Operational Space Weather Forecasting Needs for Manned Exo-LEO Missions

Space Weather Workshop

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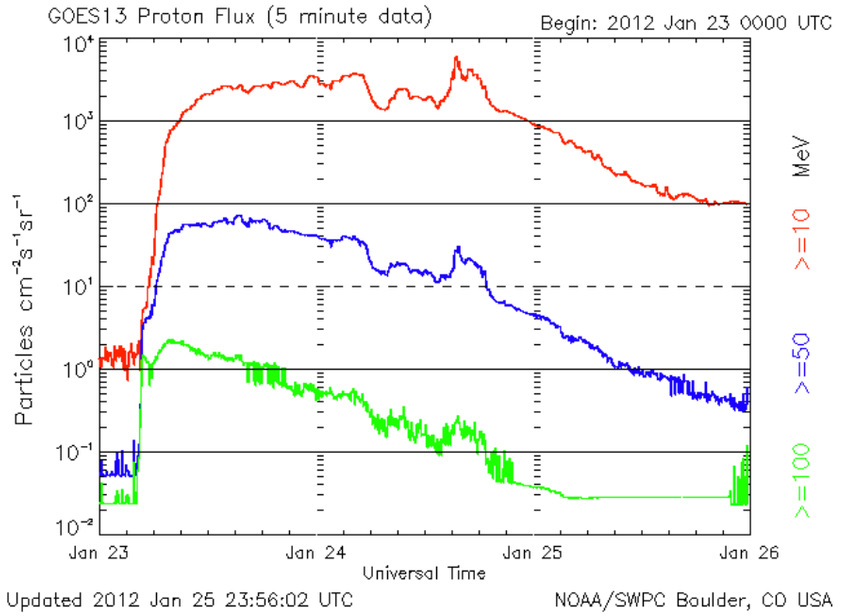
Current State: ISS SEP Operations

- All SEP forecasting/nowcasting is based on direct SRAG-SWPC interface

- SRAG flight controller monitors console during space weather contingency operations such as Solar Energetic Particle (SEP) events
  - Alert/Warning messages to management and flight control team
  - Ensure ISS radiation monitoring system availability

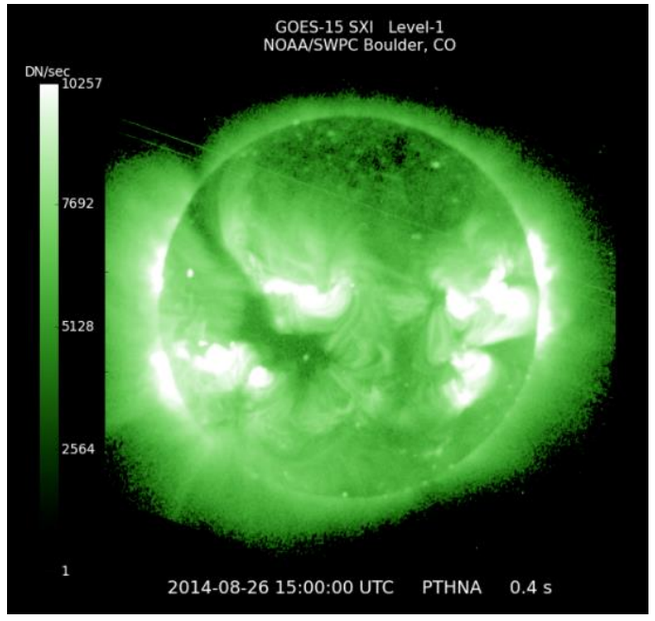
- If SEP dose projection is determined to be negligible, then no action will be taken



- If energetic particle event has increased above threshold or radiation detector alarm activation is confirmed, inform crew to remain in higher shielded areas during intervals of high risk orbital alignments.

- ISS higher shielded locations used to protect crew
  - Service module aft of treadmill (panel 339), Node 2 crew quarters, and U.S. Lab

- This response evolves over several hours with international coordination. Beyond low earth orbit missions will require this process to be much faster. SEPs can reach peak flux levels in < 5 hours.

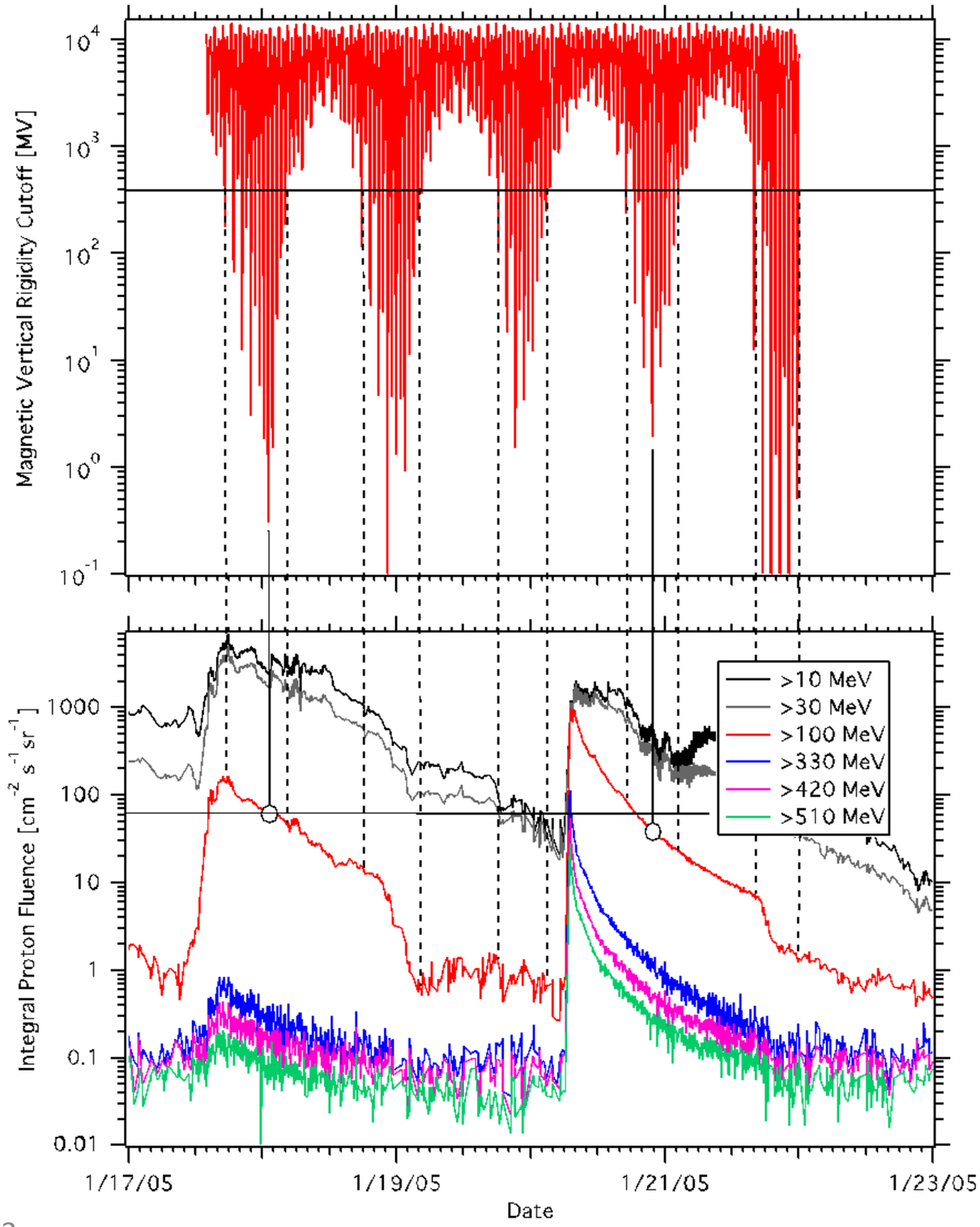


How Do Exploration and LEO (ISS/Shuttle) Missions Differ?

- The graphs to the right show impact to ISS – behind the geomagnetic field
- Top graph shows the magnetic vertical rigidity cutoff
  - The geomagnetic field is in essence a ‘filter’ of ionizing particles
  - Places where the cutoff is low (high latitudes) ionizing particles can stream into ISS altitudes
  - Cutoff modulates – ground track passes in and out of high latitudes.
- Exposures to ISS crew have not been extreme due to significant protection by the geomagnetic field during the most intense SEP time intervals
  - Operationally, impact modulated by phasing between SEP event and portion of ground track at upper latitudes – ~10 min twice per 90 min revolution for ~12h per day.

Missions beyond LEO where crew-vehicle system spends substantial time in ‘free-space’ the scenario is very different:

Human-vehicle will see full extent of storm!



Timing Results for 10 Large SEP Events in Dose

SEP Event Date	Onset Time	Duration (Days)	Peak Flux (66.13 – 95.64 MeV)	Fluence >66.13 MeV	Fluence >95.64 MeV	Peak Dose Rate (cGy/Hr)	Total Dose (cGy)	Time to Peak Flux (66.12 – 95.64 MeV) (Hr)	Time to Peak Dose Rate (Hr)	Time to 10% Dose (Hr)	Time to 50% Dose (Hr)	Time to 90% Dose (Hr)
1989/10/19	13:05:00	13.96	10.90	3.96e8	1.80e8	1.15	21.84	26.3	26.3	9.8	29.8	134.1
2000/07/14	10:35:00	5.67	10.70	2.79e8	8.66e7	1.19	13.24	5.8	2.6	1.8	7.3	23.8
2000/11/08	23:40:00	5.93	11.10	2.42e8	6.30e7	0.956	10.63	4.0	4.3	2.5	7.5	16.8
1989/09/29	11:50:00	10.45	3.72	1.64e8	7.38e7	0.580	9.17	8.0	8.1	3.6	11.6	28.8
2003/10/28	11:20:00	3.93	6.86	2.05e8	5.66e7	0.480	9.10	12.9	13.1	5.1	14.1	42.3
2001/11/04	16:45:00	5.10	9.83	1.61e8	3.84e7	0.672	6.49	33.6	33.7	4.9	29.2	36.2
2005/01/15	23:55:00	8.28	10.19	1.14e8	4.87e7	2.04	6.37	103.3	103.3	52.3	104.5	113.8
2012/03/07	02:00:00	5.58	1.76	8.19e7	2.62e7	0.187	4.06	13.4	13.4	11.2	25.2	47.2
2001/04/15	14:00:00	5.71	2.47	4.40e7	2.19e7	0.512	2.73	1.7	1.2	0.9	3.7	65.4
1989/08/12	15:25:00	12.92	1.52	5.40e7	1.71e7	0.104	2.36	13.1	85.8	11.8	86.3	119.3

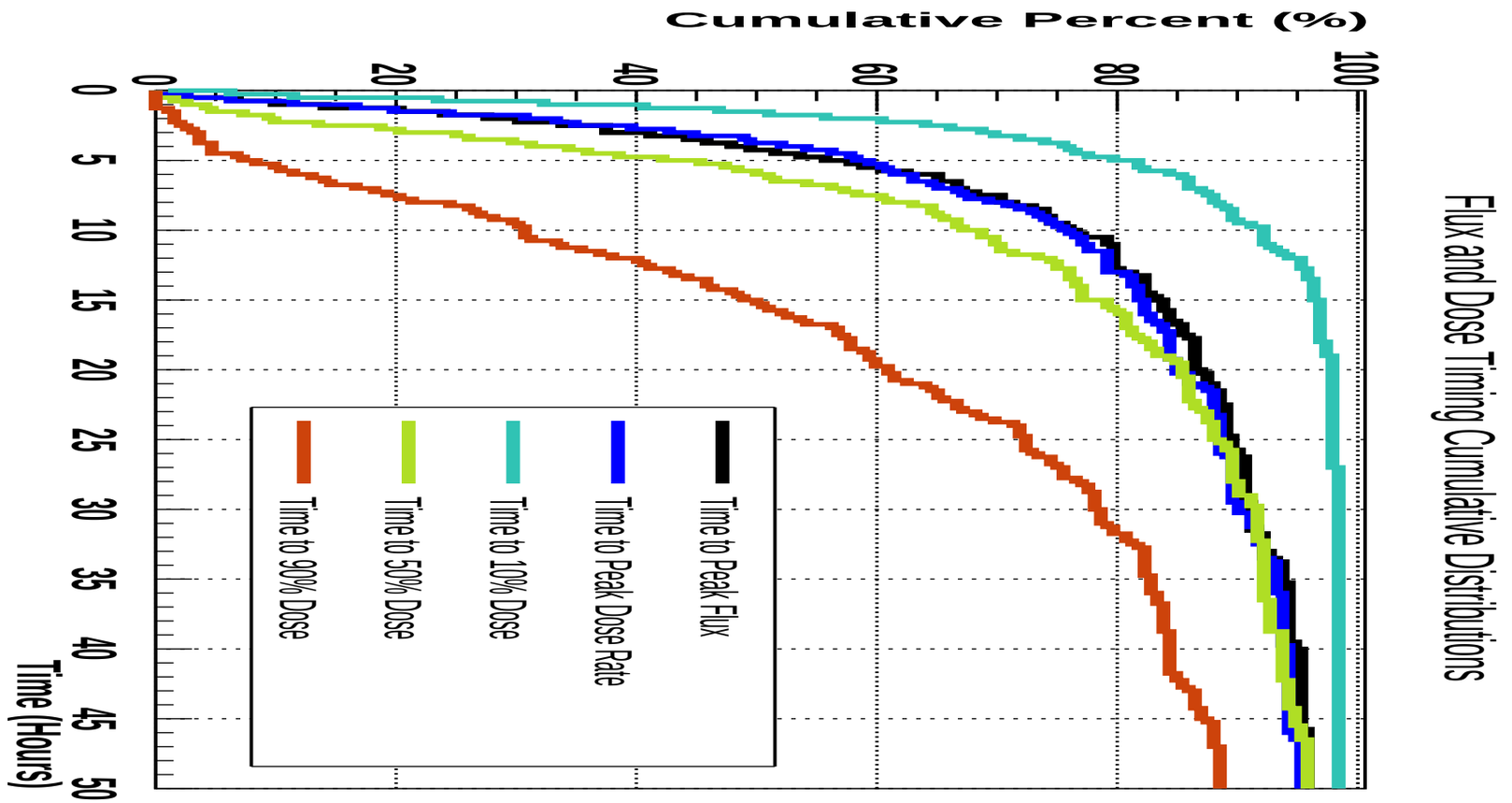
Flux and fluence units are [MeV^{-1} cm^{-2} s^{-1} sr^{-1}] and [cm^{-2}]. Dose calculated for 10 g/cm^2 Al sphere.

Uncertainty in timing is approx. ± 30 min.

1989/10/19, 2005/01/15, 2001/04/015, 1989/08/12 consist of multiple SEP events in quick succession.

Flux-Dose Timing Comparison: Cumulative Distributions

- Time to Peak Flux (**black**) and Time to Peak Dose Rate (**blue**) are very similar
- Events that reach peak flux after 20 hours, also reach 50% dose (**green**) at about the same time



Beyond Low-Earth Orbit Differences - Gateway

- Each SEP event will impact Gateway
  - Will need more detailed forecasting to discern which ones may be serious with advance warning
  - NASA will continue to utilize SPWC for core forecasting for Gateway, but additional operational tools will be utilized for fast response to mission control
- Big Three questions the Console Operator always fields during periods when large active regions are present on sun:
  - Will there be an event (SEP)?
  - How intense will it be?
  - How long will it last?

Need reliable <u>forecasts</u> of SEP <u>event peak flux and temporal evolution</u>

- To help answer these questions SRAG-CCMC have collaborated on a joint project to assemble suite of models in scoreboard framework that includes) both US and EU component

Integrated Space Weather Project Requirements

★ Required Functionality

Target Functionality

Probability Forecast

Cadence	All Clear Forecast		M + X Flares	X Flares	CME	Fast CME	>50 MeV	>100 MeV
6 hr	24 hr	48hr						
★	★		★	★	★	★		★

Event Onset Forecast

Event Onset	Peak 10 MeV	Peak 30 MeV	Peak 50 MeV	Peak 100 MeV	Onset Profile	GLE	Connectivity
★	★	★		★	★	★	★

Intensity Profile Forecast

Time Profile	Duration	Time to Peaks	Time and Peak 10 MeV	Time and Peak 50 MeV	Time and Peak 100 MeV	ESP	Dose
★	★	★	★		★		★

Recommendations

- We need to communicate evolving forecast needs and requirements to forecasting centers (SWPC) and researchers to establish core forecasts beyond LEO

- Create international/national SEP forecasting collaborations between/within space agencies

  - Not only at modeler/scientific project level, but at space agency operations/implementation level: SRAG/CCMC

- Lay the groundwork for Gateway by developing forecast tools now that can be tested during ISS operations and short Gateway missions, before longer Gateway missions take place

- Build the foundation for human Mars missions by collaborating on space weather architectures that could be possibly flown on manned vehicles to provide input data for forecast models at locations away from Sun-Earth