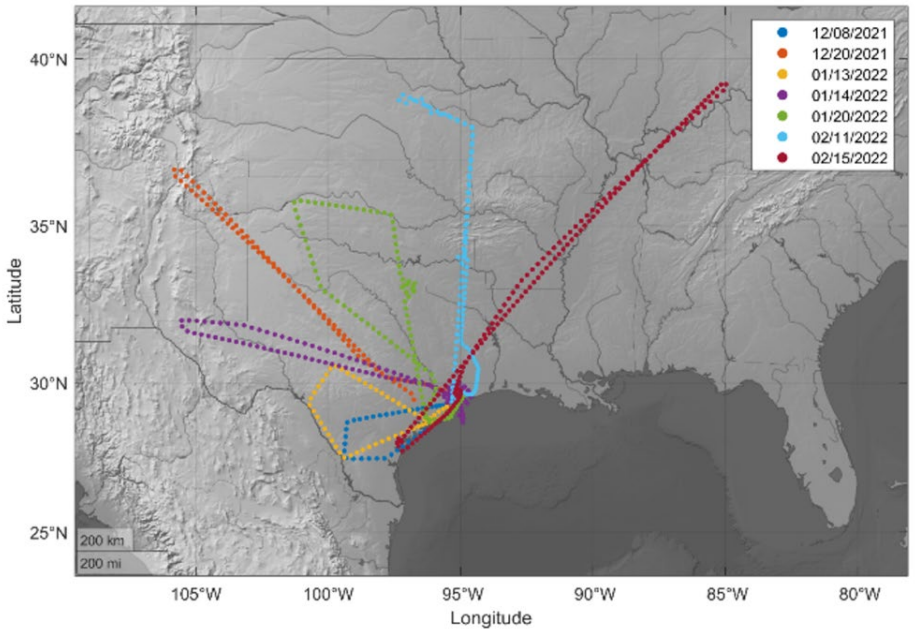
- Sensitive to all important particle types over relevant range of energies
- Measure (and record) relevant dosimetric quantities
- Size and Mass
- Power
- Data Storage/Telemetry
- Ease of Use
- Safety and Environmental Constraints
- Tissue Equivalence is highly desirable, especially in terms of nuclear (neutron) cross section.
- Instrumentation needs to be good enough, not perfect…need multiple affordable instruments rather than single “perfect” instrument.

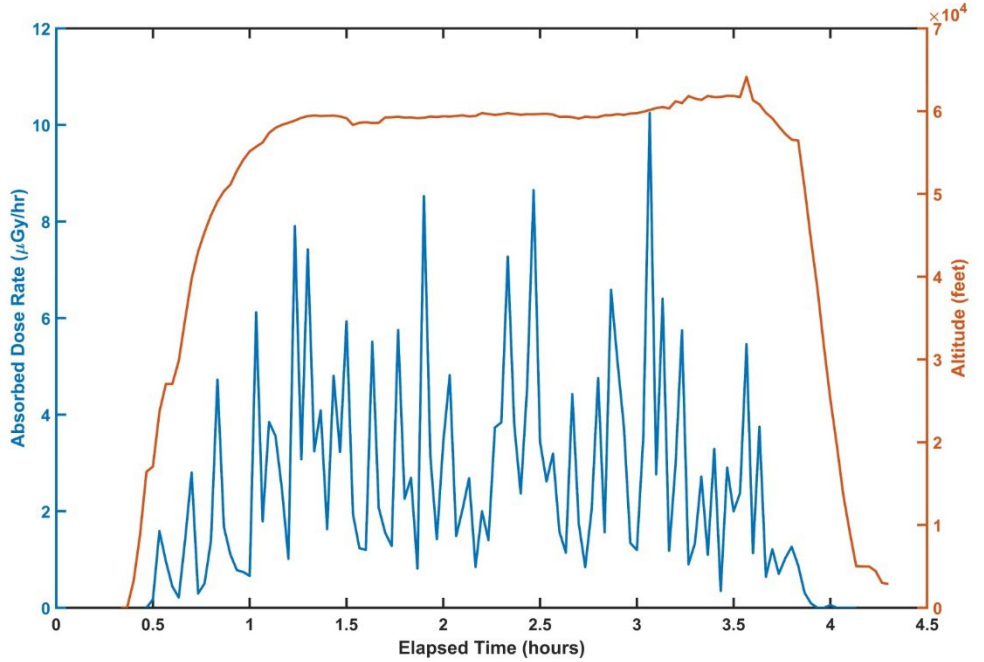
Air Tissue Equivalent Dosimeter (AirTED)

- Measures lineal energy spectra, absorbed dose and dose equivalent received from ionizing radiation during flight.
- Size of shoebox, weighs ~3 lbs
- 10-Watt power draw
- Two detectors to better cover expected particle species and energy ranges at aviation altitudes
  - Tissue Equivalent Proportional Counter (TEPC) for high-LET particles (secondary neutrons)
  - Silicon PIN diode for low-LET (relativistic protons, pions, muons, electrons, photons…)
- includes environmental sensor suite and Realtime Clock
- Data stored on-board and retrieved post-flight
- Time-resolved data can be interpreted spatially and temporally with services such as FlightAware

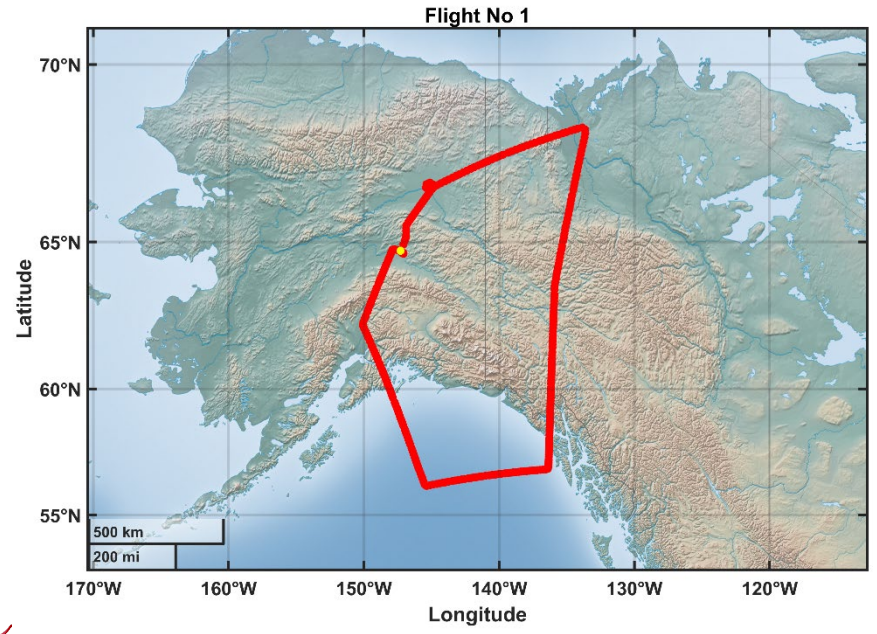


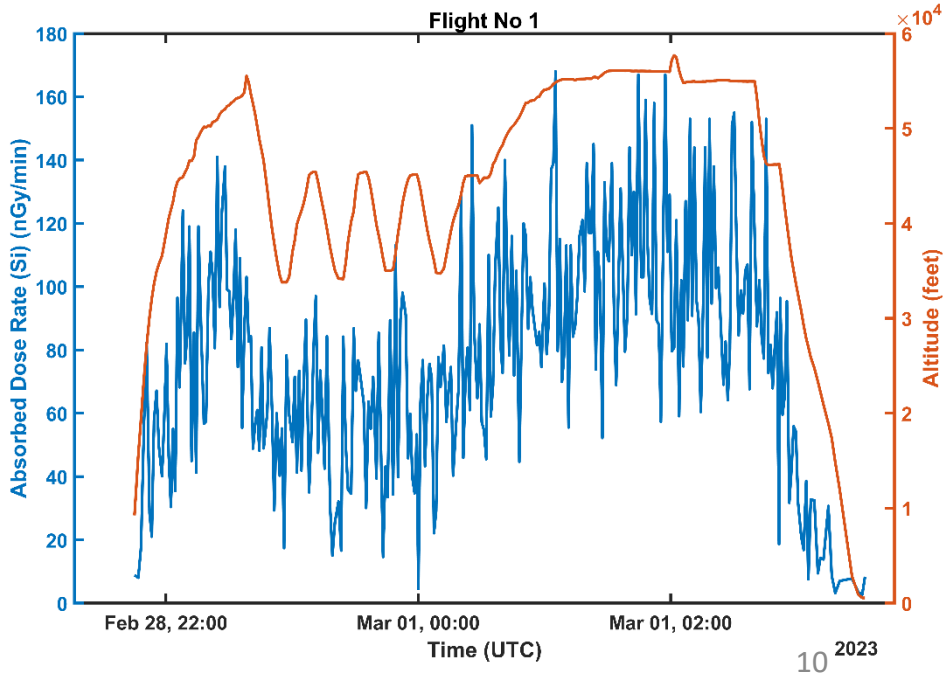
AirTED TEPC dose rate and altitude profile from a WB-57 flight out of NASA JSC/Ellington



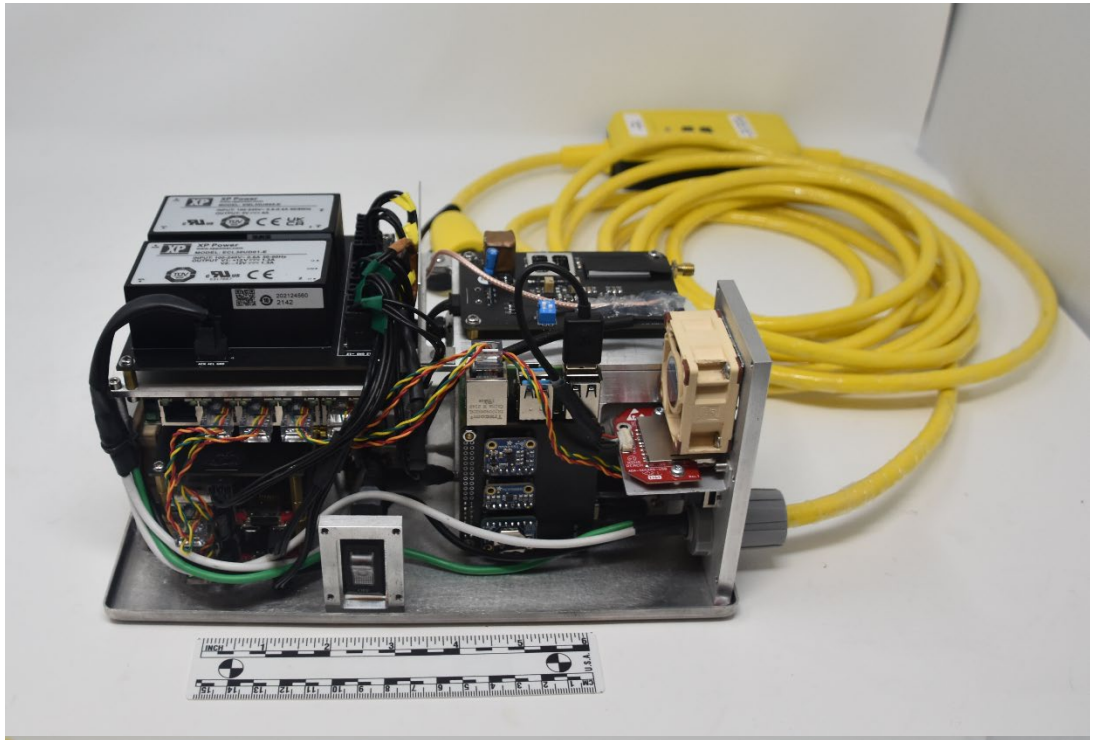


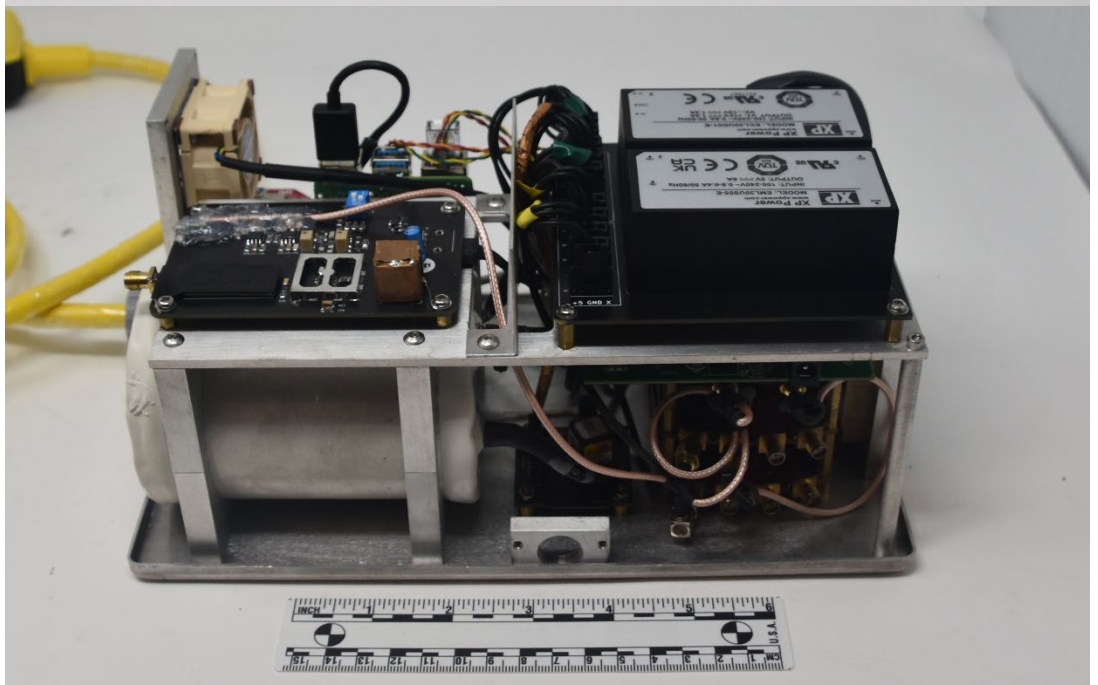
AirTED Si PIN diode dose rate and altitude profile from WB-57 flight out of Eielseon AFB





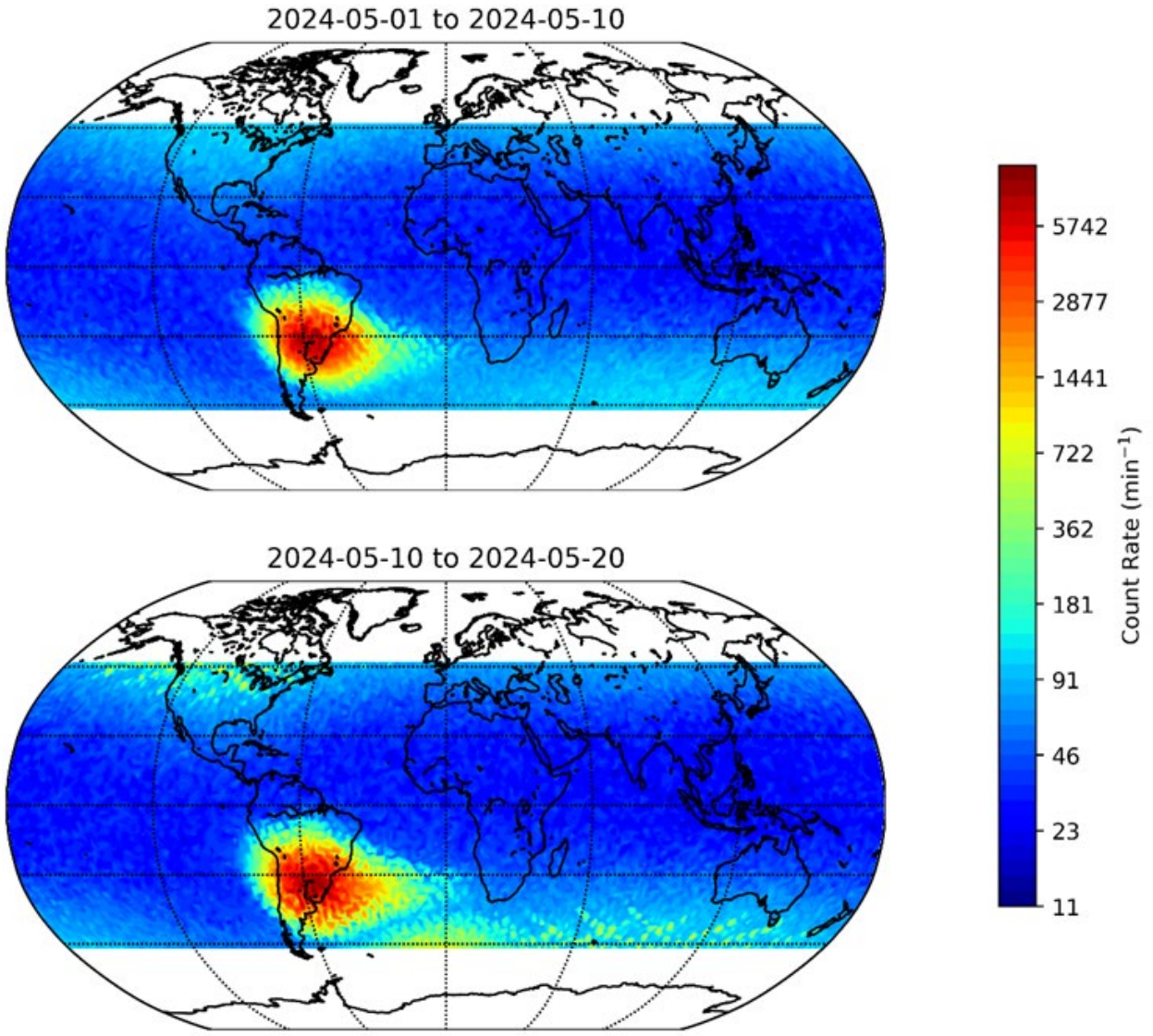
SpaceTED on ISS



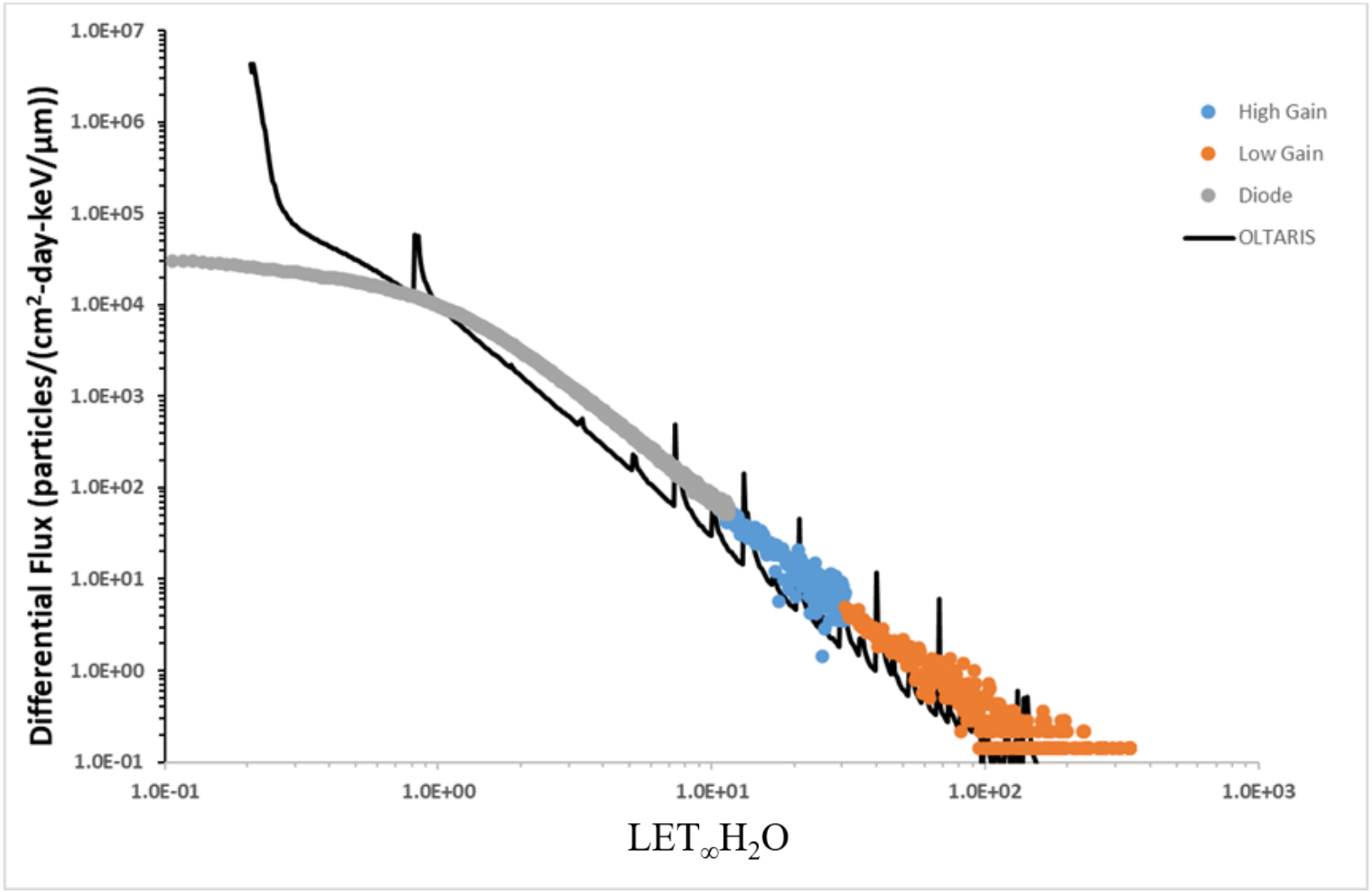


Detected effect of SPE aboard the ISS

- 11 May 2024 Solar Particle Event
- Earth-directed CME injected energetic particles into the trapped radiation belts
- Disrupted geomagnetic field
- SAA and Electron Cusp regions intensified
- Aurora borealis seen as far south as Florida

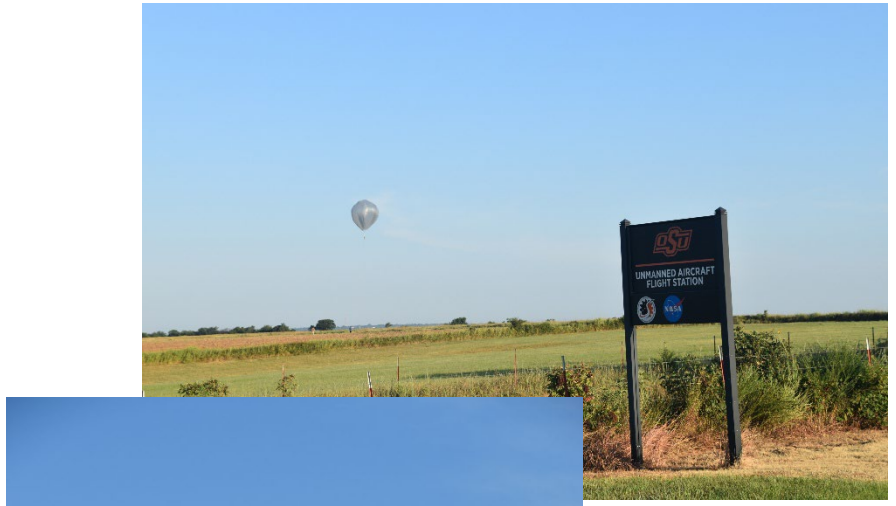


SpaceTED ISS Results
Linear Energy Transfer Spectra



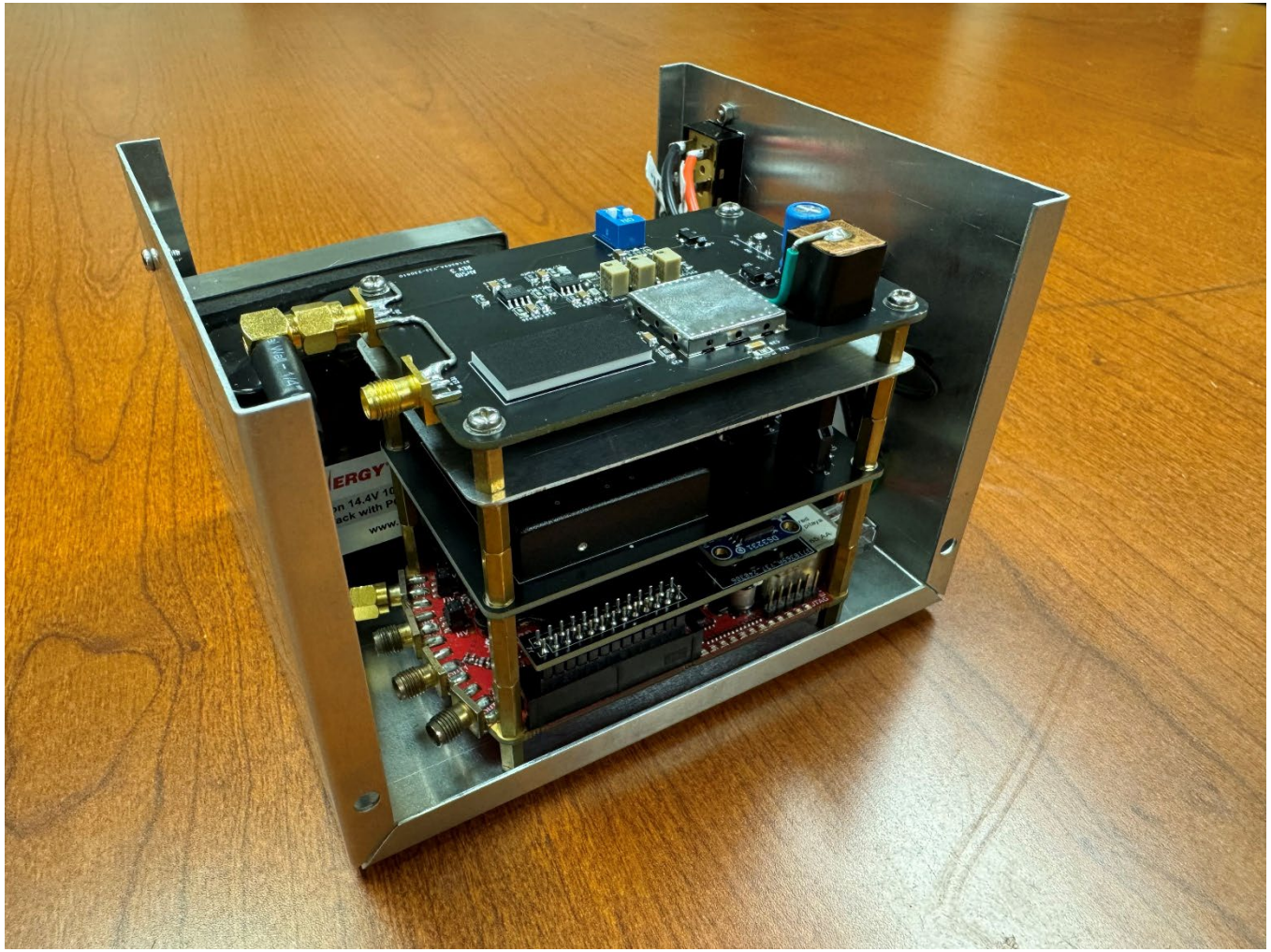
AirSiD Heliotrope Flights

- Heliotrope (Solar Balloon) flights launched from OSU Unmanned Aircraft Flight Station
- Balloons made of painters drop plastic, clear packing tape and Carbon Black (to help balloons absorb heat).
- 3 kg max payload, including transponder, cut down mechanism.
- Payload automatically cut down when balloon reaches programmed latitude or longitude or after specified flight duration.
- Two flights this summer (June 10 and August 14) and (maybe) one this week.
- Longer term plan to develop technology so we can launch during an SPE and also to include full, battery-powered AirTED.

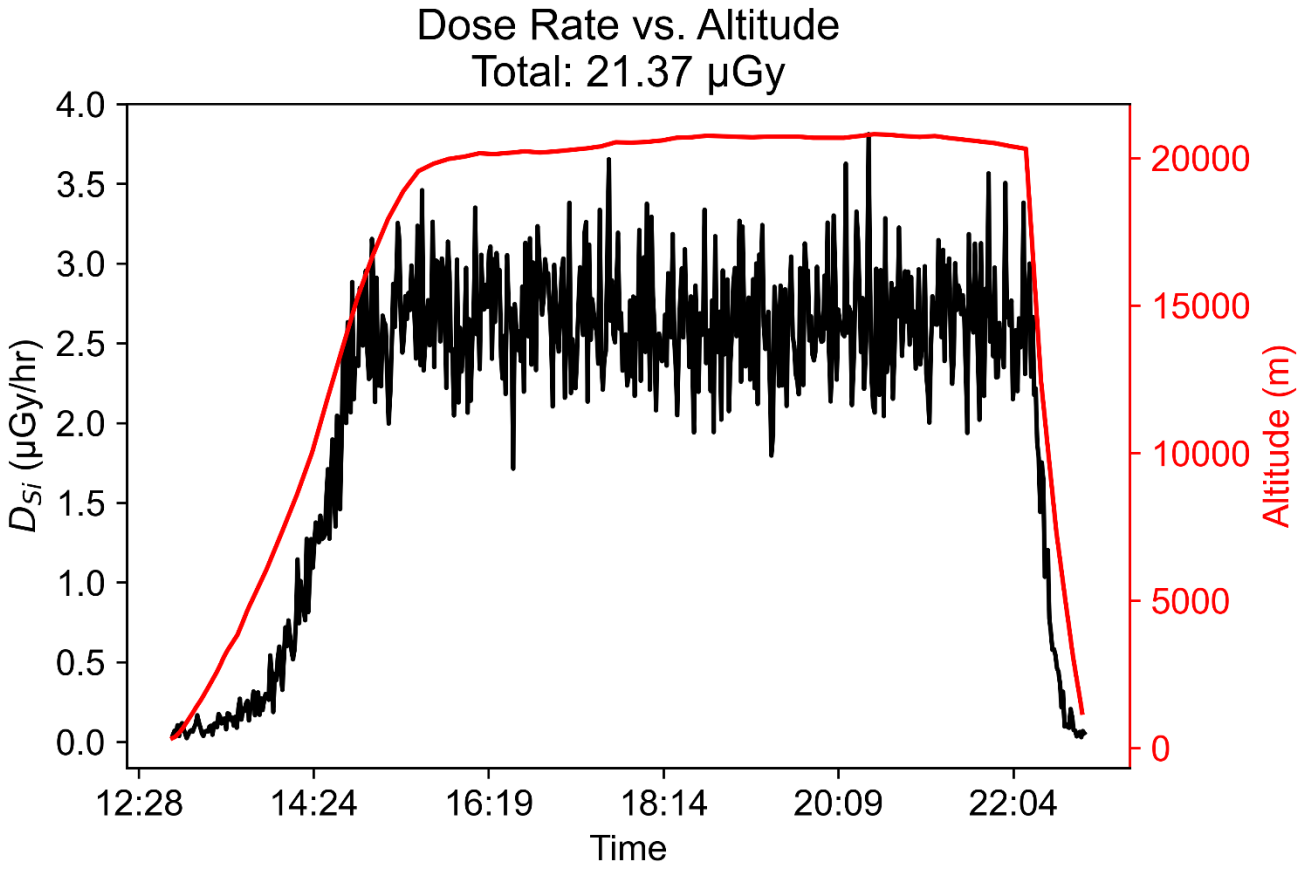


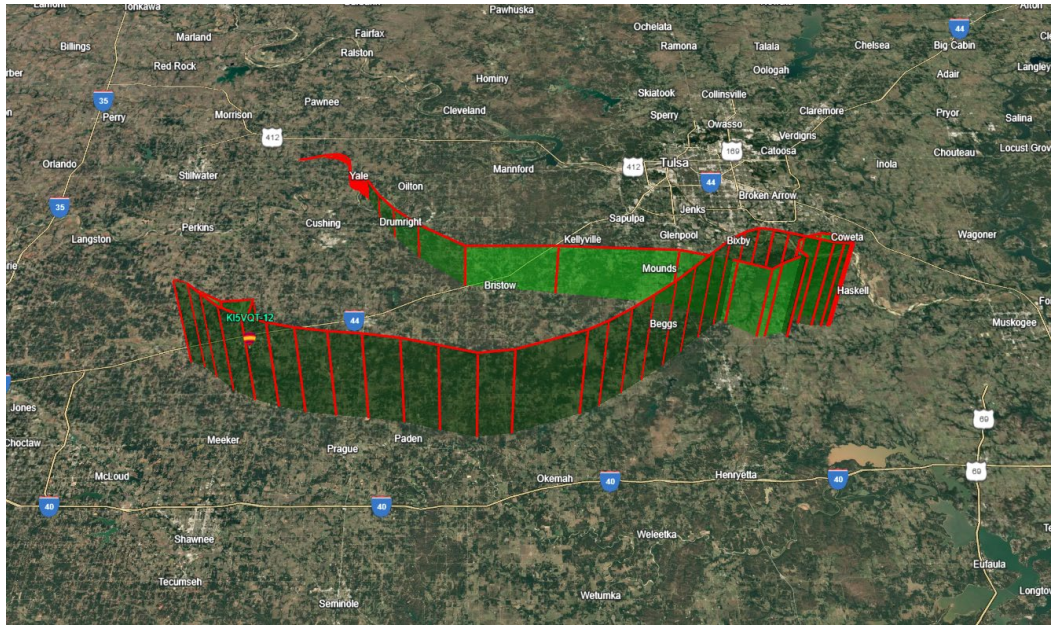
AirSiD = AirTED – TEPC + battery power

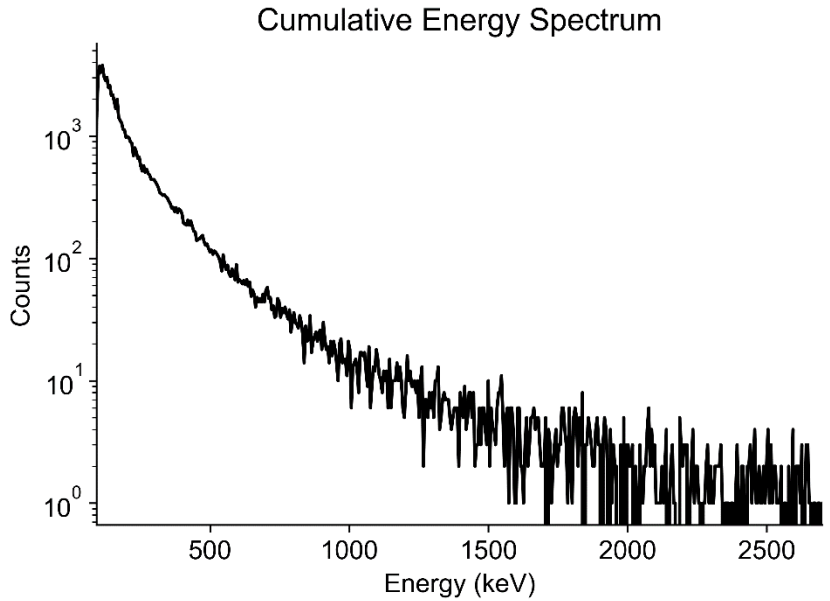
- AirSiD contains Si PIN diode, 3D accelerometer, temperature and pressure sensors, Red Pitaya spectrometer.
- Rechargeable battery pack good for ~20 hours of operation.
- Mass with batteries, 1.7 kg.



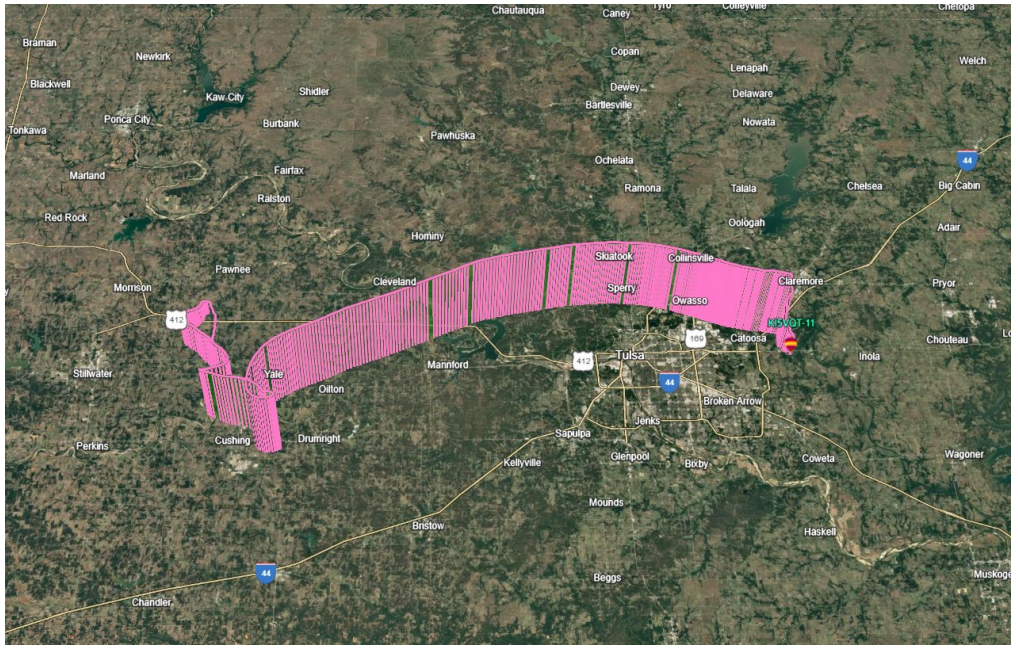
June 10, 2025 Flight
AirSID Measurement: 21.4 μGy
CARI-7A estimate: 23.2 μGy

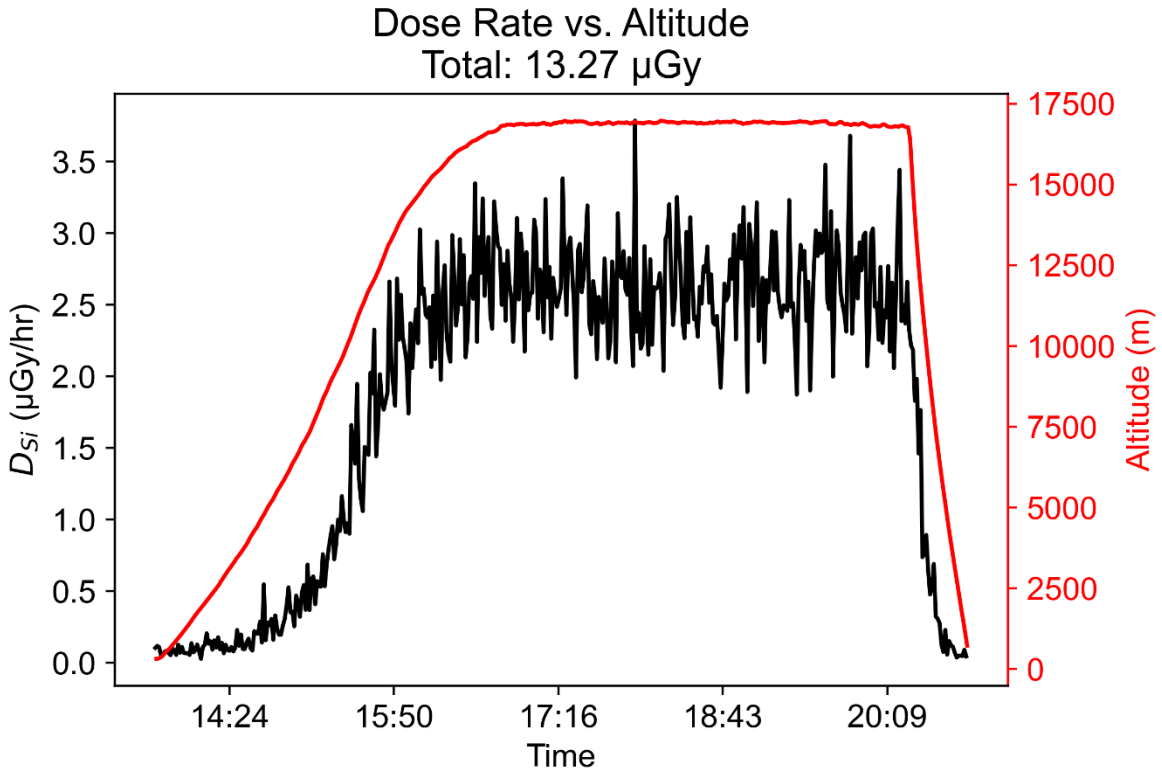


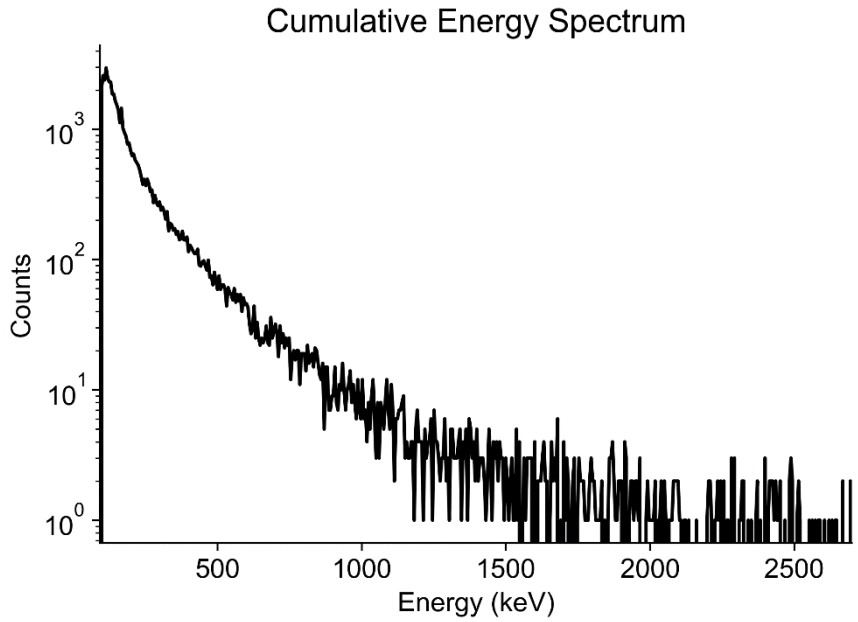




August 14, 2025 Flight
AirSID Measurement: 13.3 μGy
CARI-7A estimate: 14.8 μGy







Conclusions

- “If you can’t join them, go around them.” Concentrating on Stratospheric Heliotrope balloon flights rather than flights on commercial aircraft due to lack of opportunity and available aircraft platforms
- Currently only flying AirSiD (Si detector) on balloon flights due to mass/power constraints.
- Working to adapt AirTED (Si detector + TEPC) for use on balloon flights by reducing mass and power.
- Ultimately hope to develop “quick launch” capability in order to launch when solar conditions indicate high likelihood of Solar Particle Event and/or Geomagnetic Storm hitting Earth.