SEP FORECASTING FROM THE LUNAR GATEWAY

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Solar Energetic Particle (SEP) Forecasting at the Gateway

Solar Energetic Particle (SEP) events are short timescale (days) increases in energetic protons with a wide range of energies (tens of keVs to GeVs) and intensities. They are almost always associated with eruptive solar flares and coronal mass ejections (CME).

SEPs are hazardous to electronics and humans in space. As humans pursue space exploration outside of low Earth orbit, the understanding, monitoring, and forecasting of SEP events becomes increasingly important.

This project aims to use particle data taken onboard the Lunar Gateway by ESA’s ERSA/SREM detector to provide SEP forecasts at the vehicle.

Credit: NASA, https://www.nasa.gov/missions/artemis/gateway-halo-a-deep-space-home/

Space Radiation Environment Monitor (SREM)

TABLE I
LIST OF THE SREM CHANNELS AND THE CORRESPONDING ENERGY RANGES OF DETECTED PROTONS AND ELECTRONS [3]

SREM	Proton Energy	[MeV]	Electron Energy	[MeV]
Bin	E_{min}	E_{max}	E_{min}	E_{max}
TC1	27	∞	2.00	∞
S12	26	∞	2.08	∞
S13	27	∞	2.23	∞
S14	24	542	3.20	∞
S15	23	434	8.18	∞
TC2	49	∞	2.80	∞
S25	48	270	–	–
C1	43	86	–	–
C2	52	278	–	–
C3	76	450	–	–
C4	164	∞	8.10	∞
TC3	12	∞	0.80	∞
S32	12	∞	0.75	∞
S33	12	∞	1.05	∞
S34	12	∞	2.08	∞

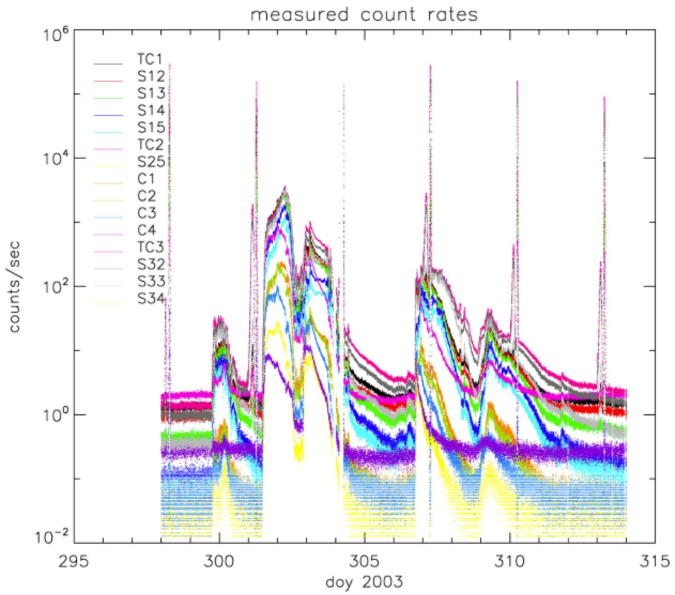


Fig. 10. Count-rates of INTEGRAL/SREM for the sequence of October-November 2003 SEPEs, versus the Day of Year (DOY) 2003.

Previous Flights

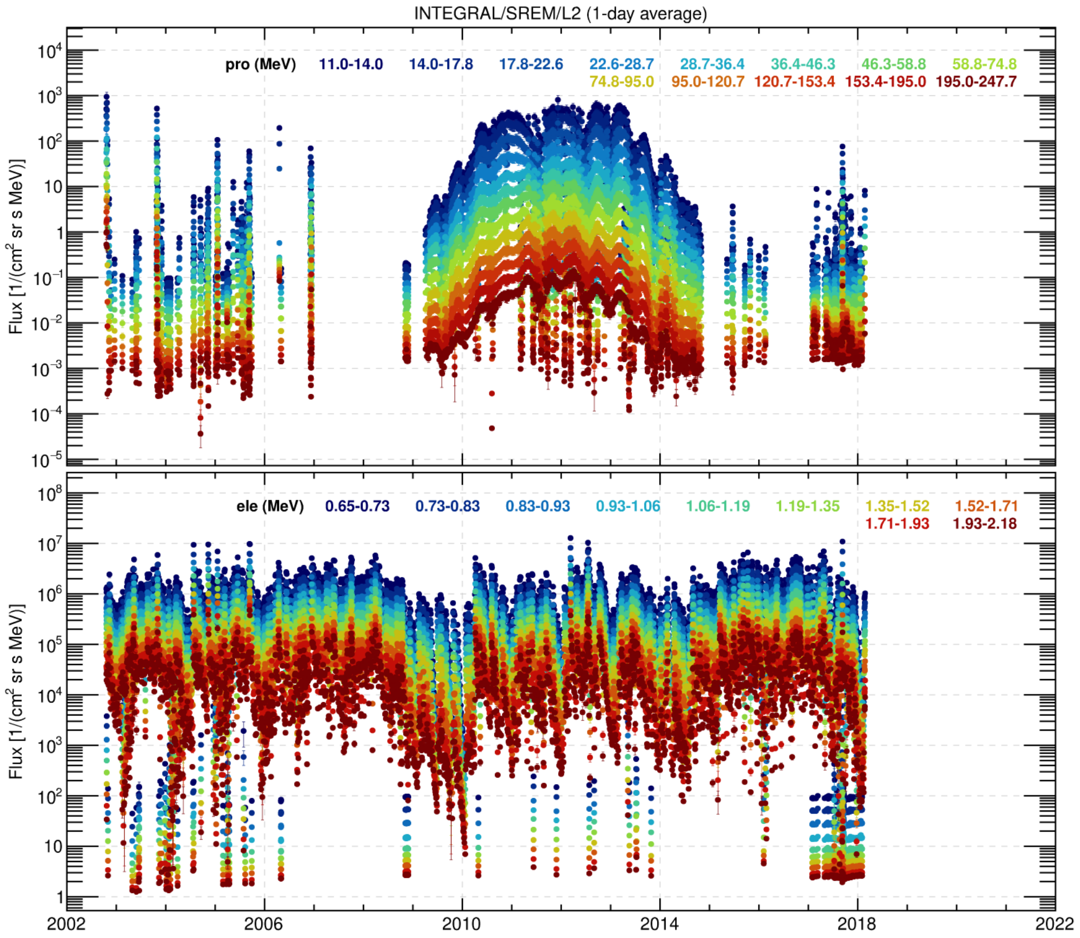
Proba-1	LEO	Oct 2001 - today
INTEGRAL	HEO	Oct 2002 - today
Rosetta	Interplanetary	2004/03 - 2016/09
Giove-B	MEO	2008/04 - 2012/07
Herschel	L2	2014/05 - 2013/04
Planck	L2	2014/05 - 2013/10

Sandberg et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 59, NO. 4, AUGUST 2012, DOI: 10.1109/TNS.2012.2187216

Credit: ESA, https://www.youtube.com/watch?v=6iRuXObDYUU

Prepare Historical INTEGRAL/SREM Data

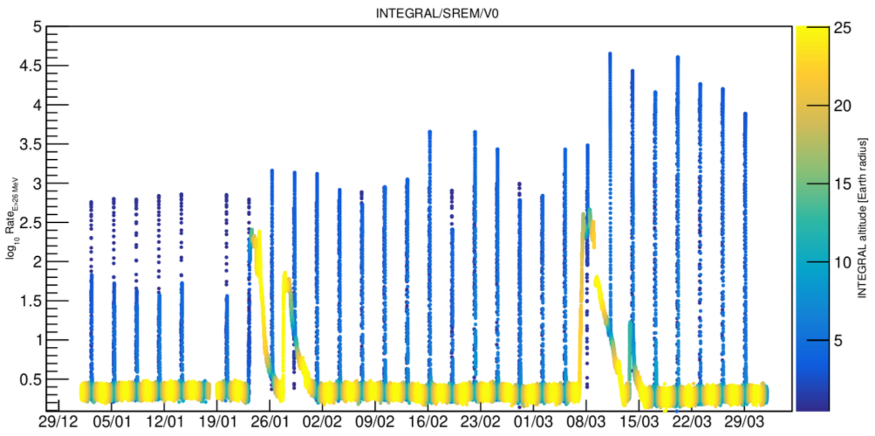
Daily proton (top) and electrons (bottom) L2 fluxes with exclusions using recommended quality flags.



- ERSA/SREM will provide counts (V0) and unfolded fluxes (L1b) in real time
- ERSA/SREM L2 calibrated fluxes will be provided within 6 months, but may be provided in near real time once an algorithm has been established
- **Provide both V0 and L2 INTEGRAL/SREM fluxes for training**
- Proton and electron fluxes are needed for training UMASEP

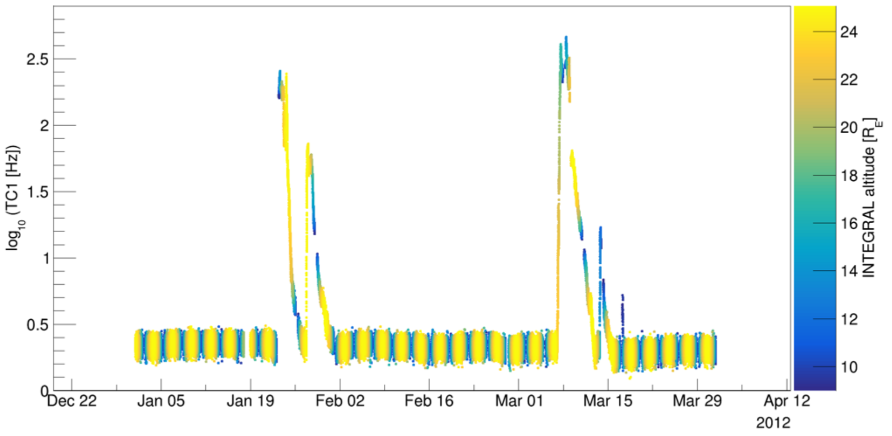
INTEGRAL/SREM SEP Events

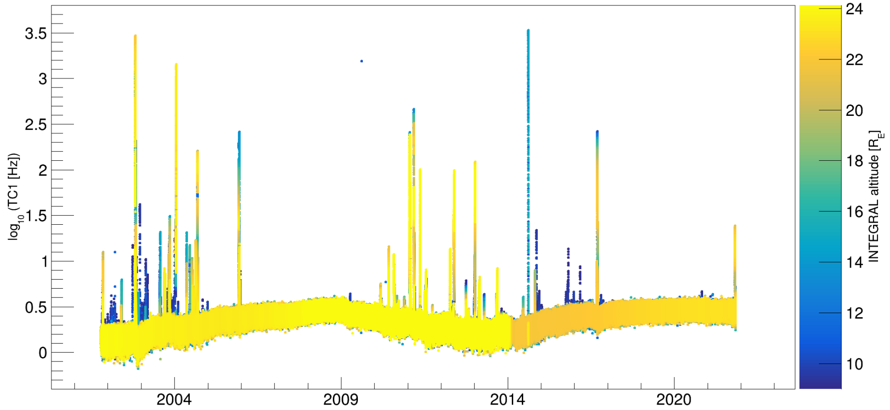
- Select INTEGRAL/SREM proton count rates and fluxes above 9 RE to exclude radiation belt



TC1 count rates

Selection above $9R_E$

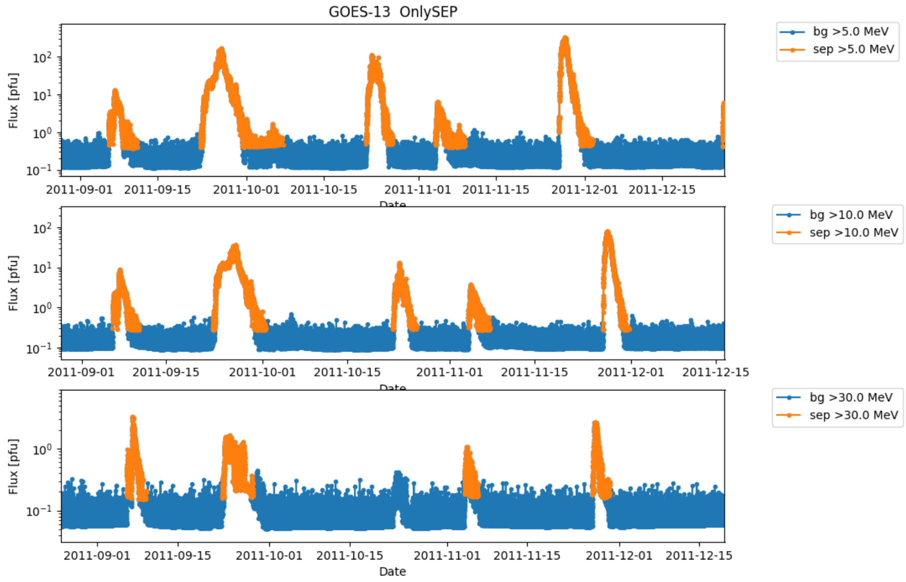




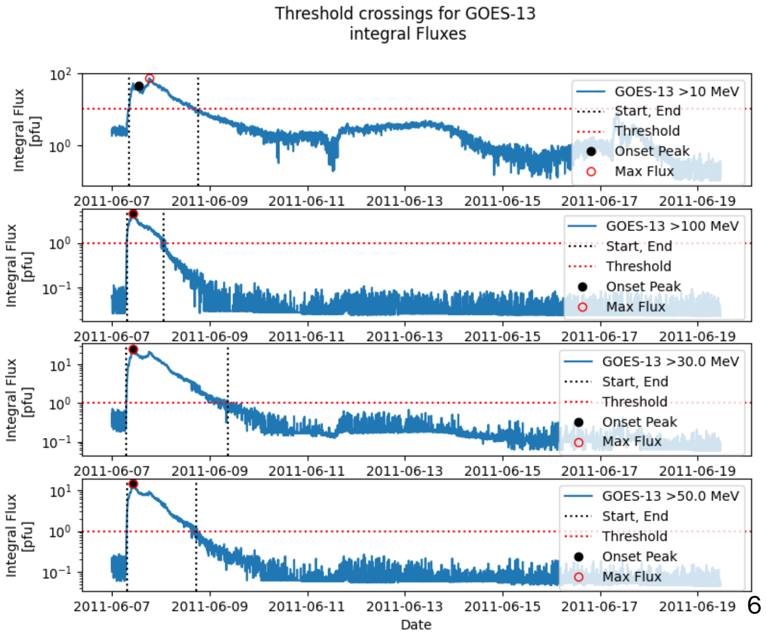
INTEGRAL/SREM SEP Events

- Prepare SEP event lists using the fetchsep python package, installable via pip (https://github.com/ktindiana/fetchsep, developers K. Whitman, R. Egeland)
- Use the threshold of >30 MeV exceeds 1 pfu to define SEP event start and end times and derive fluxes and fluences needed for UMASEP-Gateway30 training

fetchsep idsep to automatically identify all SEP events in the SREM time series



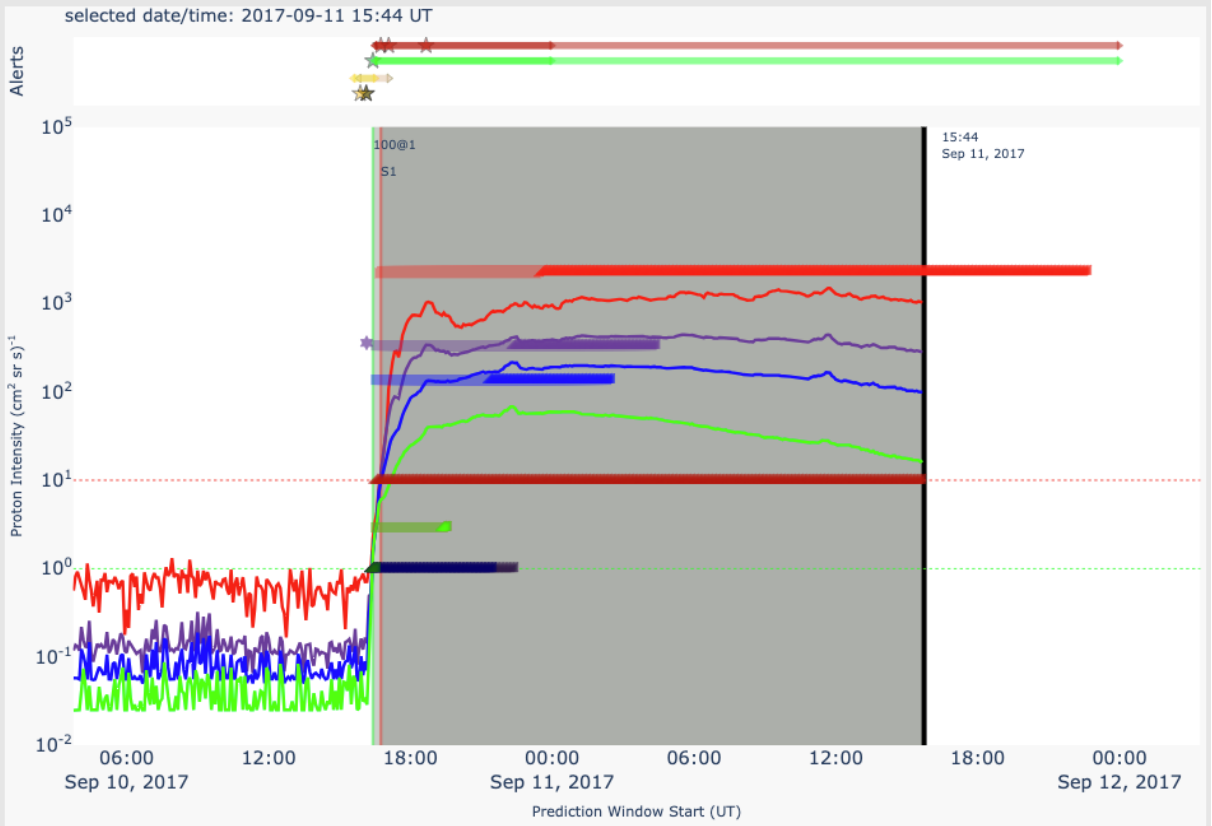
fetchsep opsep to extract information for each individual SEP event



Training of UMASEP-30Gateway

- Provide SEP event timing, proton fluxes, and fluences to the UMASEP model developer
- Using INTEGRAL/SREM electrons as input and prepared proton information, UMASEP will be trained to make forecasts based off SREM data
- Produce a forecast product like on the SEP Scoreboards but using data available directly on the vehicle

UMASEP forecasts for 2017-09-10



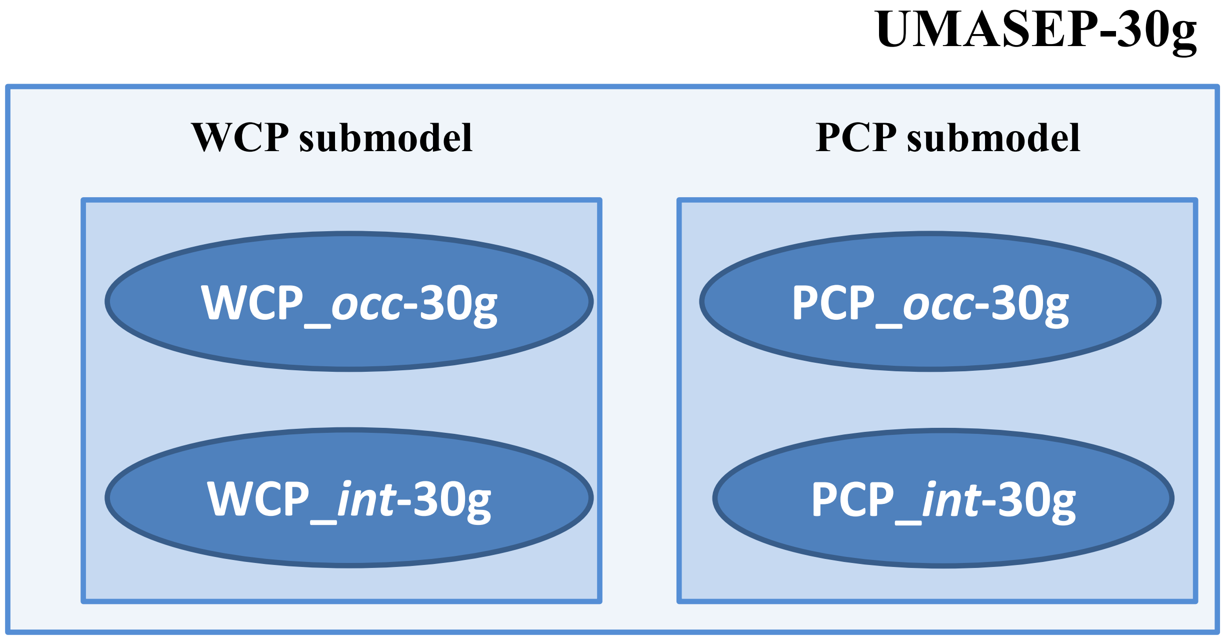
SEP Intensity Scoreboard:
https://sep.ccmc.gsfc.nasa.gov/intensity/

UMASEP-30g architecture

- UMASEP-30g will be composed of 2 submodels, WCP and PCP.
- Each submodel has a component that predicts the occurrence (*occ*). If an occurrence is predicted, the intensity component (*int*) is triggered.

The "*occ*" components predict the SEP event occurrence

The "*int*" components predict the SEP event intensity



- The WCP-*int*/PCP-*int* are trained using ML-based techniques
- The WCP-*occ*/PCP-*occ* are trained using UMA's own techniques

Slide provided by Marlon Núñez

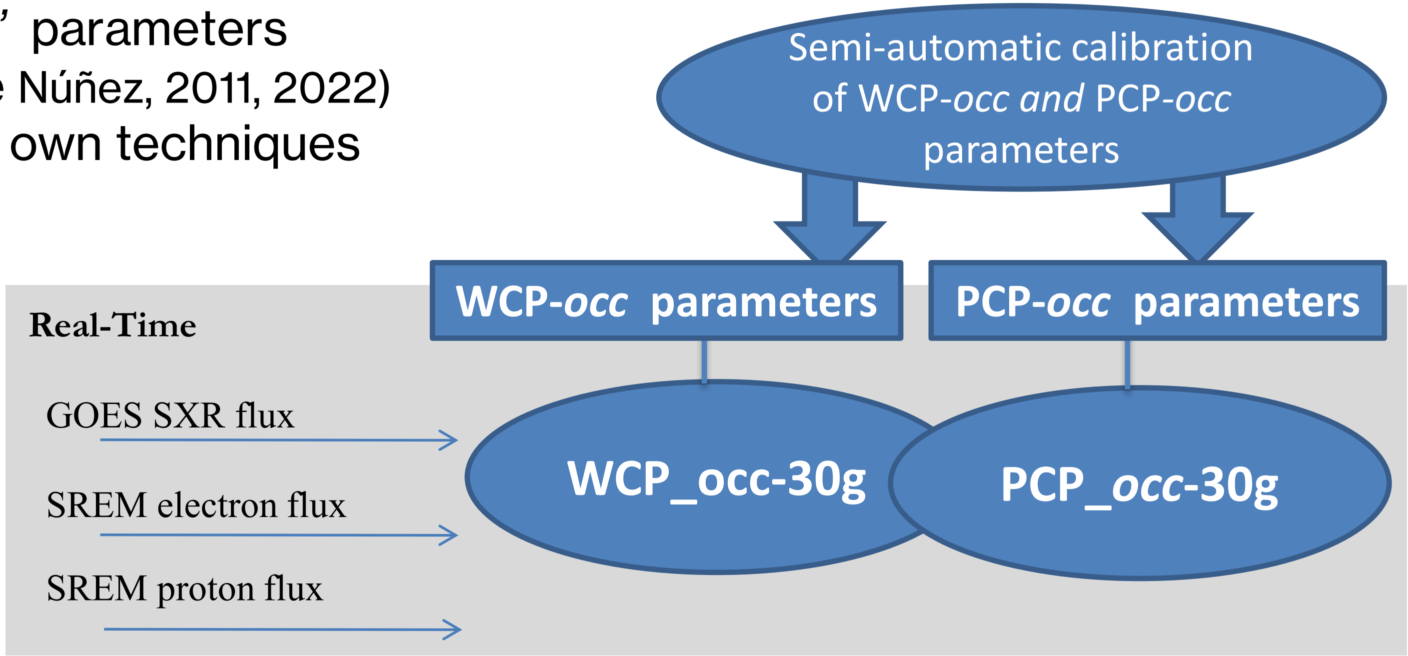
Training the event occurrence prediction components

The “occ” components are based on algorithms with parameters (Núñez 2011, 2022).
The calibration/training of the “occ” parameters follows theses steps:

1) **Update the Reference Table of the Evaluador** with SWPC SEP event onset times (i.e., for determinig the hits)

2) **Iteratively do (until satisfactory CSI performance):**
   1a: Run the UMASEP-30g in the Evaluador with SXR/proton/electron fluxes for calculating POD, FAR, AWT and **CSI**
   1b: Adjust the “*occ*” parameters (e.g., *f*, *p*, *n,* see Núñez, 2011, 2022) by using UMA’s own techniques

3) **Real-time operation**



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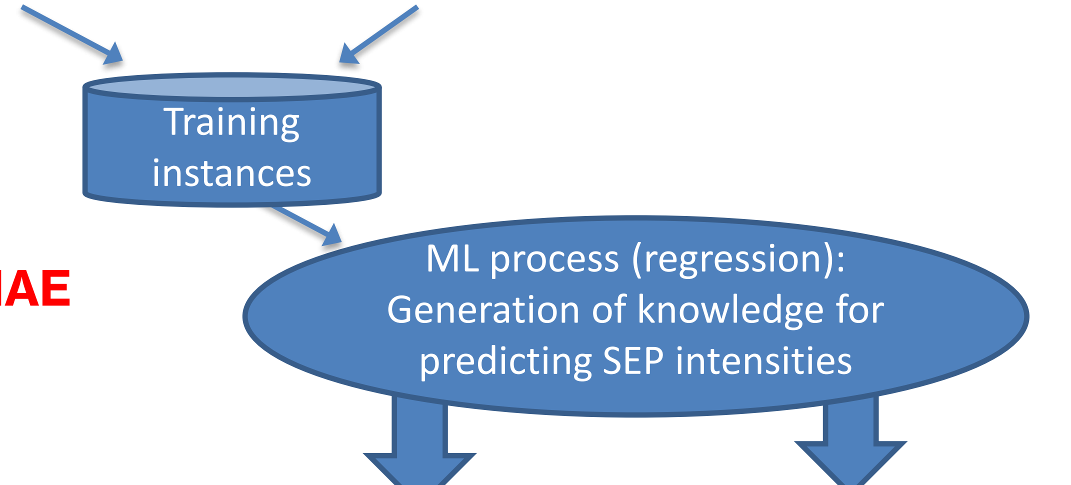
Training the SEP event intensity prediction components

1) Creating a Training Table

Post-event empirically-calculated attributes:
- Magnetic connection estimation (from WCP*occ*)
- Other intermediate results (from WCP/PCP_*occ*)

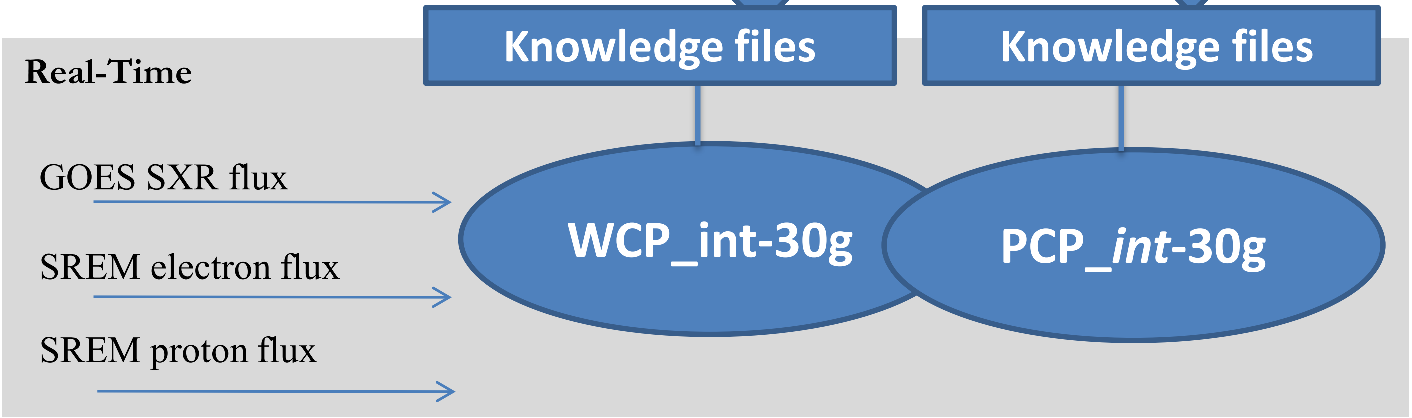
Historical-observation-based attributes:
- Associated GOES SXR peak intensities,
- Observed >30 MeV SREM proton/electron fluxes



2) Generating the ML-based regression knowledge bases

- Tree-based regression trees
- The purpose is to minimize the **MAE**

3) Real-time operation



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Summary

UMASEP-30G will be trained using historical INTEGRAL/SREM data

When ERSA/SREM on the Lunar Gateway starts providing data in real time, UMASEP-30g can immediately start providing SEP forecasts for the vehicle and the lunar environment

SEP forecasting using instruments located on the vehicle will become increasingly important as humans carry out exploration missions to distant locations where communications delays become significant and limiting

This study and resulting model will be a step towards the standalone space weather products needed by astronauts of the future

Image credit: NASA, https://www.nasa.gov/humans-in-space/lunanet-empowering-artemis-with-communications-and-navigation-interoperability/