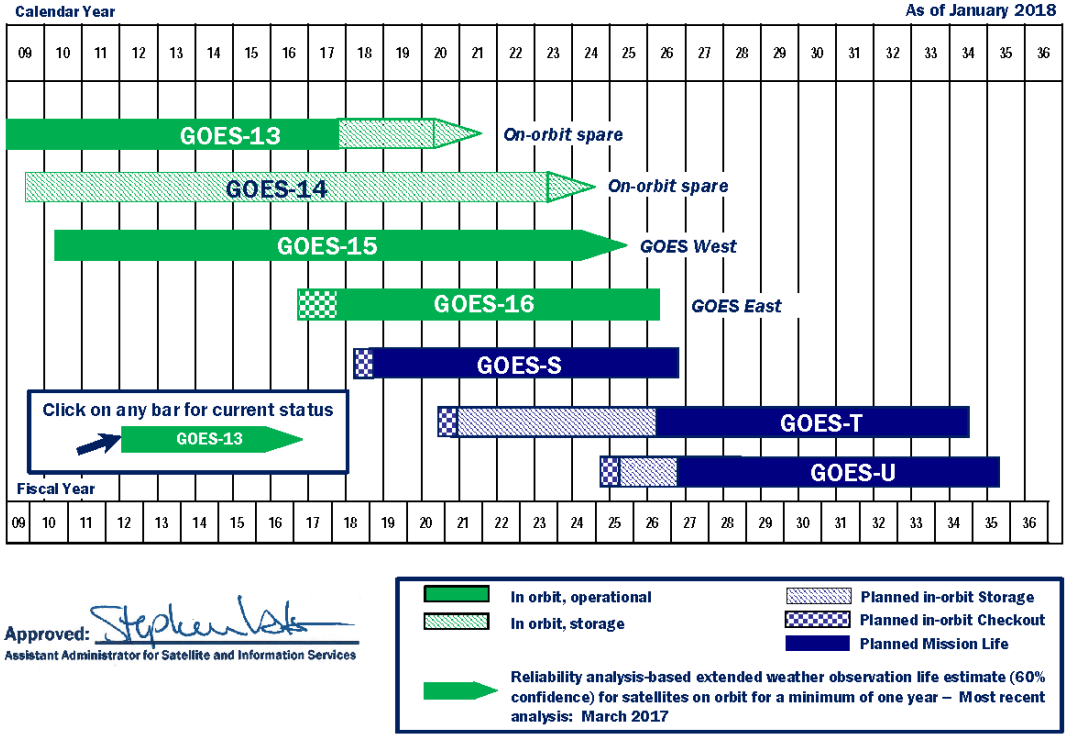
GOES 16 Observations During the Solar Energetic Particle (SEP) Event of 10 September 2017

Juan Rodriguez[1,2], Brian Kress[1,2] and Jing He[3,4]

1. University of Colorado CIRES
2. NOAA National Centers for Environmental Information
3. Middlebury College
4. NOAA Hollings Scholar

Two Successful GOES-R-series Launches So Far

GOES-R (16) launched 19 Nov 2016

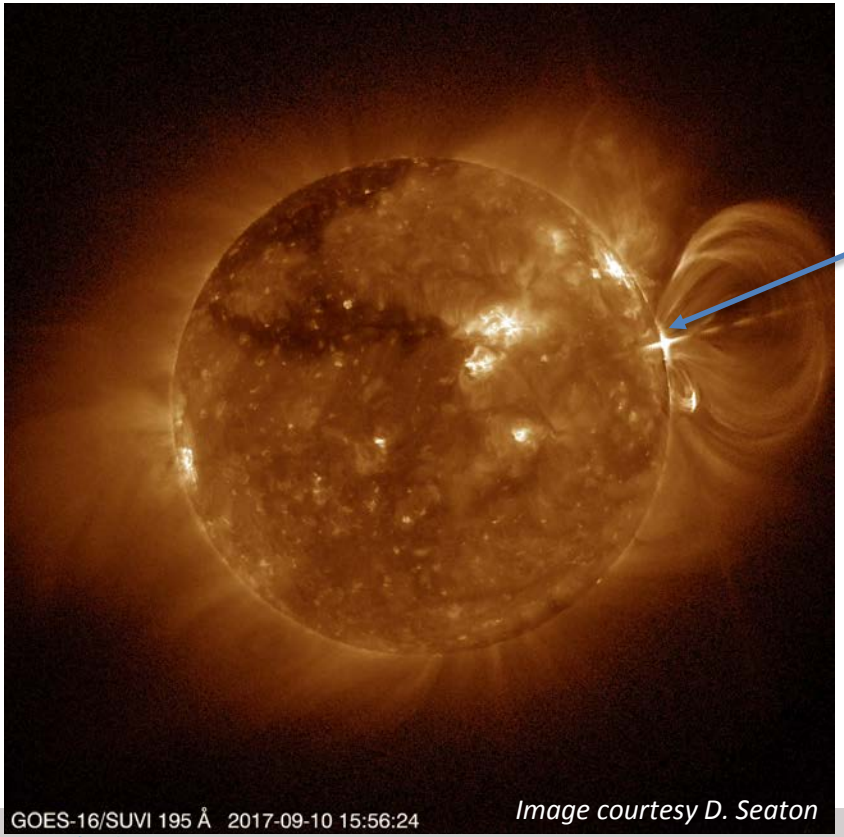


GOES-S (17) launched 01 Mar 2018

GOES-R Solar Instruments: SUVI and EXIS

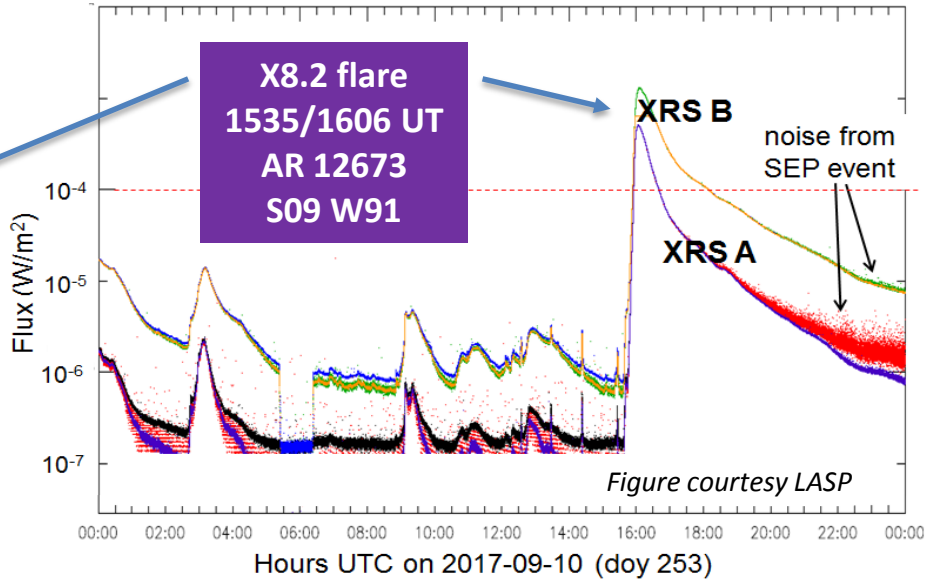
Solar Ultraviolet Imager (SUVI)

Images solar atmosphere in 6 EUV bands (94, 131, 171, 195, 284, 304 Å)



Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS)

XRS: new instrument, same two soft X-ray bands as flown on GOES since 1974



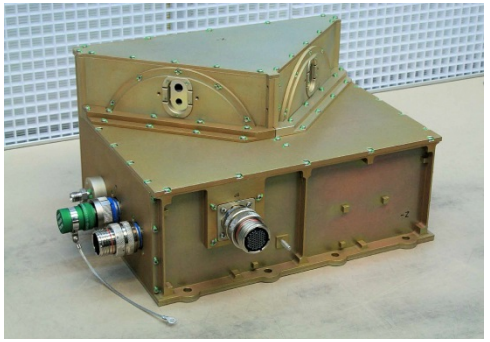
EUVS: new instrument, 7 EUV lines + Mg II

GOES-R Space Environment In-Situ Suite (SEISS): Magnetospheric Particles

Magnetospheric Particle Sensor – Low Energy (MPS-LO):

Spacecraft frame charging

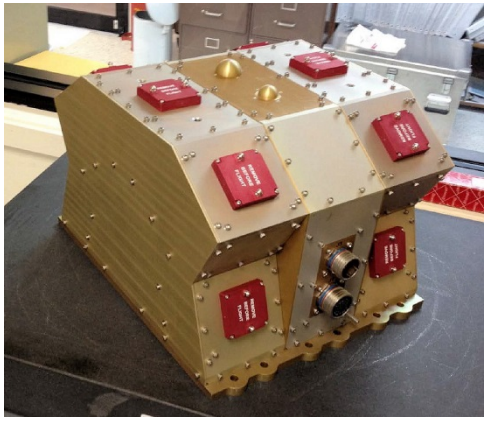
- Electrostatic analyzers
- 14 angular zones (12 unique) + 2 background zones
- 30 eV-30 keV electrons: 15 energies
- 30 eV-30 keV ions: 15 energies



Magnetospheric Particle Sensor – High Energy (MPS-HI):

Spacecraft internal charging, >2 MeV electron alerts

- Solid-state telescopes (5 per species)
- 50 keV-4 MeV, >2 MeV electrons: 11 energy bands
- 80 keV-12 MeV protons: 11 energy bands
- Two hemispherical dosimeters:
  - 100 mil (2.54 mm) Al: >1.2 MeV electrons, >22 MeV protons
  - 250 mil (6.35 mm) Al: >2.8 MeV electrons, >37 MeV protons



Magnetic field vector from GOES tri-axial fluxgate magnetometer is essential for calculating pitch angle for each telescope / zone and for conversion of flux to phase space density as a function of the first adiabatic invariant

GOES-R Space Environment In-Situ Suite (SEISS): Solar Energetic Ions

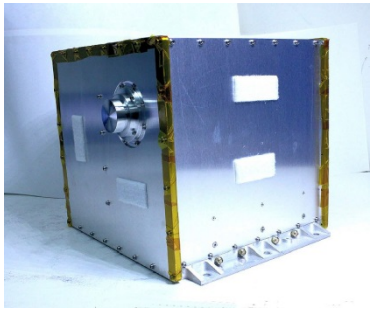
Solar and Galactic Proton Sensor (SGPS):

Solar radiation storm alerts, polar-cap HF communication (airlines), radiation dose, solar array degradation

- Two SGPS on each satellite, one looking W and one looking E
- Three solid-state telescopes per SGPS
- 1 MeV-500 MeV, >500 MeV protons: 14 energy bands
- 4 MeV-500 MeV alphas: 12 energy bands (not processed)
- Two highest-energy proton bands replace the four HEPAD bands

Energetic Heavy Ion Sensor (EHIS):

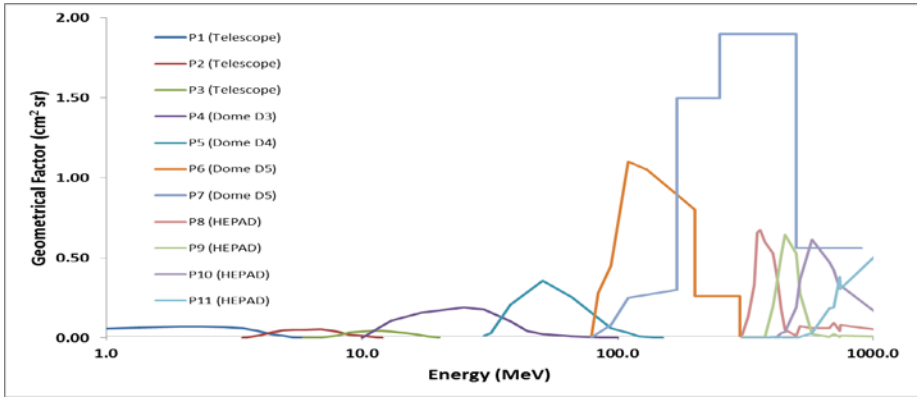
Satellite single event upsets, radiation dose

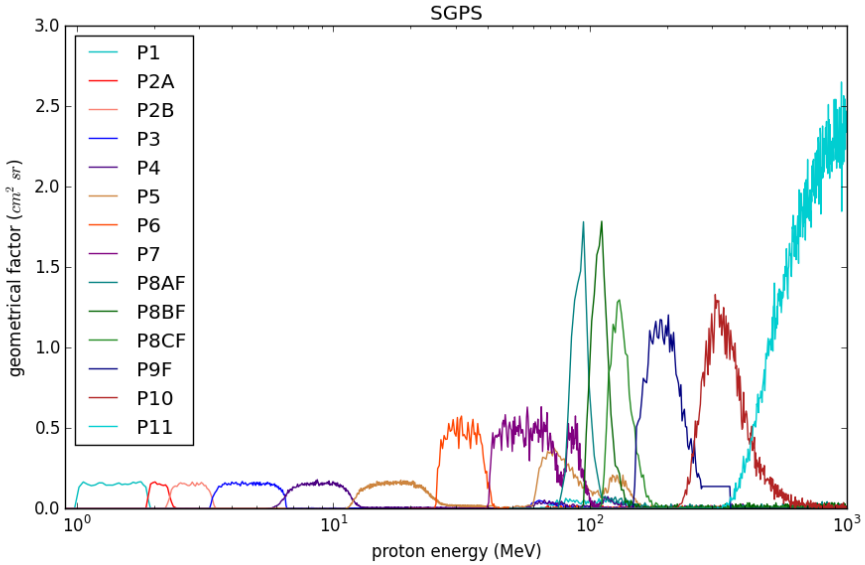


- 10-200 MeV/nucleon
- Distinguishes H, He, Z = 4-29 (Be-Cu, incl. CNO, Ne-S, Fe)
- 5 energy bands, one look direction (radially outward)

Comparison of EPEAD+HEPAD and SGPS Solar Proton Geometrical Factors

GOES 13-15 EPEAD + HEPAD

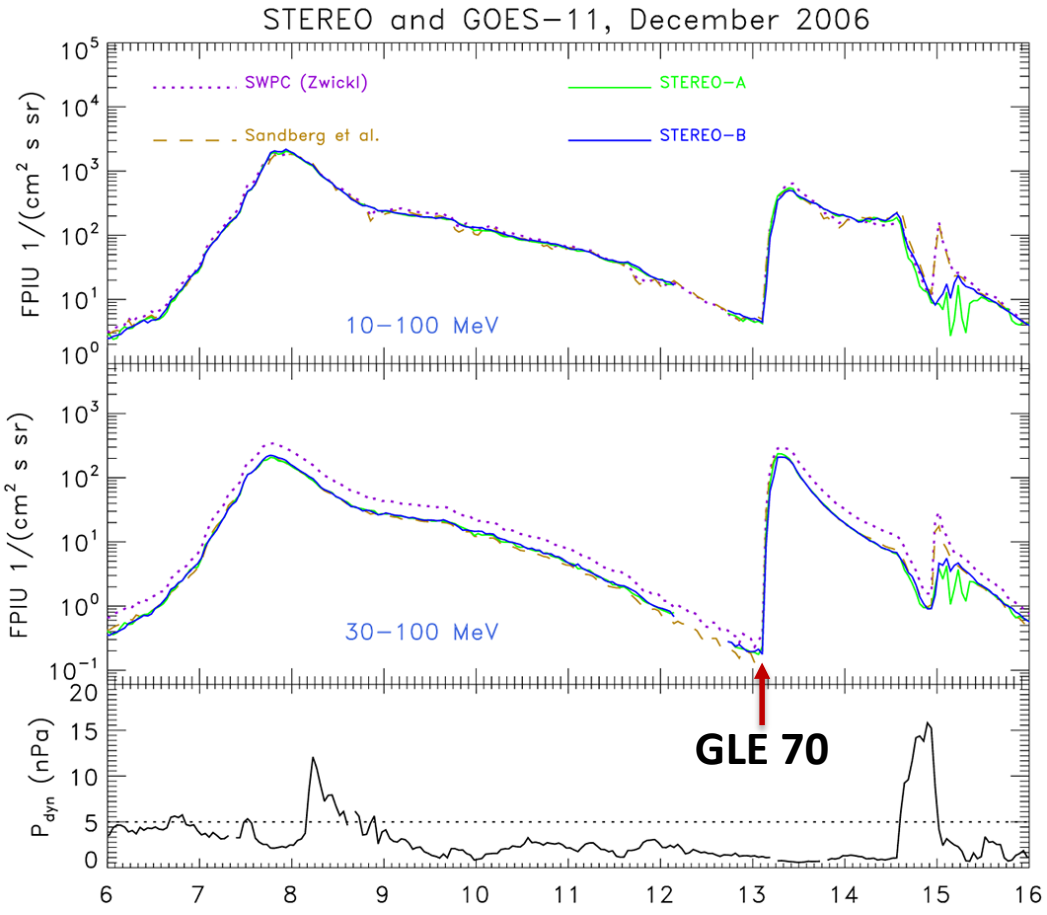




- **EPEAD:**
  - **2 per satellite, eastward and westward look directions: 7 channels from 1 solid state telescope, 3 domes**
  - **P6 and P7 responses dominated by side/rear entry at higher energies**
- **HEPAD:**
  - **1 per satellite: 4 channels, 1 look direction (zenith)**
  - **Solid state telescope with Cerenkov radiator and photomultiplier tube**
  - **Significant nadir response**

- **SGPS:**
  - **2 per satellite, eastward and westward look directions: 14 energy channels from 3 solid state telescopes**
  - **Improved spectral resolution especially >100 MeV**
  - **P11 integral channel >500 MeV**
  - **P9-P11 have similar front and rear responses, no side entry**
  - **P10 and P11 approximately correspond to energy range of HEPAD P7-P11**

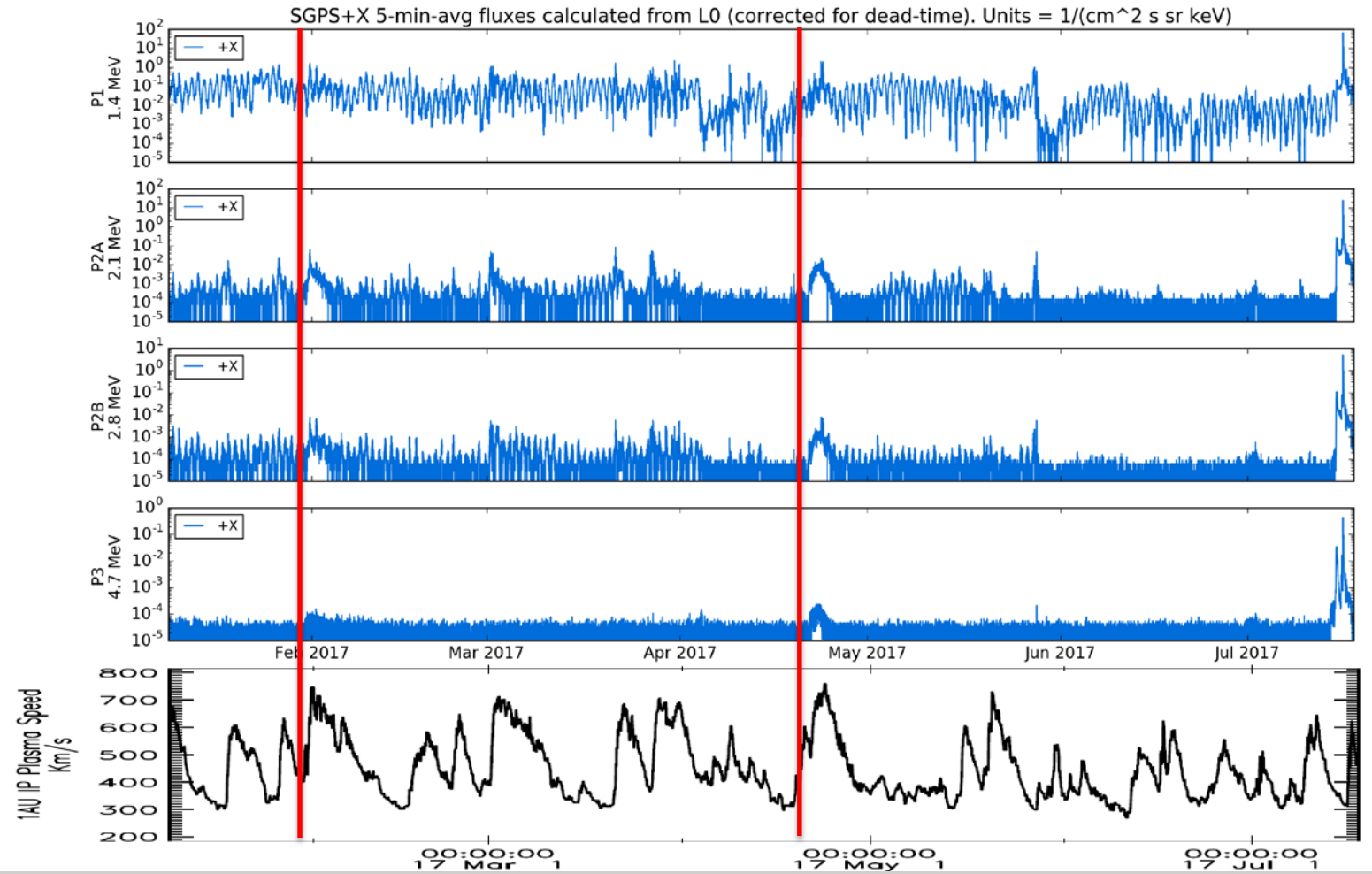
December 2006 SEP Events: Fortuitous for Cross-Calibration



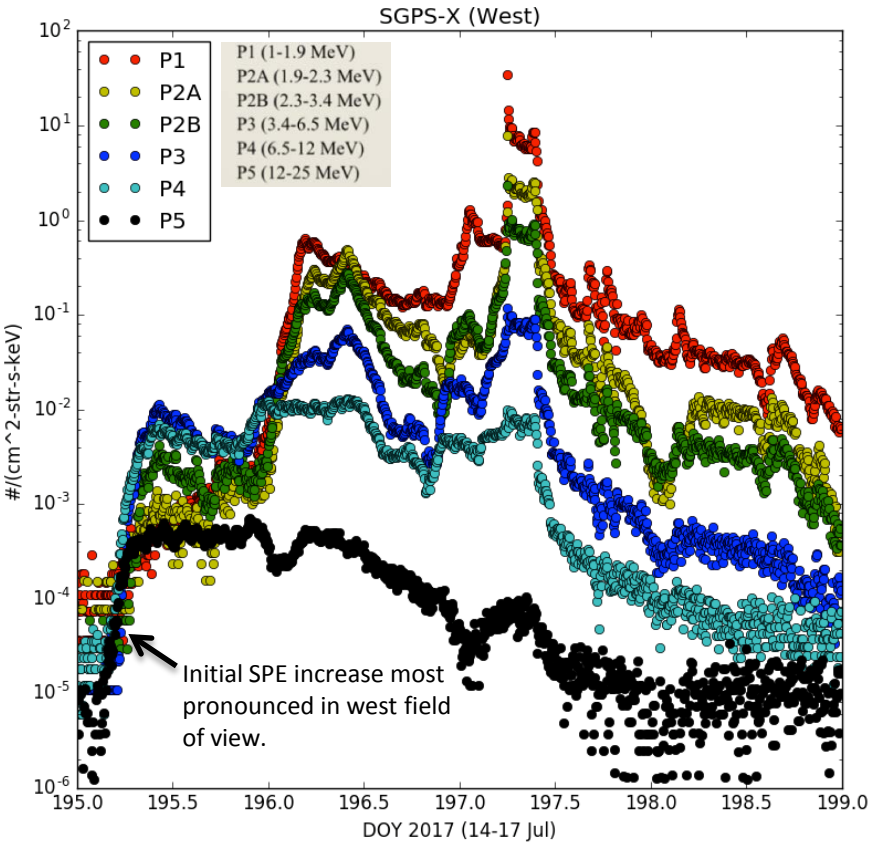
Rodriguez et al., Space Weather, 2017

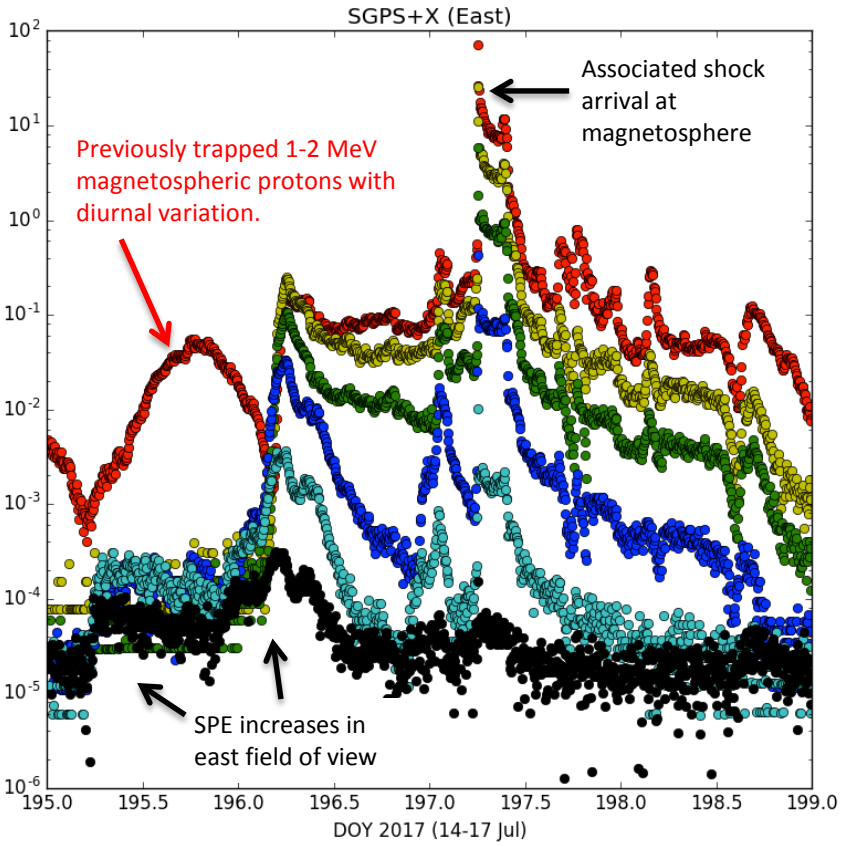
- Final SEP events of Solar Cycle 23
  - Included GLE 70
- Allowed us to cross-calibrate:
  - GOES 10, 11, 12, **13**
  - STEREO

GOES-16 SGPS CIR/Shock-Accelerated Events, January-July 2017



GOES-16 SGPS 14-17 July 2017 SEP Event





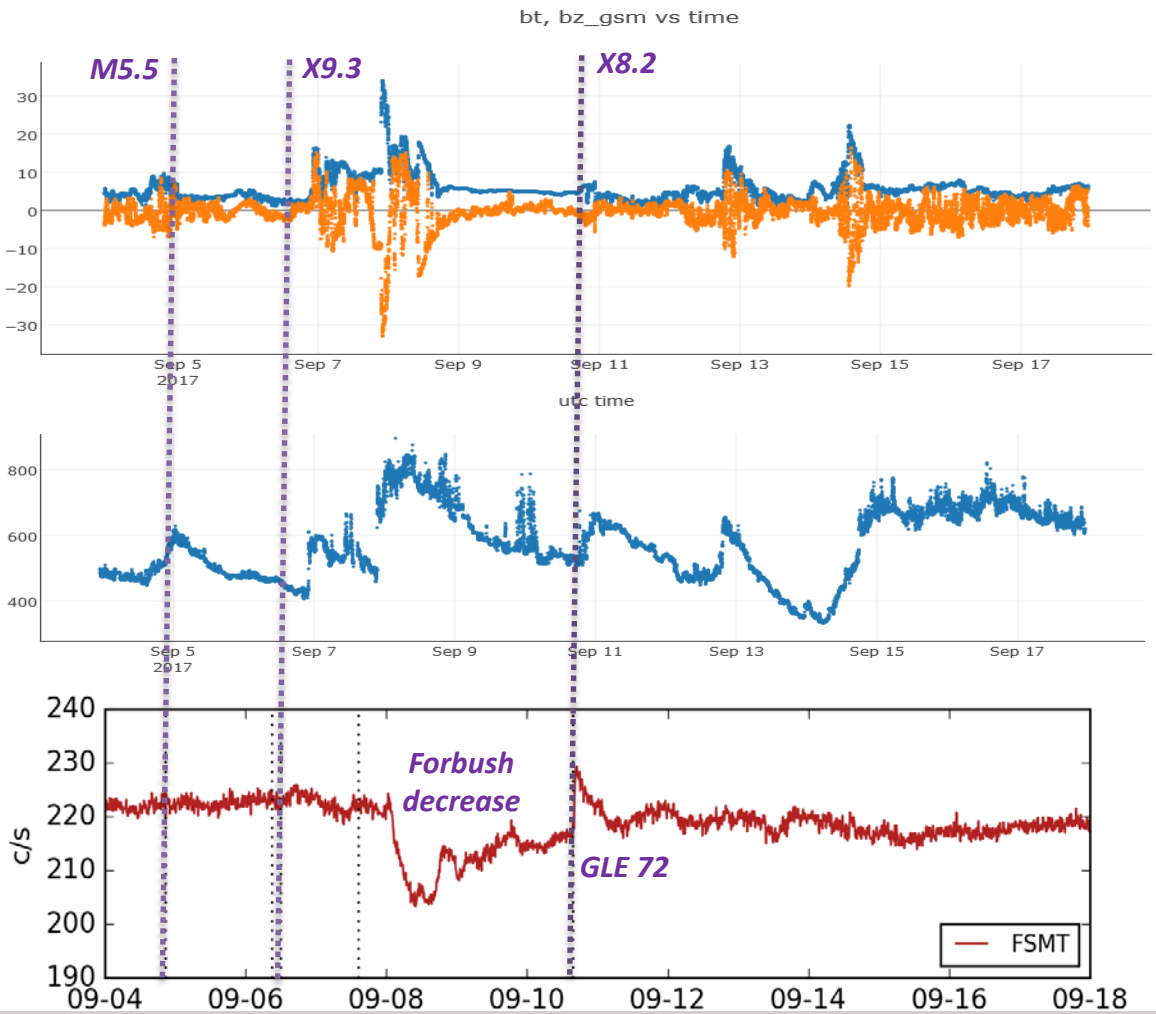
14-17 July 2017 SEP event 5-min averaged proton fluxes in SGPS telescope 1 (T1) (1-25 MeV). This event had a small response in T2 fluxes (25-80 MeV), and no discernable response in T3 fluxes (80 to >500 MeV).

September 4-17, 2017: Flares, CMEs, SEPs, CIRs

DSCOVR Bt and Bz (nT)

DSCOVR Vsw (km/s)

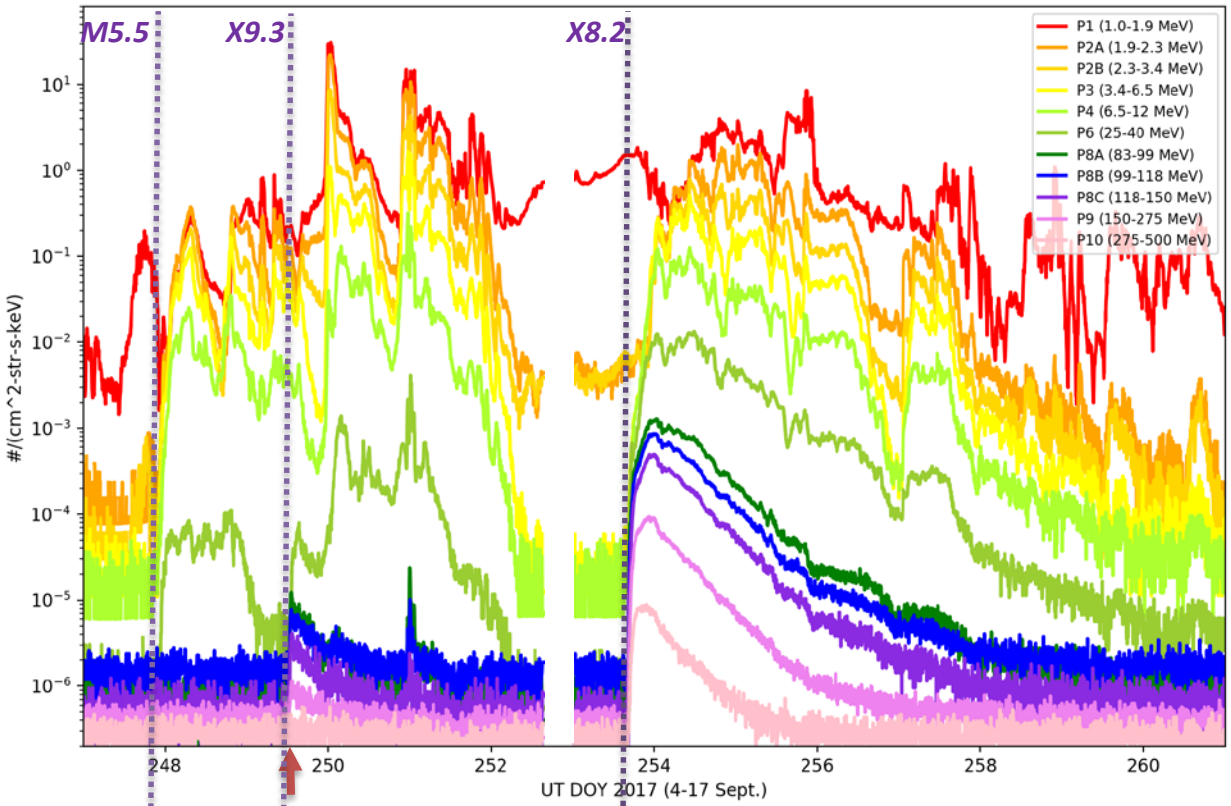
Fort Smith neutron monitor



FSMT data from EU Neutron Monitor Database courtesy of Bartol Research Institute

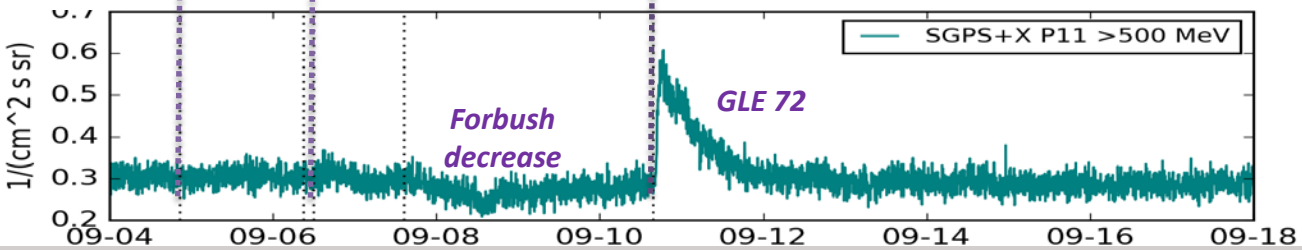
September 2017 Solar Proton Events

GOES-16 SGPS+X Protons



First SGPS-T3 response (80 to >500 MeV) to SEPs on Sept. 6th.

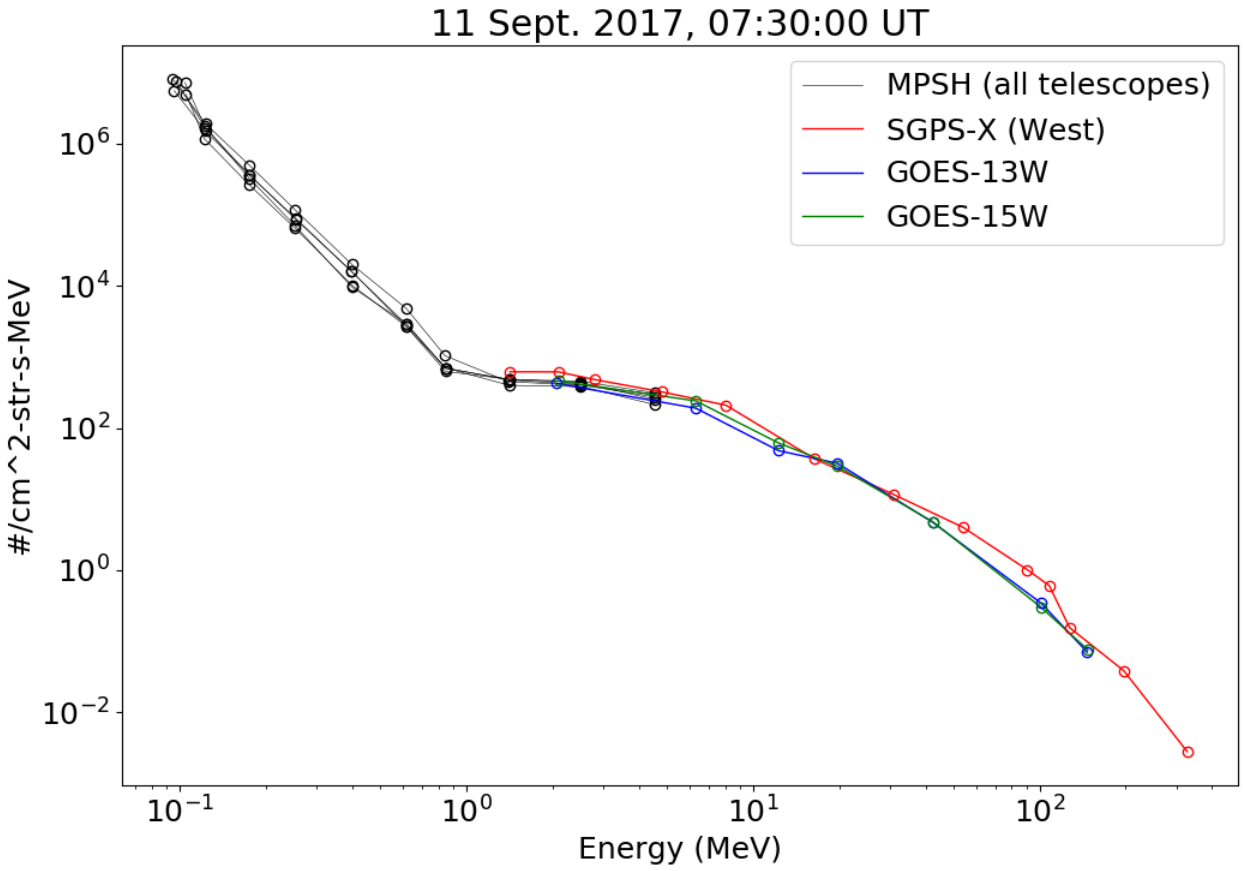
GOES-16 SGPS+X >500 MeV protons



CIRES

Cooperative Institute for Research in Environmental Sciences
UNIVERSITY OF COLORADO **BOULDER** and **NOAA**

Cross-calibration: GOES-13, -15 (EPS), and -16 (SGPS & MPS-HI) Spectra from Sept. 2017 GLE



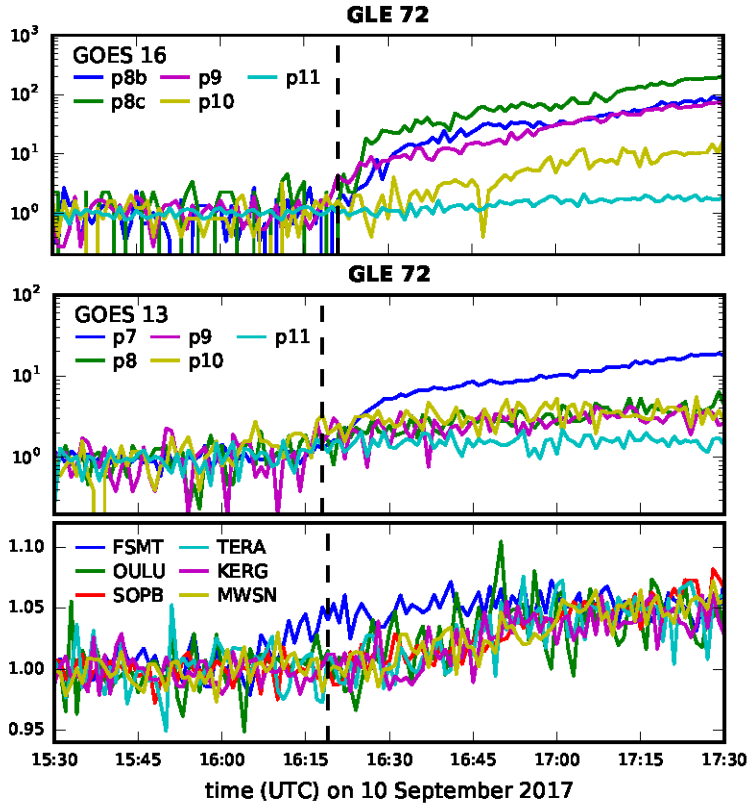
SEP Event Onset Detected First in G13 510-700 MeV Rates and Fort Smith NM Rates

$$I(\tau) = \left\{\frac{1}{\tau_c}\sum_{t=\tau-\tau_c}^{\tau} N(t)\right\} \Big/ \left\{\frac{1}{\tau_b}\sum_{t=\tau-\tau_0-\tau_b}^{\tau-\tau_0} N(t)\right\}$$

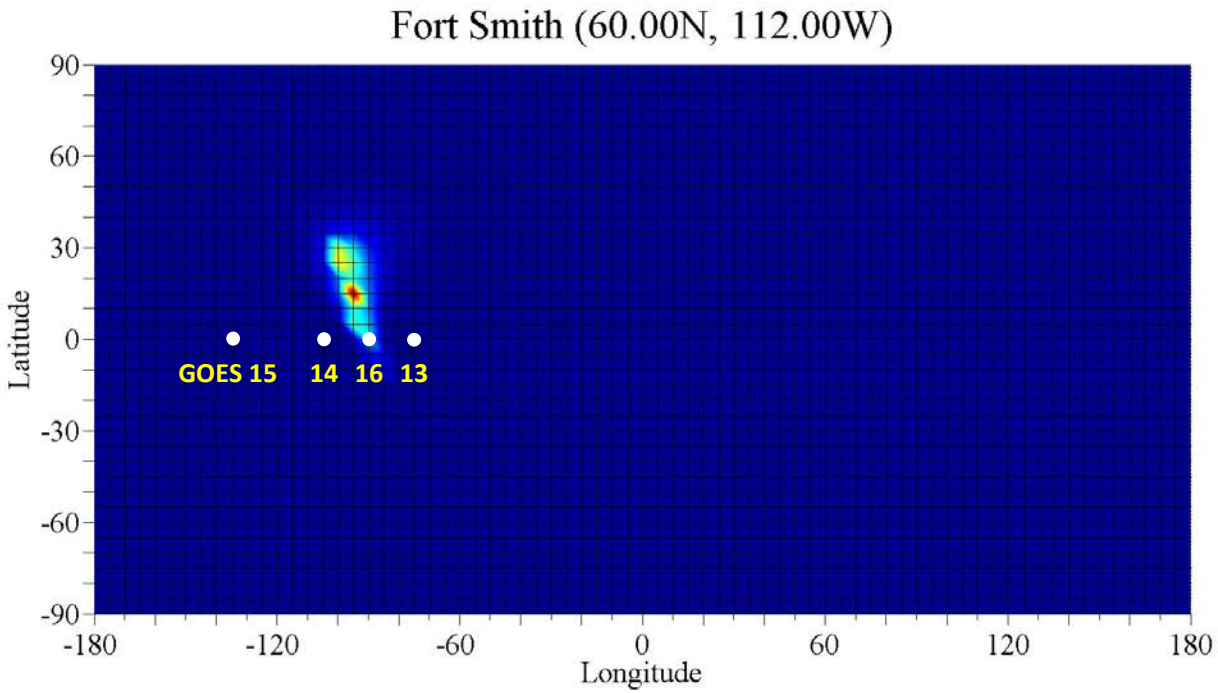
3-min running average of 1-min accumulations normalized to 75-min baseline, compared to predetermined thresholds

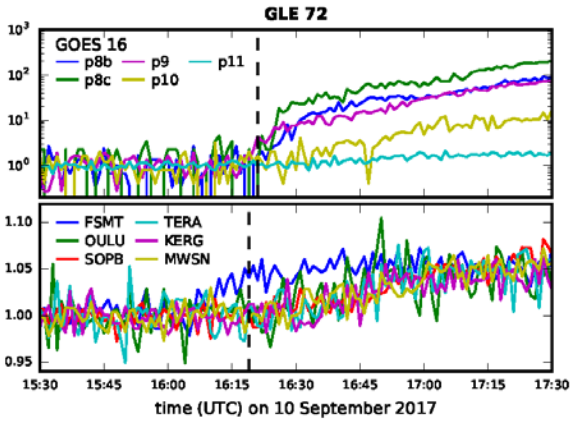
(method of He and Rodriguez [Space Weather, 2018] based on Kuwabara et al. [Space Weather, 2006])

Observatory	Onset Time (UTC)
Neutron Monitors	**16:19 (FSMT)** 16:48 (OULU) 16:52 (TERA)
GOES 13	**16:18 (HEPAD P10)** 16:22 (EPS P7)
GOES 14	16:20 (HEPAD P9) 16:22 (EPS P7)
GOES 15	16:20 (HEPAD P10) 16:22 (EPS P7)
GOES 16	16:21 (SGPS P9) 16:23 (SGPS P8C)



Fort Smith NM Asymptotic Directions Similar to GOES Lat, Lon





Asymptotic directions from http://www.crd.yerphi.am/Directivity_Functions_Neutron_Monitors

Funded by VarSITI (Karapetyan, JGR, 2017)

Conclusions

- After an 8-month wait, the energetic SEP event of 10 September 2017 was observed in all GOES-16 solar proton channels
- This event enabled cross-calibration of all channels with GOES 13, 14 and 15 observations
  - Similar to December 2006 SEP events, in which we had three older GOES and one new GOES (13)
- The X8.2 flare was partly obscured just behind the limb, and not very well magnetically connected to the Earth
- However, the SEP event was sufficiently energetic to cause the first ground-level enhancement (GLE 72) since May 2012
- The early-event particle anisotropy is a rich case for further study