Radiation Measurements on ISS and Biosentinel from the May 2024 and June 2024 Space Weather

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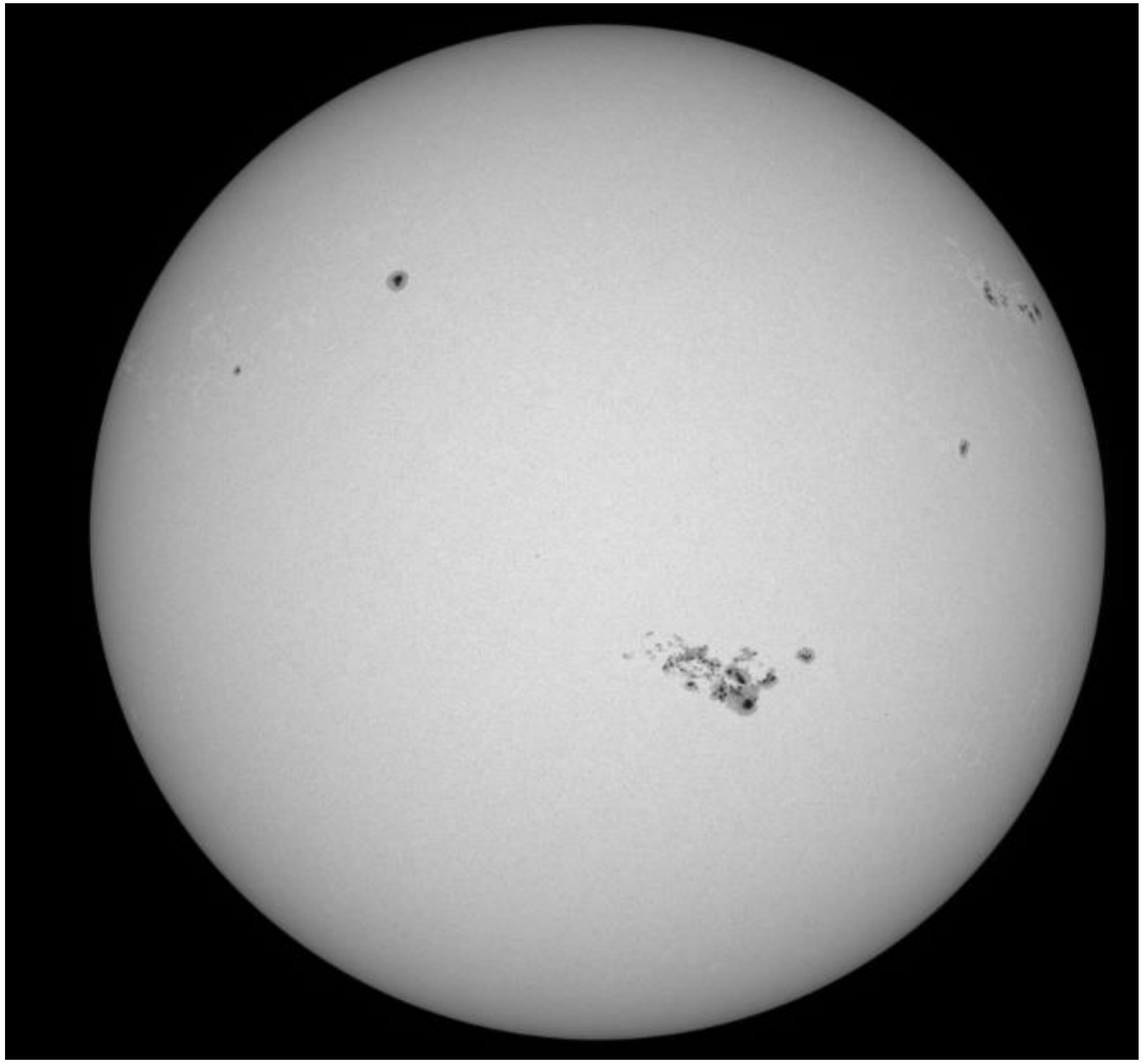
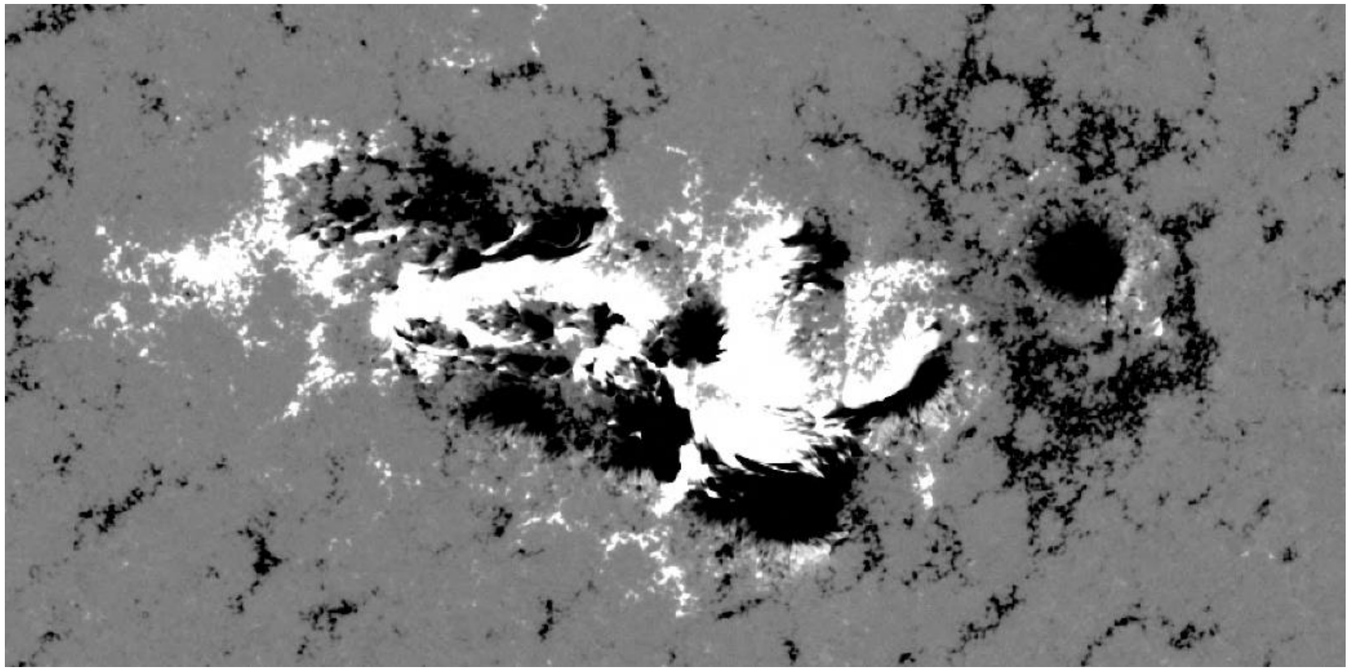
May and June Space Weather

- May 2024 brought a spectacular geomagnetic storm, the largest in 20 years
- Actually consisting of multiple small CME’s forming a train of events, the active region that spawned this space weather also produced a relatively minor ESPE
- The same AR on its second rotation round the disk also spawned a moderate “S3” solar storm
- This talk explores the evolution of this space weather event, the dosimetric impacts at ISS and Biosentinel and the impacts of the transient radiation belt that was formed in its wake

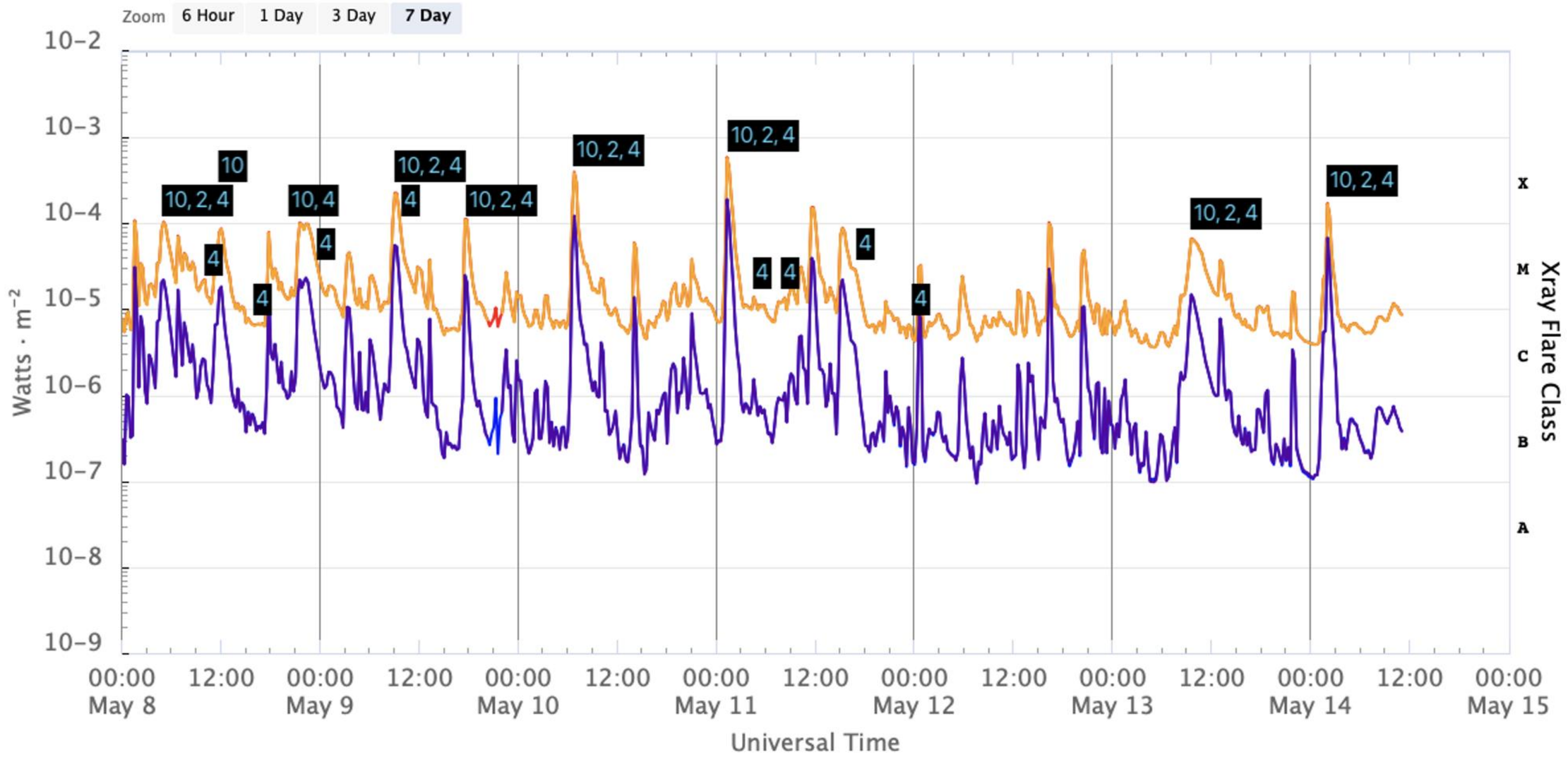
AR3664





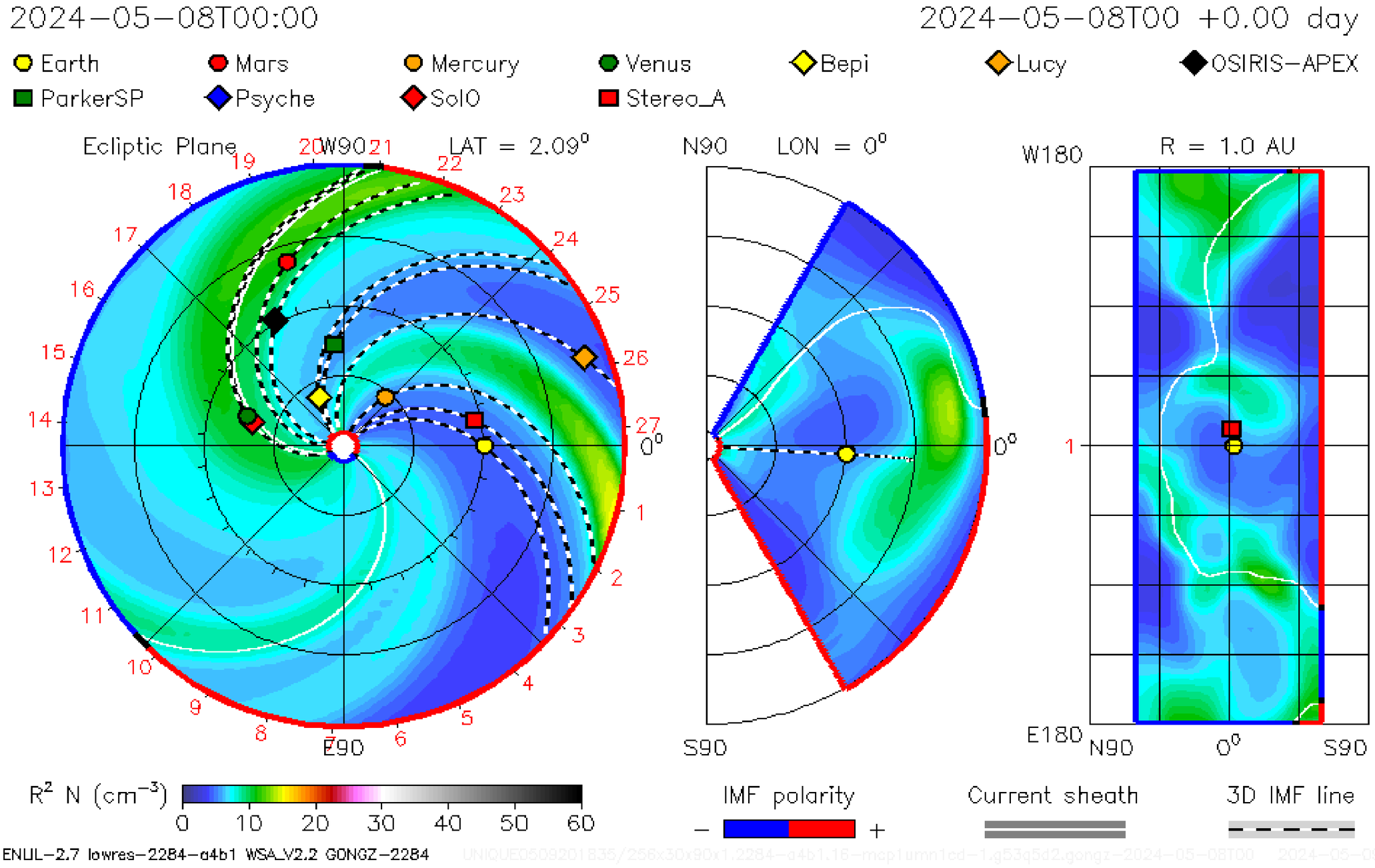
SDO HMI White Light (left) and Magnetogram (right)

GOES X-Ray Flux (1-minute data)



Updated 2024-05-14 11:06 UTC

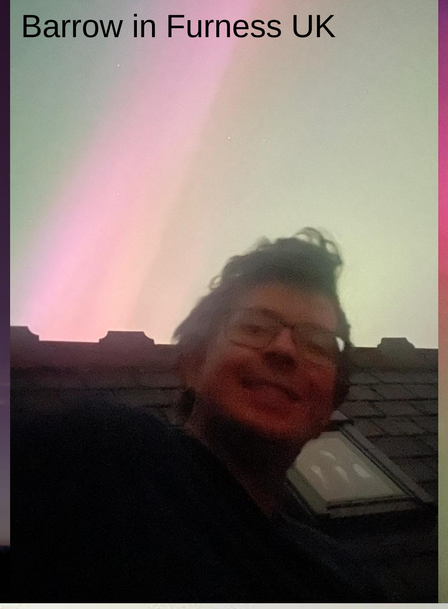
Space Weather Prediction Center

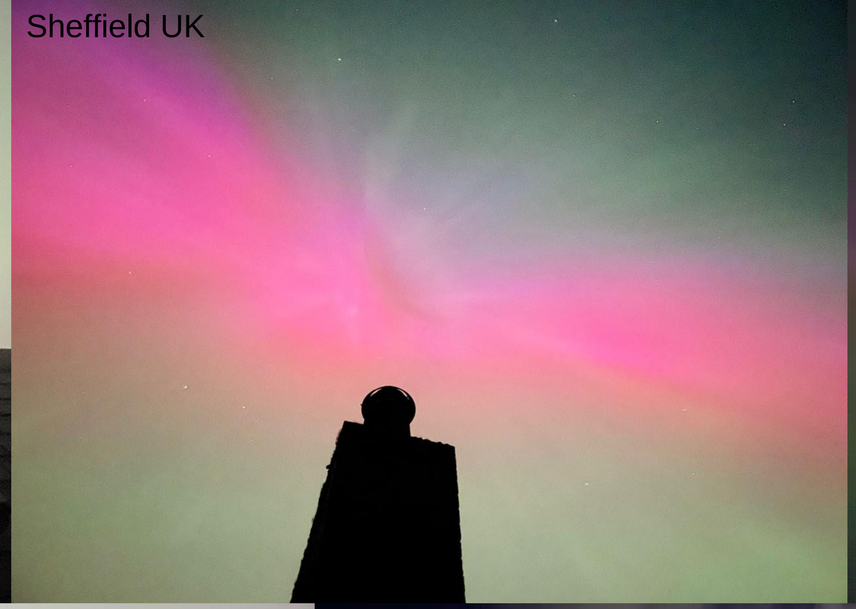


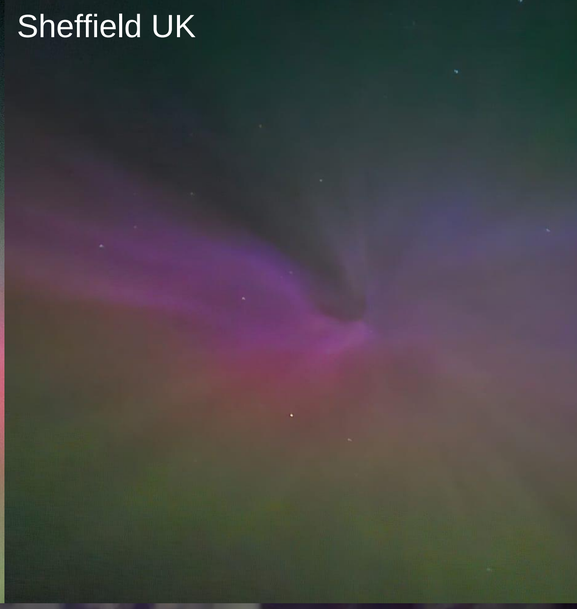
WSA-ENLIL simulation of plasma density for 3 CME structure (from DONKI) - note changed magnetic connectivity in CME wake

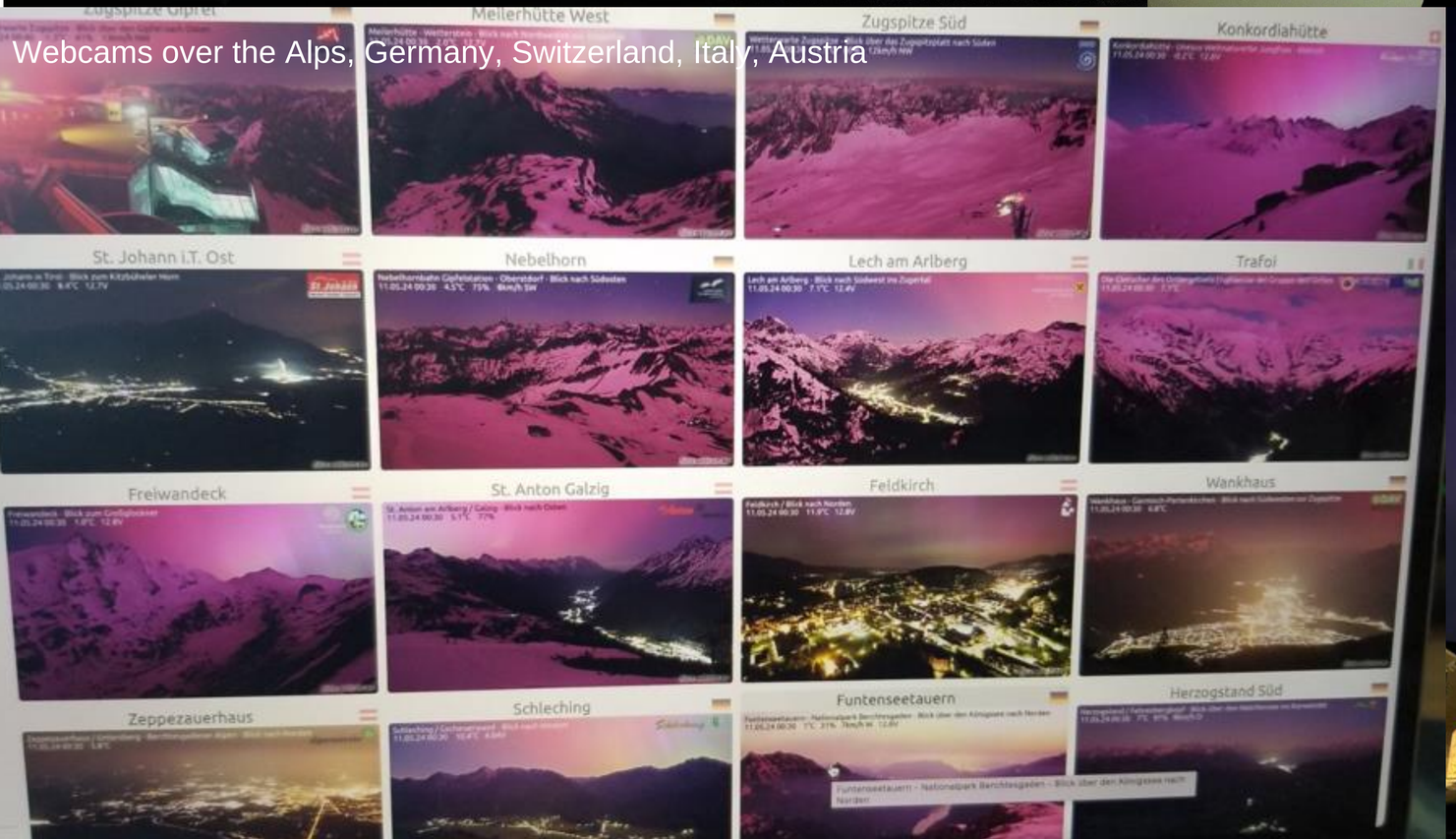

SWPC
2024-05-07 12:00:00
Mag + Solar Wind
7 days@5 min
2024-05-14 12:00:00
[Active] ACE+DSCOVR
Bz GSM (nT)
Bx
By
Bt
100
50
0
-50
-100
Phi GSM (deg)
315
135
Away +
Towards -
Density (1/cm³)
1000
100
10
1
Speed (km/s)
1100
900
700
500
300
Temperature (°K)
1e+6
1e+5
1e+4
Kp
Ap
9
8
7
6
5
4
3
2
1
0
DSCOVR ACE ACE+DSCOVR error suspect density < 1
(date)
2024-05-07
12:00:00
May 8
May 9
May 10
May 11
May 12
May 13
May 14


Outside Oxford, UK

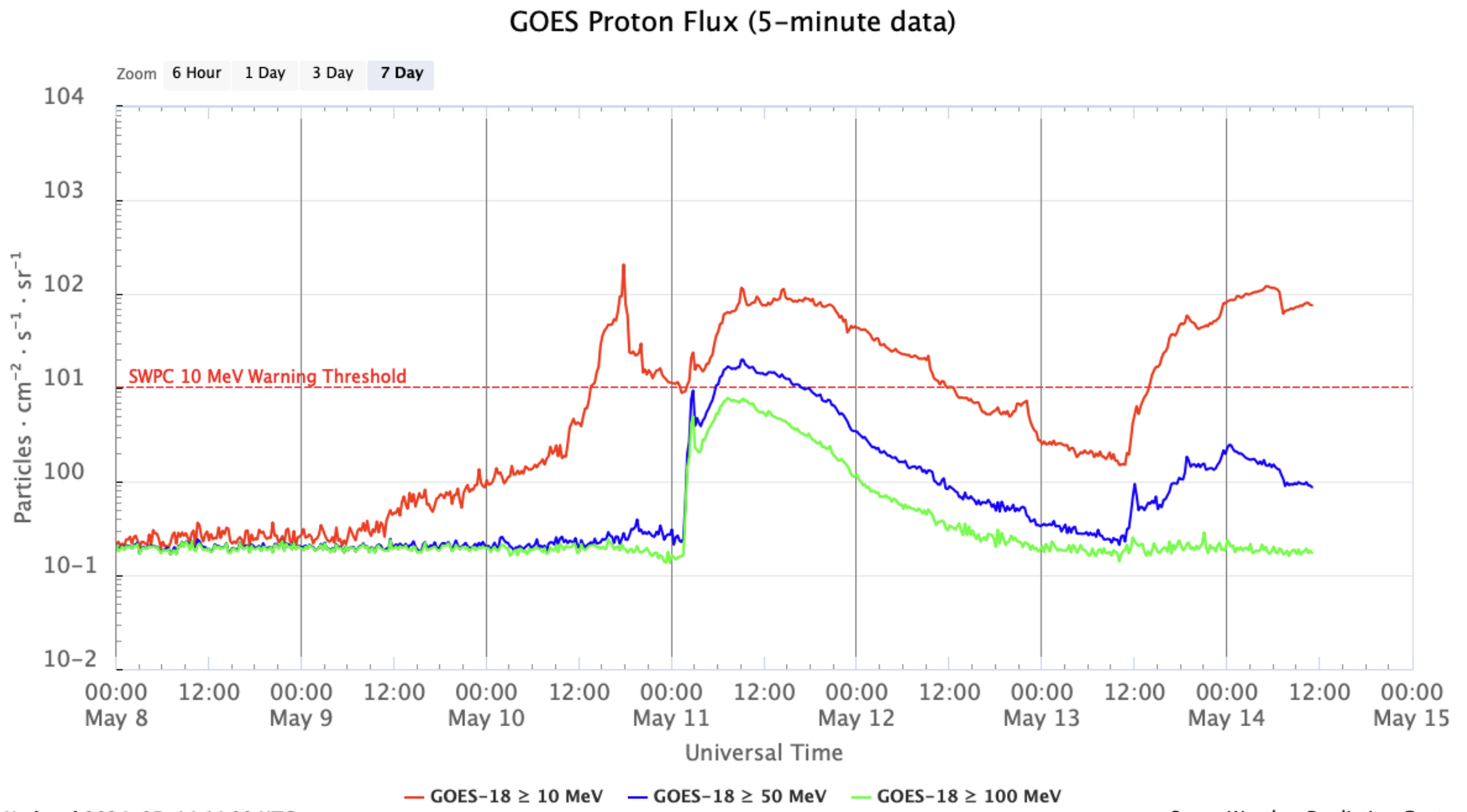

Barrow in Furness UK


Sheffield UK


Sheffield UK

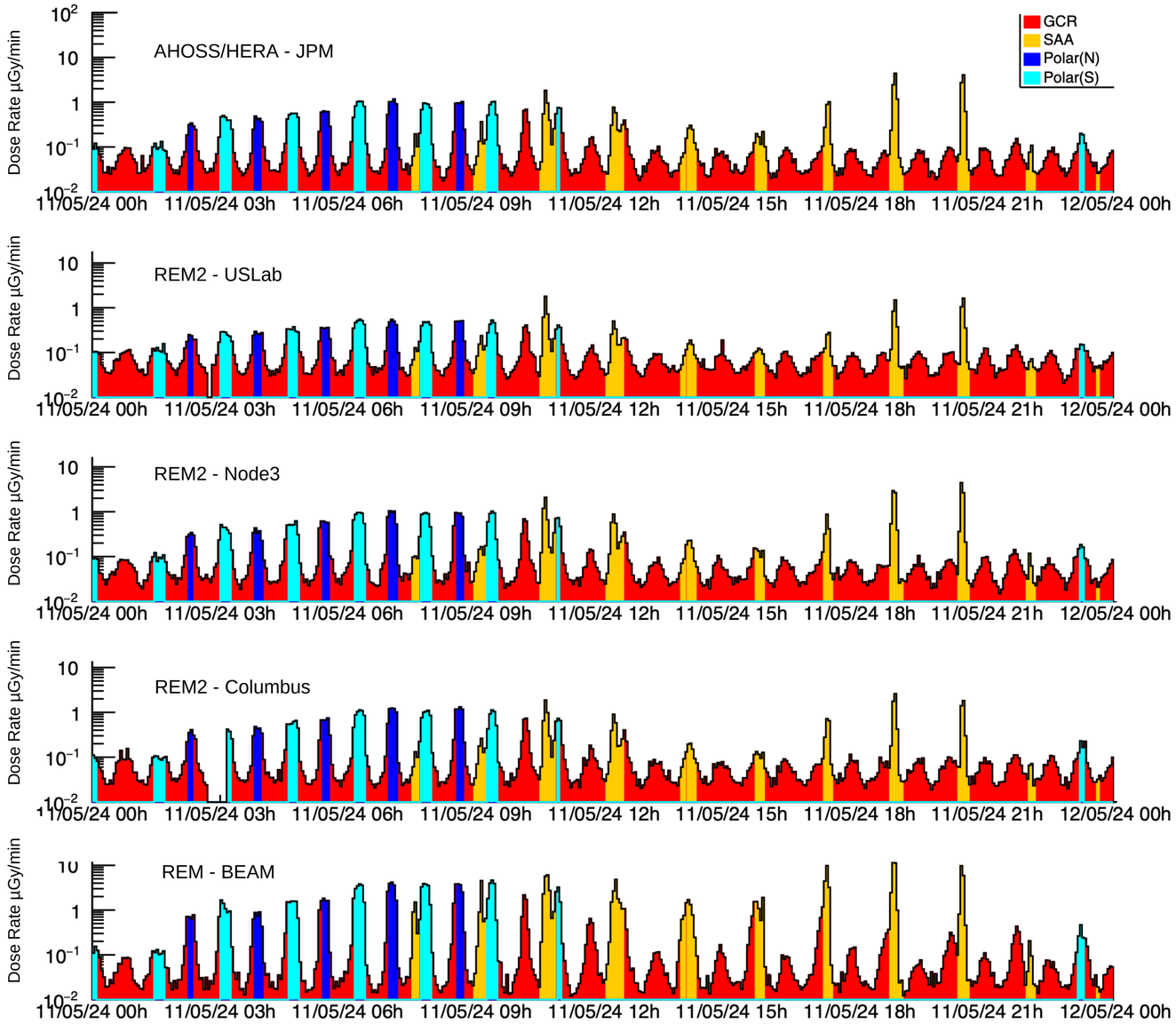

Webcams over the Alps, Germany, Switzerland, Italy, Austria
Meilerhütte West
Zugspitze Süd
Konkordiahütte
St. Johann i.T. Ost
Nebelhorn
Lech am Arlberg
Trafoi
Freiwandeck
St. Anton Galzig
Feldkirch
Wankhaus
Zeppezauerhaus
Schleching
Funtenseetauern
Herzogstand Süd


College Station, Texas



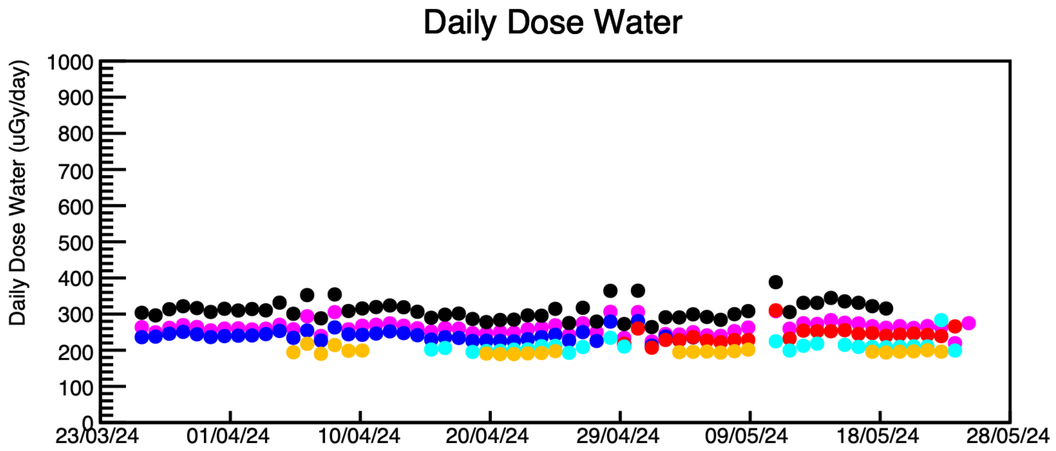
Characteristic fast rise time from magnetically well connected SPE despite center disk location of AR

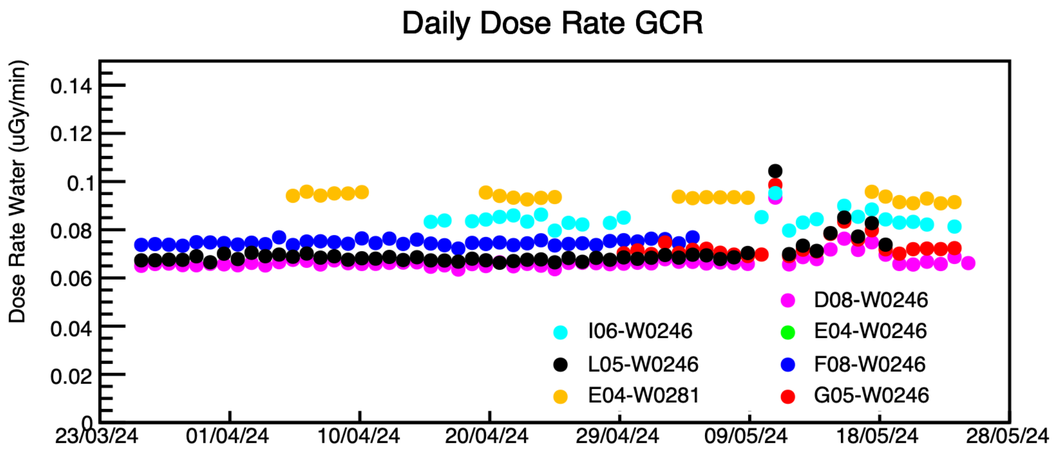
Observed Dose Rates - GMT132/May 11th 2024

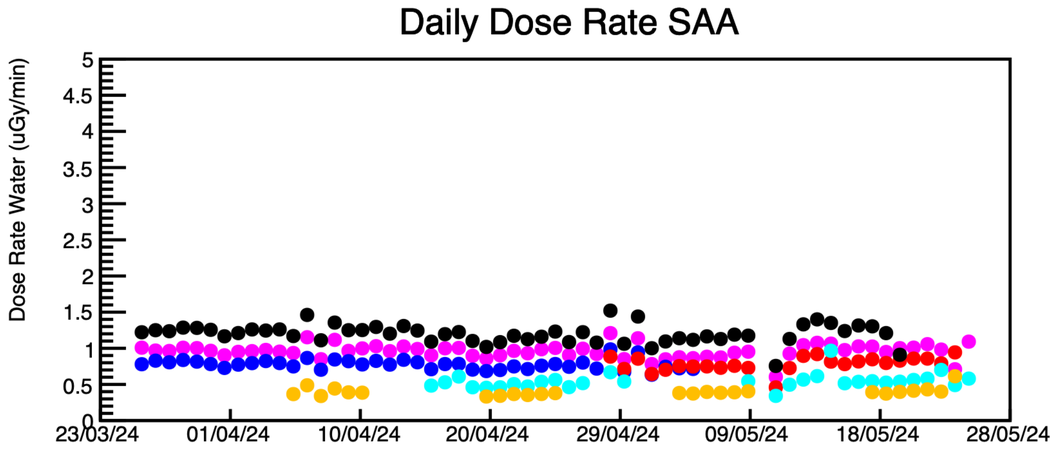


- Sun produced ESPE on May 11th, associated with X5.8 flare
- 1 pfu threshold for >100 MeV GOES protons crossed at 0200 GMT, peaked at 7.78 pfu at 0715 GMT and fell below threshold at 0030 GMT GMT133/May 12th
- ISS phased for high risk alignment start of ~0100 GMT - 0930 GMT
- Characteristic “flat top” structure in passes - due to high KP/lowered cutoffs

Dose Rate Trending for REM2 in ISS







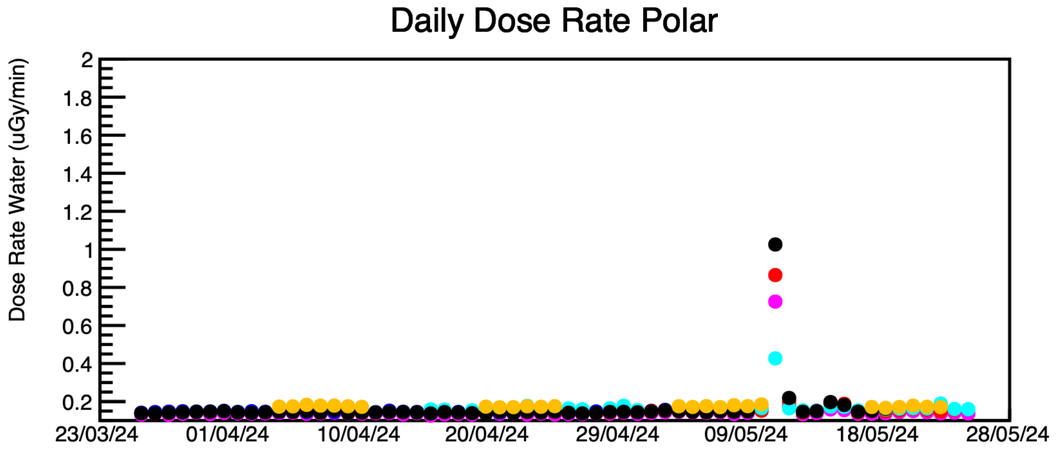
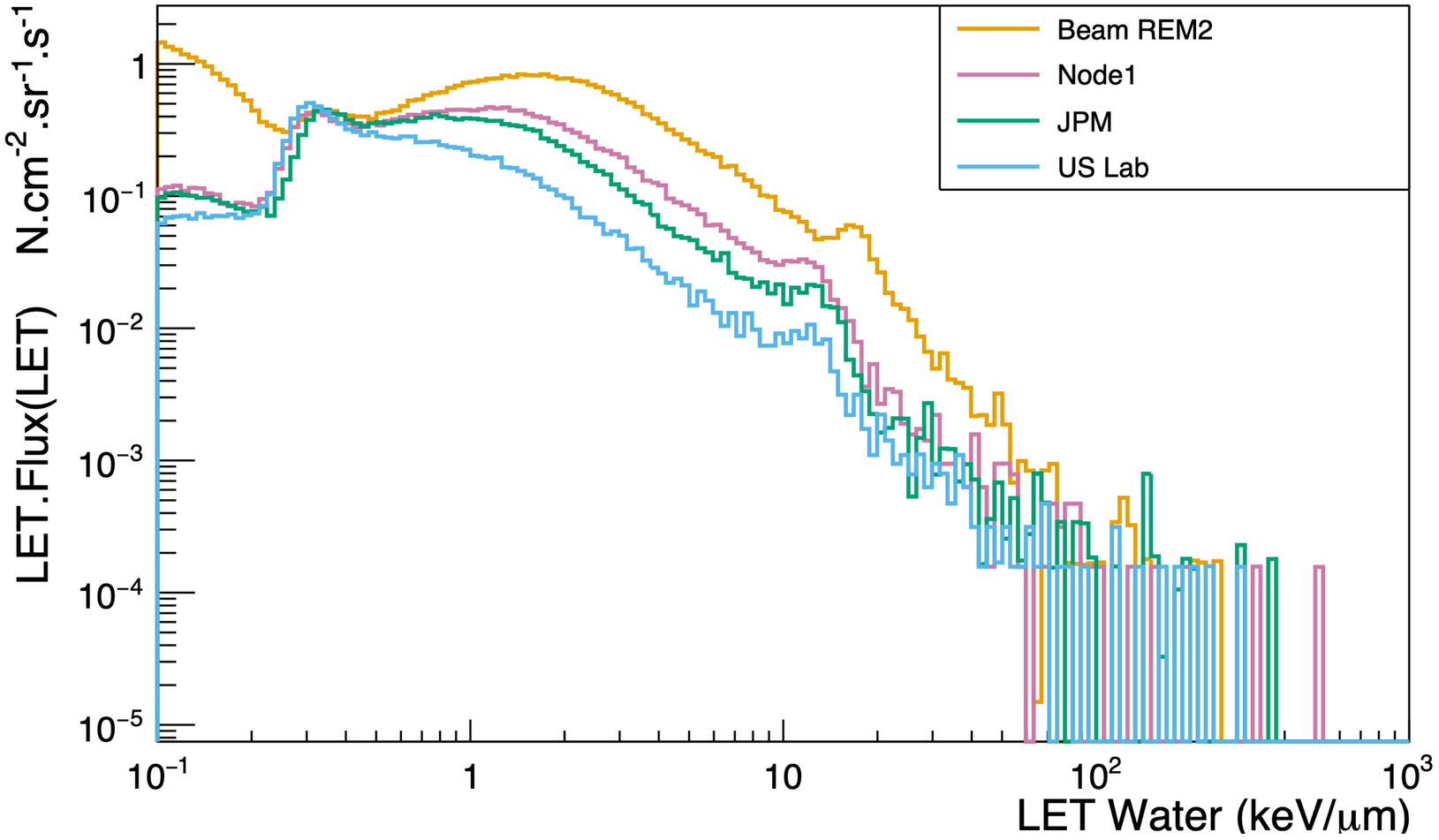


Figure 1: REM2 Daily absorbed dose rates in water for last 60 days. SAA : McIlwain L < 3, B < 23000 nT, Polar : L > 3, GCR : not SAA (includes Polar).

Overall not a very large impact to daily dosimetry

Observed LET Spectra L>4 - GMT132 ESPE



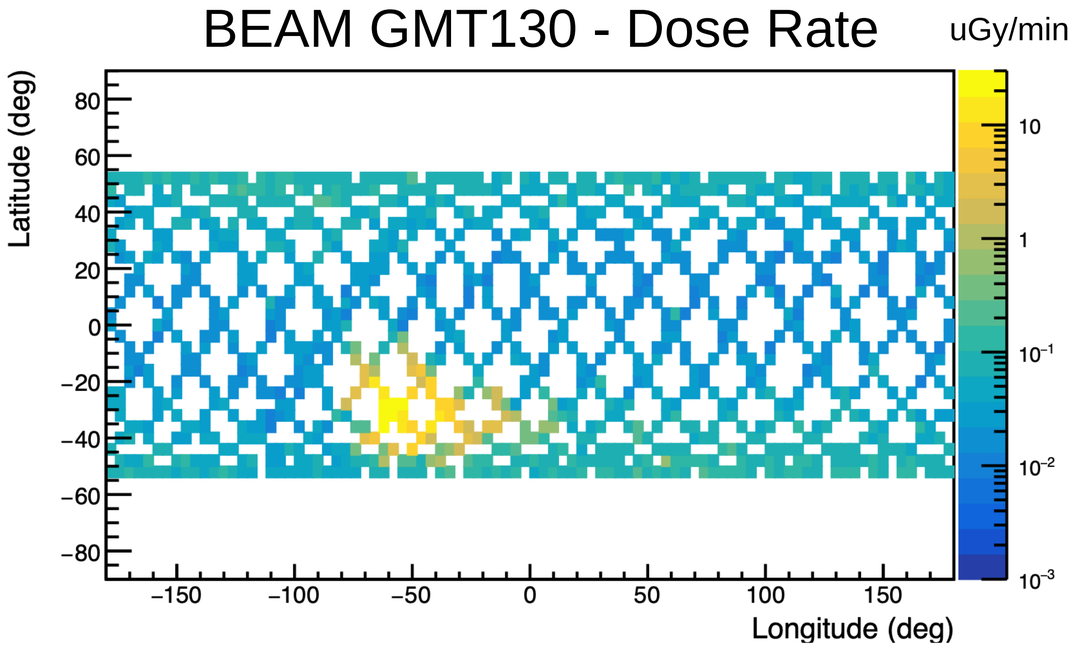
L>4 Quality Factors

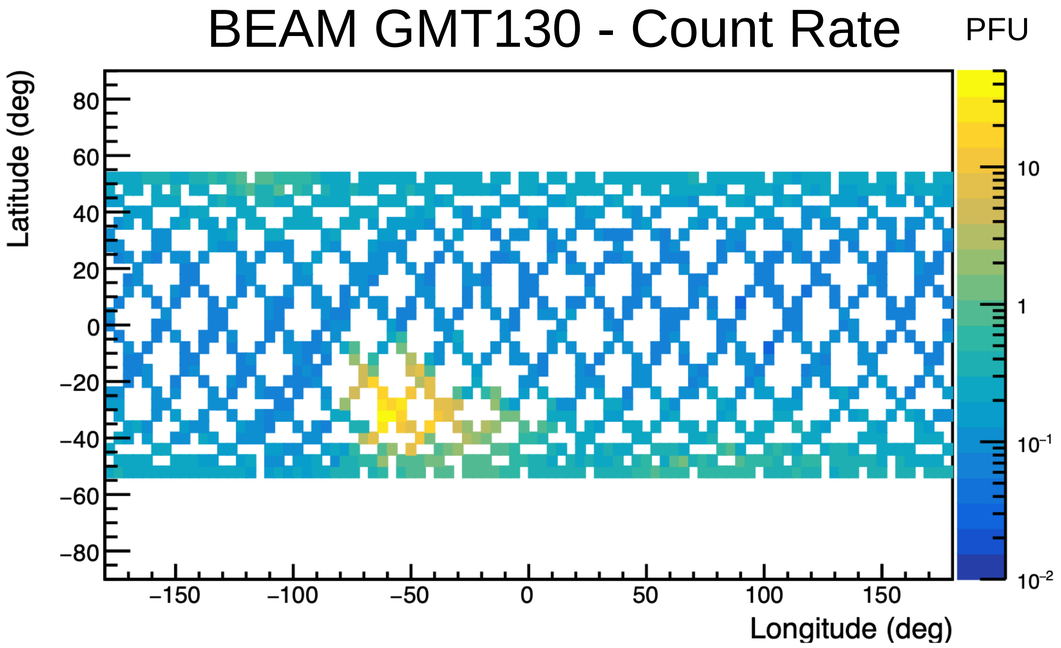
BEAM - 1.22

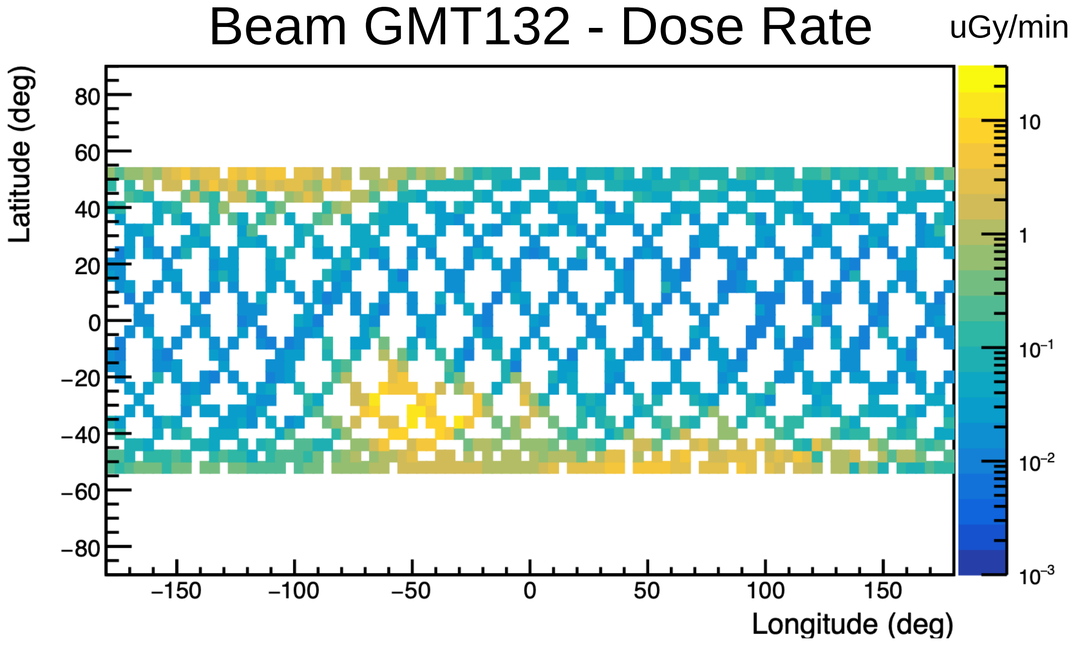
Node1 - 1.32

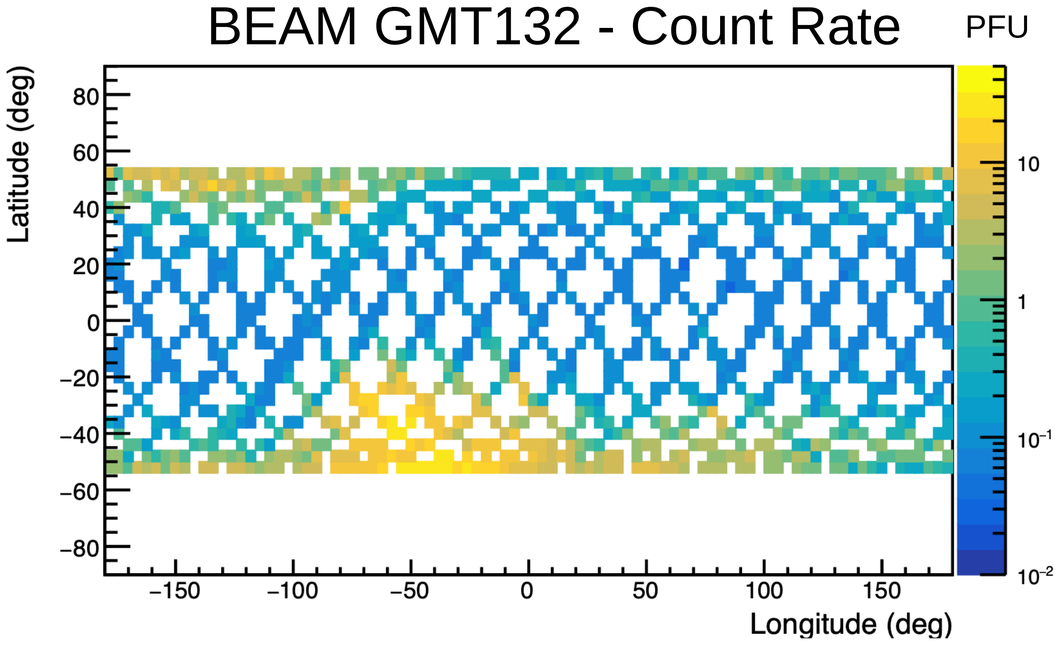
JPM - 1.35

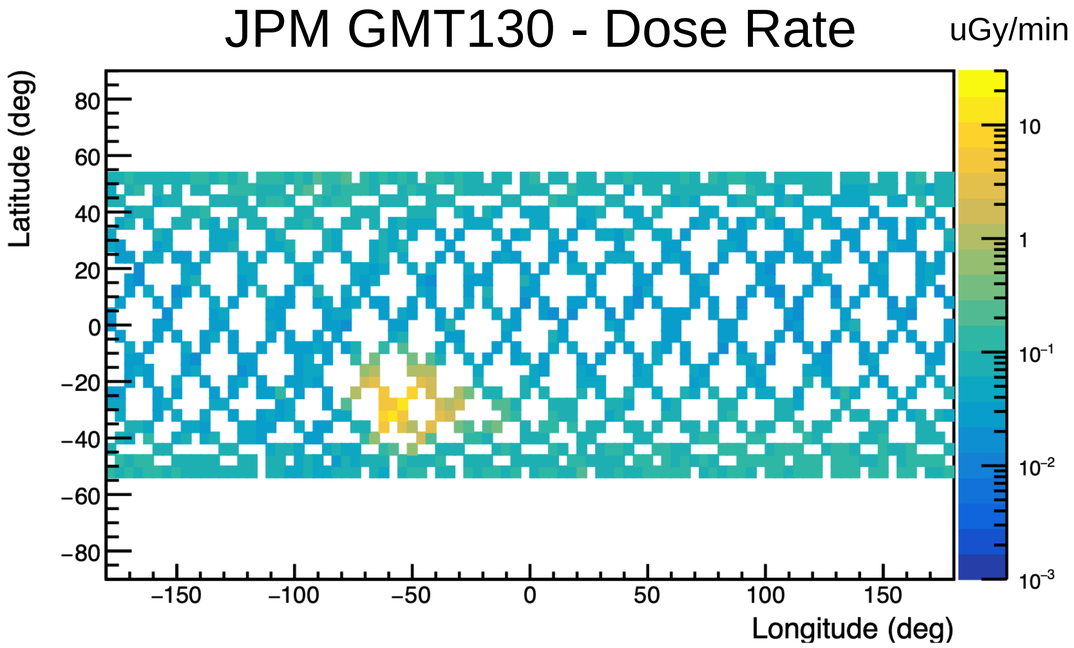
LAB - 1.63

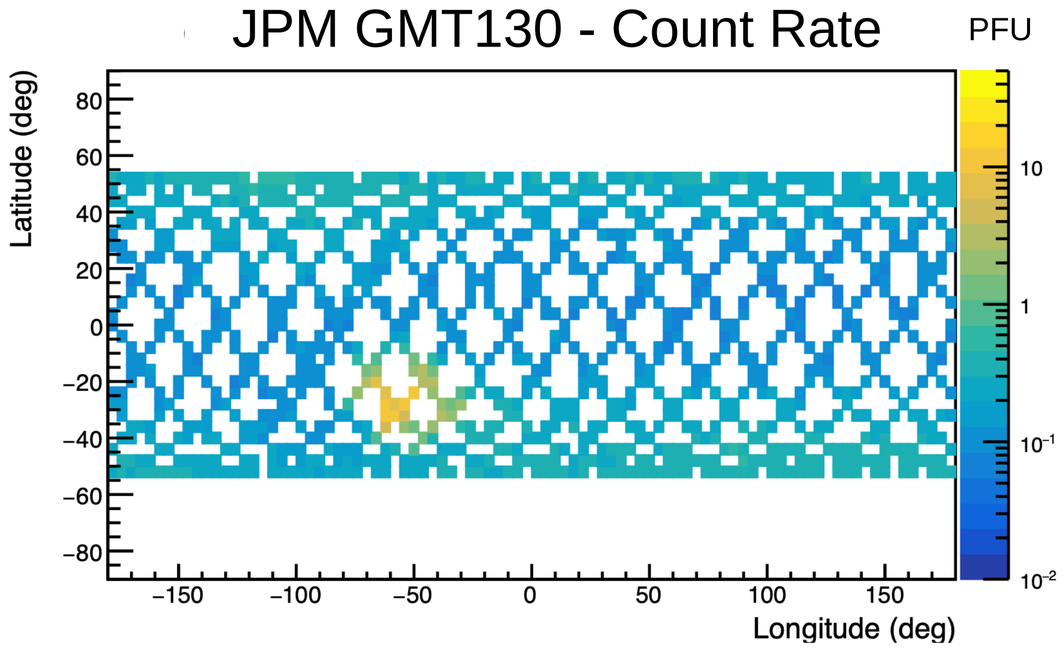

BEAM GMT130 - Dose Rate
uGy/min
Latitude (deg)
Longitude (deg)

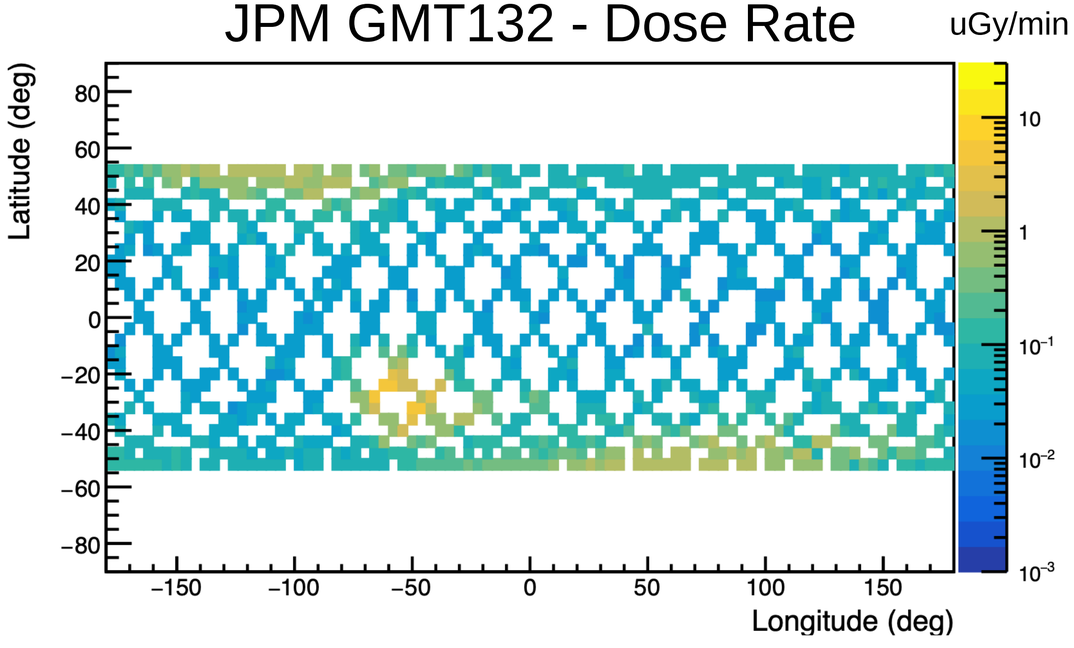

BEAM GMT130 - Count Rate
PFU
Latitude (deg)
Longitude (deg)

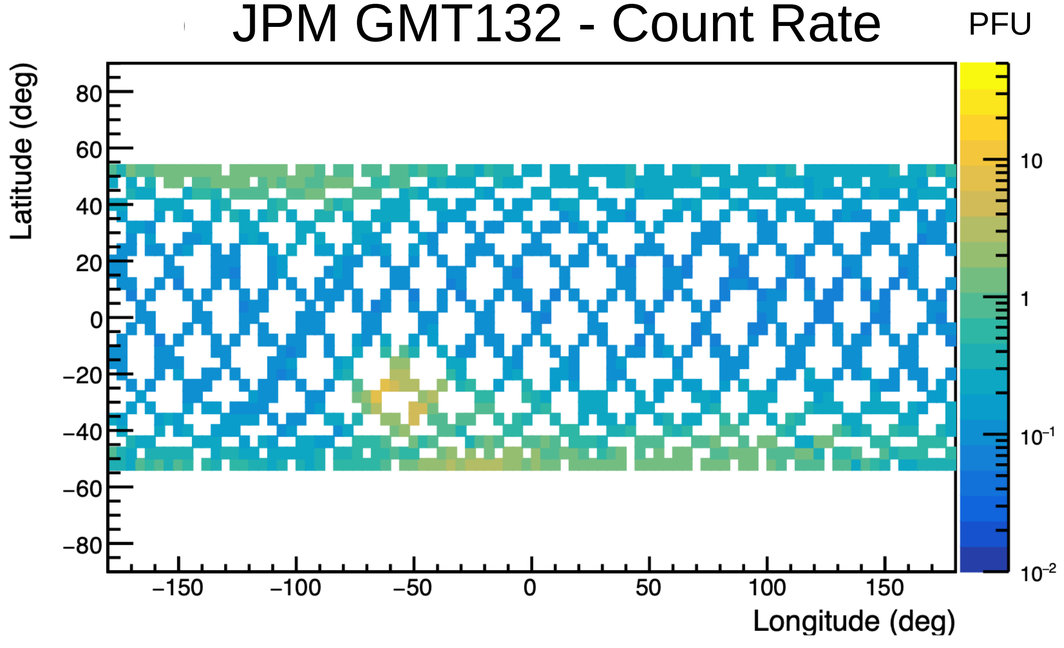

Beam GMT132 - Dose Rate
uGy/min
Latitude (deg)
Longitude (deg)


BEAM GMT132 - Count Rate
PFU
Latitude (deg)
Longitude (deg)

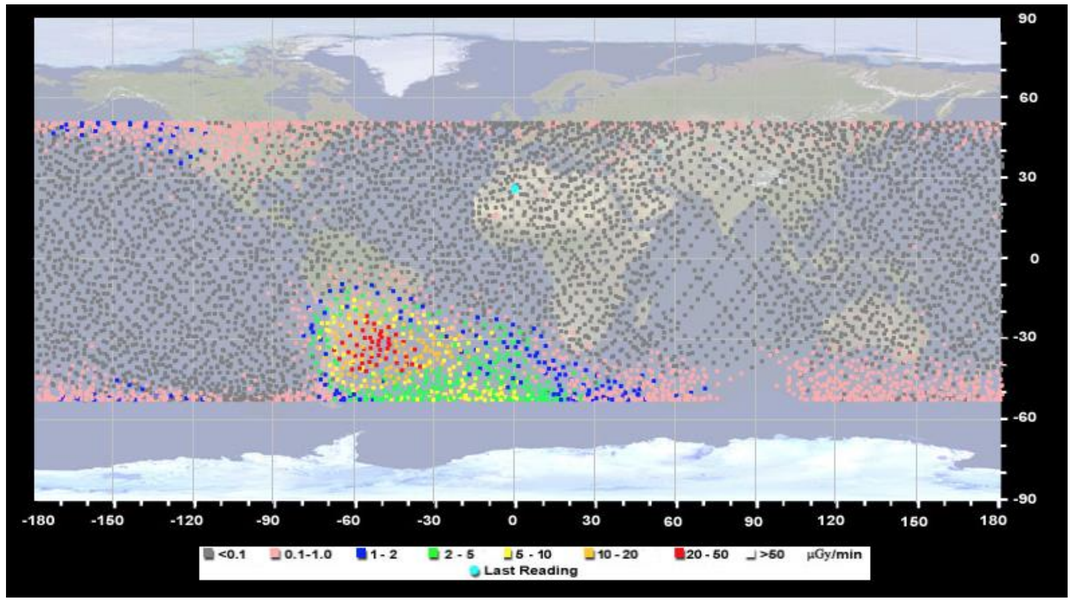

JPM GMT130 - Dose Rate
uGy/min
Latitude (deg)
Longitude (deg)


JPM GMT130 - Count Rate
PFU
Latitude (deg)
Longitude (deg)

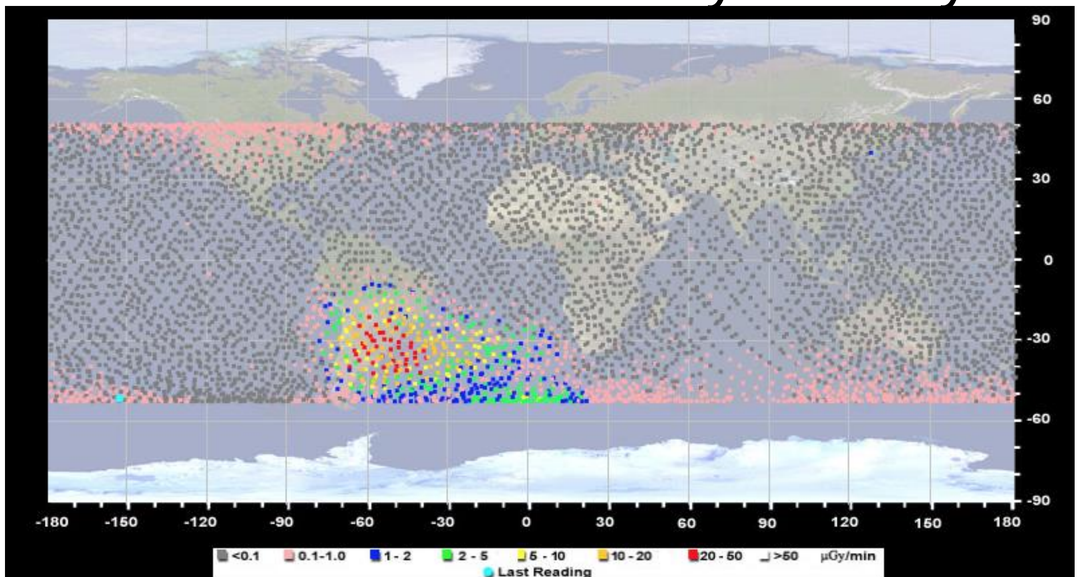

JPM GMT132 - Dose Rate
uGy/min
Latitude (deg)
Longitude (deg)


JPM GMT132 - Count Rate
PFU
Latitude (deg)
Longitude (deg)

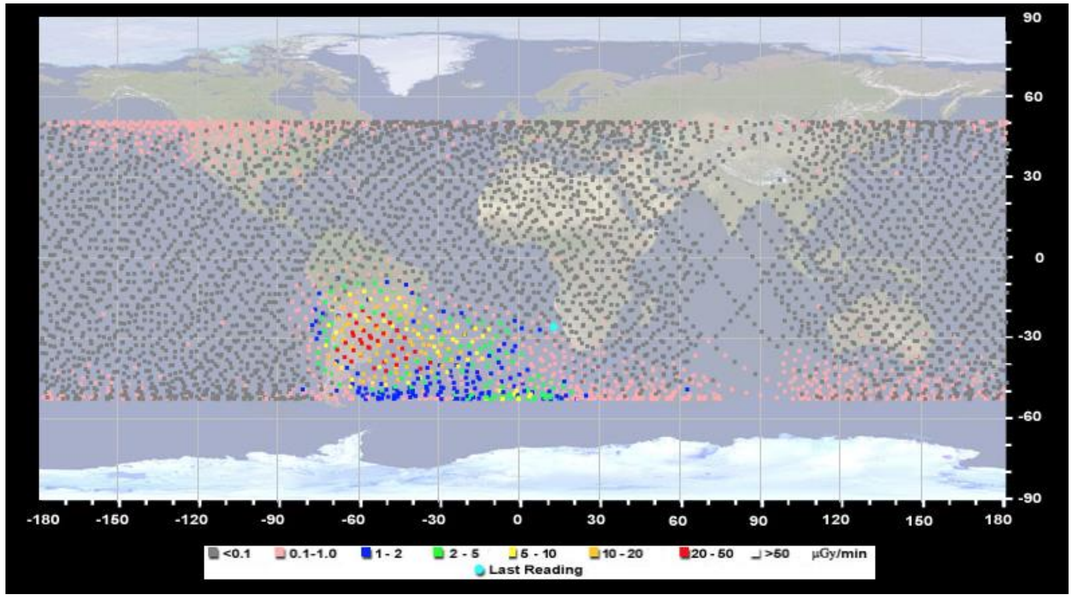
BEAM Dose Rates May 13 (GMT133)-May 18

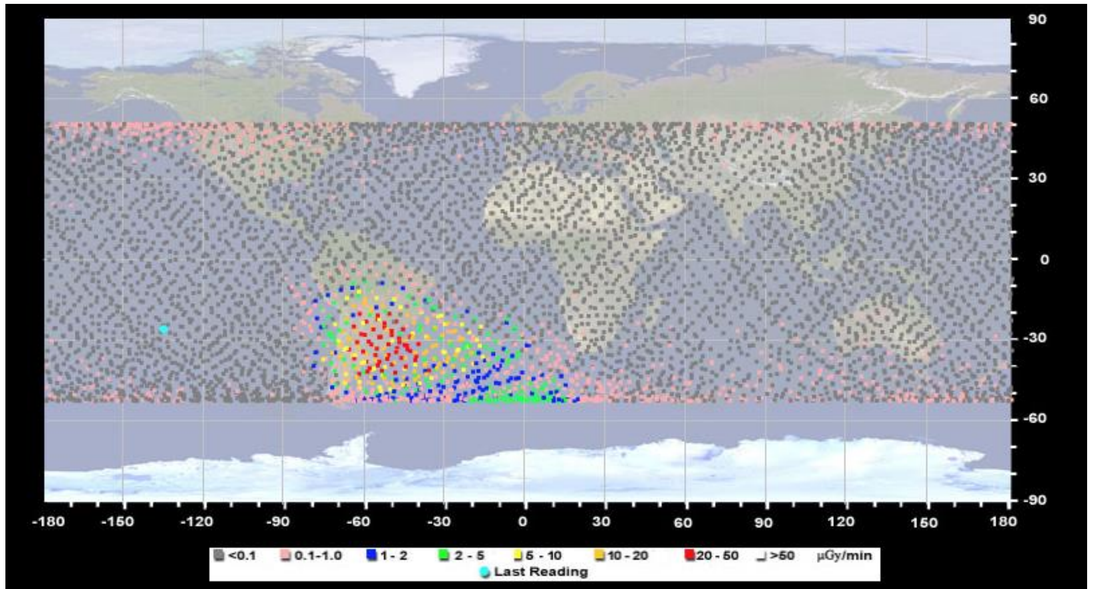


BEAM Dose Rates May 18-May 23

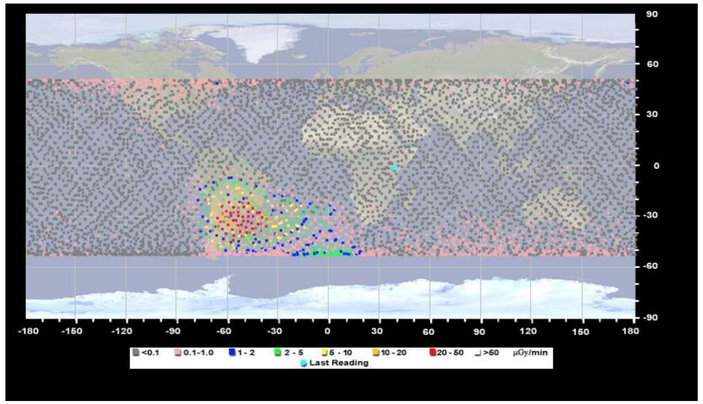


BEAM Dose Rates May 23-May 28

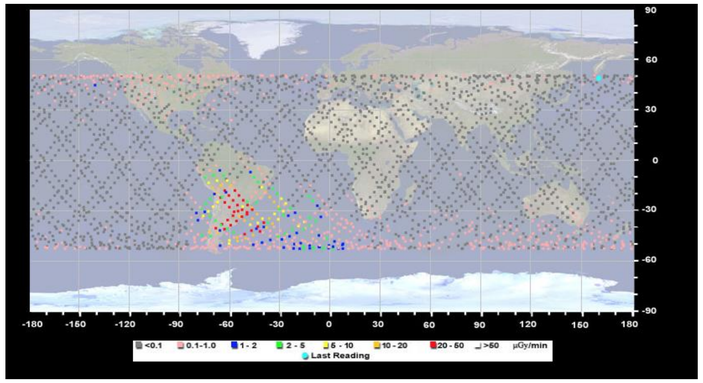




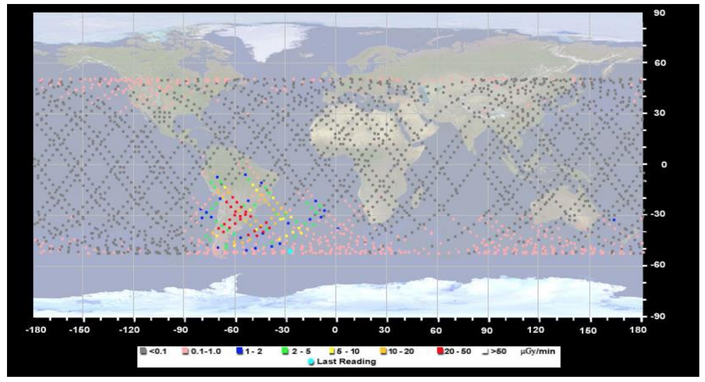
BEAM Dose Rates June 2nd - June 7th

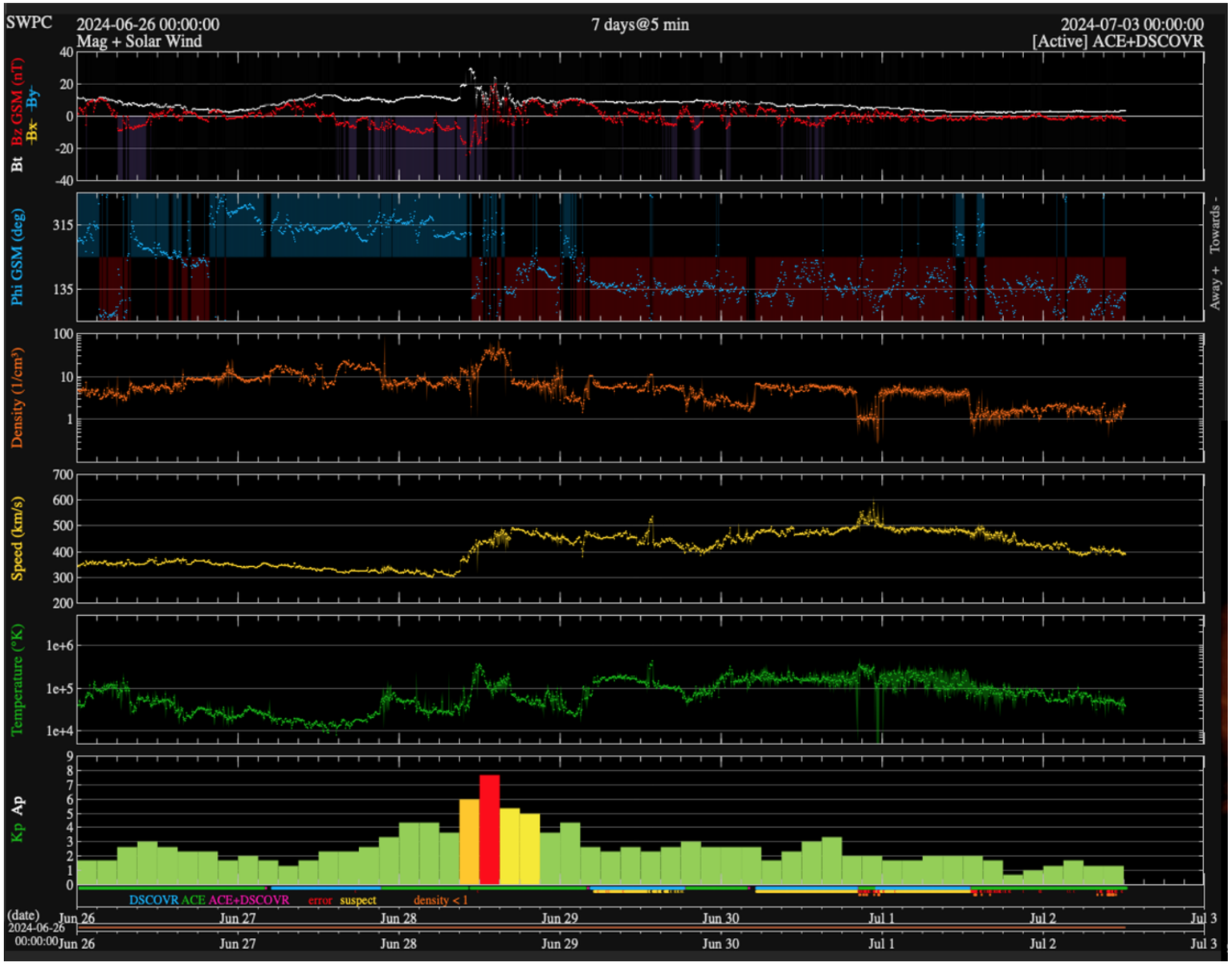


BEAM Dose Rates June 26th - June 28th



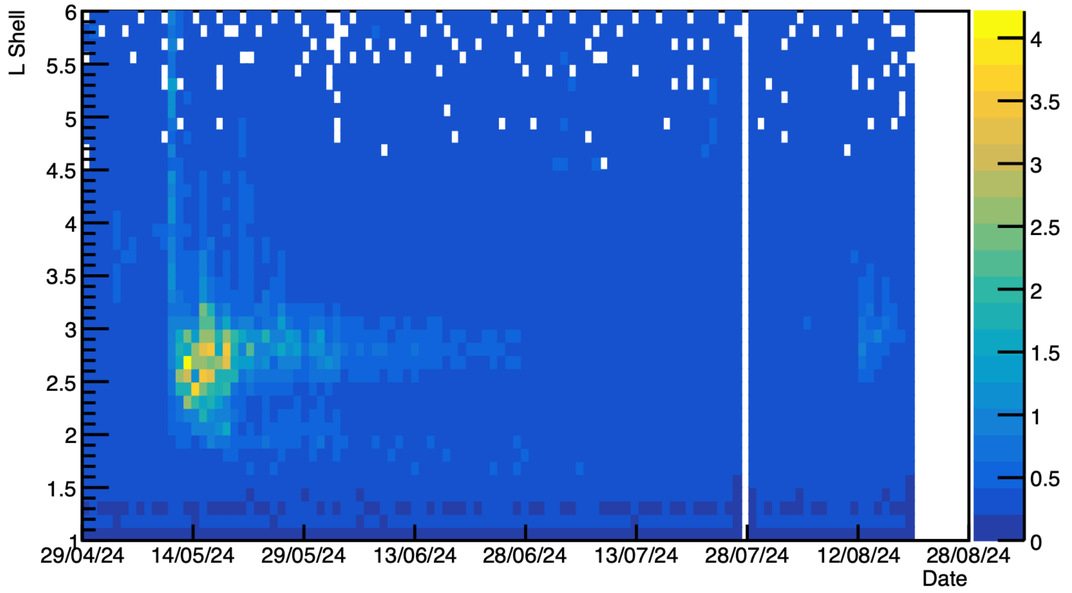
BEAM Dose Rates June 29th - June 30th



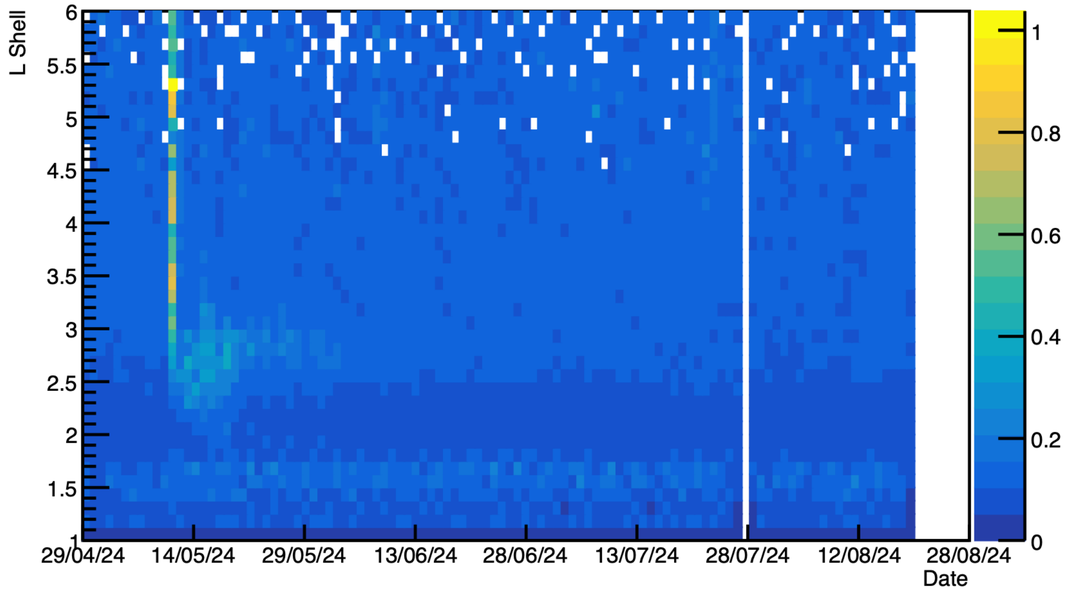


Dose and Flux vs L -> JPM/AHOSS

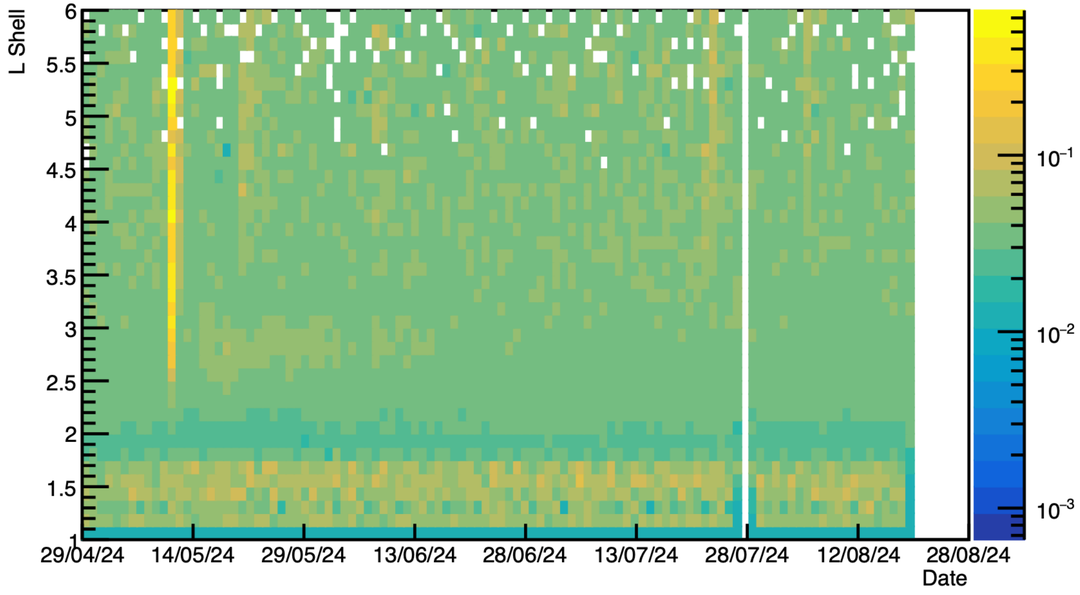
C03_W0332 all flux vs L shell



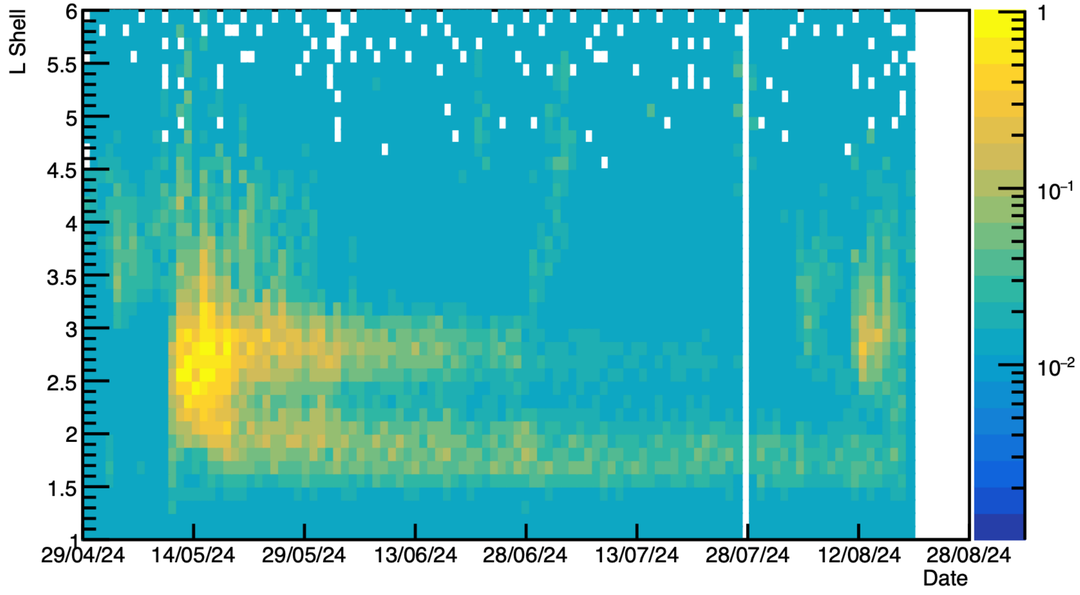
C03_W0332 dose rate vs L shell



C03_W0332 proton flux (LET > 1 keV/um) vs L shell

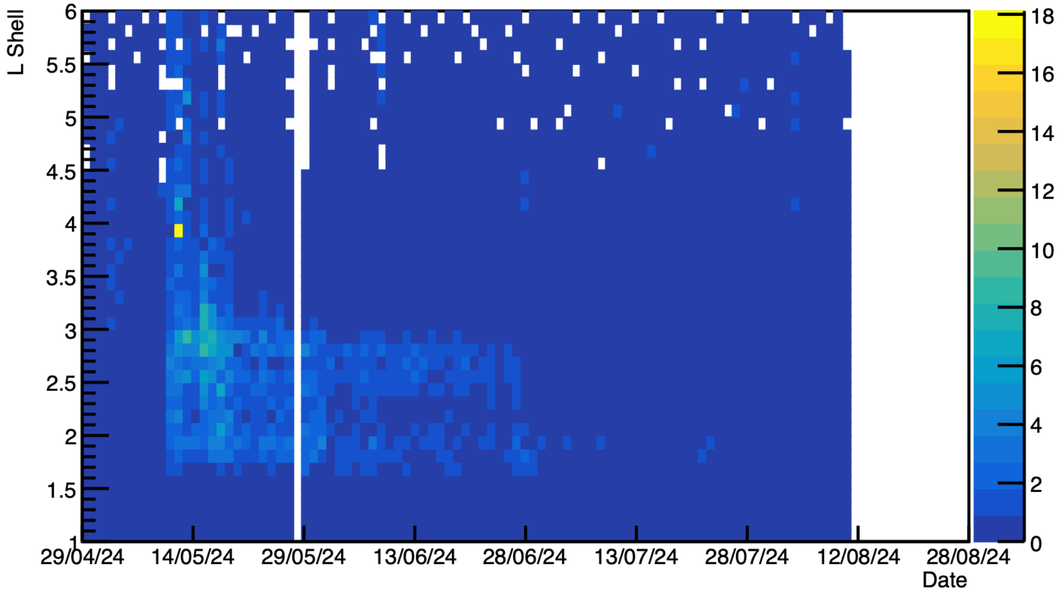


C03_W0332 electron flux (counts 5 keV - 100 keV) vs L shell

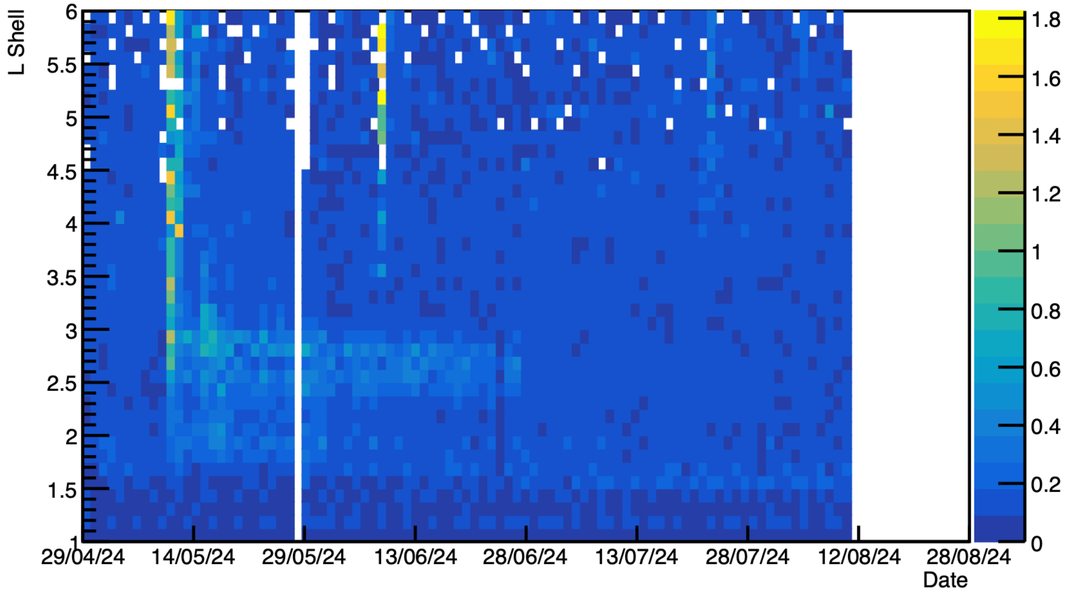


Dose and Flux vs L -> BEAM

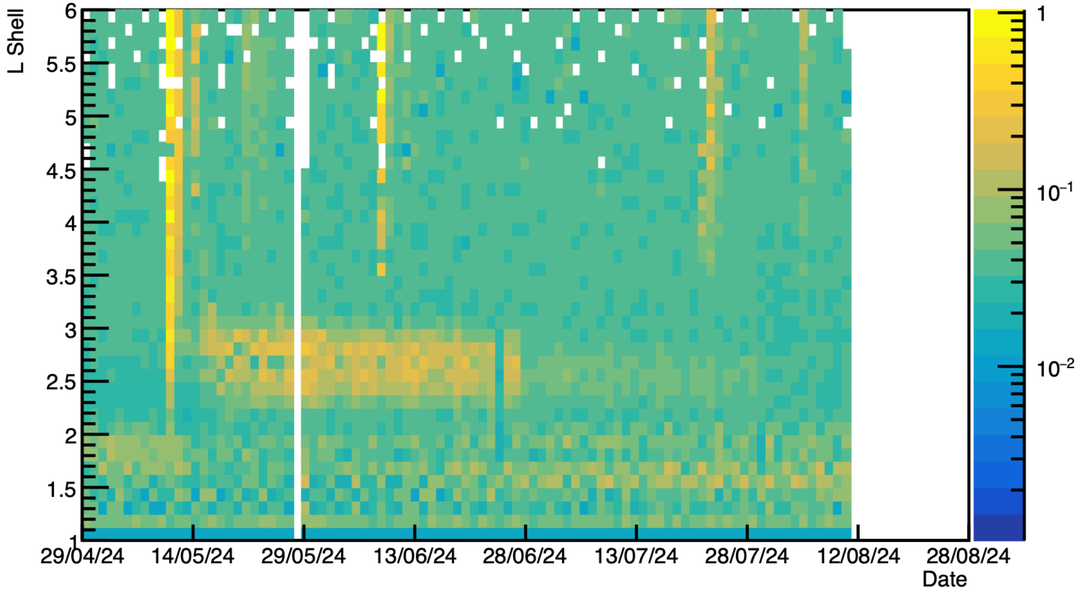
H10_W0099 all flux vs L shell



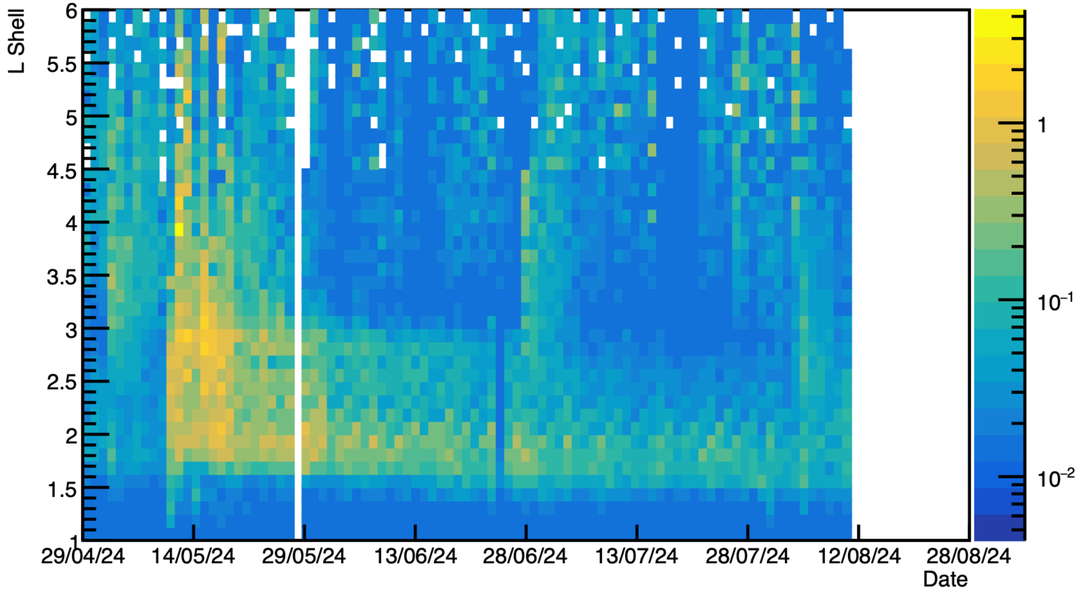
H10_W0099 dose rate vs L shell



H10_W0099 proton flux (LET > 1 keV/um) vs L shell

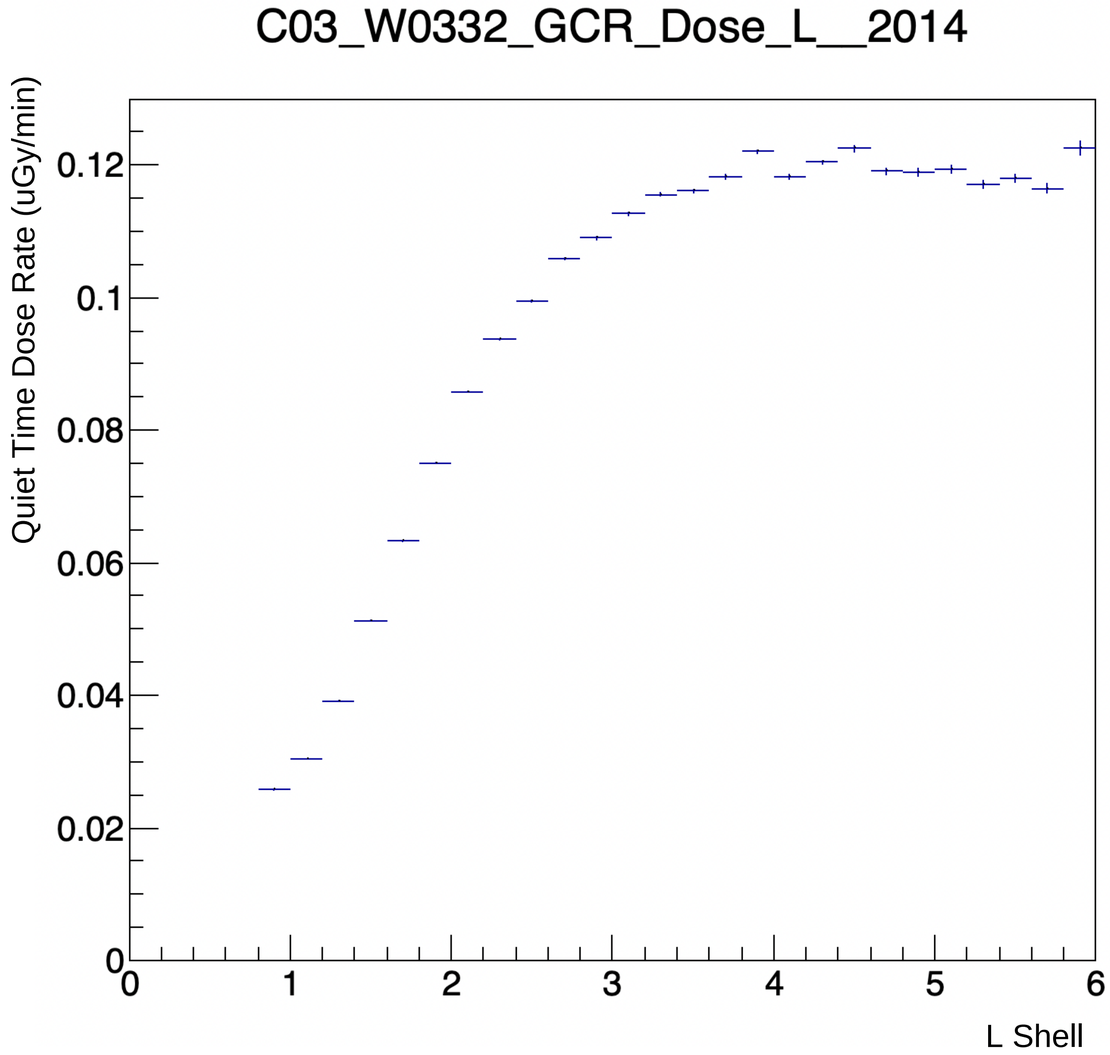


H10_W0099 electron flux (counts 5 keV - 100 keV) vs L shell



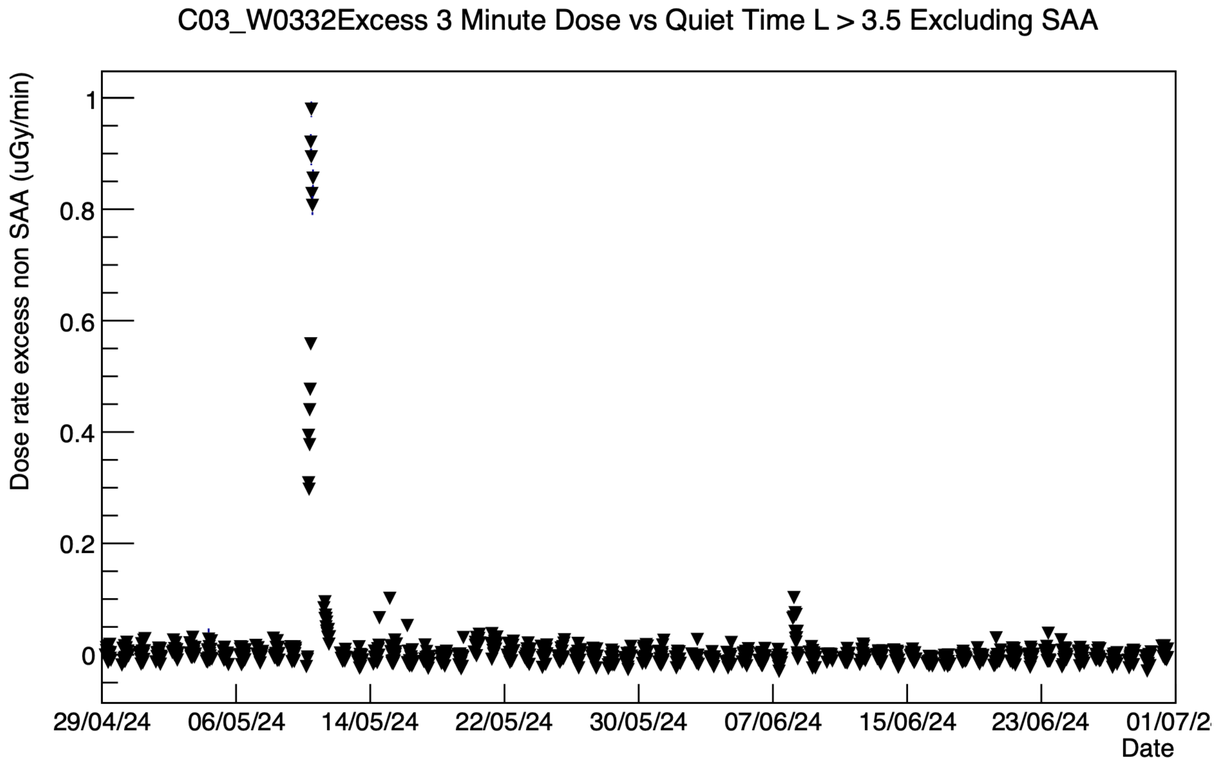
Calculation of Extra Doses from SPE and Belts at ISS

- We now know that the extra belt persisted for around 7 weeks after the May SPE
- Use dose vs L relationship from quiet time to subtract off background GCR contribution
- Exclude SAA from analysis - we know from dose rate trending that SAA stayed flat
- Also - can use L>3.5 as rough SPE/Belt split, but this does not work for GMT132



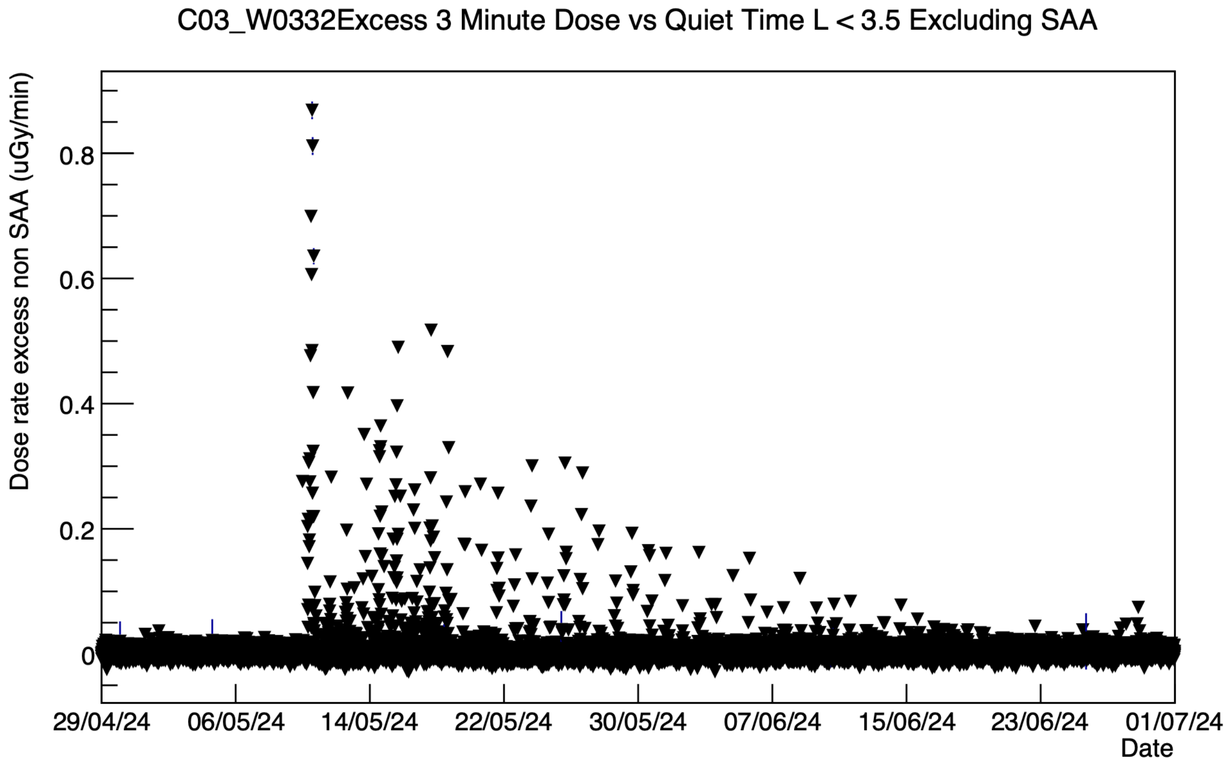
Example Background Subtracted Dose Rates - C03-W0332 (AHOSS in JPM)

L > 3.5



22.30 uGy

L < 3.5

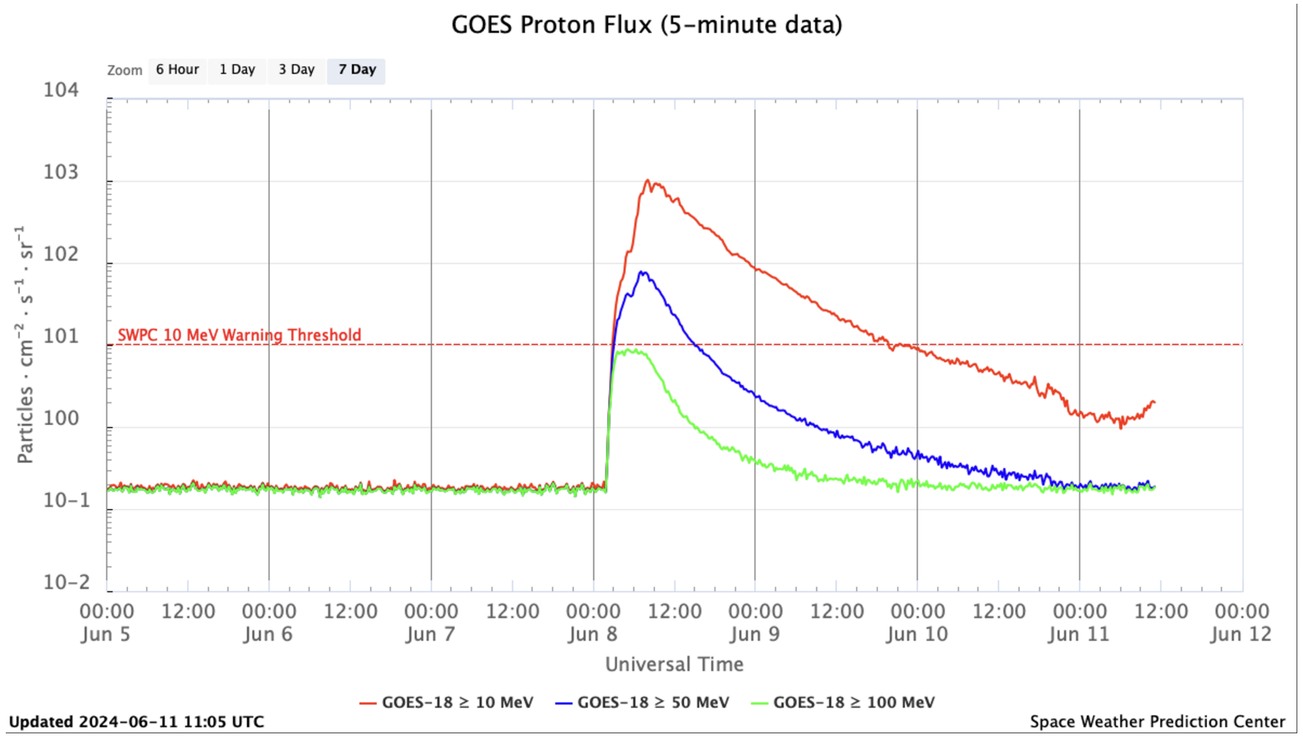


88.25 uGy

Another way of looking at this - 51.25 uGy from GMT132/133 with proton enhancement, 55.58 uGy from trailing 6 week period
For comparison at Biosentinel - total dose from May SPE series ~25 mGy (Si)

An Aside - S3 Solar Storm from June 2024

- S3 solar storm in June 2024 from same AR that caused May space weather after rotating back around the disk
- Doses barely registered in ISS - station not well phased, no opening of the cutoff from geomagnetic storm (quiet time)
- Biosentinel dose - 68 mGy (Si), 85 mGy (H20)

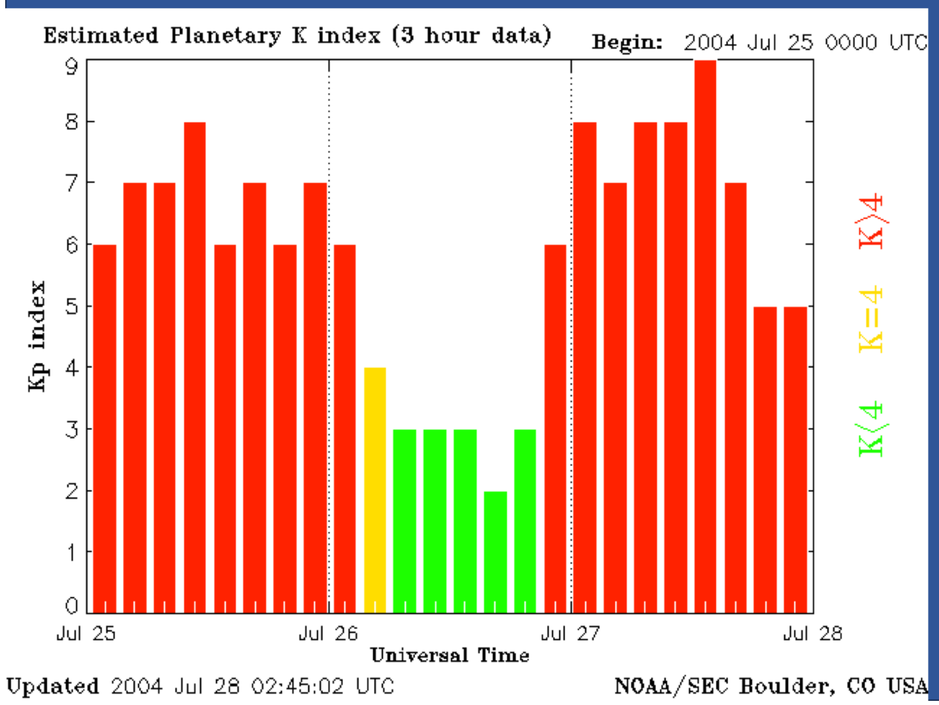


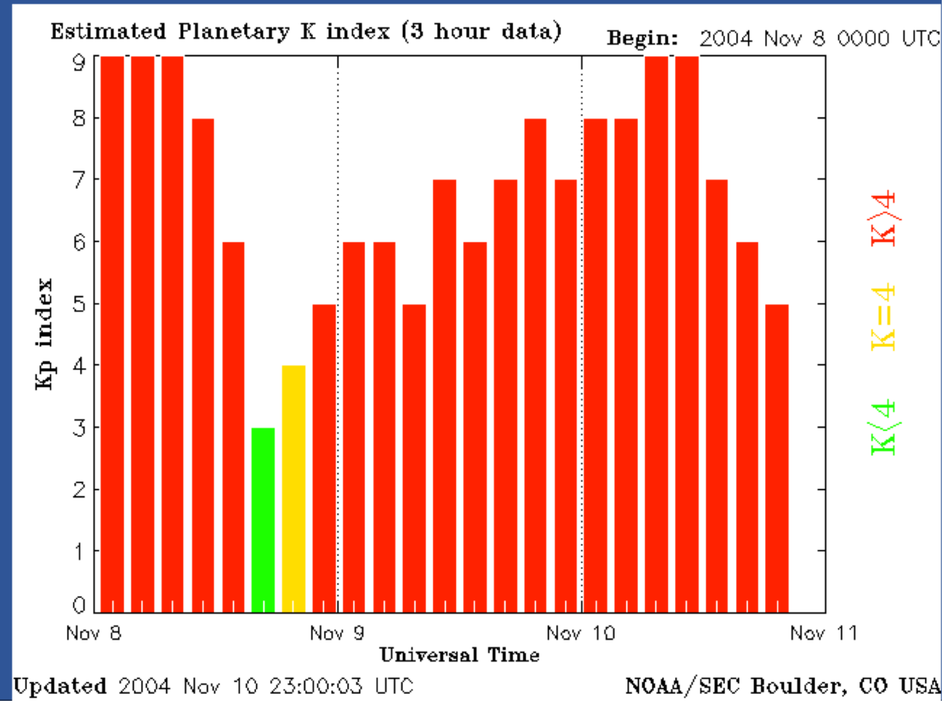
Belt Enhancements

In July and November 2004, there were two significant geomagnetic storms and subsequent belt enhancements

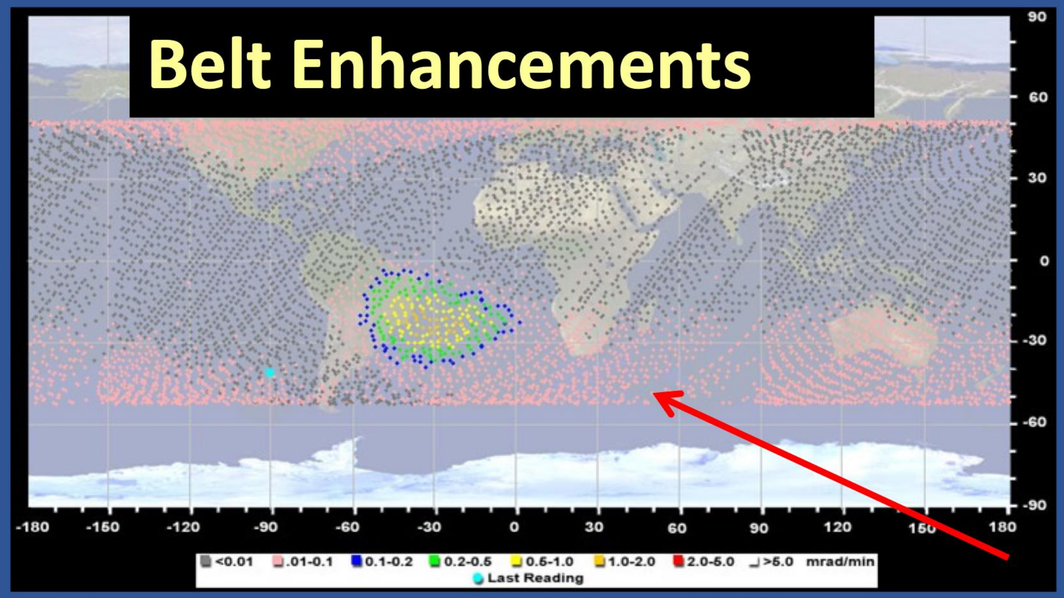
NOAA Region 652 erupted on 25 July, 2004 producing an Earth-directed coronal mass ejection (CME) impacting the geomagnetic field early on 27 July.

NOAA Region 696, erupted on 7 November 2004 resulting in a series of Earth-directed coronal mass ejections (CMEs) generating severe geomagnetic storming. Another second eruption on 8 November 2004 produced further periods of strong geomagnetic storming on 9-10 November.

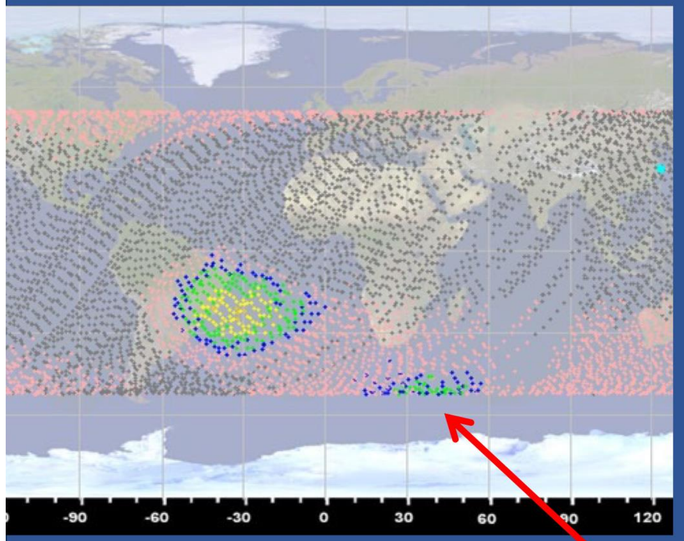




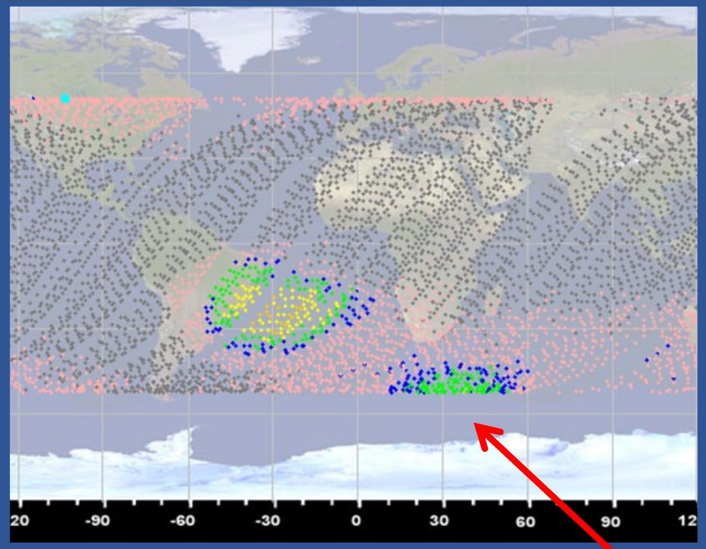
Belt Enhancements



Normal



July 2004
Electron Enhancement



Nov 2004
Proton Enhancement

Conclusions

- A lot of rich dynamic behavior can be observed as a result of interactions of magnetosphere with CME with energetic particles in the mix
- In the case of this event, it seems like the additional enhancement in dose from belt enhancements exceeded the primary proton dose
- Extra dose still low regardless
- S3 storm in June barely registers at all due to phasing of ISS - gives 85 mGy at Biosentinel!
- More (small) electron enhancements visible in data following August 12th CME
- Presumably more to come during solar maximum (?)

Historical Comparison of May 2024 Solar Storms

WHAT: How did the G5 Geomagnetic Storm Compare to Other Major Events?

Index	MAY 2024	OCT 2003	MAR 1989	MAY 1921	SEP 1859
Disturbance Storm Index (nT)	-412	-383	-589	~ -907	~-1200
A_p-Index	271	204	246	NA	NA

Disturbance Storm Index (Dst): An index of magnetic activity derived from a network of near-equatorial geomagnetic observatories that measures the intensity in space of the ring of westward current around Earth (higher negative values generally correlate with stronger storms)

A_p-Index: The average from eight daily values gives the A_p-index of a certain day (every 3-hour K-value - or measure of geomagnetic activity - is converted into a linear scale). Days with higher geomagnetic activity have a higher daily A_p-value.

Loveland Pass, Colorado, 5/10/24. Credit: Dan McManus, SWPC.

Boulder, Colorado, 5/10/24. Credit: Jon Lash, SWPC.