Cross-Comparisons of GOES HEPAD Solar Proton Fluxes

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High-Energy Proton and Alpha Detector (HEPAD) Telescope Measures >330 MeV Protons

- 34° half-angle conical field-of-view directed radially anti-Earthward
- Two silicon detectors
  - Double coincidence gives S5 channel with roughly >70 MeV passband
- Fused-silica Cerenkov radiator
  - Proton threshold in fused silica is ~320 MeV
- Photo-multiplier tube (PMT)
  - Absolute calibrations linked to specific high voltage settings determined before launch and adjusted post-launch
- Proton channel rates (P8-P11) from triple coincidence of silicon detectors and Cerenkov radiator + PMT
- Two alpha channel rates – SEP signal very rare in these (e.g. Jan 2005 GLE 69)
- P11 channel reportedly inconsistent with neutron monitor observations

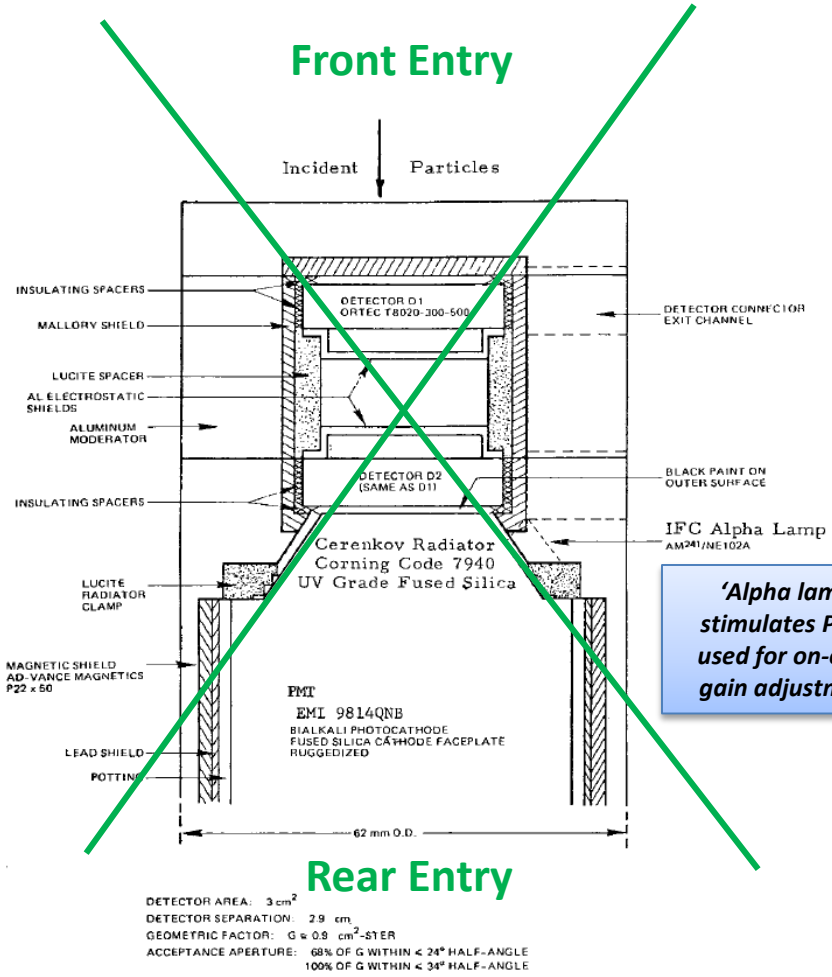


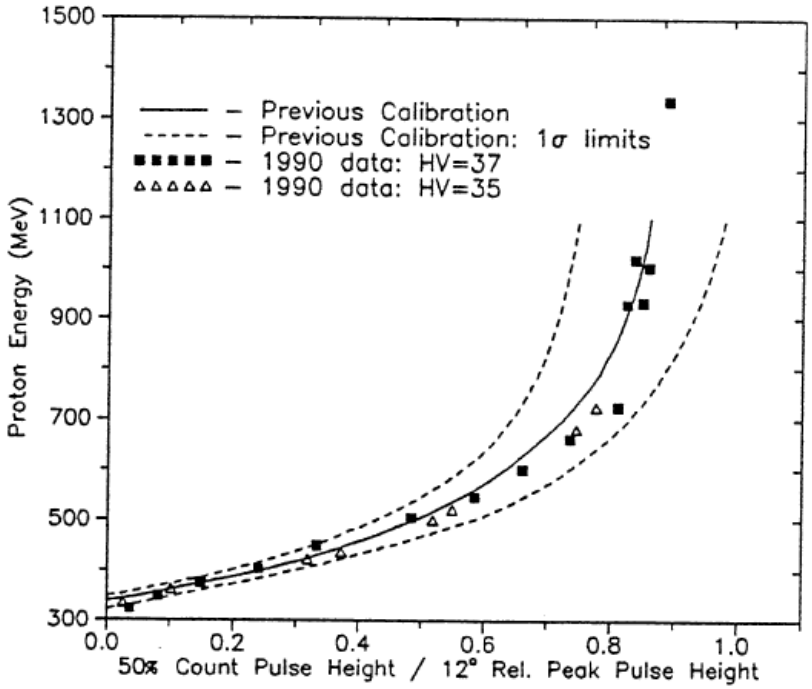
Fig. 2. Telescope assembly.

'Alpha lamp' stimulates PMT, used for on-orbit gain adjustment

From Rinehart, Nuclear Instruments and Methods, v. 154, pp. 303-316, 1978.

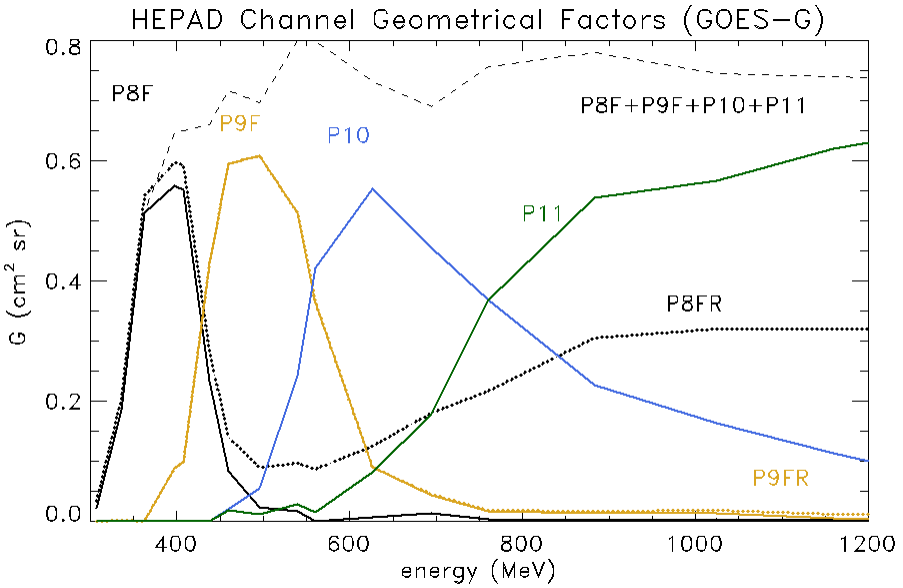
HEPAD Calibration Curve

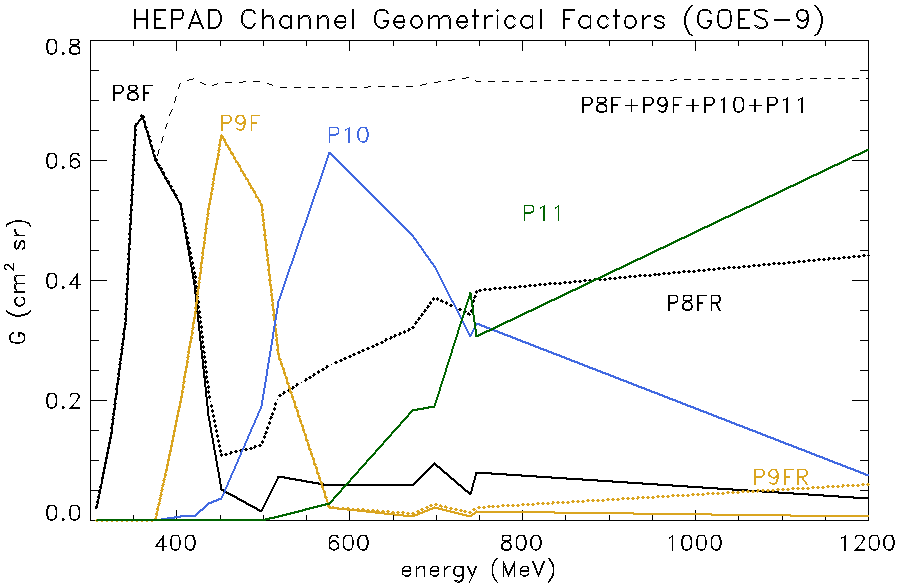
- Two HEPADs were calibrated by Panametrics at Brookhaven National Laboratory (BNL) Alternating Gradient Synchrotron (AGS) using a similar set-up
  - GOES-G (SN6): March 1985
  - GOES-9 (SN002): February 1990
- Proton energy vs. median pulse height curve from BNL calibrations
  - Pulse heights saturate at relativistic energies
  - P11 channel energies particularly sensitive to uncertainty in HV setting
- Voltage step changes:
  - GOES-6: factor of 1.045 per step
  - GOES 13-15: factor of 1.023 per step



HEPAD Geometrical Factors

- Front entry measured at 0°, 12° and 24°
- Rear entry measured at 144°, 156°, 168° and 180°
  - Significant for P8 and P9
- Front and rear entry can be combined into a single geometrical factor assuming isotropic flux
  - Implicit correction for rear entry





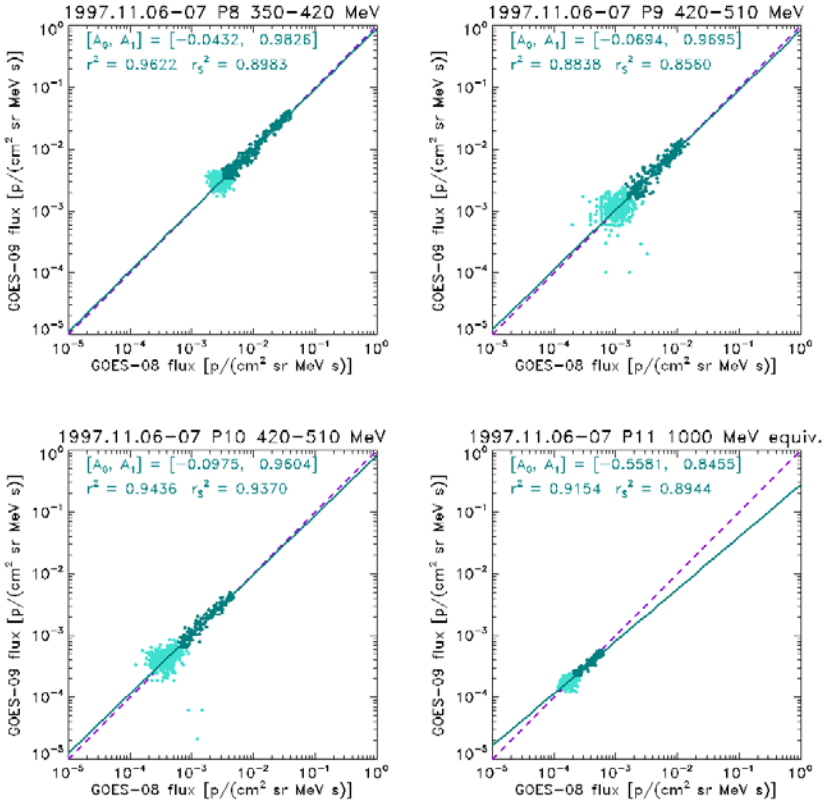
The HEPAD Record (GOES 4-15)

Satellite	Launch	History
4	1980-09-08	Failed 1980-12-15
5	1981-05-22	Failed 1982-10
6	1983-04-28	Very long data record (1983-1994): GLE 39 (1984-02-16) was first
G	1986-05-03	Calibrated at Brookhaven; launch vehicle exploded
7	1987-02-26	Calibrated at Brookhaven; triple coincidence logic did not work on orbit
8	1994-04-13	Potential calibration transfer from GOES-9 based on GLE 55 (1997-11-06)
9	1995-05-23	Calibrated at Brookhaven; short data record (3 GLEs) due to s/c issue
10	1997-04-25	Very long data record (1998-2009) incl. most GLEs of Solar Cycle 23
11	2000-05-03	HV changed at least twice, known date 2003-11-04; P11 inconsistent
12	2001-08-23	Step changes during two GLEs (2003-10-28 and 2005-01-20)
13	2006-05-24	HV increased (9.5% gain increase) on 2012-01-18
14	2009-06-27	HV increased 4 steps on 2012-09-11; mostly in storage
15	2010-03-04	HV increased (31% gain increase) on 2012-01-12

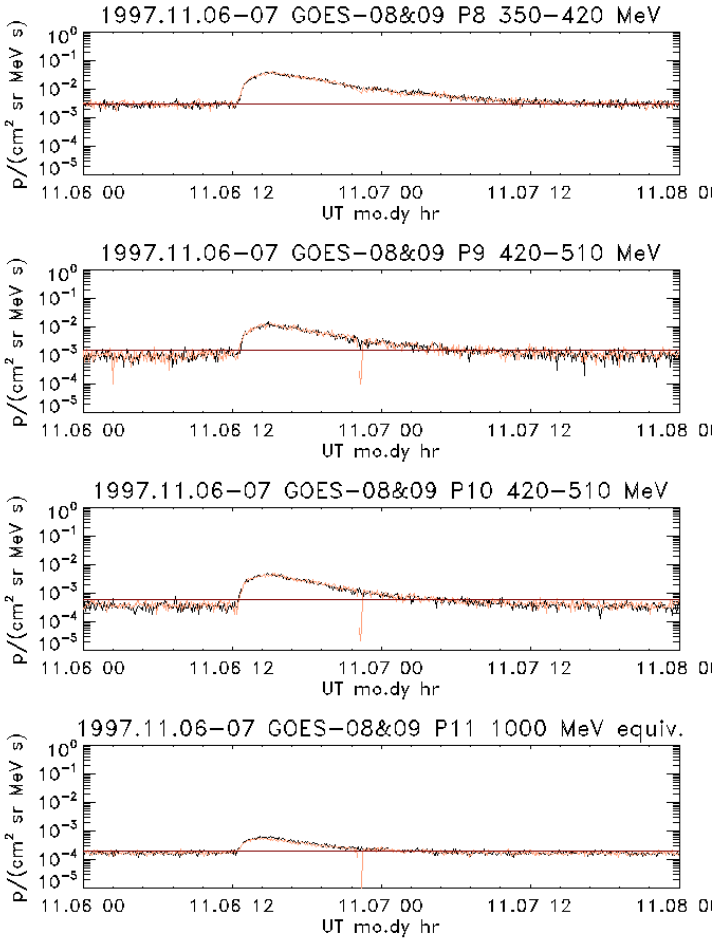
Cross-Comparison Method

- Fit log10(flux) vs. log10(flux) in individual SEP events using 5-min averages
- Assume:
  - SEP flux energies are above geomagnetic cutoffs
  - Fluxes are isotropic over telescope field-of-view (and over rear entry)
- Exclude GCR backgrounds from fit
  - Otherwise increased scatter distorts fit
- But do not subtract before fit
  - Otherwise baseline will shift from event to event

GOES-9 vs. GOES-8, 6-7 Nov 1997 (GLE 55)

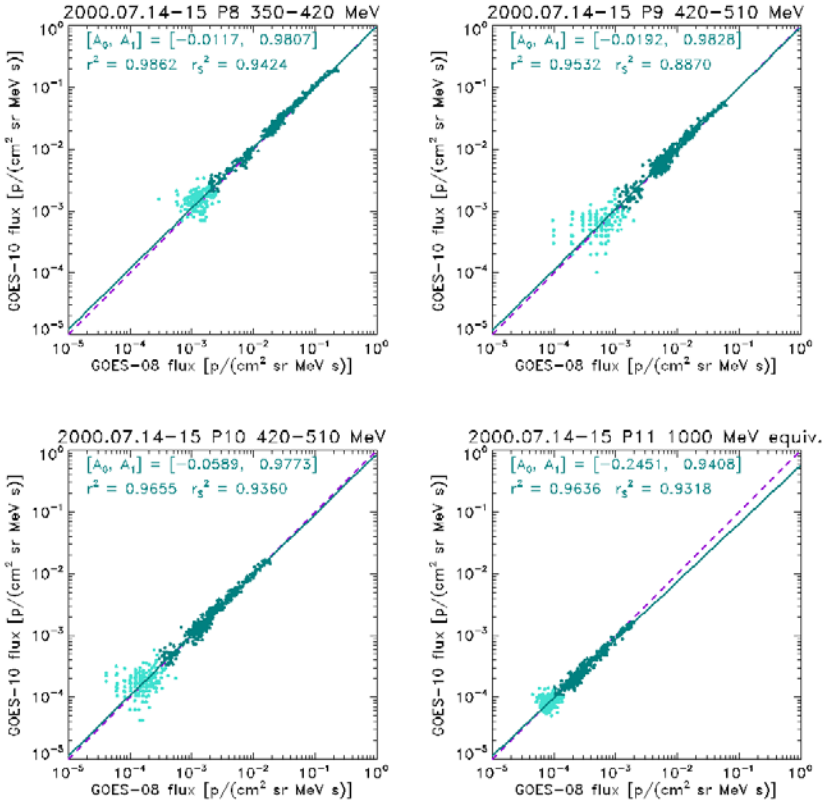


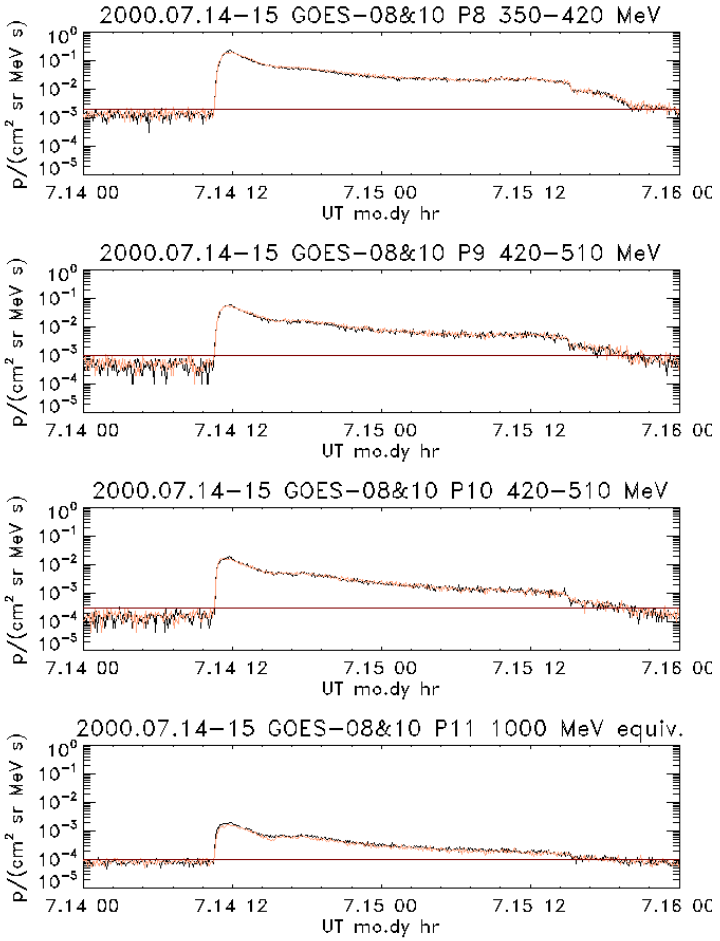
$log_{10}(GOES\text{-}Y) = A0 + A1 * log_{10}(GOES\text{-}X)$



black = x, orange = y

GOES-10 vs. GOES-8, 14-15 July 2000 (Bastille Day event, GLE 59)

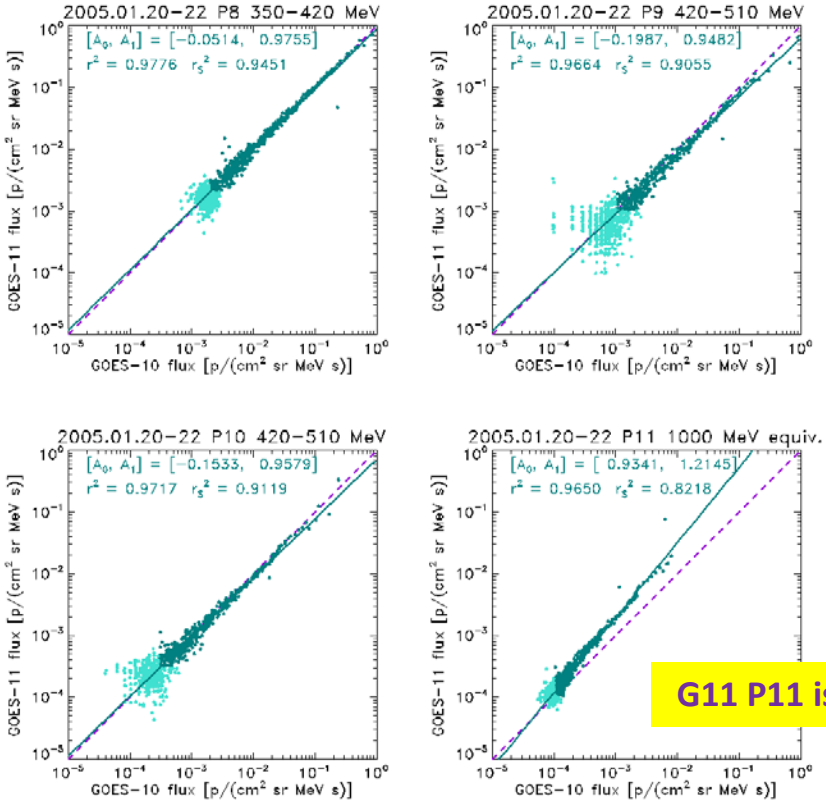




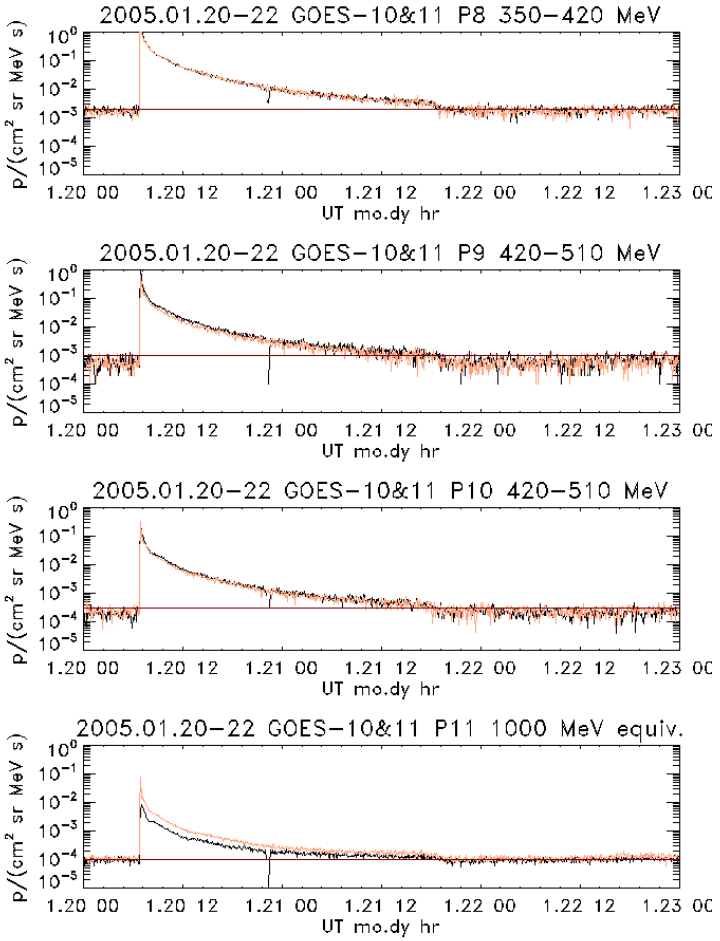
$log_{10}(GOES\text{-}Y) = A0 + A1 * log_{10}(GOES\text{-}X)$

black = x, orange = y

GOES-11 vs GOES-10, 20-22 Jan 2005 (GLE 69)



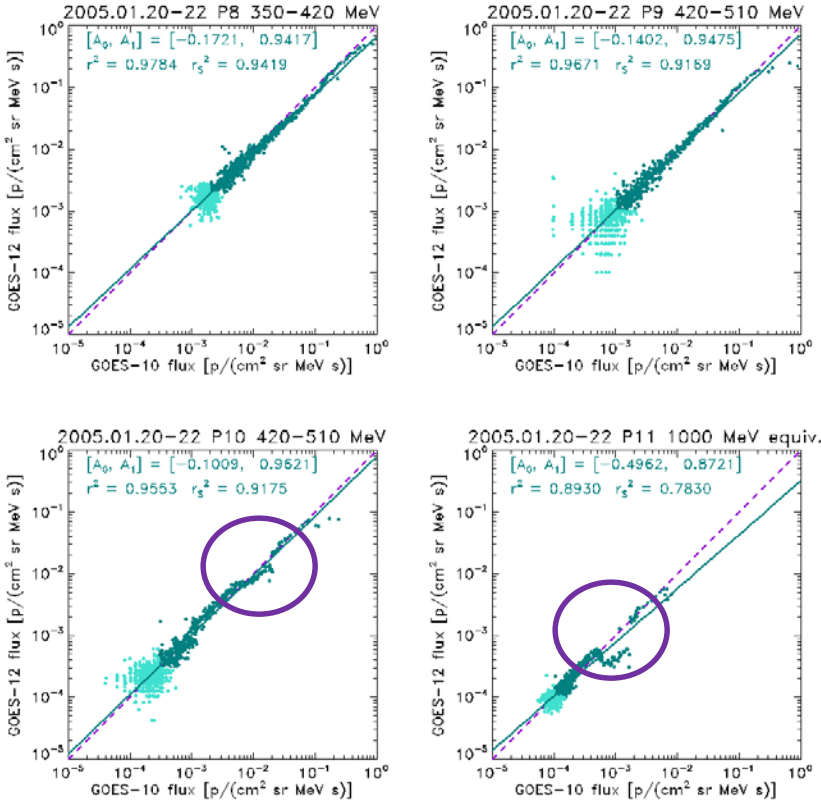
G11 P11 is high

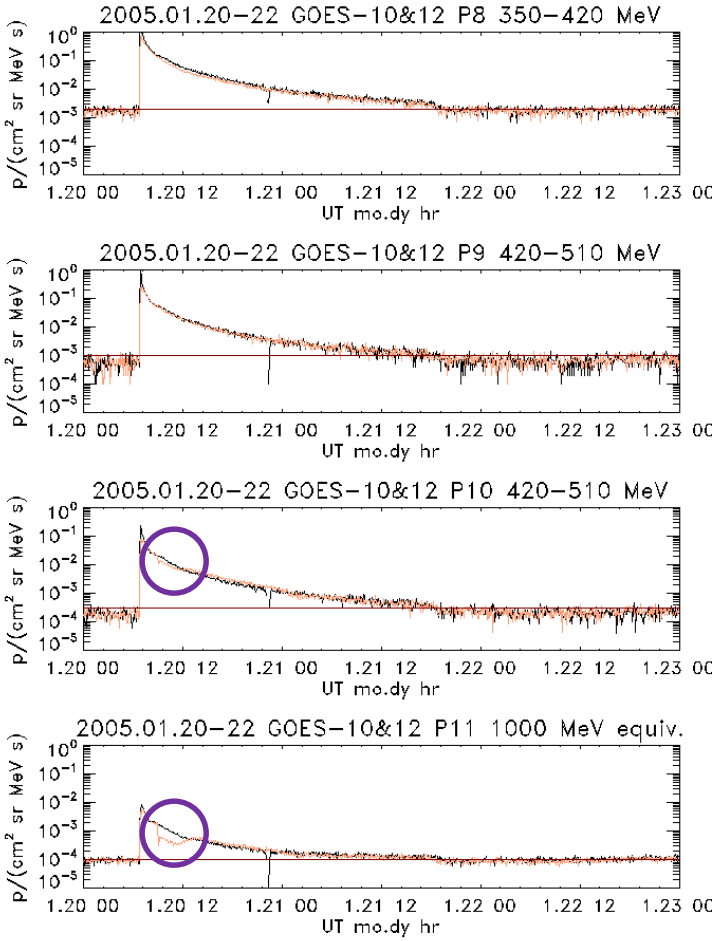


$log_{10}(GOES\text{-}Y) = A0 + A1 * log_{10}(GOES\text{-}X)$

black = x, orange = y

GOES-12 vs GOES-10, 20-22 Jan 2005 (GLE 69)





Step changes in GOES-12 P10 and P11 (origin currently unknown). Affect cross-calibration, need to be removed.

GOES 8-12 HEPAD Cross-Comparisons: Initial Results

$log_{10}(GOES\text{-}Y) = A0 + A1 * log_{10}(GOES\text{-}X)$

	Satellites		Event Start Date	P8		P9		P10		P11	
	X	Y		A_1	r^2	A_1	r^2	A_1	r^2	A_1	r^2
	8	9	1997.11.06	0.9826	0.9622	0.9695	0.8838	0.9604	0.9436	0.8455	0.9154
	8	10	2000.07.14	0.9807	0.9862	0.9828	0.9532	0.9773	0.9655	0.9408	0.9636
	8	10	2001.04.15	0.9671	0.9534	0.9638	0.9171	0.9449	0.9252	0.8676	0.9259
	10	11	2000.07.14	1.0384	0.9850	0.8992	0.9513	0.9099	0.9634	1.1164	0.9603
	10	11	2001.04.15	0.9746	0.9485	0.9100	0.9279	0.9369	0.9463	1.2317	0.9368
*	10	11	2003.10.28	0.9633	0.9542	0.9056	0.7908	0.8235	0.8498	0.7372	0.6173
	10	11	2005.01.20	0.9755	0.9776	0.9482	0.9664	0.9579	0.9717	1.2145	0.9650
	10	11	2006.12.13	0.9320	0.9578	0.8878	0.9056	0.8961	0.9440	1.1059	0.9390
	10	12	2006.12.13	0.9289	0.9701	0.9514	0.9245	0.9538	0.9649	0.9612	0.9670

** GOES-11 HEPAD gain was low during Halloween events*

Summary of Observations

- GOES-6 (1983-1994) and GOES-10 (1998-2009) provide longest and most reliable series of HEPAD observations
- GOES-9 was calibrated at Brookhaven
  - Compares well with GOES-8 during GLE 55
  - In turn GOES-8 compares well with GOES-10
- GOES-11 HV was low during Halloween 2003 events, high during other GLEs
  - GOES-11 P11 always inconsistent with other satellites
- GOES-12 exhibited unexplained step changes during 2003 Oct 28 and 2005 Jan 20 events
  - Otherwise compares well with GOES-10
- Solar Cycle 24 has not provided sufficiently large or energetic events for cross-comparison
  - To date, GOES 13-15 P11 cannot be cross-compared using SEP fluxes
  - Need to combine events observed by a given satellite pair (at same HV setting) in order to have more points for more robust fits, or use GCRs