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Timepix-Based Mixed-Field Characterization

for Dosimetry and Model-Based Exposure Assessment

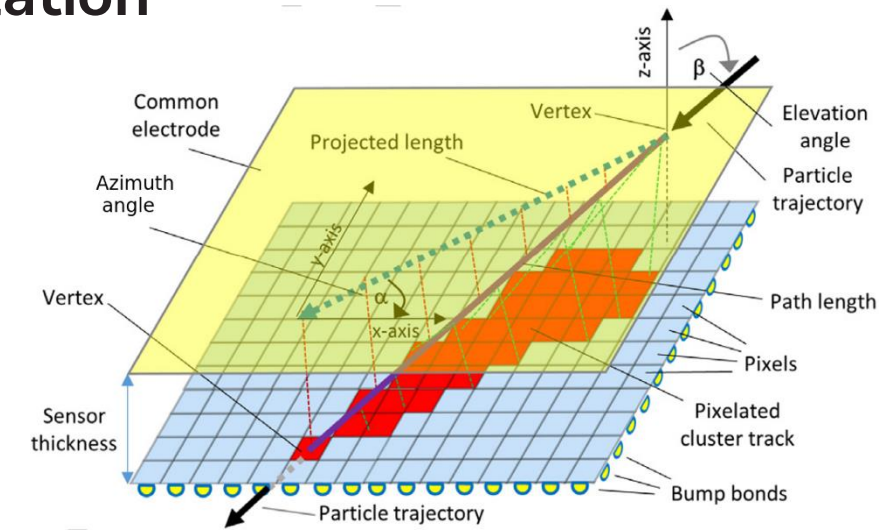
Radiation field decomposition

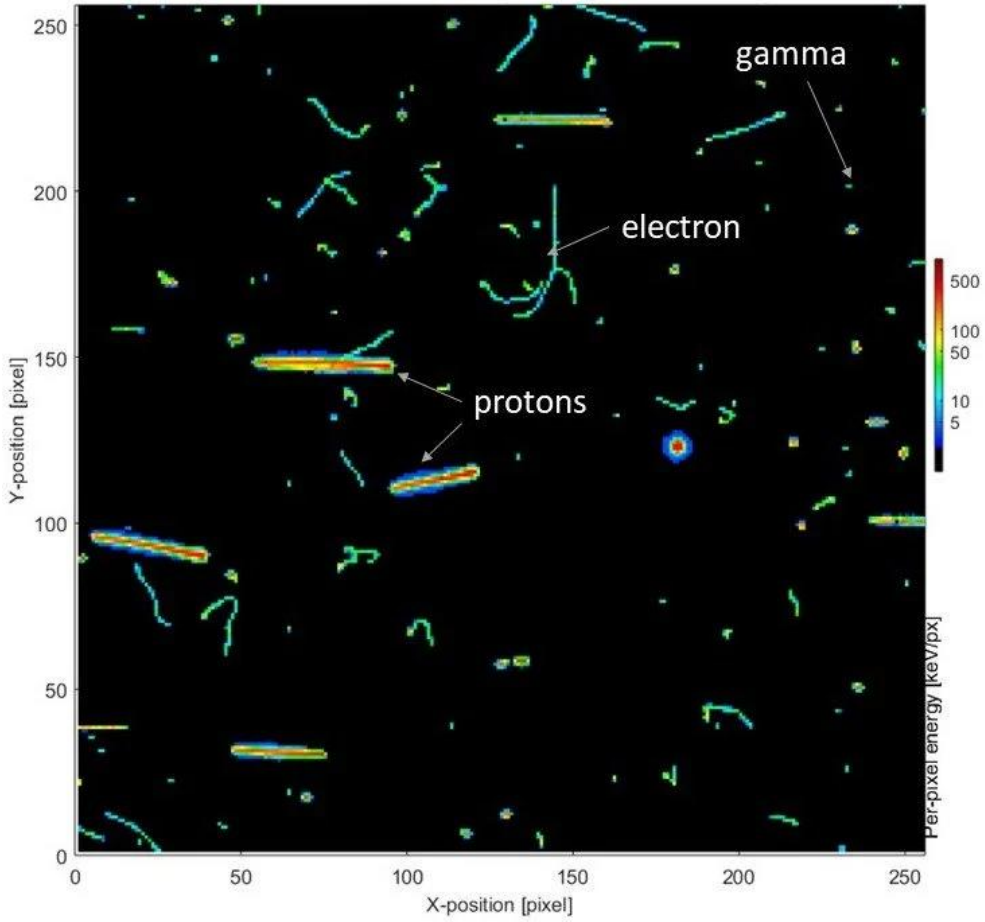
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= To identify particles by type, energy, and direction.

TraX Engine

> TraX Engine SW for data analysis:
  > Best-performing NN: 1. Photons+electrons; 2. Protons; 3. Ions
> Gamma-ray source assesment
> LET calculation



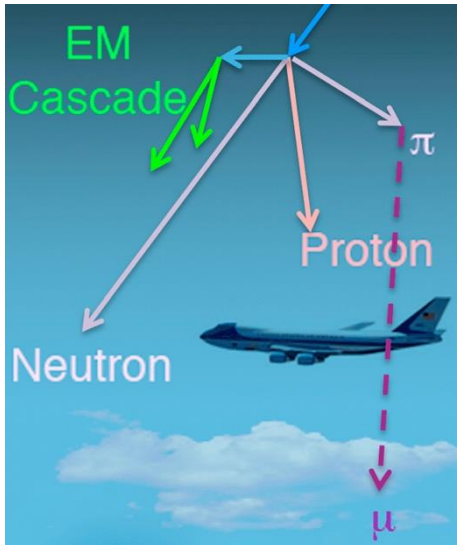


AdvaDose project

- **Real-world radiation environments** often deviate significantly from well-defined reference radiation fields.
  - Spectral composition, particle type, angular distribution

Main goal:

- To monitor and characterize **variations in the radiation field** relative to reference conditions.
- To extend the **particle-type classification** to include:
  - **Neutrons**; **electrons**; **photons**; **protons**; **muons**; **ions**



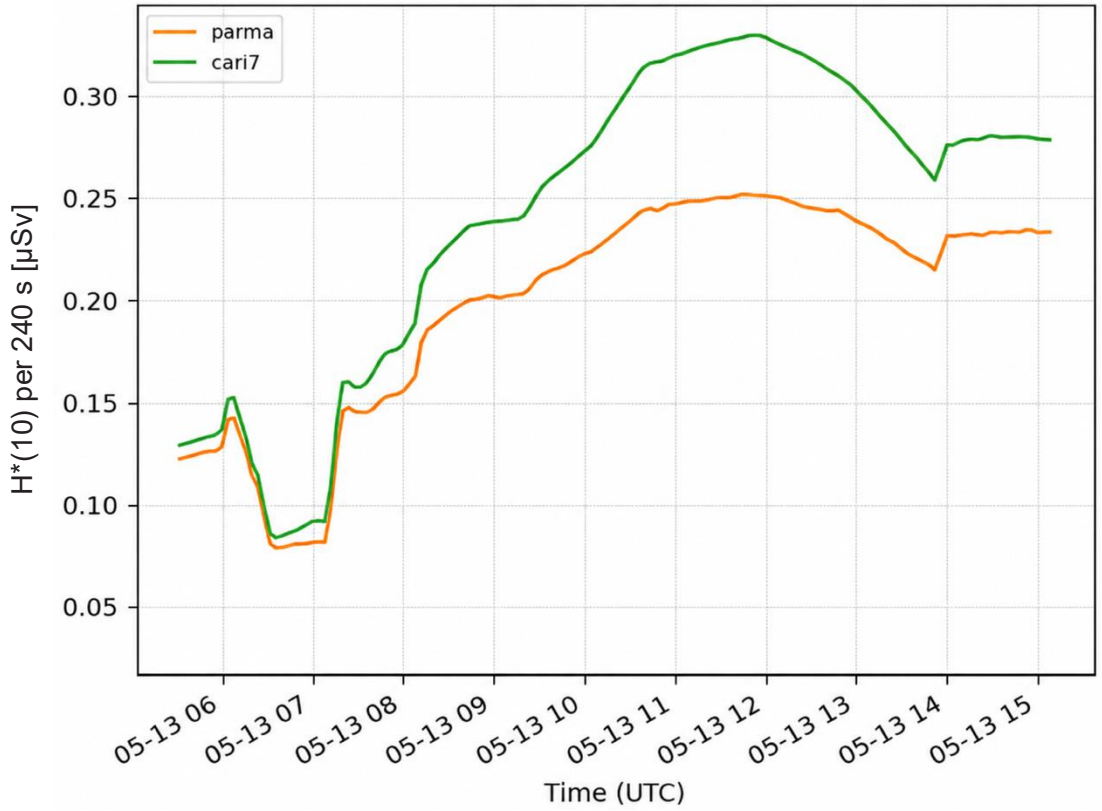
Aircraft dosimetry

- **Standalone operation** or **integration into existing monitoring systems**.

Radiation transport models validation

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- **Timepix-based detector resolving particle-specific counts can help to validate and tune transport models**
- **Aircraft dosimetry**
  - Calculated E differs significantly between models
  - High lattitudes are particularly challenging
  - Not all effects are fully undestood
  - Radiation field decomposition may provide additional information to conventional measurements



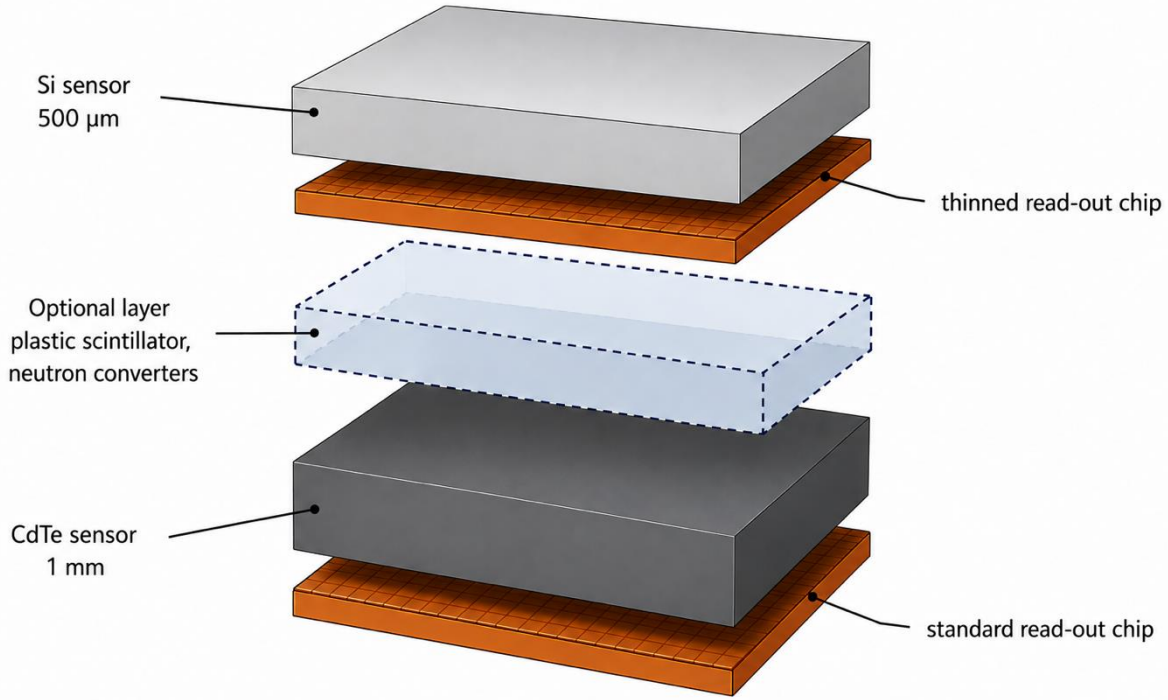
Detectors for Aircrafts and Space

Readout Electronics:

- **TPX3**
  - **Data-driven acquizition → No tracks overlap & Time stamp for each pixel → best performing classification**
- **TPX2**
  - **No space-use licensing restrictions**
  - Preamp with Adaptive Gain → up to **3.2 MeV/pixel**
  - Dynamic SW radout under development

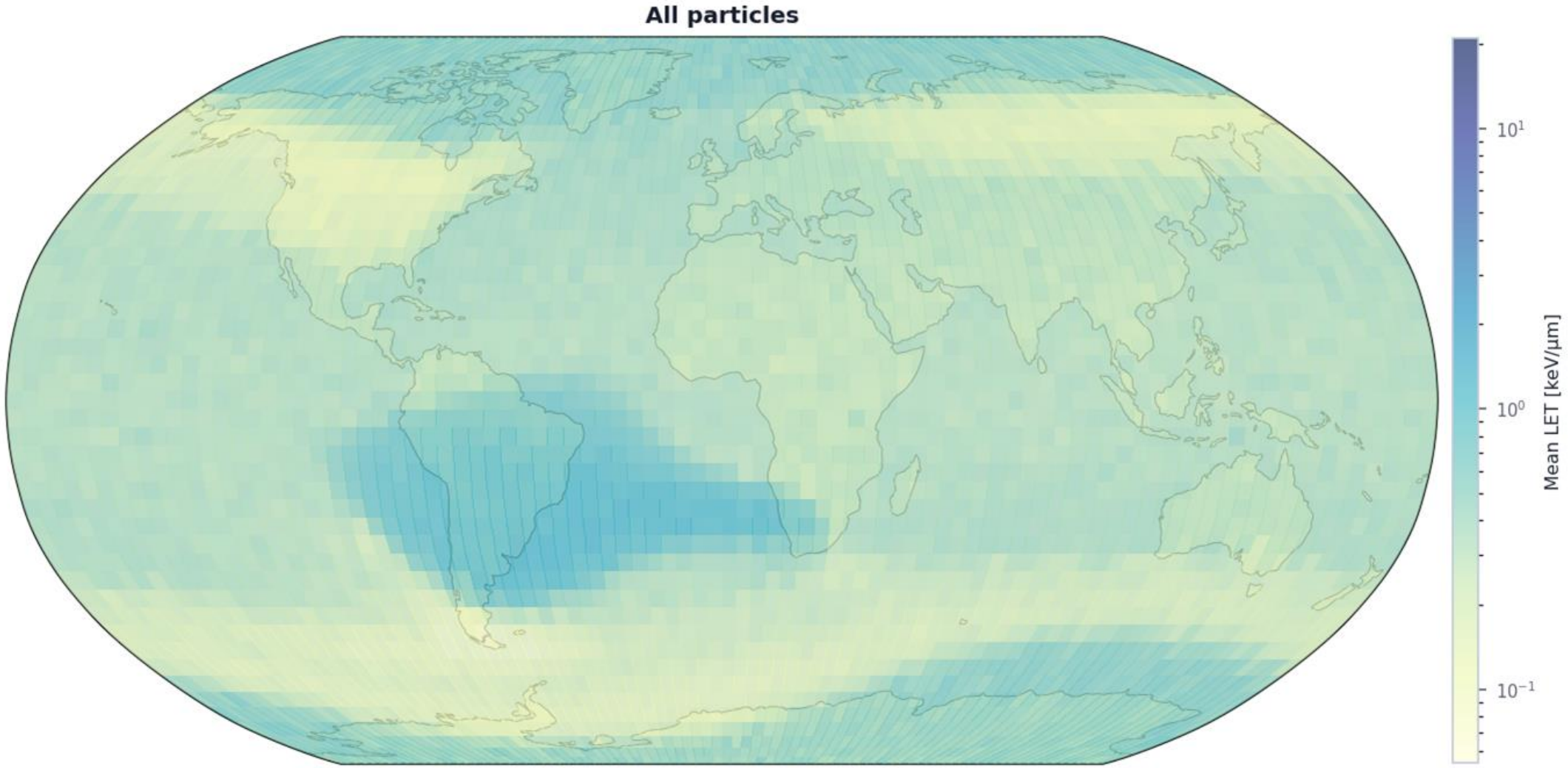
Sensor material:

- **Si 500 um** and/or **CdTe 1 mm**
  - One single device
  - Telescope, fully synchronised



Variability of the radiation field in LEO with TPX3

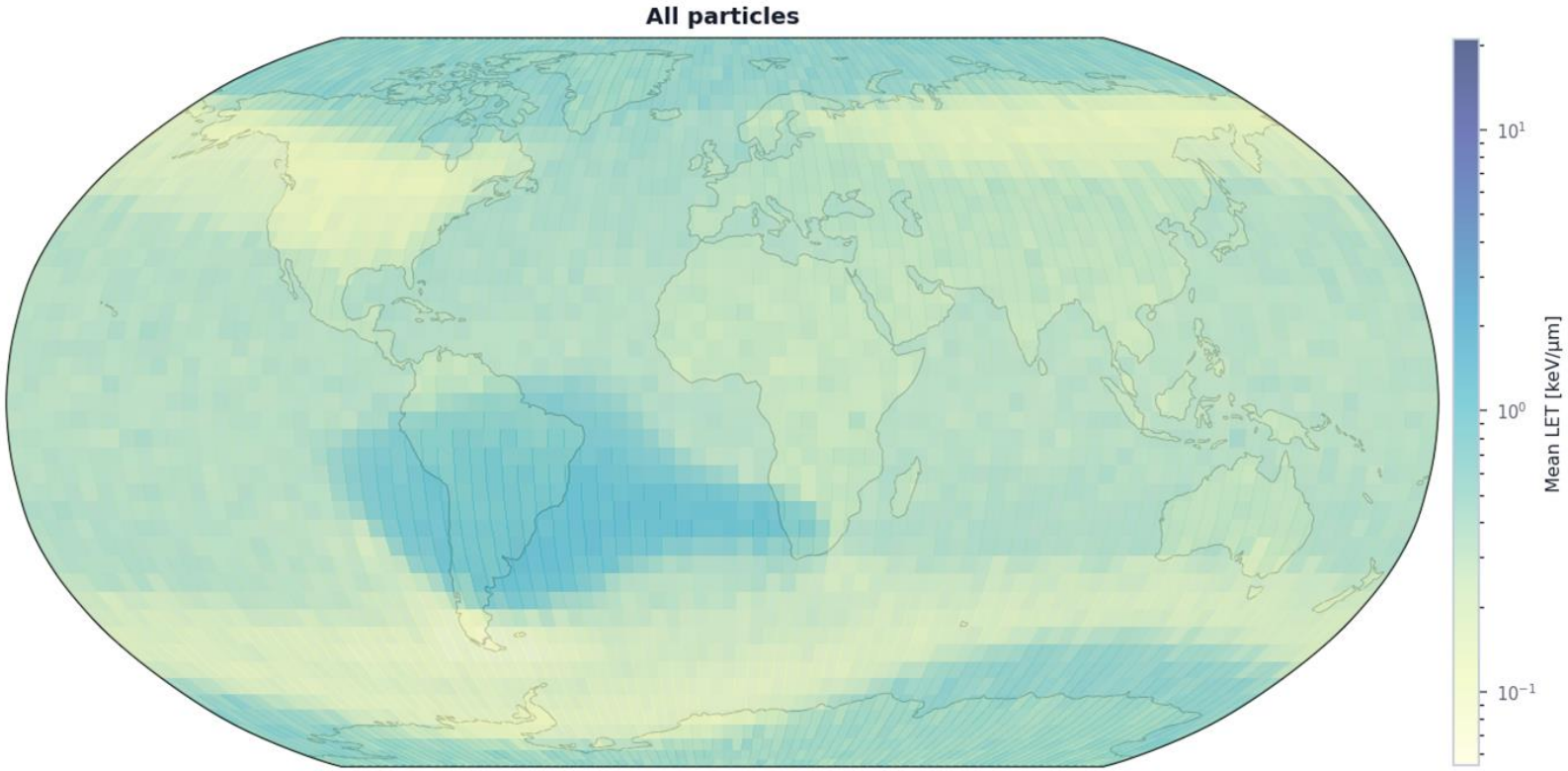
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LET on LEO

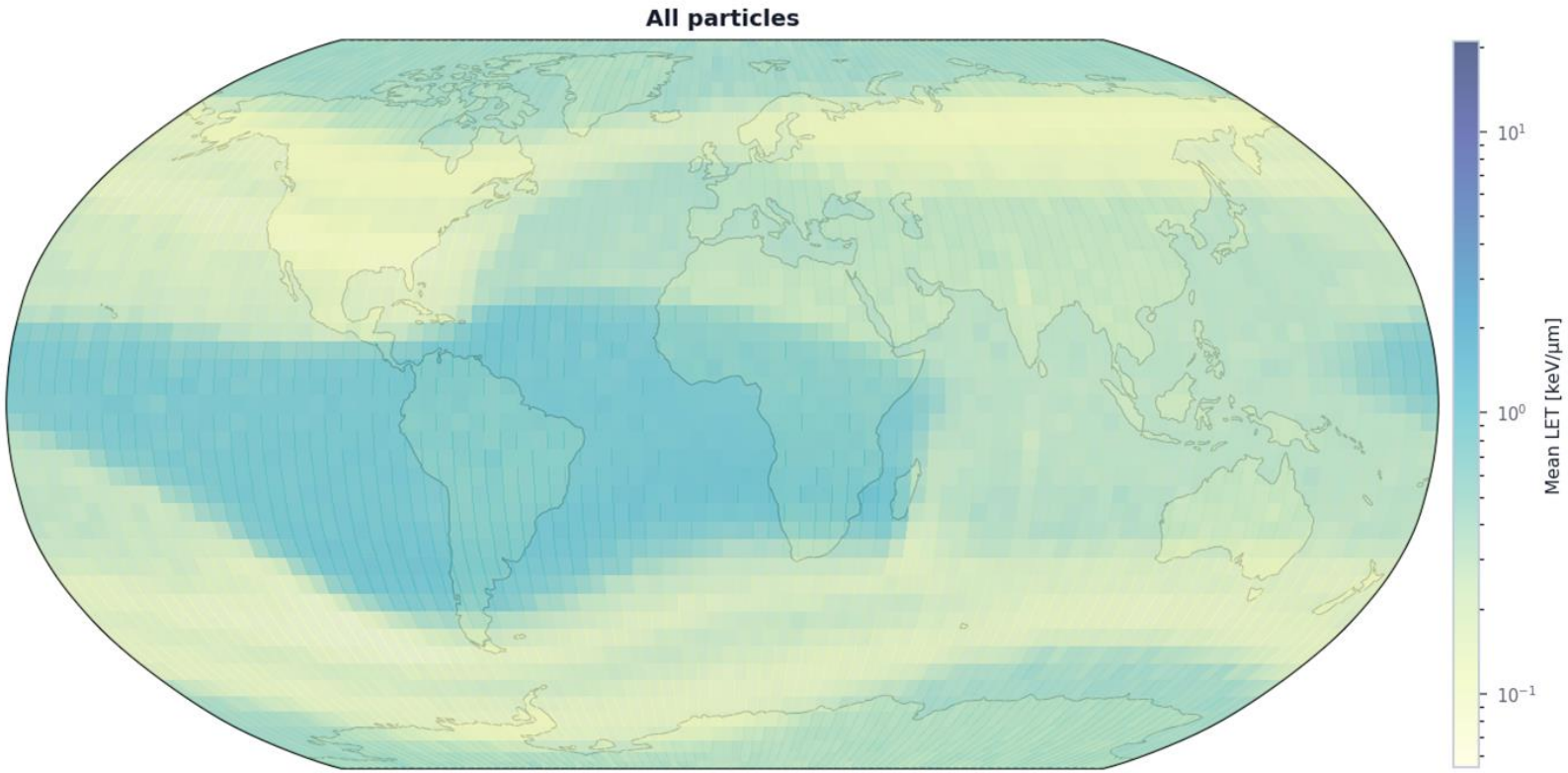
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- OneWeb JoeySat, 86.68° inclination
- January – October 2024, 76.5 days live time
- Mean altitude 613 km
- MiniPix Space (TPX3): 500 µm Si, 200 V, 5 keV threshold
- 5 mm Al shielding, frame mode
- 8,540,515 clusters
- Mean LET varies strongly with latitude and longitude



LET on LEO

- February 2025 – April 2026
- Mean altitude 1175 km
- 95.9 days live time, 21,942,133 clusters
  - Larger SAA, longer acquisition
- LET also varies strongly with altitude

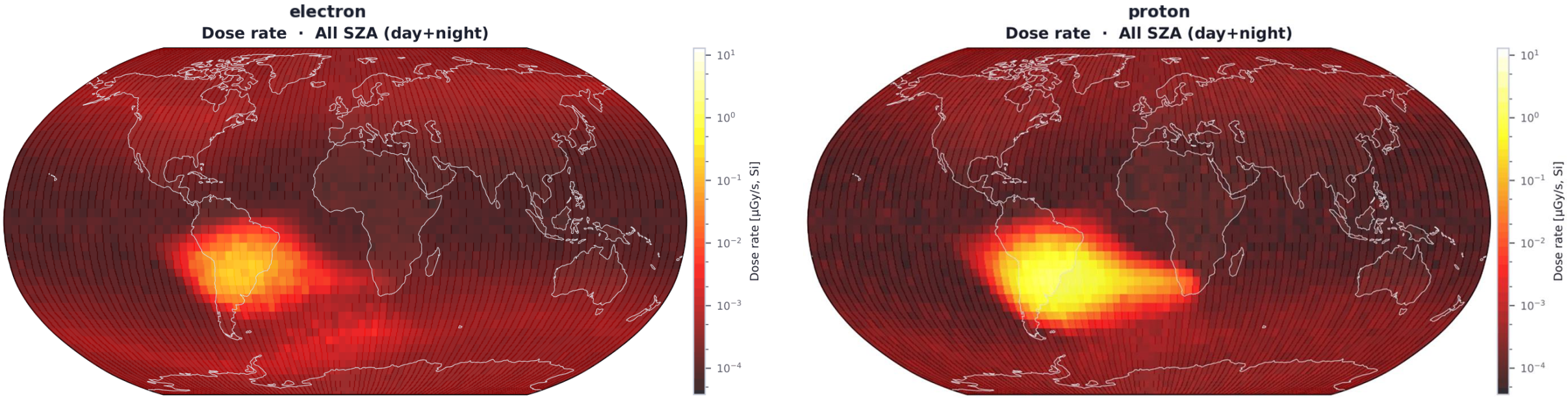


Dose rate on LEO – 613 km

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> MiniPix Space resolves the dose rate per particle type

> Protons dominate inside the SAA, electrons rise in the outer belts



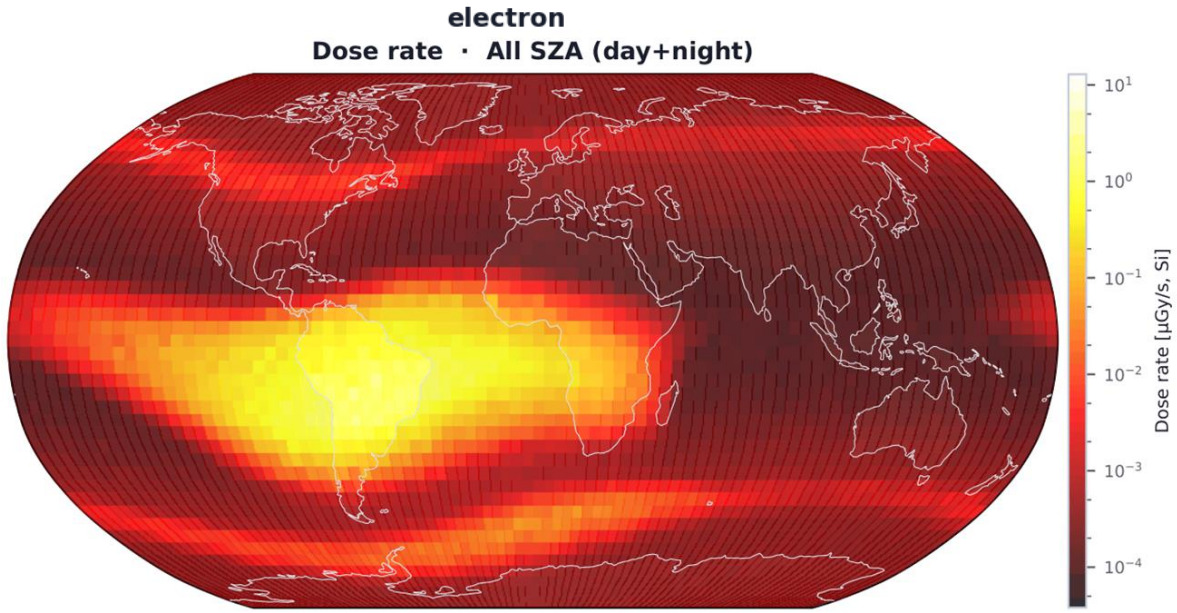
Dose rate on LEO – 1175 km

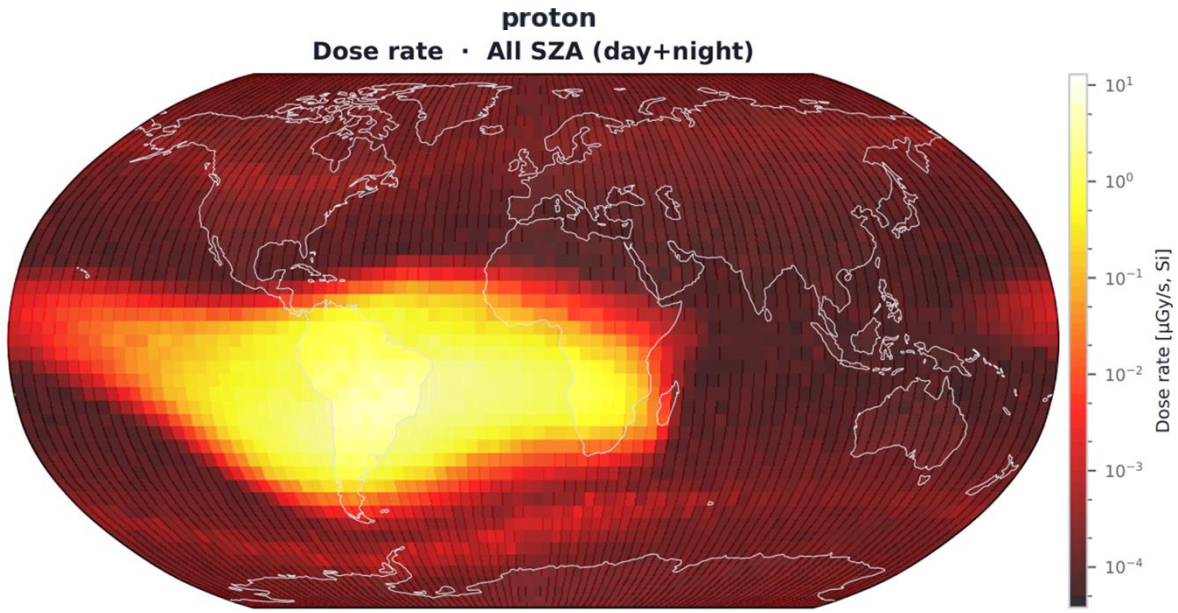
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> Stronger anisotropy at the higher altitude

> Protons reach 10 µGy/s inside the SAA

> Outer radiation belts clearly visible

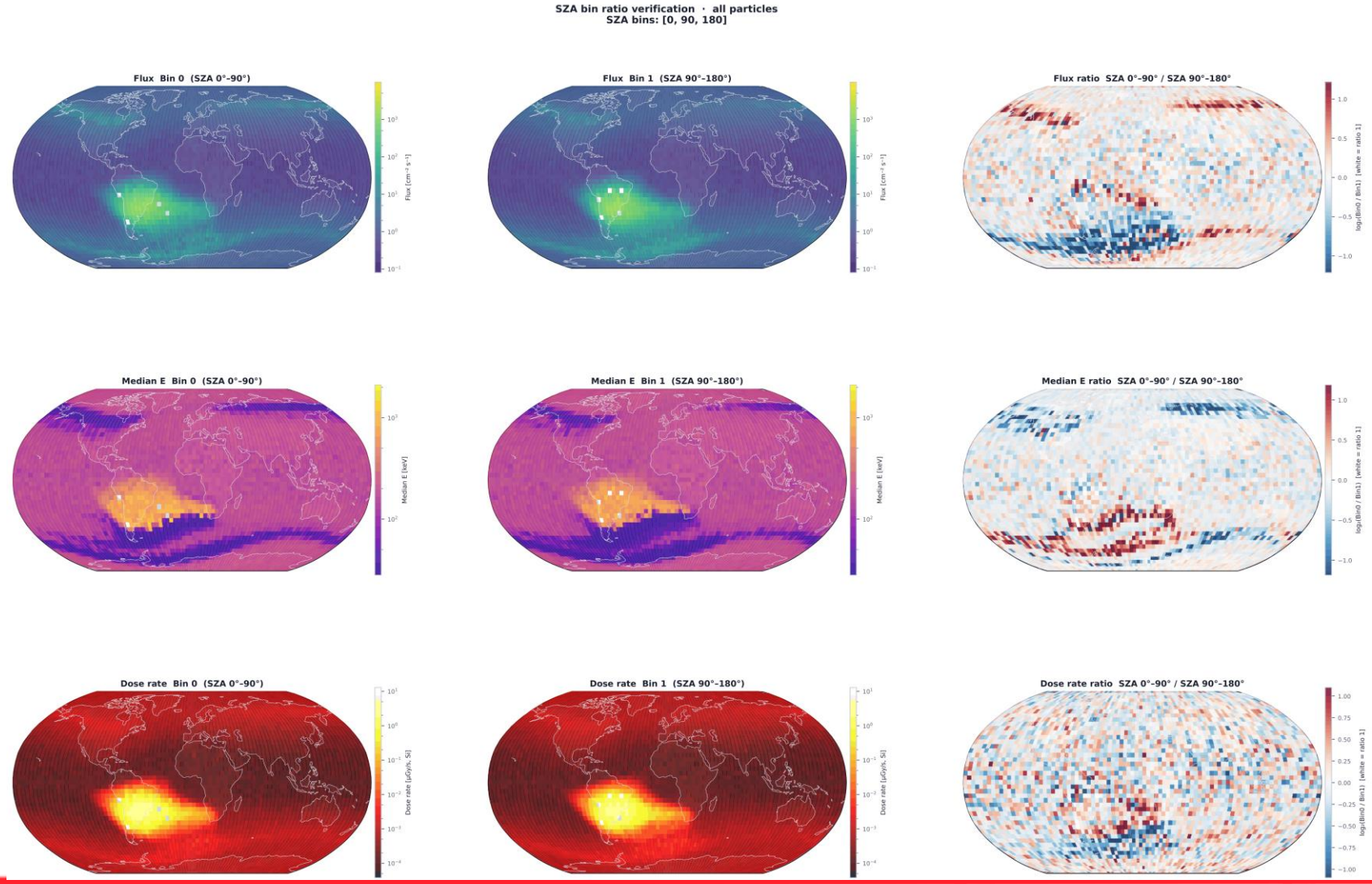




Day/night dose rates - 613 km

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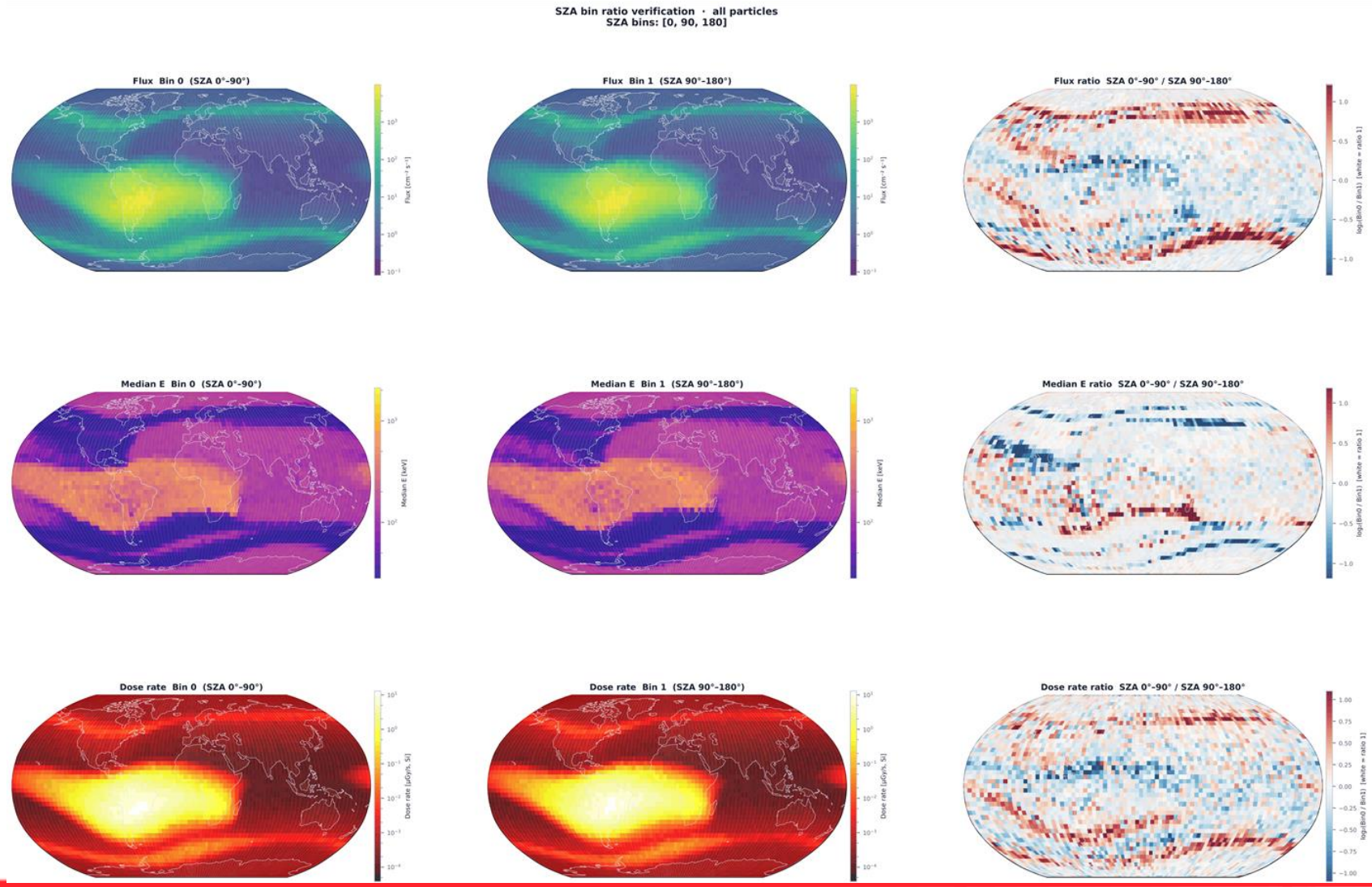
- Orbit is not Sun-synchronous, so all local times are sampled
- Columns: day, night, ratio
- Rows: flux, median energy, dose rate
- Flux and median energy ratios show distinct features
- In dose rate the two effects cancel out, the ratio is almost pure noise



Day/night dose rates - 1175 km

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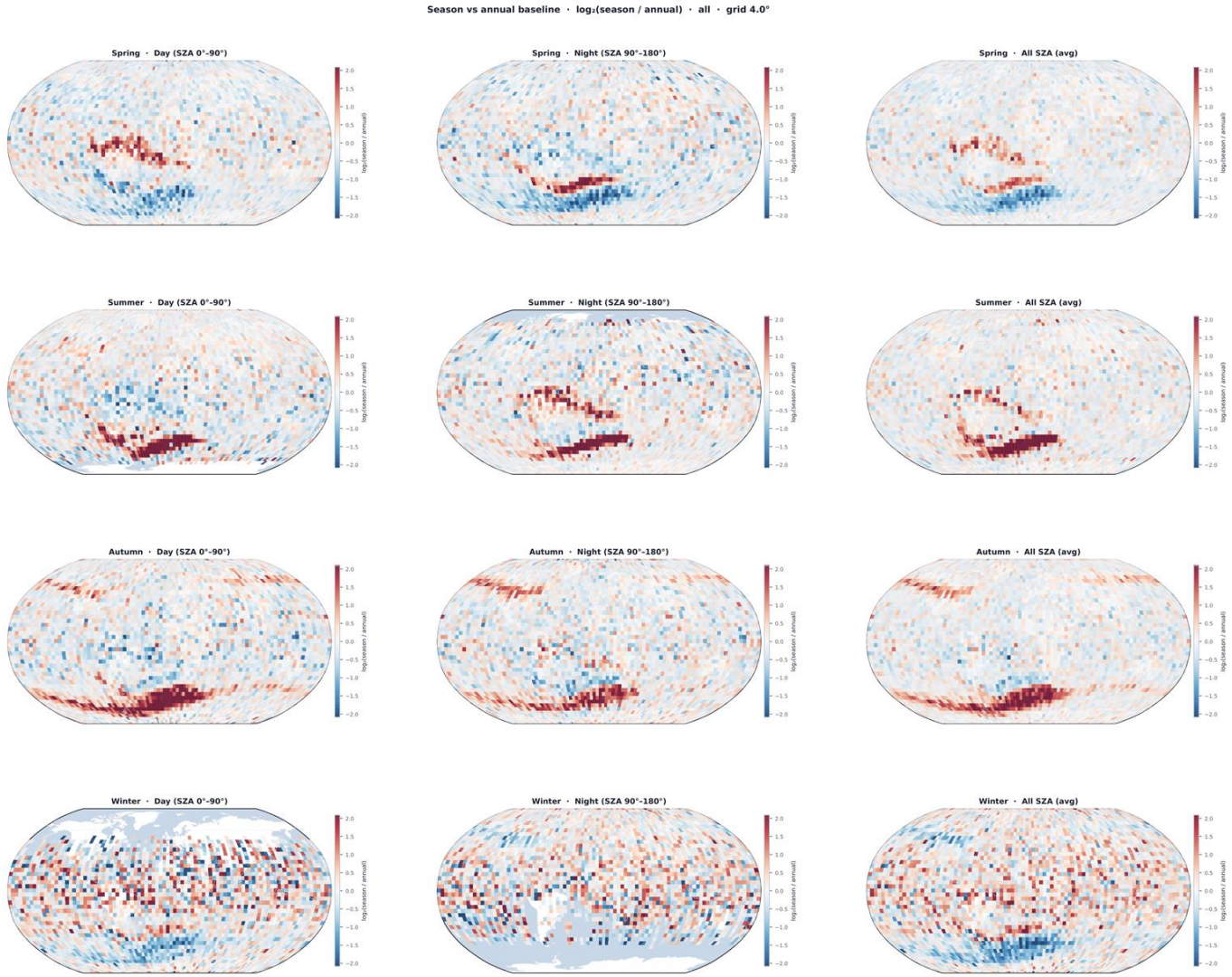
- Same layout as the previous slide
- At 1175 km the day/night change in flux outweighs the change in median energy
- The dose rate ratio now resembles the flux ratio



Seasonal ratios – 613 km

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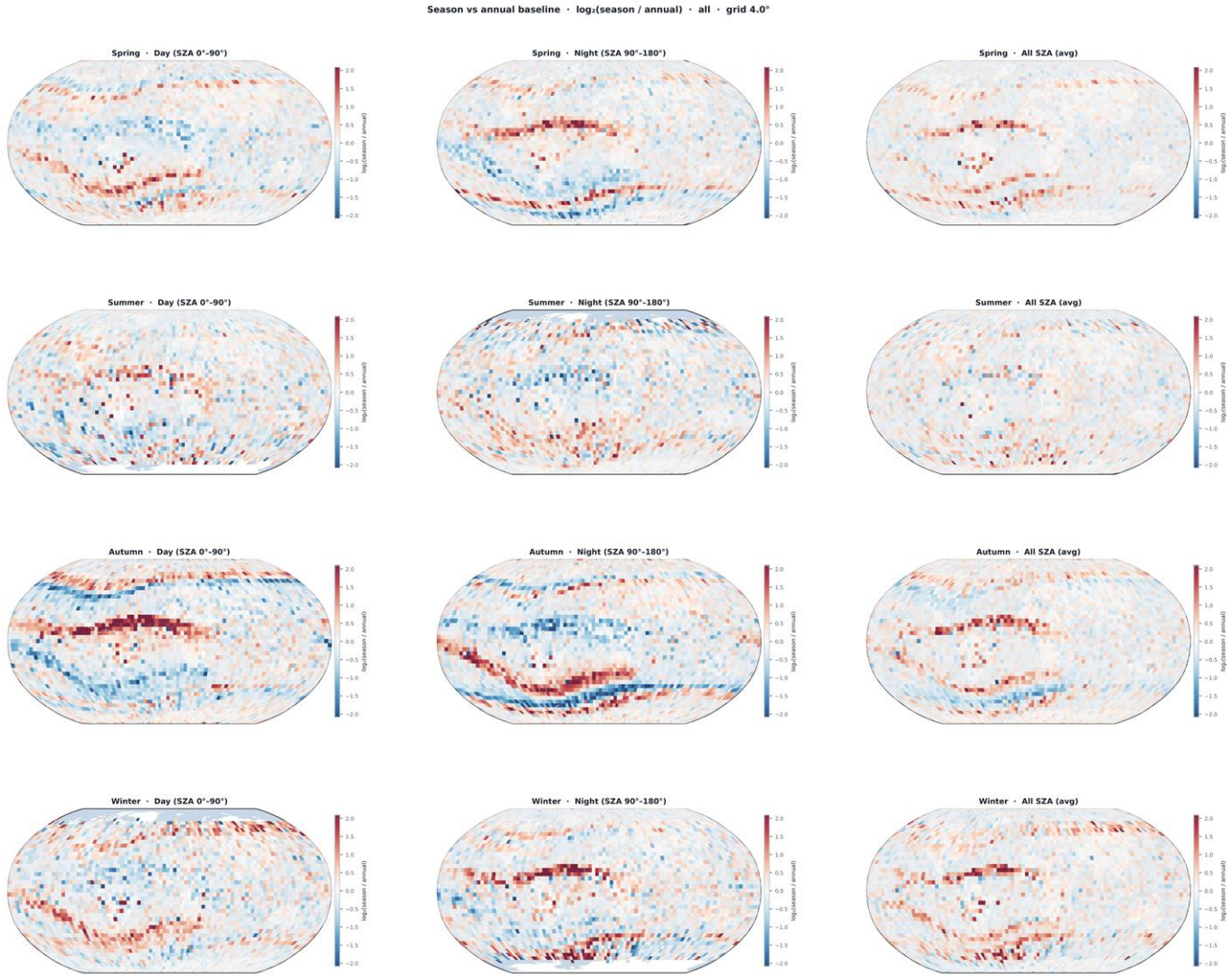
- Seasons centred on equinoxes and solstices
- Seasonal average / annual average
- Rows: spring, summer, autumn, winter
- Columns: day, night, mean
- A clear anisotropy



Seasonal ratios – 1175 km

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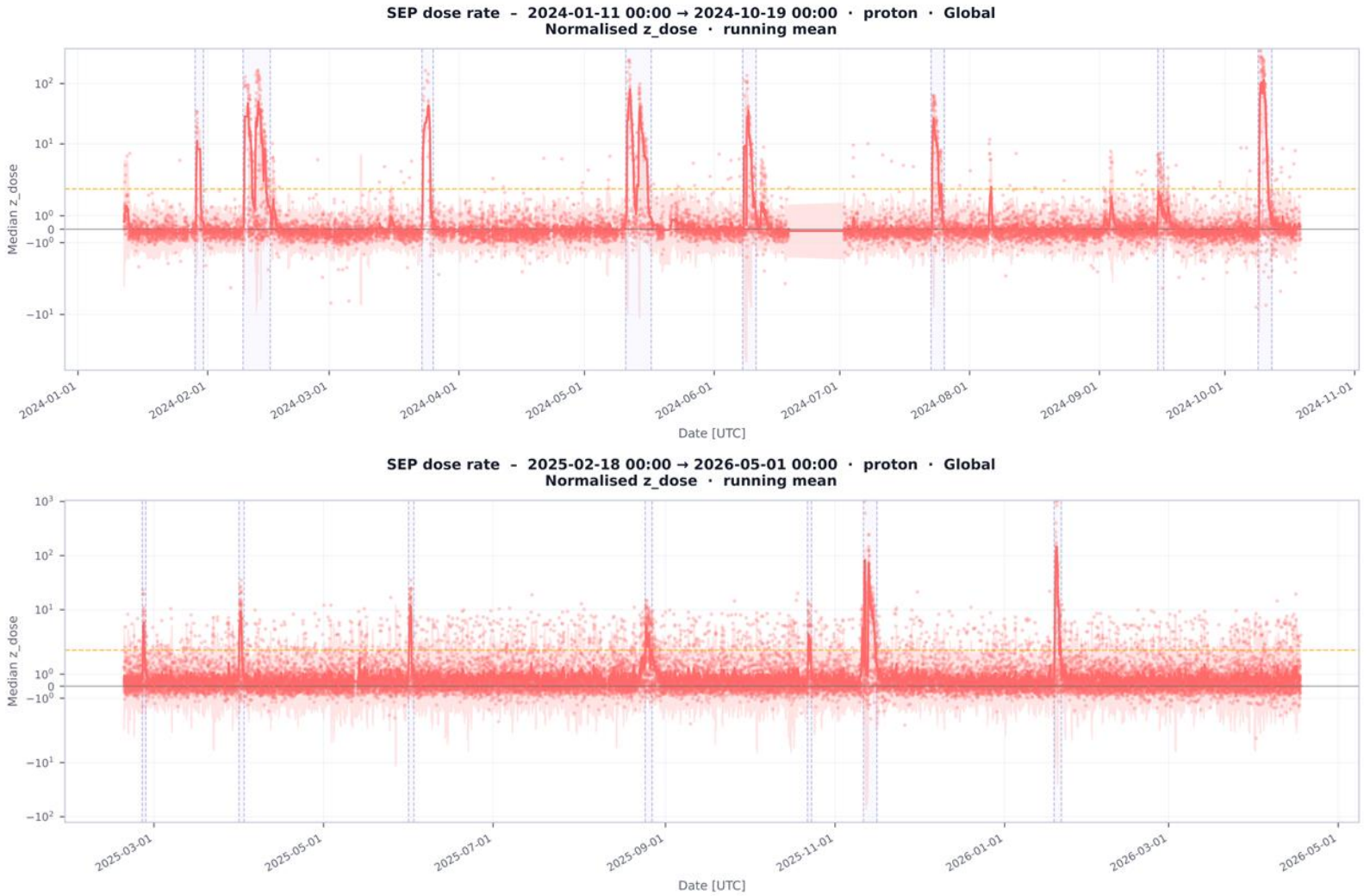
- A different anisotropy at the higher altitude
- Spring-night and day look similar



Solar particle events (SPEs) - global

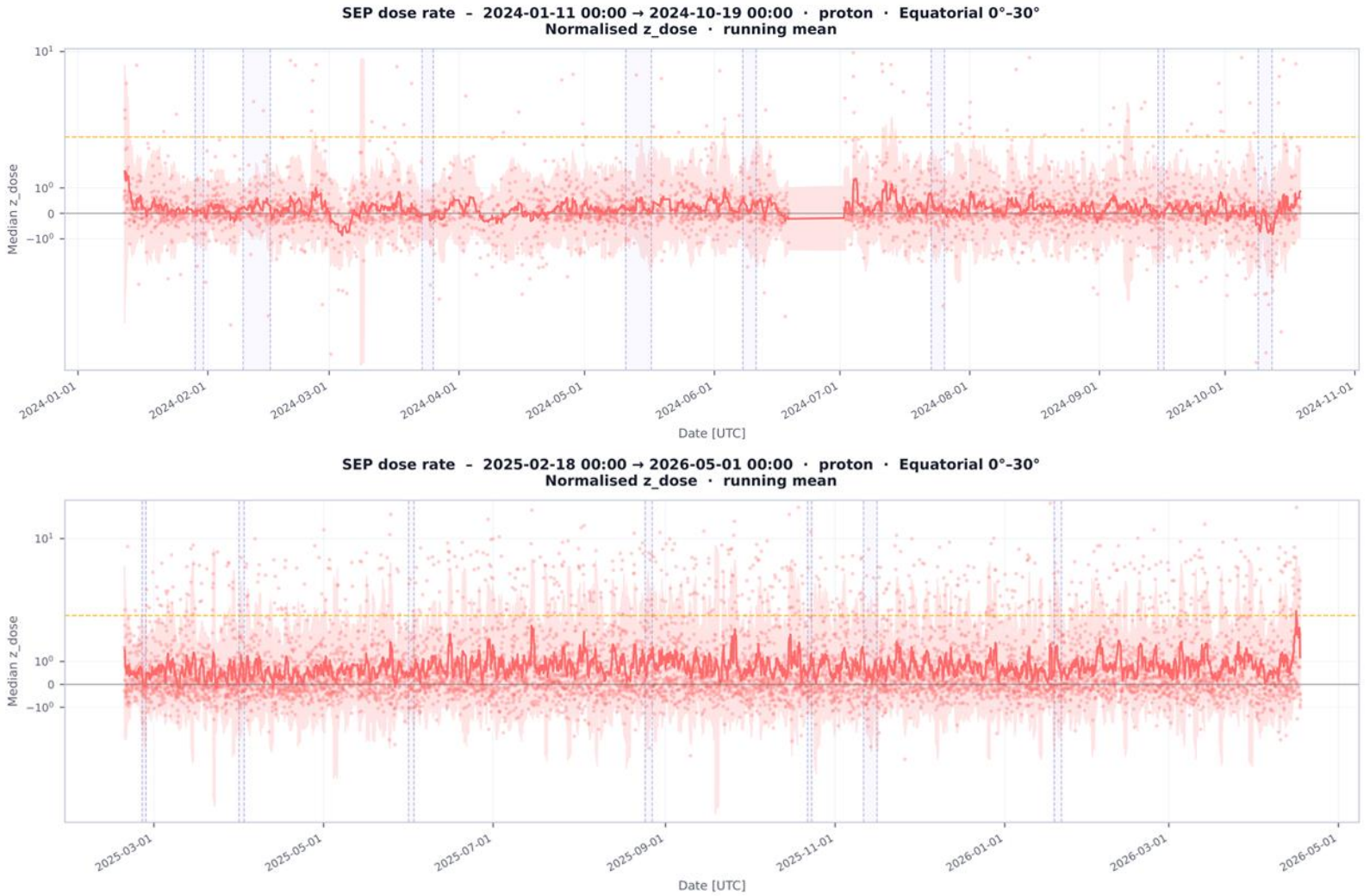
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- Proton dose rate, normalised against a running baseline
- Clear peaks mark solar particle events
- Top: 613 km, bottom: 1175 km



Solar particle events – equatorial

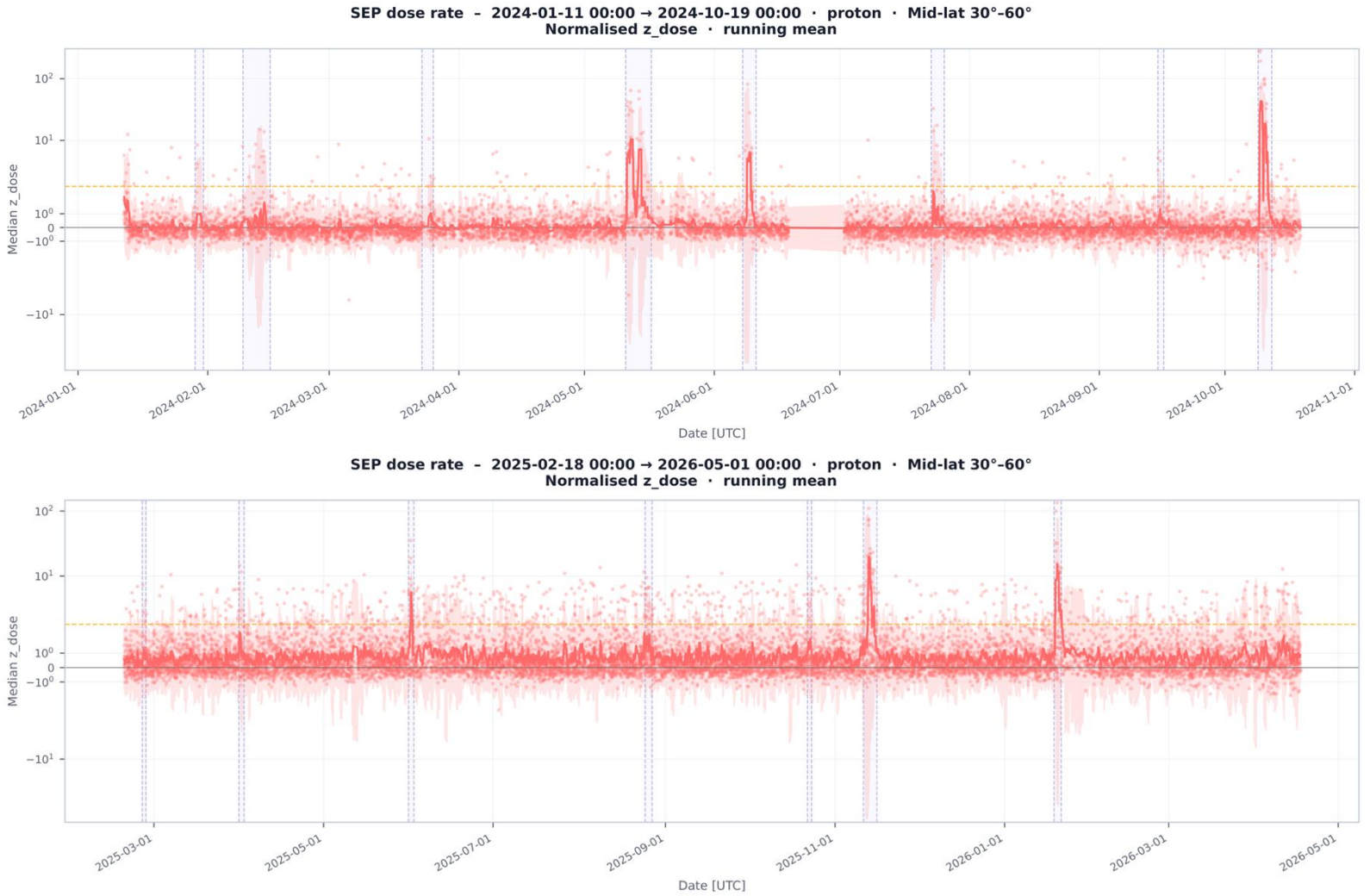
- The response is strongly latitude dependent
- Equatorial band, |lat| < 30°
- No increase in dose rate during any observed SPE



Solar particle events – mid-lat

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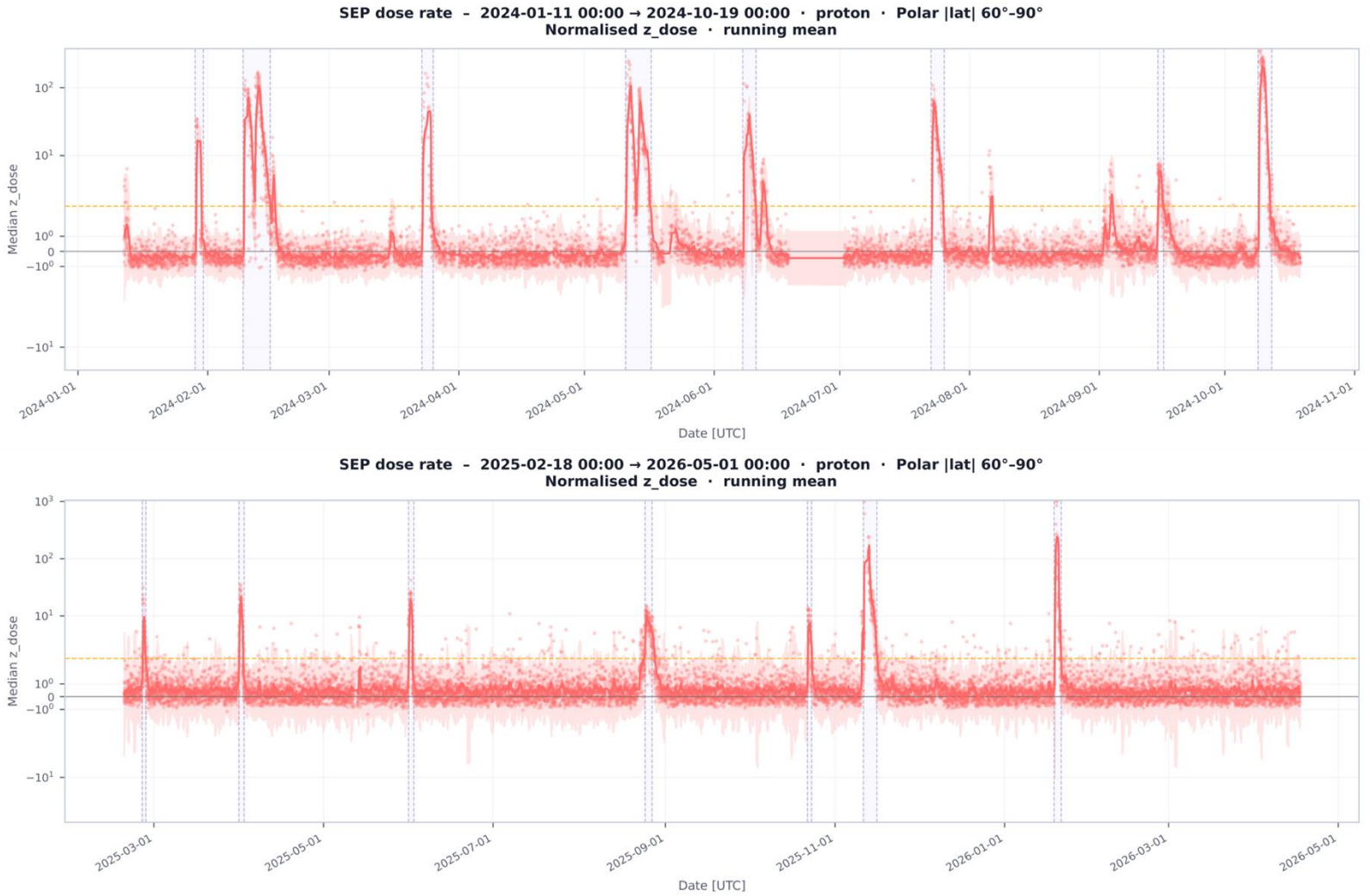
- Mid-latitudes, |lat| = 30° to 60°
- An increase during some events, none during others



Solar particle events – polar

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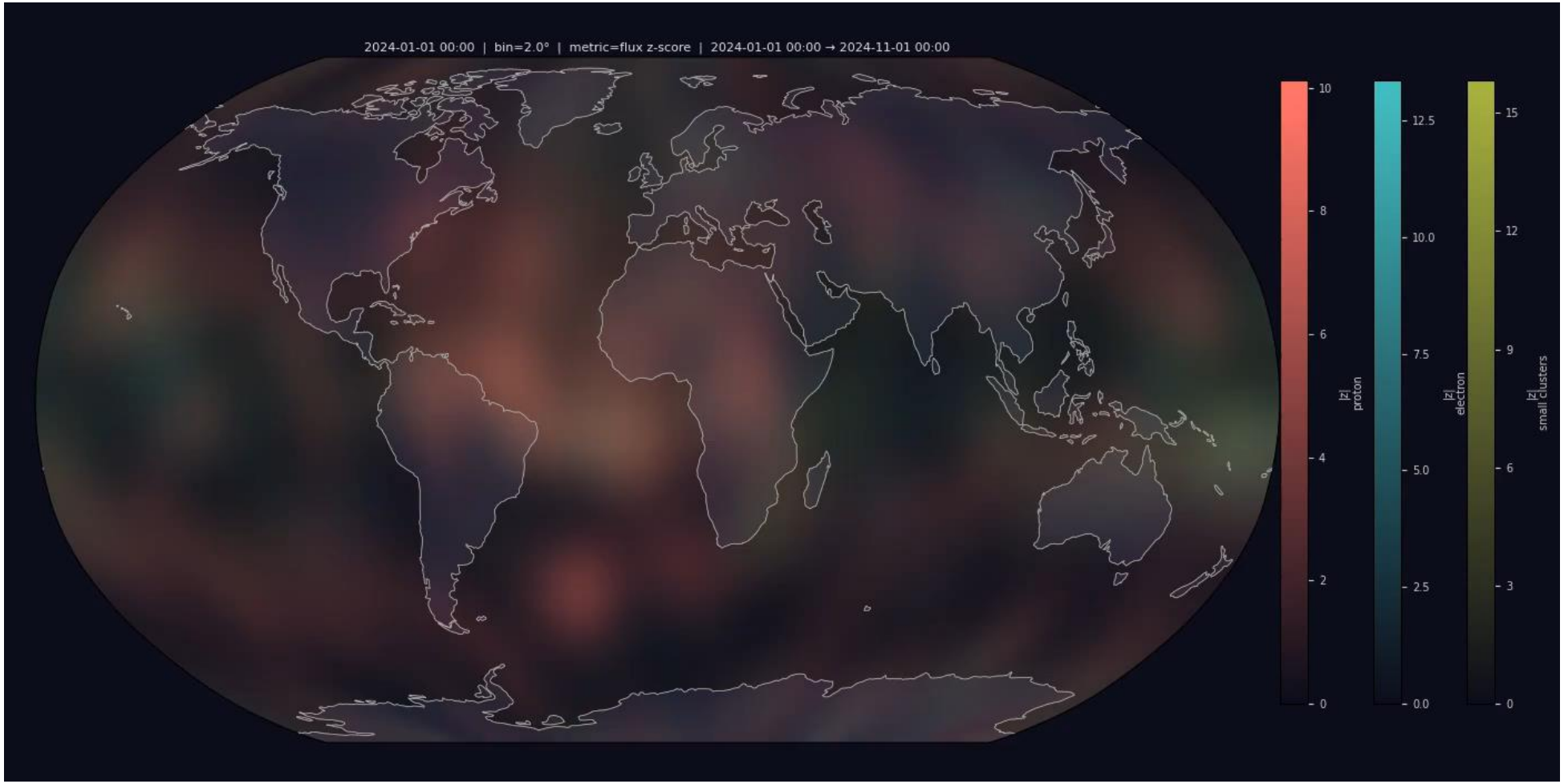
- Polar latitudes, |lat| > 60°
- The most distinct and highest peaks of all regions



Solar storm evolution video

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- 2° bins, 5-day window
- Bins shown as Gaussians
- Frames blended in time



Why pixel detectors?

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- Dose rate depends on
  - Latitude and longitude
  - Altitude
  - Time of day
  - Time of year
  - Solar particle events
- Models need all of these at once
- The data to constrain them is missing
- MiniPix Space can provide complementary in-situ data for model validation and refinement.

