ISS-RAD Measurements through Solar Cycle 25 Min. to Max.

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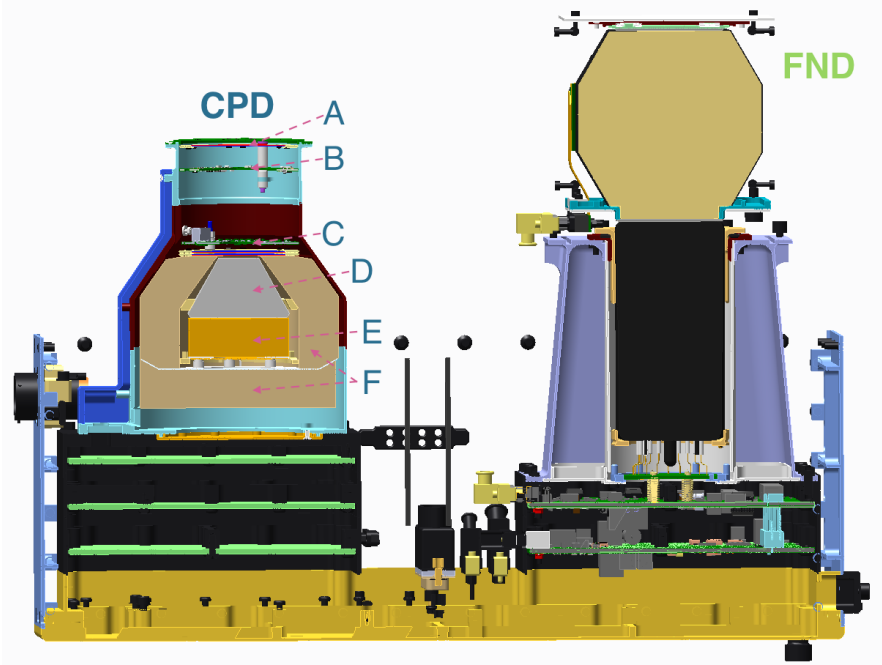
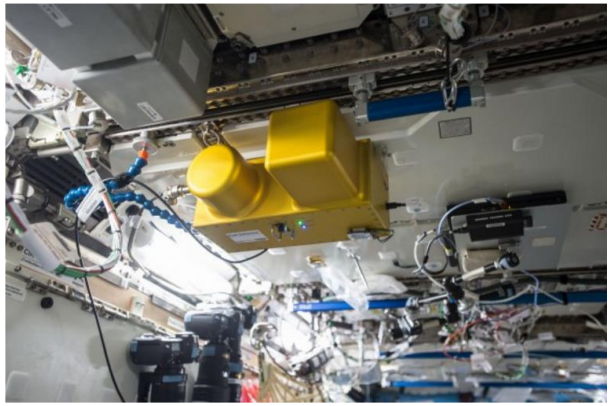
Overview & Timeline Since Deployment

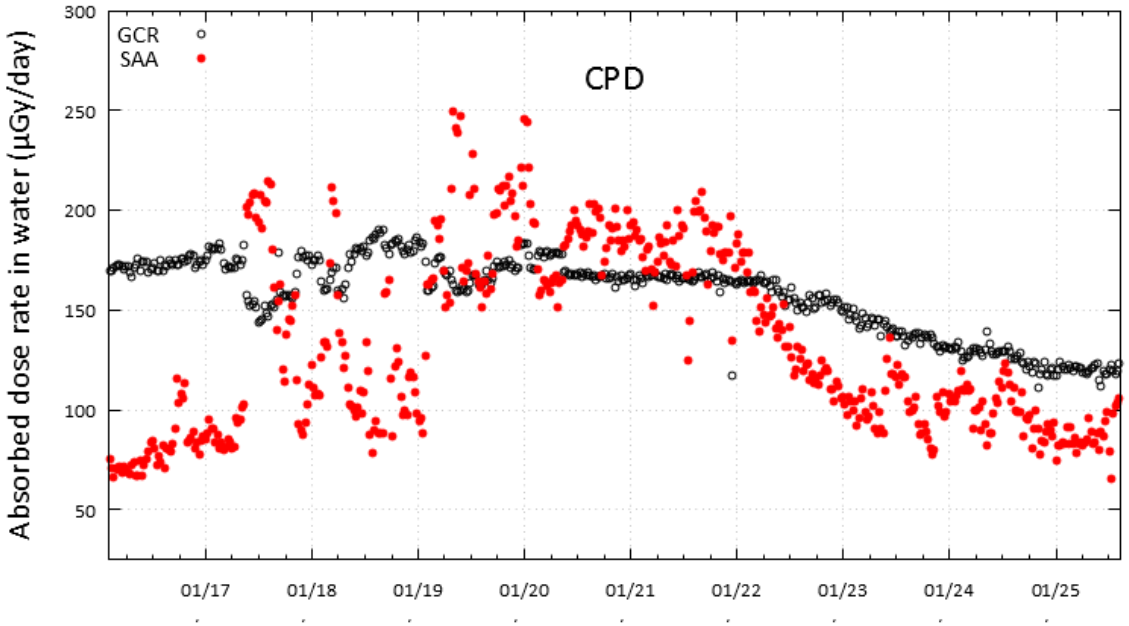
- ISS-RAD has 2 sensor heads:
  - CPD (charged particle detector)
  - FND (fast neutron detector)
  - Sensor heads connected by an interface board.
- Feb 2016 – March 2017: LAB1O3 for Activation & Checkout.
- March 2017 – May 2020: Survey.
- May 2020 – present: LAB1O6.
- Major FSW upgrade March 2021.

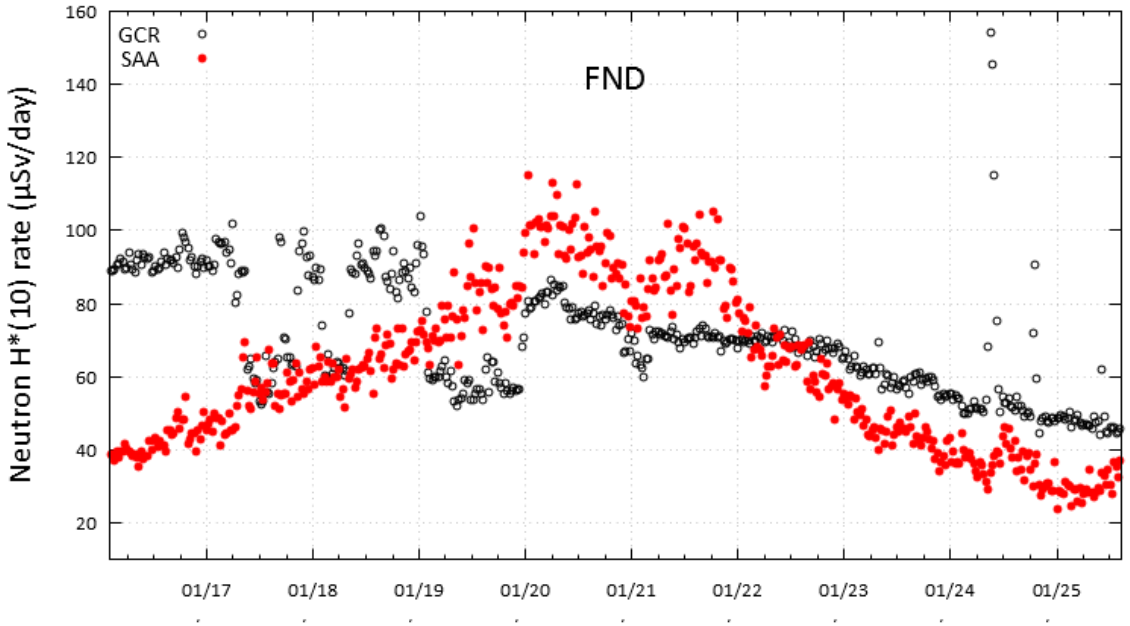




RAD at LAB1O3 Forward (+X)

Long-term Trends

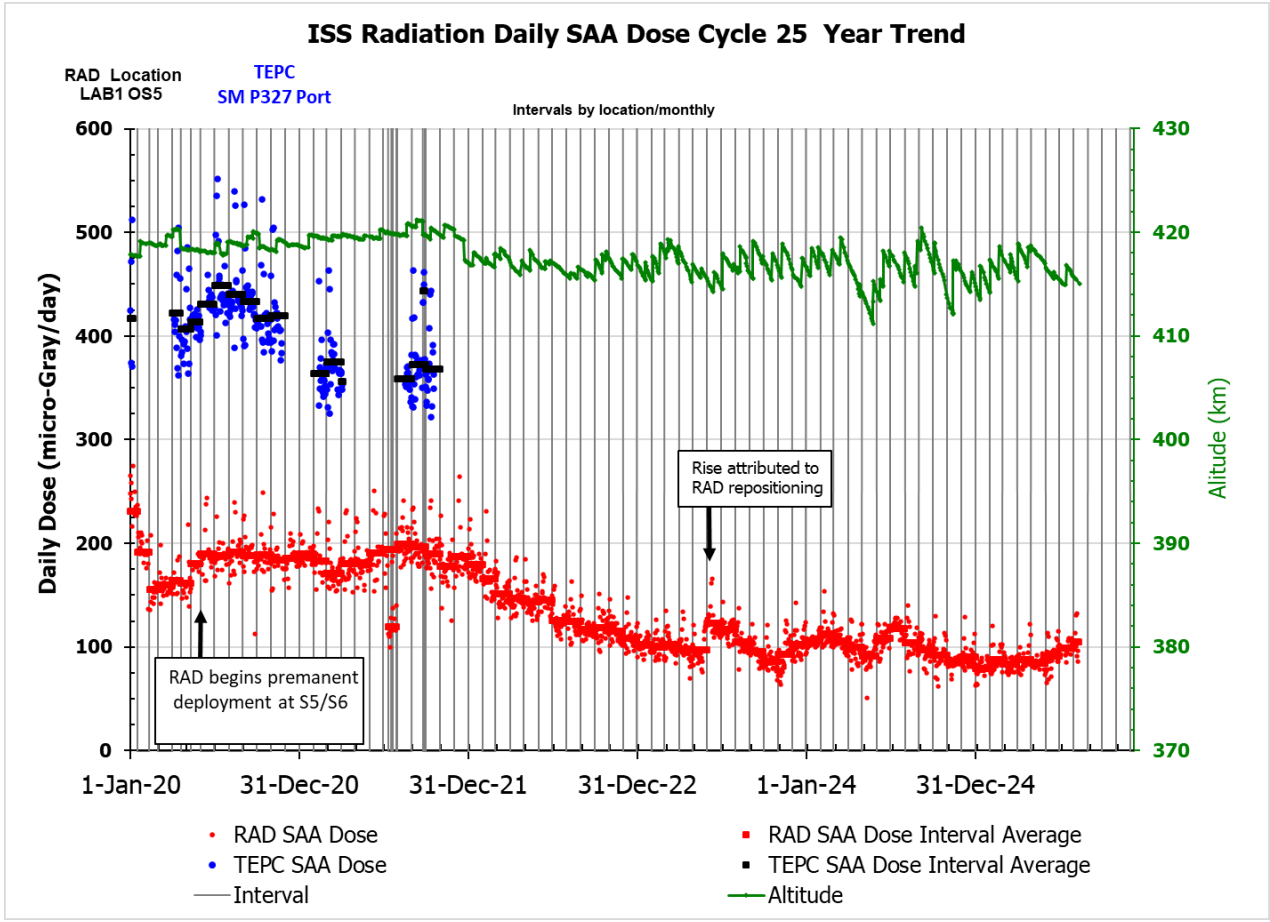




- Weekly-average rates in CPD & FND mostly track since parking in USLAB except for a few periods when FND rates were high due to formation of slot belts.
  - "GCR" here really means "non-SAA."
- Trends were more complicated in survey period.
  - Less shielded locations → lower GCR rates & higher CPD SAA rates, as expected.

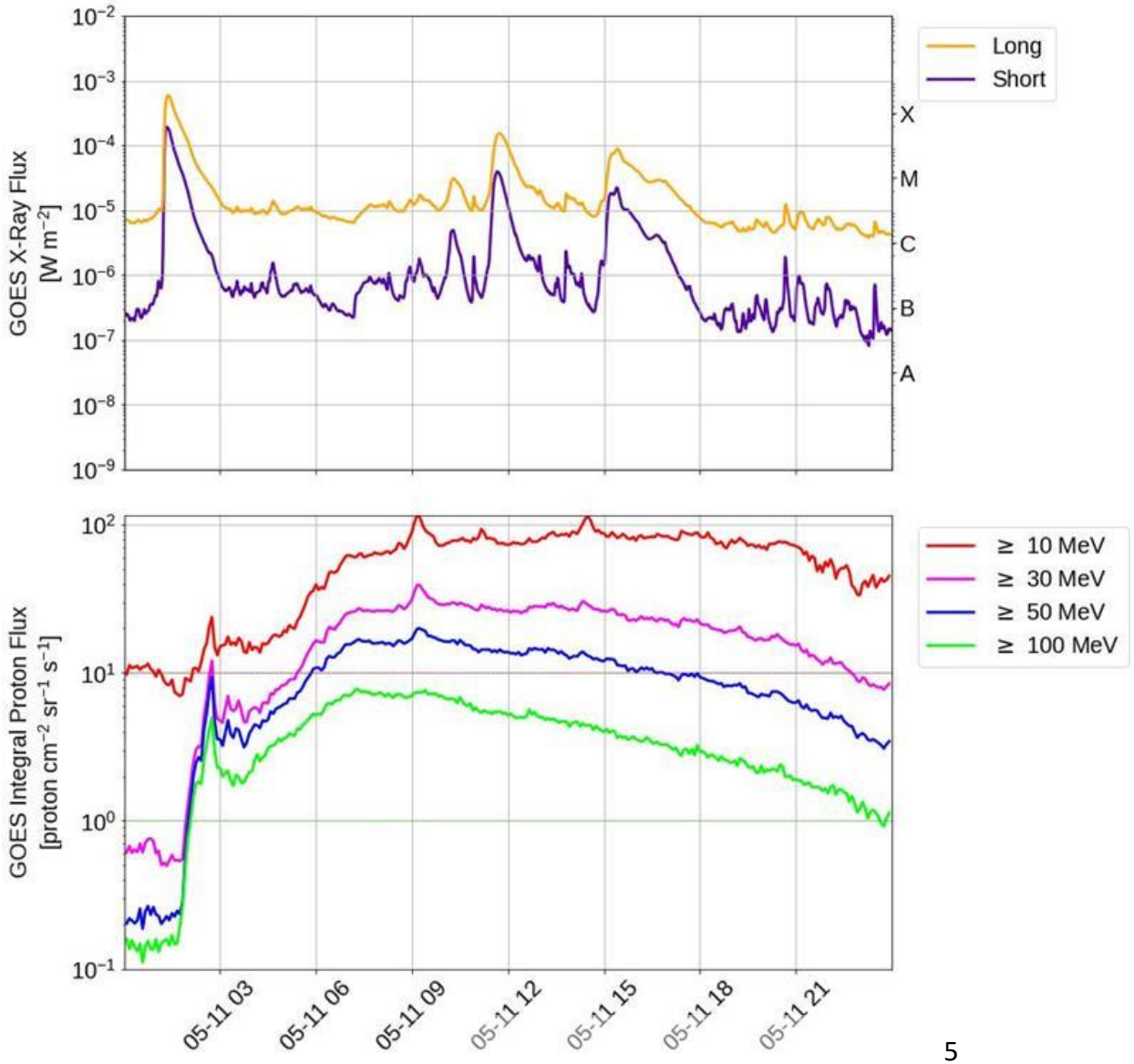
Long-term Trends

- ISS-RAD position generally stable, but some perturbations evident, especially in SAA
  - Repositioning of sensor is a major factor
  - Variation in altitude of ISS

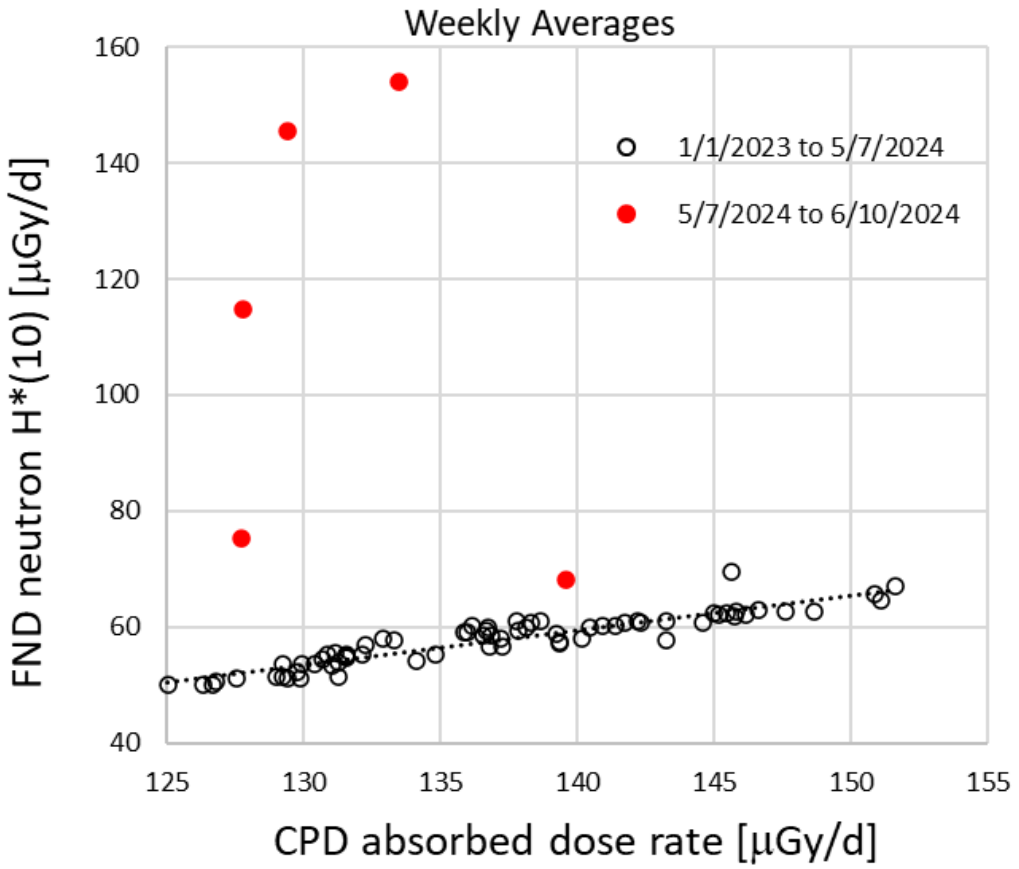


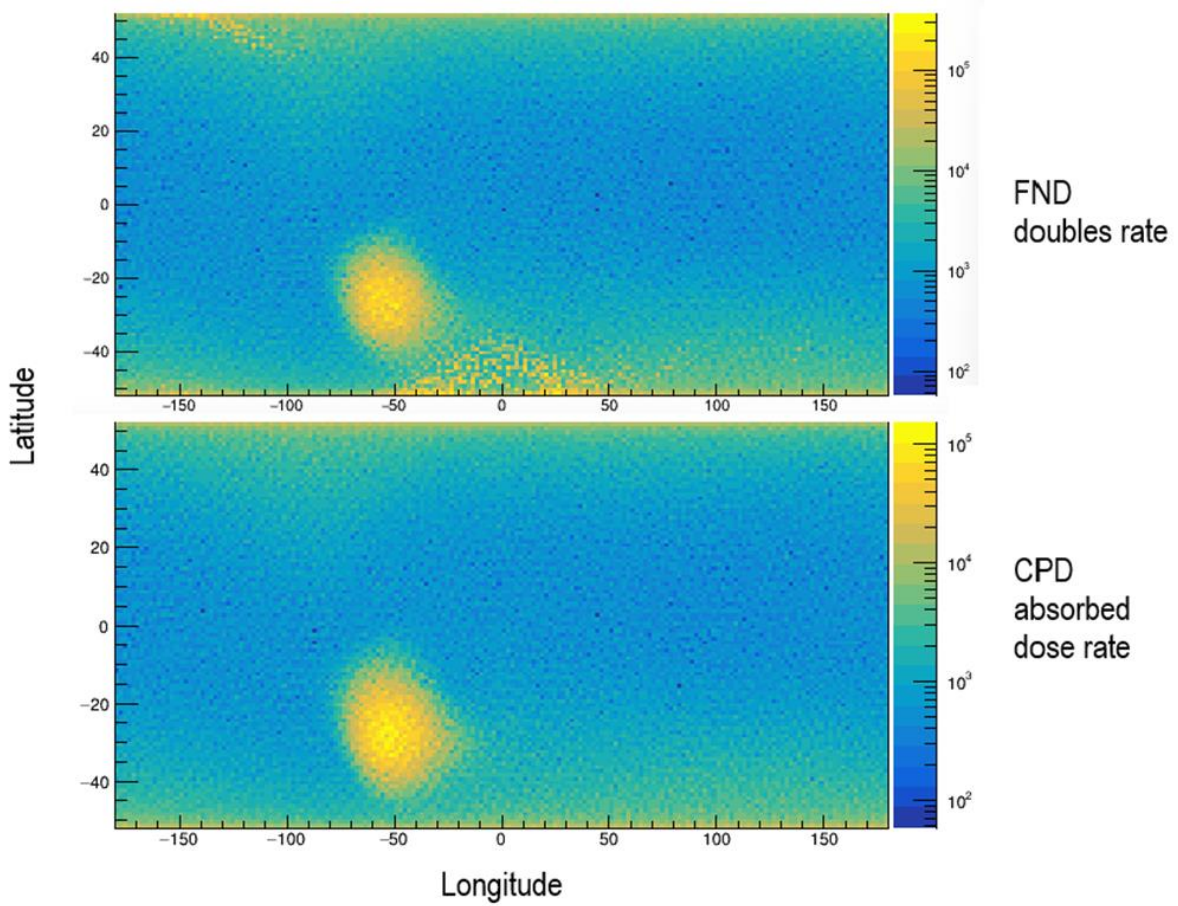
Gannon Event (2024-05-11)

- Powerful geomagnetic (G5) storm event with strong solar wind.
  - 5 Earth directed CMEs occurred between May 8-11
- Mildly powerful ESPE from SC25
  - >100 MeV integral flux peaked just over 7 PFU



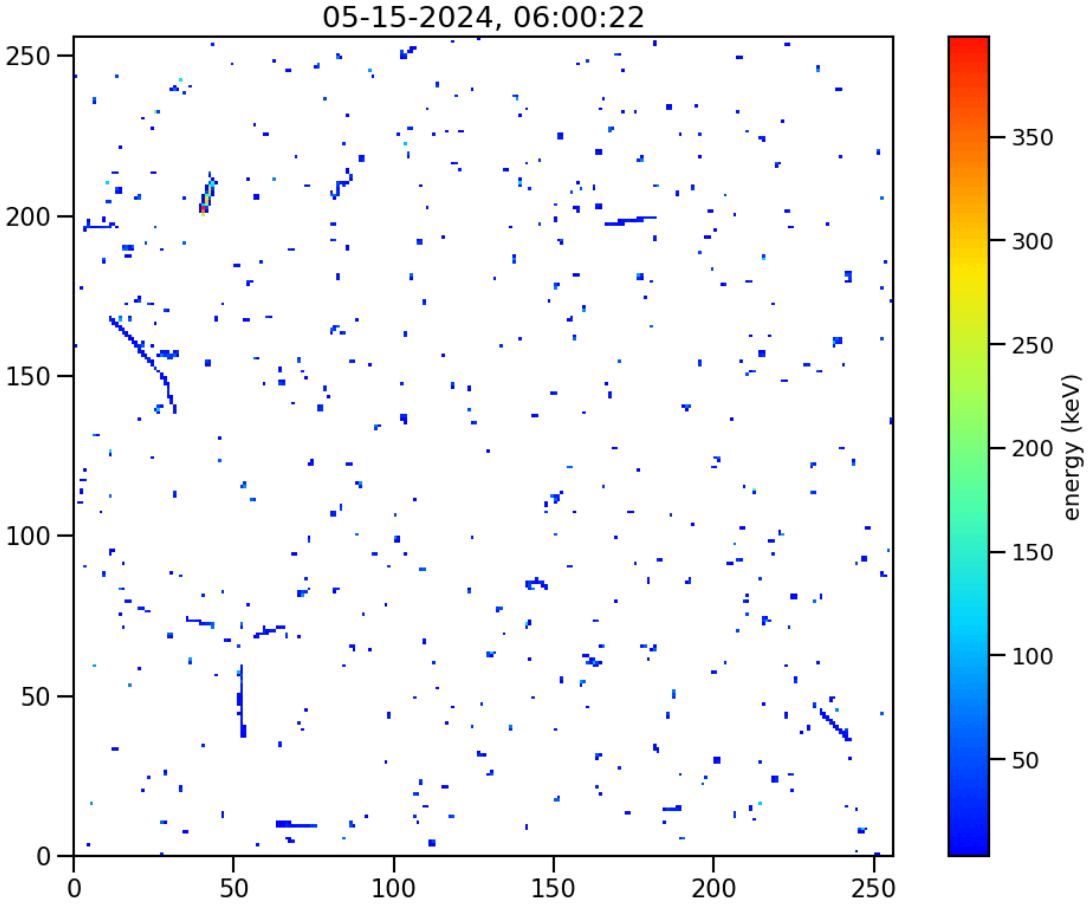
Slot Belts Form After Geomagnetic Storms



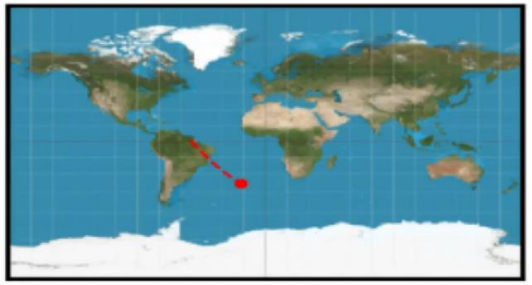


- CPD dose rate and FND H*(10) rate outside the SAA strongly correlated before storm.
- Non-SAA FND dose equivalent increased by 2x – 3x after Mother's Day storm of 2024, persisted for a month, N and S slot belt regions visible in lat-lon plot.

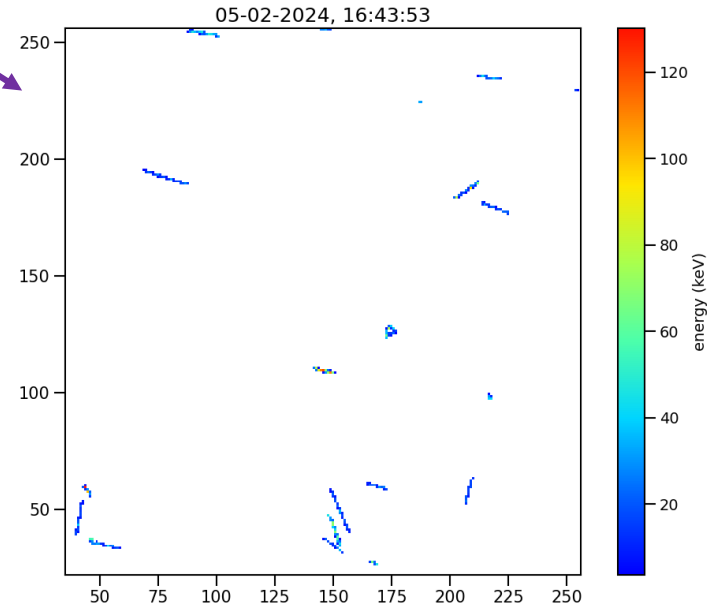
ISS Transiting the Slot Belts



Slot Belt REM2 Frames



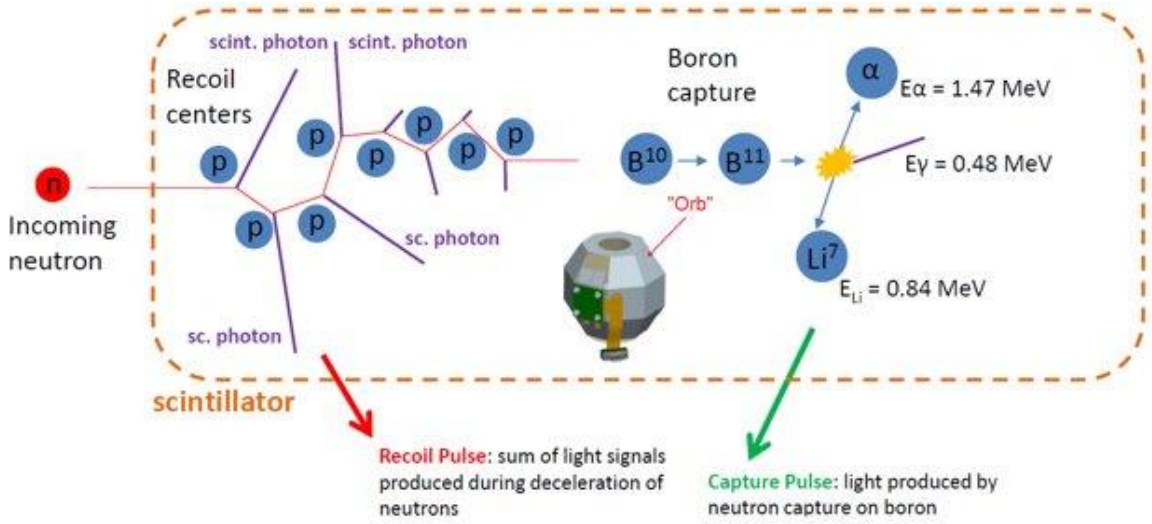
"Typical" Frame



- Slot belts largely electrons pushed inward from outer VAB, present as bremsstrahlung X-Rays in REM2 Timepix sensors inside ISS

Is It Just Background?

- Double pulse: first pulse from recoil proton(s), ~ few μs later get 2nd pulse from spontaneous fission of ^{10}B after neutron capture.
  - FND onboard analysis looks for pulse pairs and puts both time & amplitude windows on 2nd pulse which is produced by α particles in a narrow energy range.

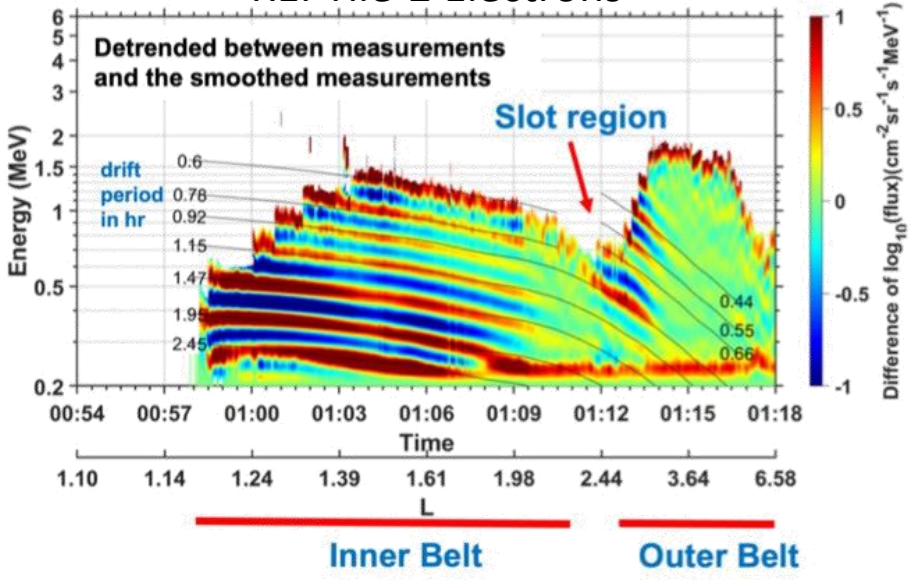


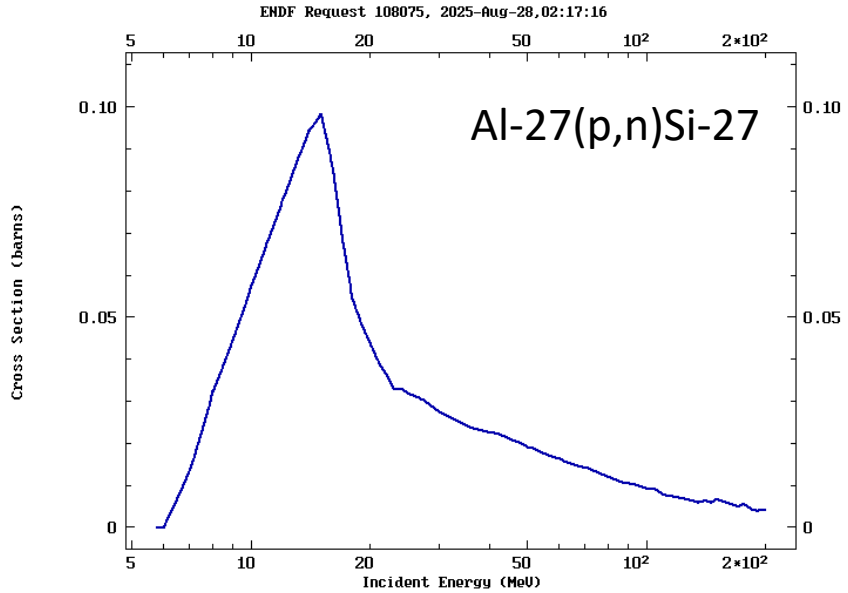
- Events with large Δt between pulses are mostly chance coincidences, use these to estimate the background recoil spectrum
  - Even if background is large, it is measured & subtracted.

How Do Slot Belt Electrons Make Neutrons?

- They Don’t! Not directly.
  - CIRBE/REPTile-2 CubeSat measured max electron energy in slot belt was ~<5MeV, too low for electron induced neutron production (GDR, etc..)
  - REPTile-2 DID measure 6.8–20 MeV protons at L ~ 2 during the storm, too low energy to be measured inside ISS, but just right for p,n interactions in aluminum

REPTile-2 Electrons



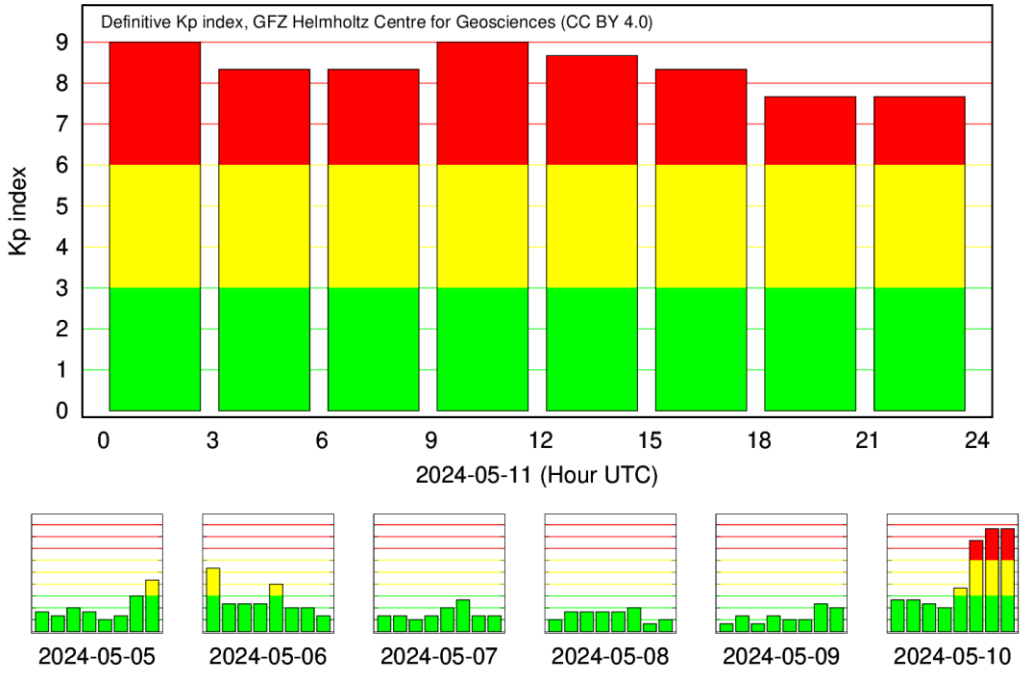


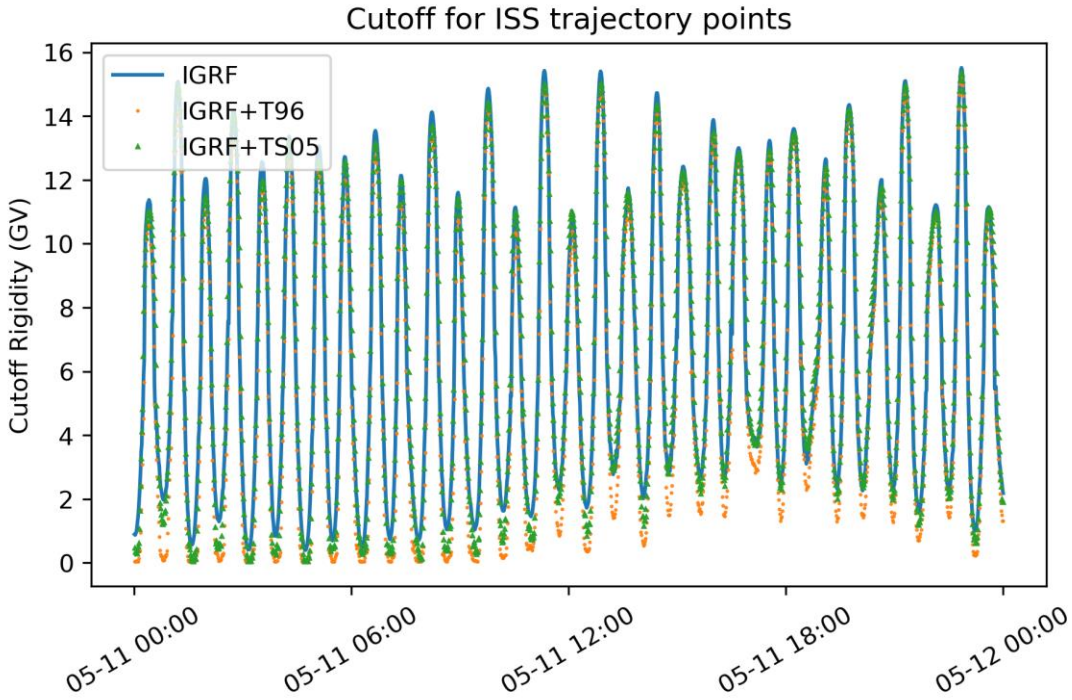
Impact on H*(10)

- Estimate an extra ~ 1.8 mSv of neutron dose equivalent in the FND energy range was received in the month after the Mother's Day 2024 event.
  - B dose from event ~ 60 μGy in water.
- Prior to 5/11/24, FND H*(10) rate was ~ 85 μSv/d and CPD (ICRP 60) dose equivalent rate was ~ 500 μSv/d, so contribution from slot belts is roughly 3 days of extra exposure.
- Previous instance seen in August/September 2017, seen also by ANS operated by MSFC. Two later instances seen, shorter duration & less intense.

Vertical cutoffs of ISS trajectory

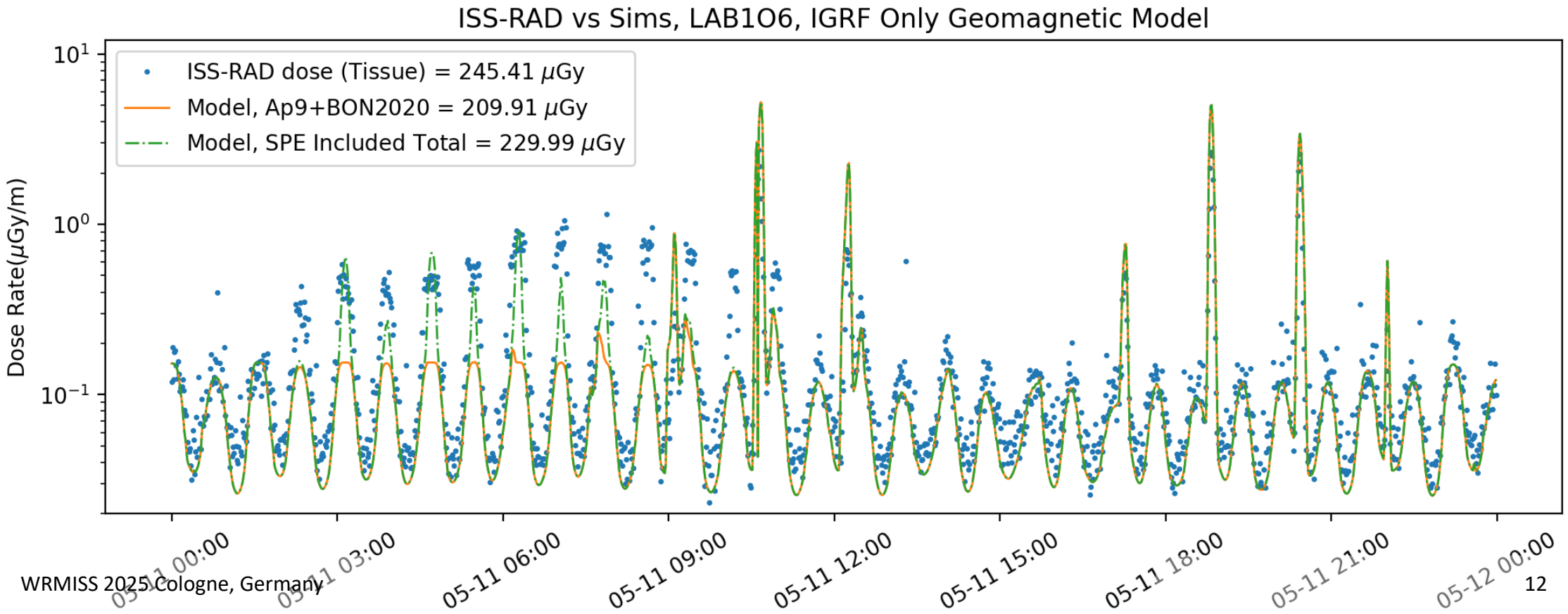
- Elevated Kp index during strong solar storms have a non-negligible effect of Cutoff Rigidity at ISS trajectory points
  - Kp during the May 2024 storm maintained >7 for duration of event day
  - Cutoff modeled for quiet IGRF and Tsyganenko ‘96 and ‘05 dynamic model





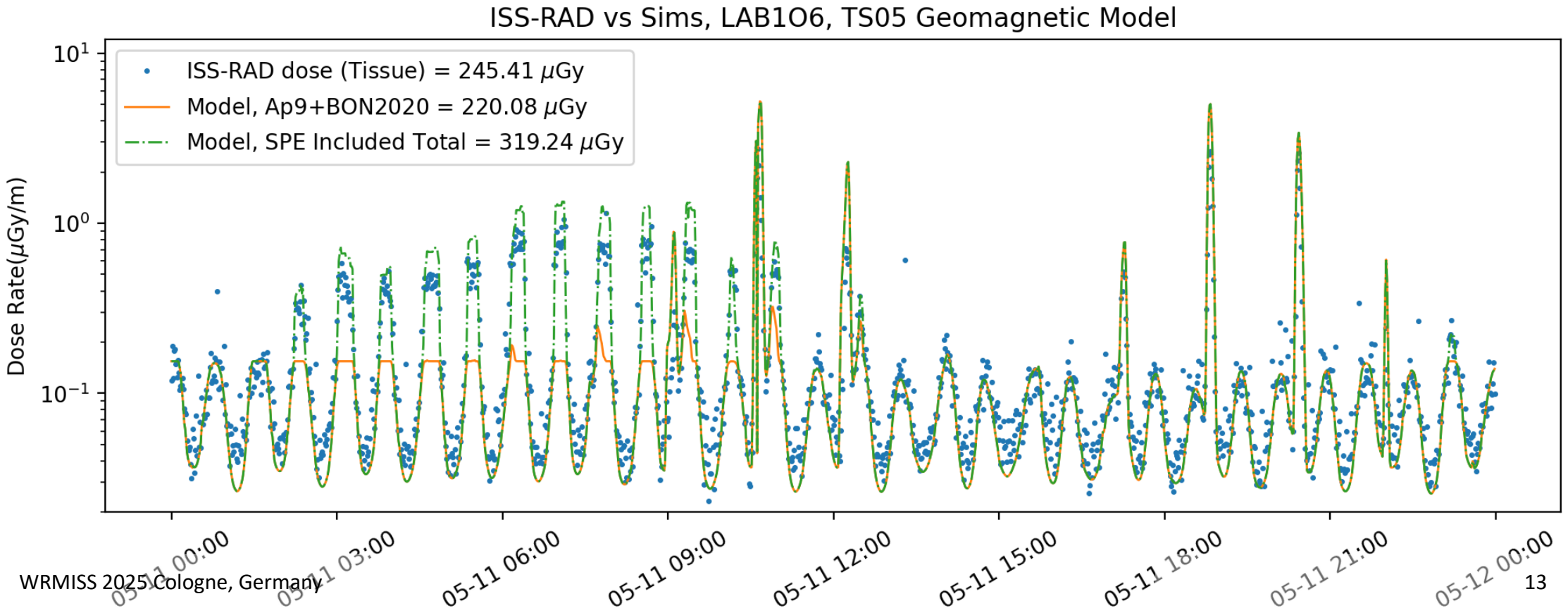
No storm impacts (IGRF only)

- What effects does geomagnetic storming have on our ability to model radiation dose in LEO?
  - Example shown using HZETRN, Ap9 and BON2020 Models, IGRF13



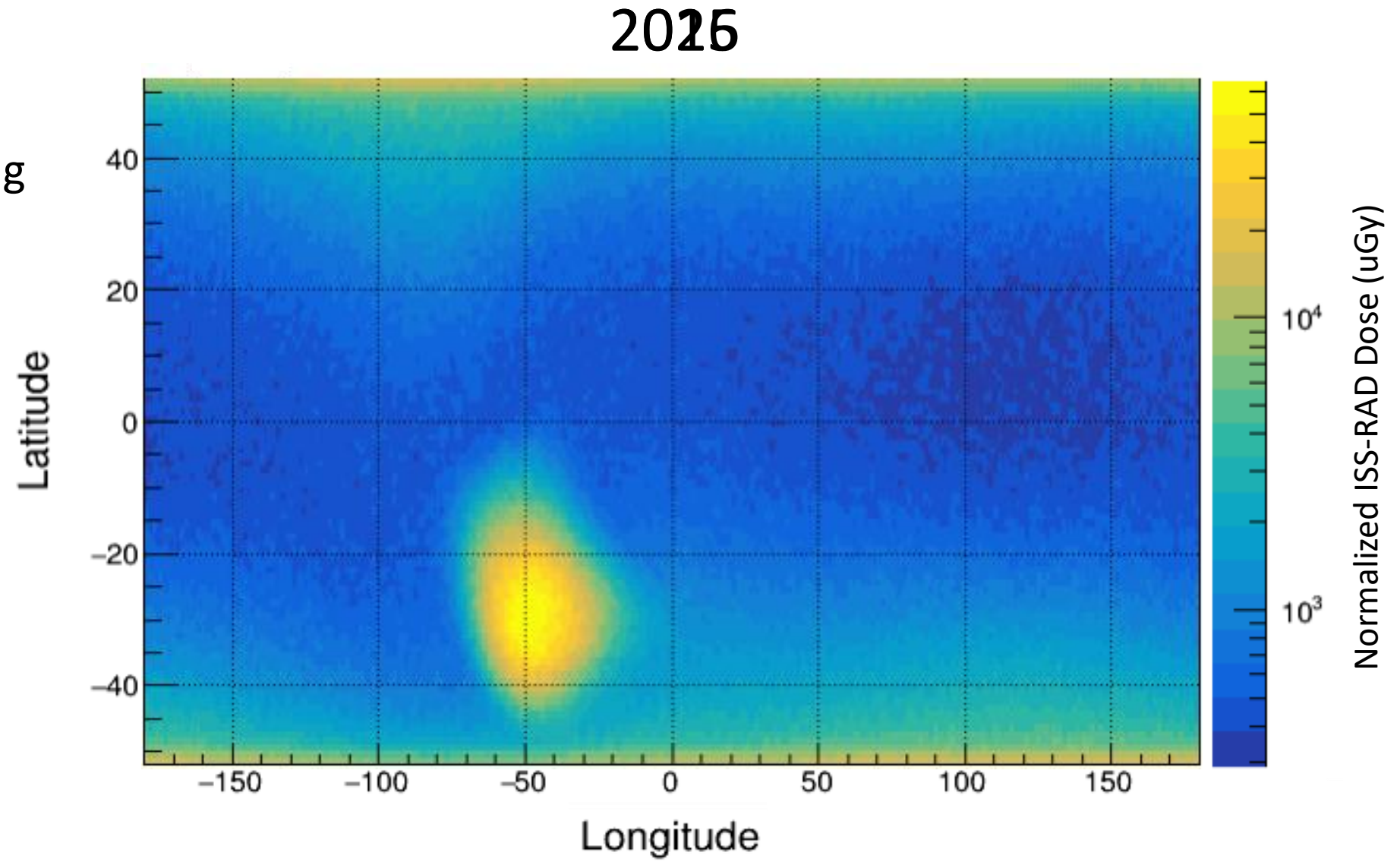
Storm impacts included (IGRF+TS05)

- Same Methodology, but with the TS05 Geomagnetic model
  - Tsyganenko ‘05 dynamic model incorporates solar wind ram pressure (nPa), Dst index (nT), K_p, etc.
  - Qualitatively Better agreement! But Quantitatively worse…
  - Trapped radiation reduced during May SPE, but not accounted for in Ap9 model!



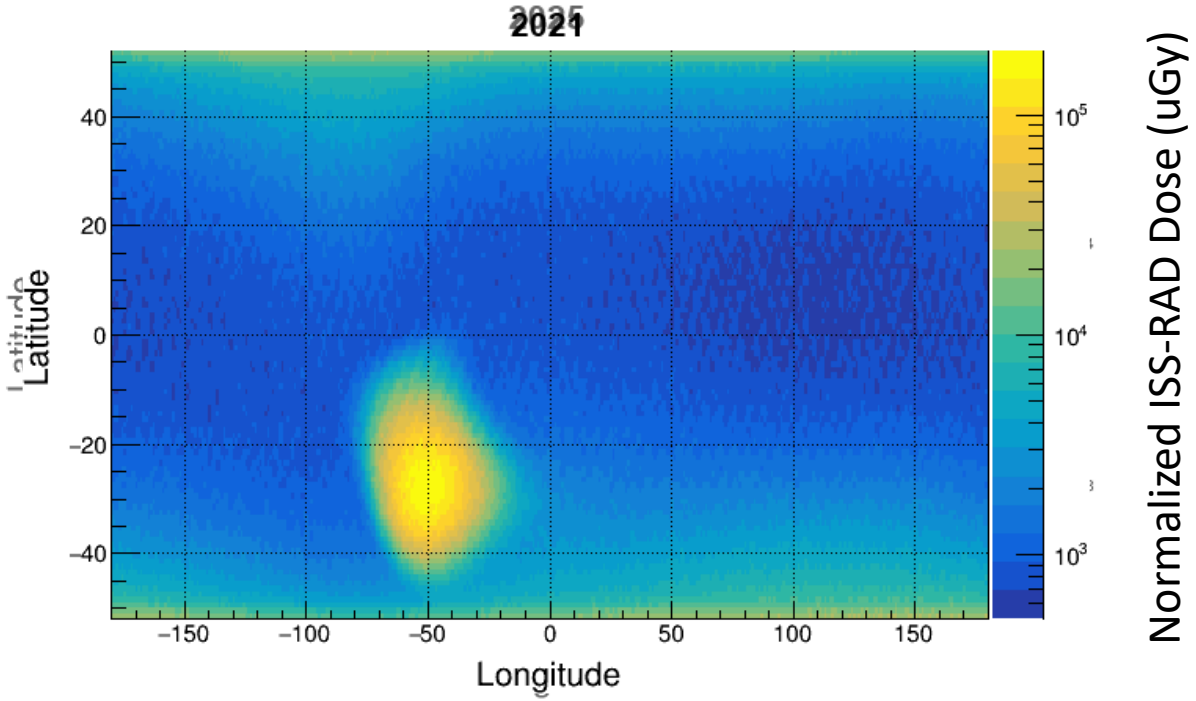
SAA Observations

- SAA is known to be drifting west, clearly visible when comparing 2016 to 2025 data.

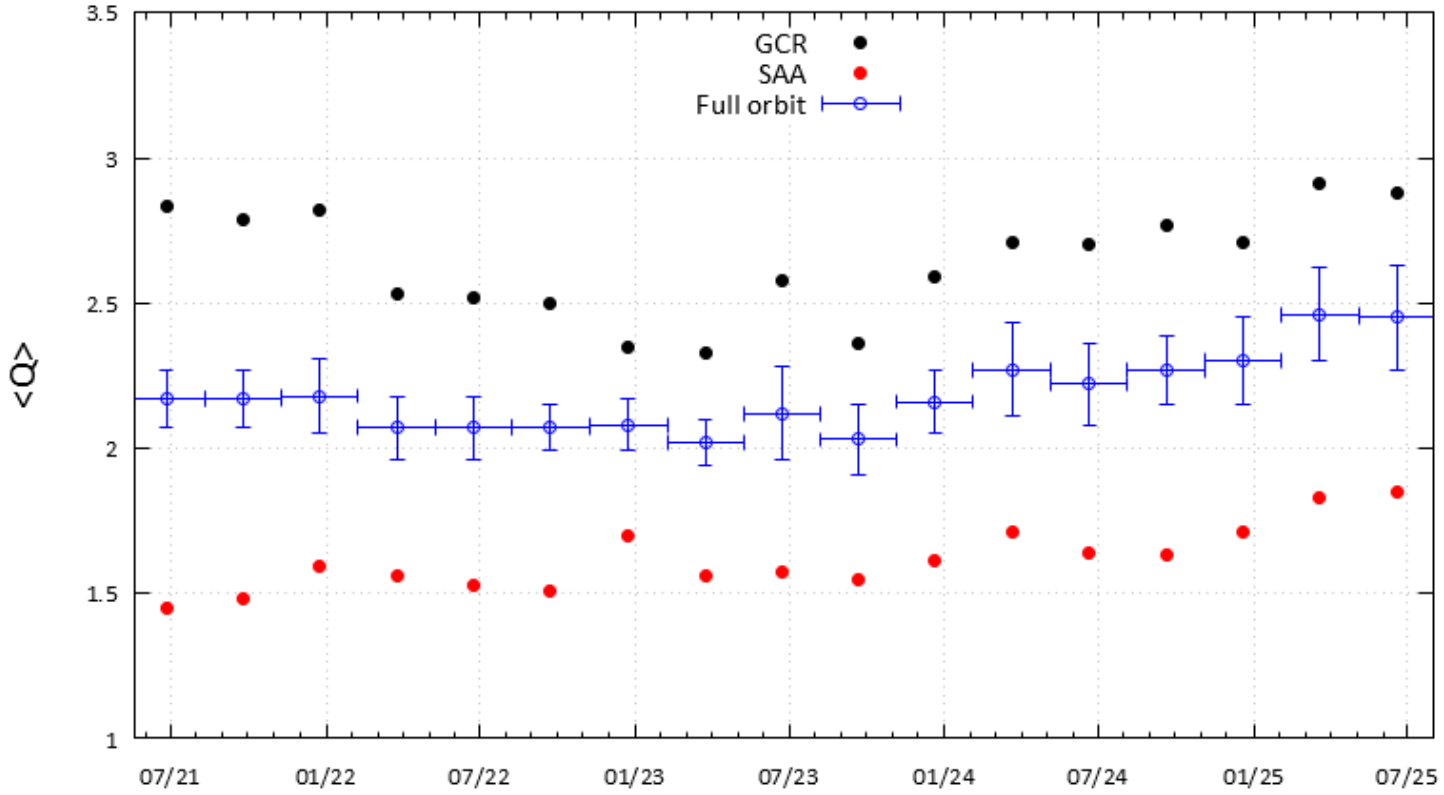


SAA Smaller?

- 2021 was solar min, 2025 ~ max.
  - SAA is effectively smaller.
- Definition of SAA as a fixed geomagnetic region (|B| field strength <22.5 μT and the McIlwain L-shell <2) may not be ideal given the time dependence.
  - Flux in SAA is a combination of trapped and GCR.
  - Shrinking SAA but fixed definition → changing mix, more GCRs relative to trapped.
  - SAA <Q> might increase as a result.



Does Data Show SAA <Q> Increasing? Maybe.



<Q> since RAD parked in USLAB

- CPD <Q> measurements are based on particles in ±30° FOV.
  - Nominal CPD orientation is zenith/nadir.
- Statistical uncertainties ~ +- 0.2 on each SAA data point → data suggest a slight <Q> increase but are not definitive.

Conclusions

- Still many things to learn from ISS-RAD after almost 10 years
- Slot belts contribute a small but non-zero neutron dose inside ISS
- Geomagnetic modeling for LEO dose calculations could benefit from refinement for periods of heavy solar activity
- Dose rate definition of SAA may be more robust than B field and L-Shell cuts

- Li, X., Xiang, Z., Mei, Y., O'Brien, D., Brennan, D., Zhao, H., et al. (2025). A new electron and proton radiation belt identified by CIRBE/REPTile-2 measurements after the magnetic super storm of 10 May 2024. Journal of Geophysical Research: Space Physics, 130, e2024JA033504. https://doi.org/10.1029/2024JA033504