Characterization of the Van Allen Radiation Belt Proton and Electron Fluxes Using SDO Spikes Data

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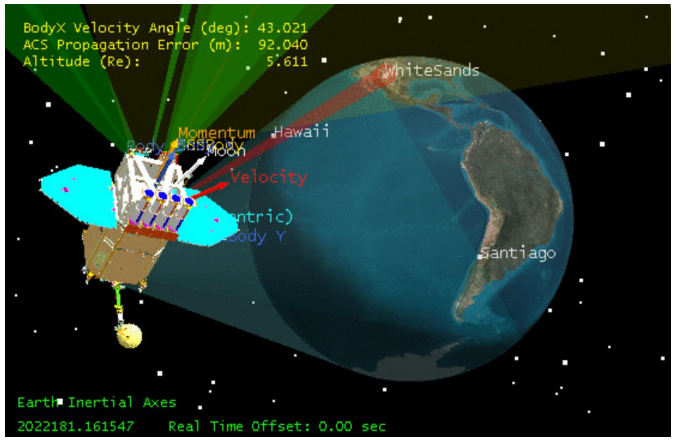
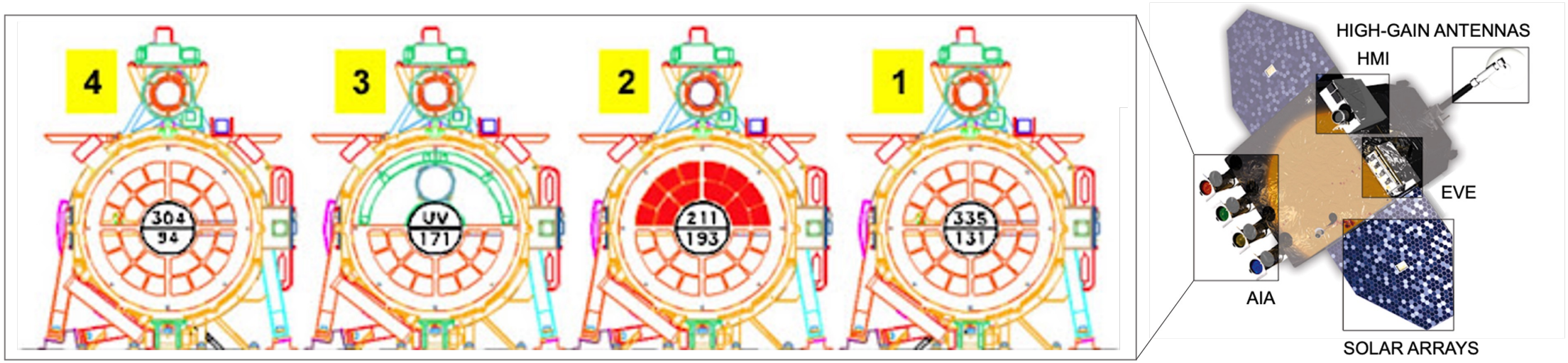
The Solar Dynamics Observatory (SDO)

- Developed by NASA's Goddard Space Flight Center
- Flagship mission of NASA's Living With a Star program
- Launched in 2010 and expected to remain operational until 2030
- Circular geosynchronous orbit inclined by 28.5° (35,789 km altitude)
  - Continuous contact with a ground station in White Sands
  - SDO orbit minimizes eclipses (happening only twice a year)

"Its primary goal is to understand those solar variations that influence life on Earth and humanity's technological systems, aiming towards developing predictive capabilities of the solar activity."



The Solar Dynamics Observatory (SDO)



Atmospheric Imaging Assembly (AIA)

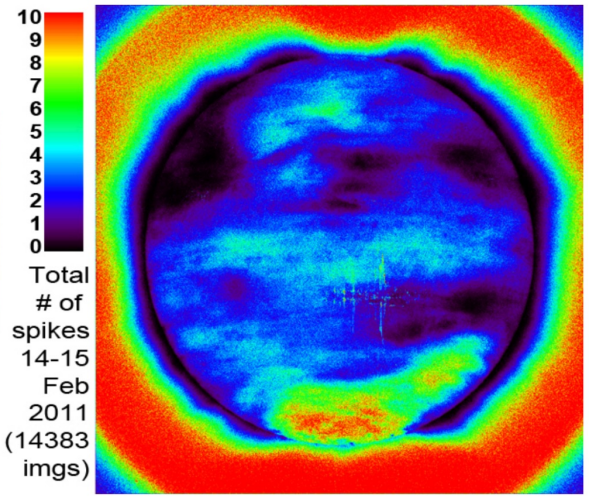
- Array of four telescopes with 1.5-arcsec spatial resolution and 12-second temporal resolution
- High-resolution full-disk images of the corona and solar transition region up to 0.5 solar radii above the solar limb
- Two ultraviolet, one visible light band and seven extreme ultraviolet (EUV)
- This research uses meta-data associated with the AIA EUV images

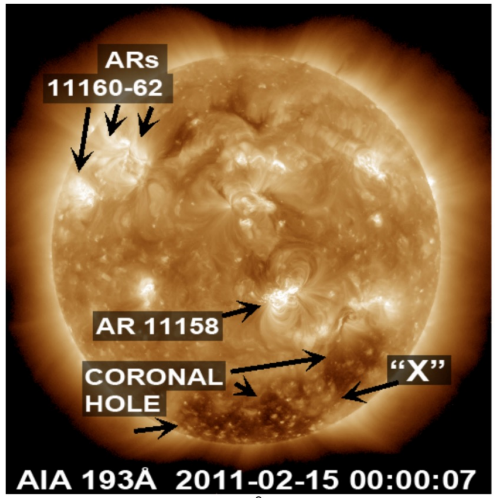
AIA Spike Data

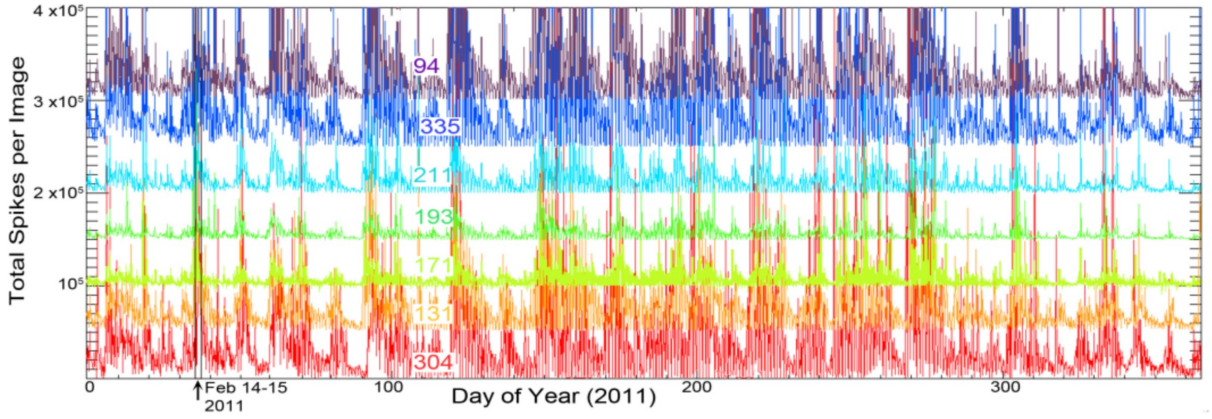
“Despiking” algorithm

- Applied by AIA investigation to remove brightened pixels from all EUV data
- Without it, AIA images would be difficult to use
- Kirk et al. (2017) showed that <0.1% of spikes are of solar origin (photons)
- The “spiked pixels” observed are predominantly of magnetospheric origin

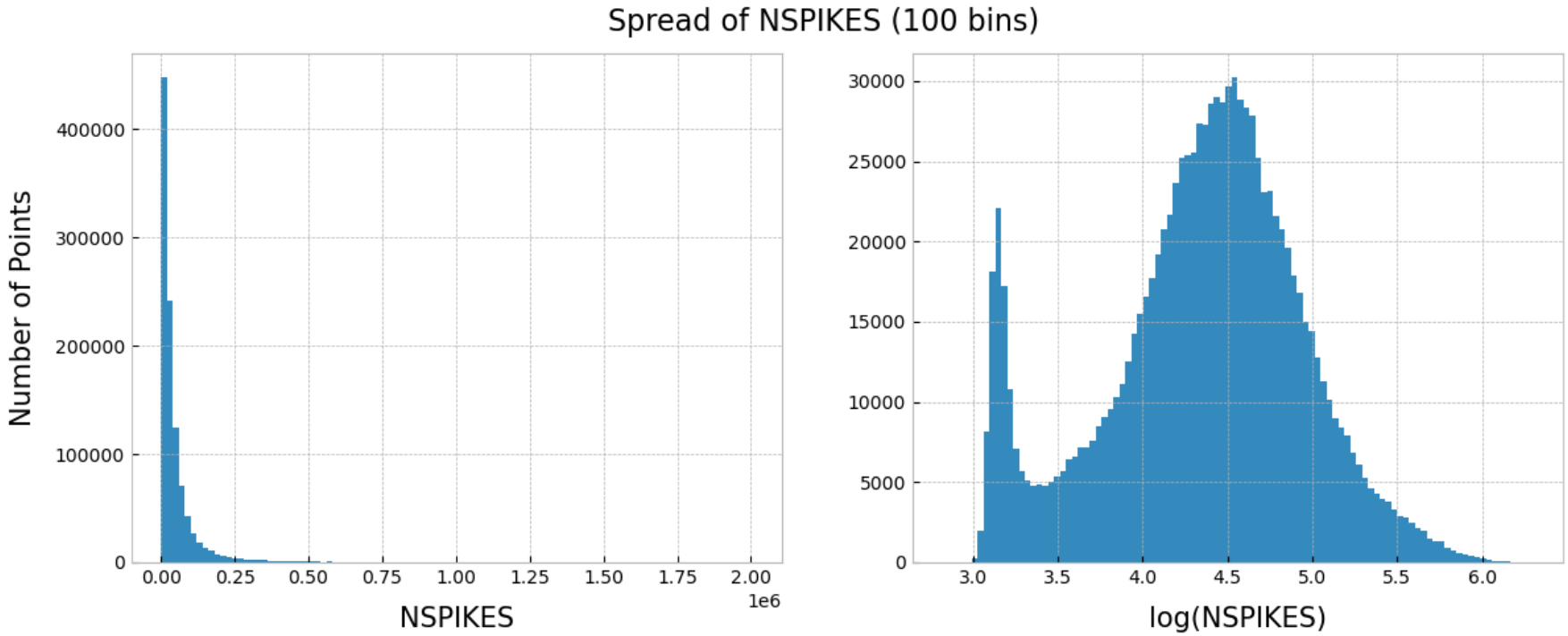
Goal of this research is to characterize the Van Allen radiation belt using the spikes in SDO’s orbit.





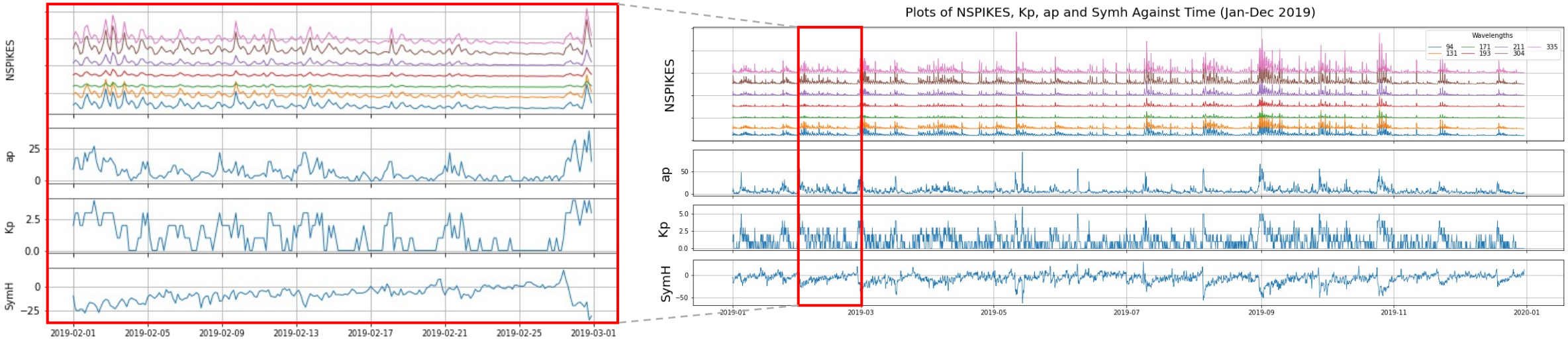


AIA Spike Data



- NSPIKES is the header name for the “despiked” pixels
- A typical 304Å image contains ~**50,000 NSPIKES** (0.3% of 16 Megapixels)
- NSPIKES can be in the millions during periods of enhanced particle flux
- Over the course of twelve years of SDO operation: there are over 200 million AIA images → **6 trillion** pixel hits

NSPIKES Correlation with Geomagnetic Indices



Geomagnetic Indices Compared:

1. Sym-H: proxy of the axially symmetric magnetic field disturbance at low and middle latitudes on the Earth's surface measured in nano-Tesla (nT)
2. K-index: quasi-logarithmic local index of the 3-hourly range in magnetic activity relative to an assumed quiet-day curve
   a) Kp: mean standardized K-index readings from 13 geomagnetic observatories between 44° and 60° N or S geomagnetic latitude
   b) ap: linear equivalent of Kp (ranges from 0 to 400 and is also calculated in 3-hour intervals)

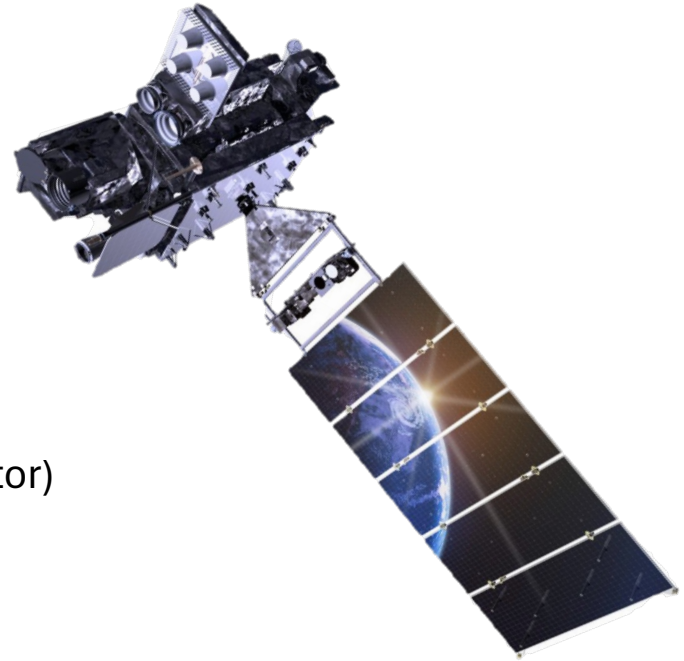
NSPIKES Correlation with Geomagnetic Indices

Wavelength (Å)	94	131	171	193	211	304	335
			Pearson Correlation (r)				
Kp	0.262 ± 0.12	0.285 ± 0.09	0.346 ± 0.03	0.312 ± 0.11	0.307 ± 0.11	0.341 ± 0.05	0.284 ± 0.13
ap	0.227 ± 0.12	0.248 ± 0.09	0.305 ± 0.06	0.273 ± 0.10	0.265 ± 0.11	0.297 ± 0.06	0.243 ± 0.13
SymH	0.265 ± 0.12	0.285 ± 0.09	0.326 ± 0.05	0.292 ± 0.10	0.293 ± 0.11	0.321 ± 0.05	0.266 ± 0.13
			Spearman Correlation (ρ)				
Kp	0.264 ± 0.04	0.258 ± 0.04	0.309 ± 0.04	0.312 ± 0.04	0.306 ± 0.04	0.315 ± 0.04	0.314 ± 0.04
ap	0.274 ± 0.04	0.268 ± 0.04	0.323 ± 0.04	0.326 ± 0.04	0.319 ± 0.04	0.328 ± 0.04	0.327 ± 0.04
SymH	0.296 ± 0.04	0.292 ± 0.04	0.322 ± 0.03	0.324 ± 0.03	0.323 ± 0.03	0.329 ± 0.03	0.328 ± 0.03

Ten year (2011-2021) mean Pearson and Spearman correlation coefficients for NSPIKES when compared with the three geomagnetic parameters (Kp, ap and Sym-H) for the seven different AIA wavelengths. In teal are marked the highest correlation values for each one of the geomagnetic indices.

GOES-14 Satellite

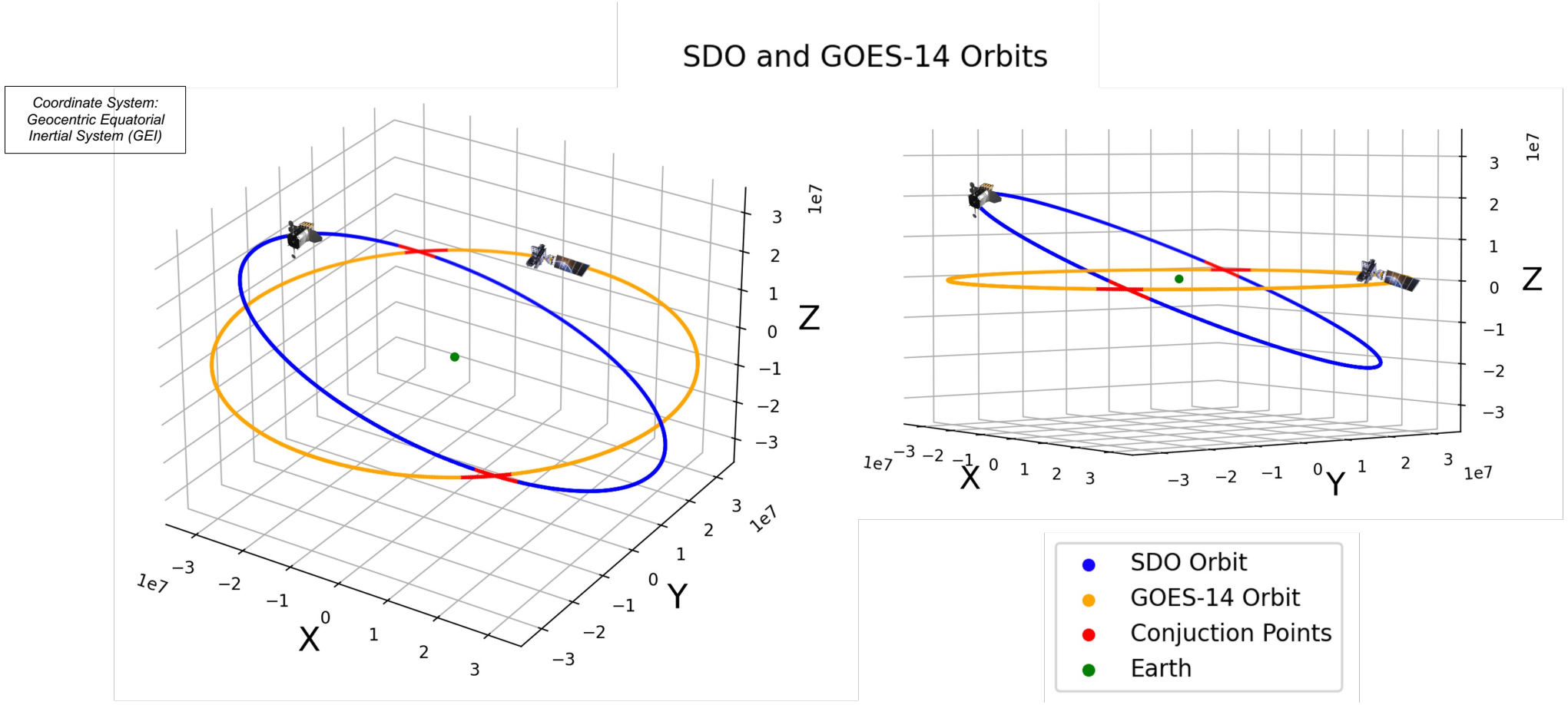
- Weather satellite part of the NOAA GOES System
- Launched on the 27th of June, 2009
- 105° West Longitude / 35,800 km altitude
  (Remember!: SDO is at 108° West Longitude)



GOES-14 Instruments:

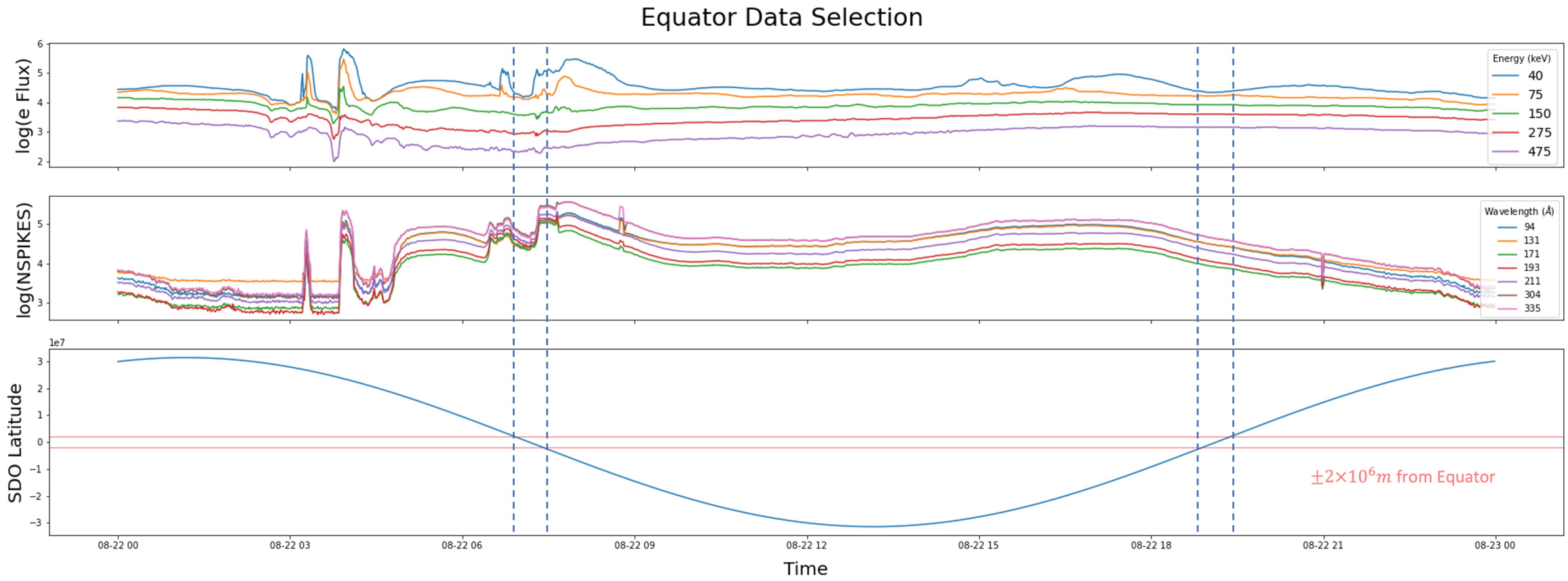
- Equipped with 9 different instruments including
- EPS/HEPAD (Energetic Particle Sensors / High Energy Proton and Alpha Detector)
  - MAGED (Magnetospheric Electron Detector)
  - MAGPD (Magnetospheric Proton Detector)
  - EPEAD (Energetic Proton, Electron and Alpha Detectors)

SDO and GOES-15 Conjunction Points



Twice a day SDO passes through the equator and comes close to (~1,642 km) GOES-14, where we compare the SDO NSPIKES with the GOES-14 protons and electrons.

Picking the Equator Data

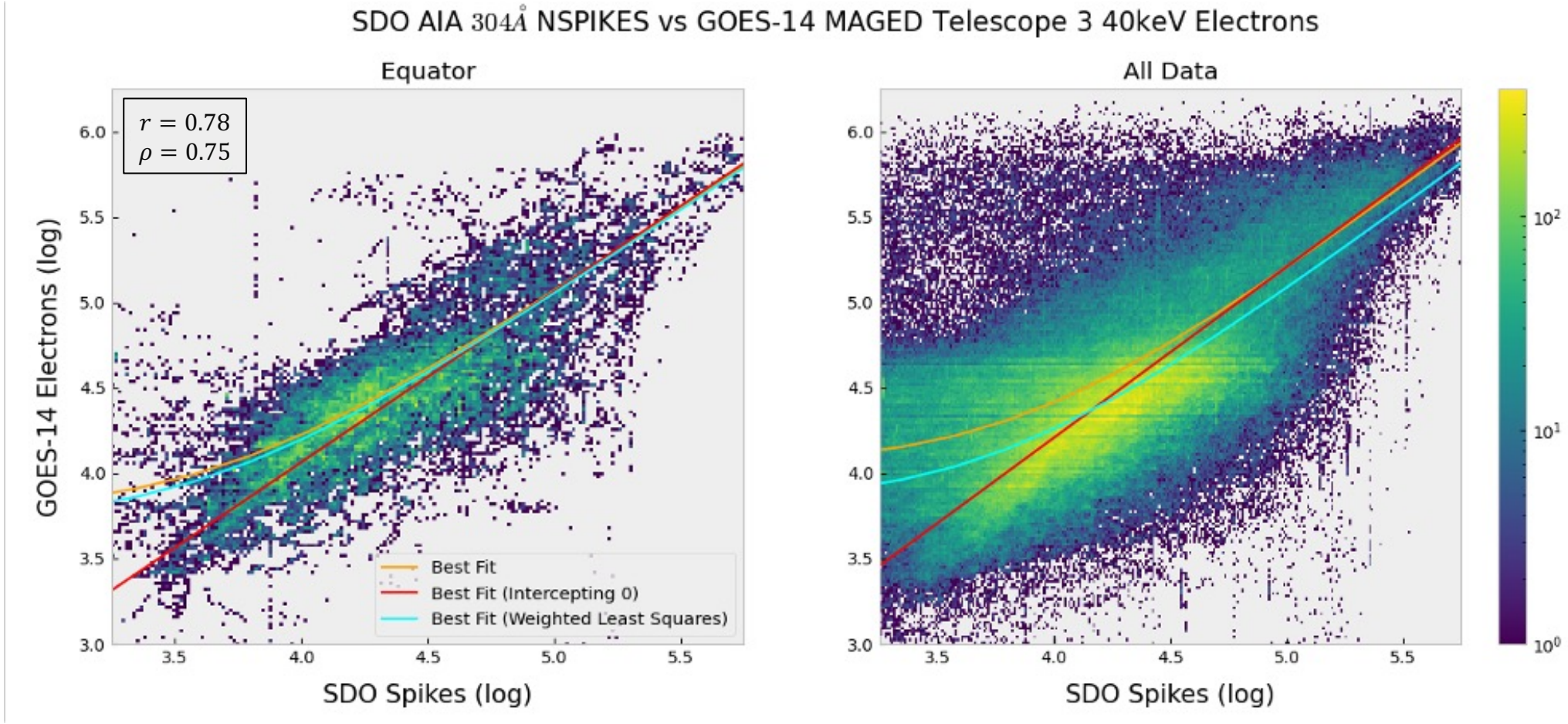


Correlation of NSPIKES with MAGED Electrons

MAGED Electron Flux	40 keV	75 keV	150 keV	275 keV	475 keV
			Pearson Correlation (r)		
Equator	0.629 ± 0.262	0.571 ± 0.239	0.404 ± 0.174	0.319 ± 0.158	0.280 ± 0.151
Non-Equator	0.513 ± 0.209	0.516 ± 0.210	0.434 ± 0.179	0.347 ± 0.150	0.290 ± 0.131
Full Orbit	0.515 ± 0.210	0.515 ± 0.210	0.430 ± 0.178	0.345 ± 0.150	0.289 ± 0.132
			Spearman Correlation (ρ)		
Equator	0.729 ± 0.009	0.712 ± 0.011	0.670 ± 0.025	0.611 ± 0.036	0.550 ± 0.039
Non-Equator	0.529 ± 0.017	0.526 ± 0.007	0.499 ± 0.004	0.456 ± 0.010	0.412 ± 0.013
Full Orbit	0.534 ± 0.016	0.530 ± 0.006	0.504 ± 0.004	0.460 ± 0.011	0.416 ± 0.014

- MAGED consists of 9 collimated solid-state telescopes each with a 30° full-angle conical field of view and collects magnetospheric electrons and provide electron flux measurements in 5 energy channels ranging from 30 to 600 keV (30–50, 50–100, 100–200, 200–350, and 350–600 keV).
- The Table presents the Pearson and Spearman correlation values for NSPIKES and MAGED Electron Flux data for the 5 different MAGED energy channels (December 2017 - February 2020). The 9 different MAGED telescopes and 7 different AIA wavelengths are accounted for by presenting the mean and standard deviation of all possible combinations.

Correlation of NSPIKES with MAGED Electrons



Correlation of NSPIKES with EPEAD Electrons

EPEAD	Spearman Correlation (ρ)						
Wavelength	94Å	131Å	171Å	193Å	211Å	304Å	335Å
Equator	0.529	0.534	0.432	0.435	0.456	0.448	0.447
Non-Equator	0.383	0.385	0.350	0.350	0.357	0.350	0.350
Full Orbit	0.387	0.389	0.351	0.352	0.359	0.352	0.352

EPEAD

- Observes electrons in the energy range above that of MAGED (three channels: >0.8, >2 and >4 MeV).
- Provides us with the dead-time corrected average flux of electrons with backgrounds and proton contamination removed.
- 2 EPEADs on GOES-14, one with a field-of-view to the east and the other one to the west.

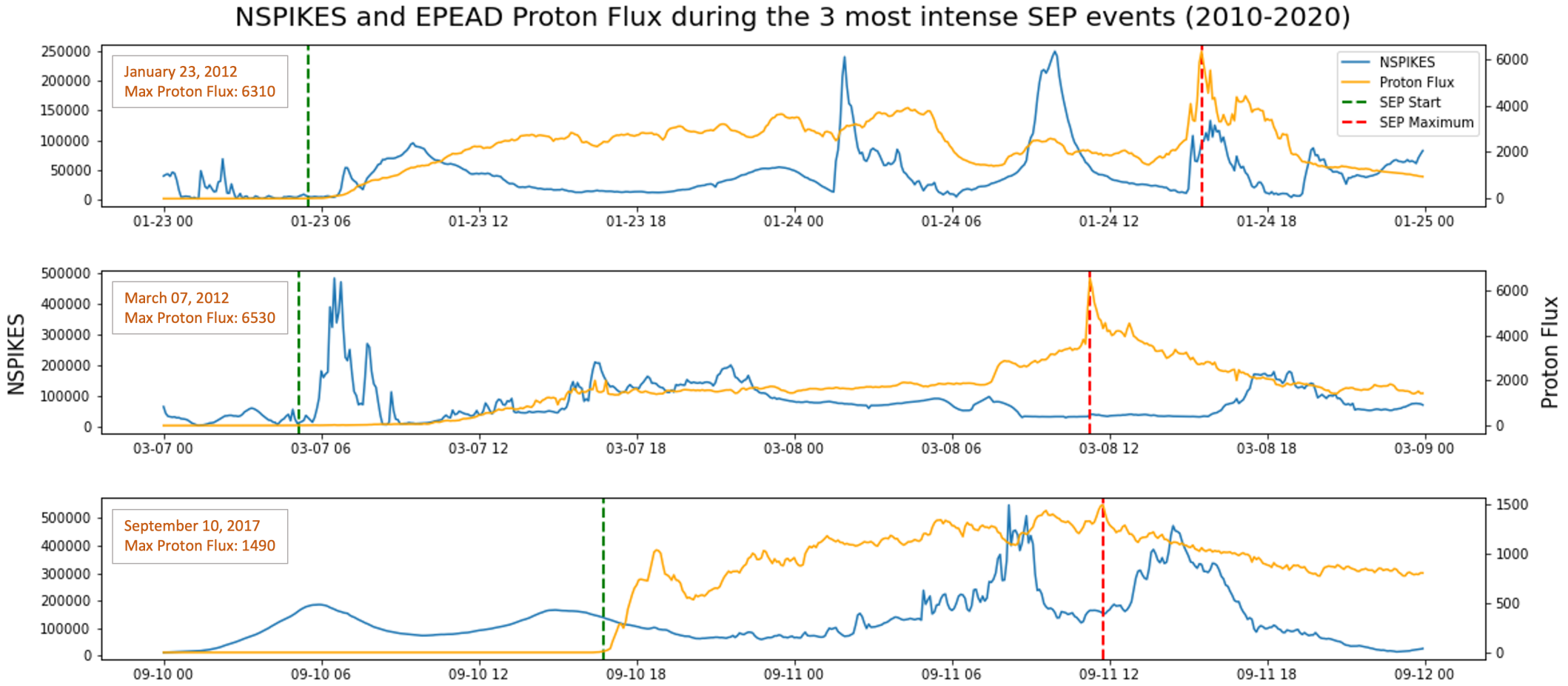
The Table presents Spearman correlation values for NSPIKES and EPEAD > 0.8 MeV (E1) electron flux data for the 7 different AIA wavelengths (December 2017 to February 2020).

Correlation of NSPIKES with MAGPD Protons

MAGPD Proton Flux	95 keV	140 keV	210 keV	300 keV	575 keV
			Pearson Correlation (r)		
Equator	0.132 ± 0.083	0.156 ± 0.091	0.190 ± 0.101	0.211 ± 0.117	0.192 ± 0.106
Non-Equator	0.149 ± 0.069	0.173 ± 0.080	0.201 ± 0.096	0.234 ± 0.107	0.212 ± 0.098
Full Orbit	0.148 ± 0.070	0.172 ± 0.081	0.209 ± 0.096	0.233 ± 0.108	0.211 ± 0.098
			Spearman Correlation (ρ)		
Equator	0.326 ± 0.052	0.357 ± 0.052	0.423 ± 0.050	0.467 ± 0.0476	0.447 ± 0.042
Non-Equator	0.306 ± 0.019	0.329 ± 0.018	0.370 ± 0.017	0.389 ± 0.016	0.345 ± 0.014
Full Orbit	0.305 ± 0.020	0.328 ± 0.019	0.370 ± 0.018	0.390 ± 0.017	0.347 ± 0.015

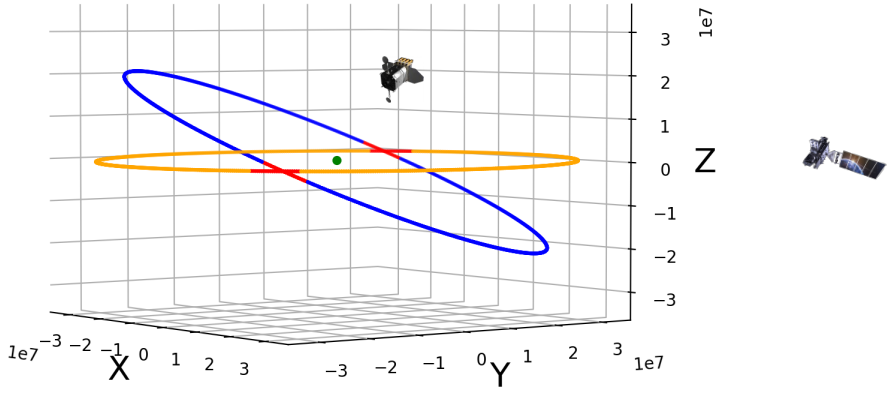
- MAGPD has 9 telescopes pointing away from the earth. The instrument collects dead-time magnetospheric protons and provides proton flux measurements ranging from 80 to 800 keV in 5 separate channels (mean flux detection values of 95, 140, 210, 300 and 575 keV).
- The Table presents the Pearson and Spearman correlation values for NSPIKES and MAGPD Proton Flux data for the 5 different MAGPD energy channels (December 2017 to February 2020). The 9 different MAGPD telescopes and 7 different AIA wavelengths are accounted for by presenting the mean and standard deviation of all possible combinations.

NSPIKES during SEP events



Conclusion

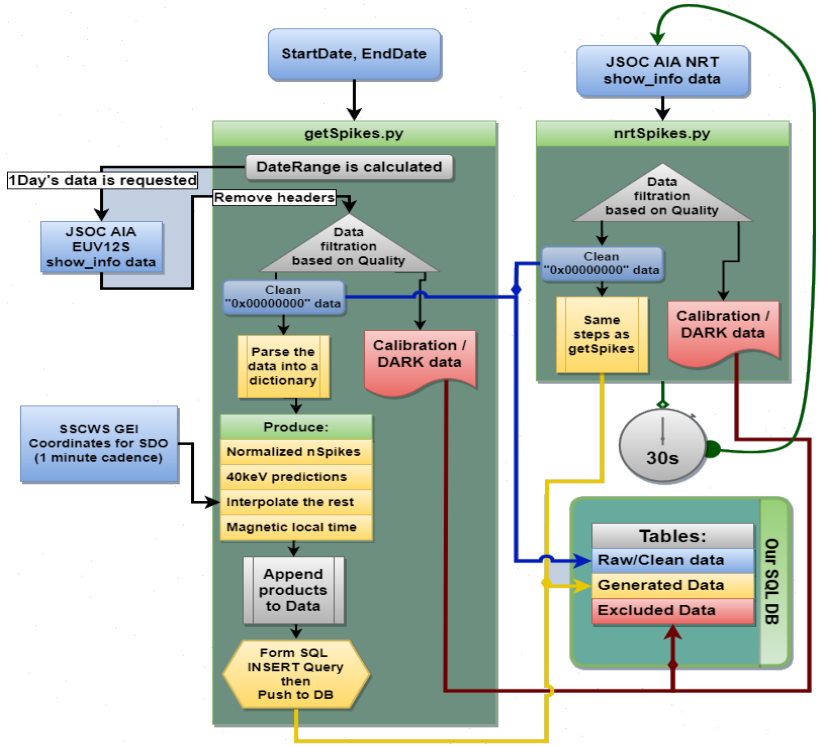
Correlation between SDO AIA spikes and	
GOES-14 MAGED Electrons	**HIGH**
GOES-14 EPEAD Electrons	**MEDIUM**
GOES-14 MAGPD Protons	**MEDIUM**
Geomagnetic Indices	**LOW**

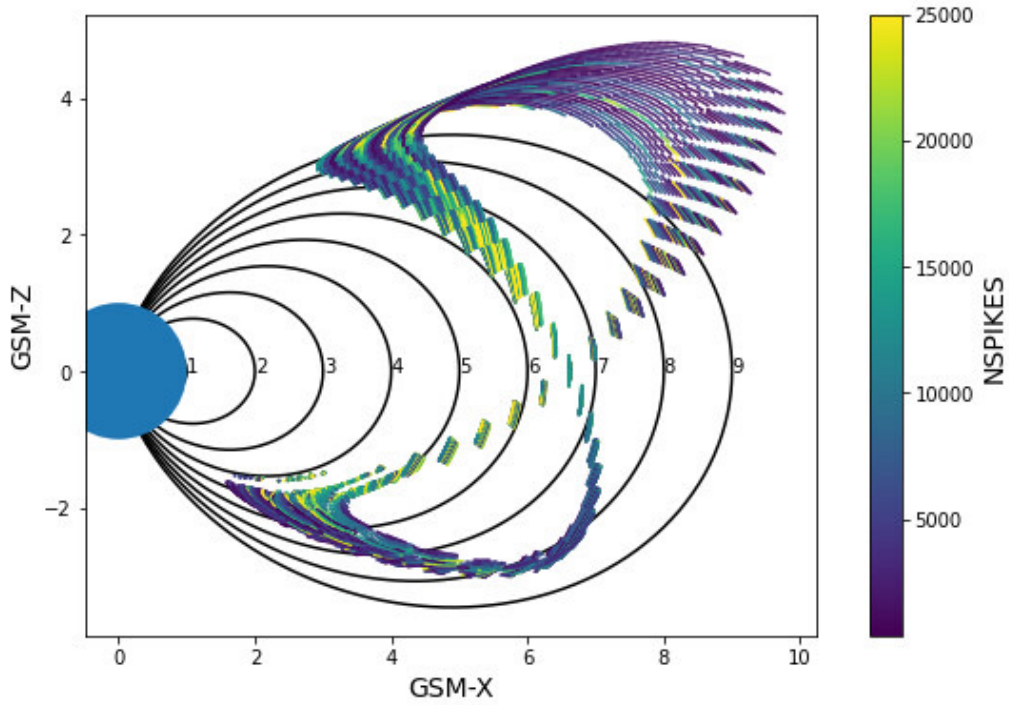


- SDO goes out of the ecliptic and can be used to measure electron densities on a unique orbit, thus helping characterize the radiation belt in areas where other satellites (GOES) can't reach.
- Most GOES satellites have been decommissioned, whereas SDO will be operational until 2030, therefore SDO can provide these values that we can't get from GOES-14.

Thus, we create a new dataset with proxy measurements from electrons of the outer radiation belt, within and out of the equator, turning the radiation belt characterization into a 3D structure.

New Developments (Summer 2023)





- Structured an SQL database with three specific tables: One for a) Clean/raw data from JSOC, another for b) Generated data from models/calculations and a third one for c) Rejected/filtered data from JSOC.
- Developed "getSpikes.py", a script that fetches and processes high-resolution data from JSOC, generating: Normalized NSPIKES 40keV predictions, interpolated GEI data and magnetic latitude, local time, and L-shell data (work in progress by NJIT Student Omar Shalaby).
- Future Work: Creating "nrtSpikes.py", a real-time script that keeps the data up-to-date using near-real time dataseries. A website with real-time information as long as historical data will be released.

Thank you for your attention!

Kasapis et al. (2023)