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WHITE PAPER ON ECP ENERGY RANGE AND FLUX REQUIREMENTS

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Technical Paper

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This whitepaper summarizes the Air Force Research Laboratory's recommended performance requirements for energetic charged particle (ECP) sensors intended for anomaly attribution.

15. SUBJECT TERMS
ECP, energetic charged particles, space particles, spacecraft charging, satellite anomalies, sensor

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White Paper on ECP Energy Range and Flux Requirements

1 Background

In March of 2015 the Secretary of the Air Force directed that all new Air Force satellite programs incorporate an Energetic Charged Particle (ECP) sensor to provide timely and accurate space environment anomaly assessments. Spacecraft anomalies caused by space environment can be broadly defined in four generic categories[1]: (1) a surface electrostatic discharge (Surface Charging) resulting from differential surface charging primarily due to hot electrons in the ambient plasma (5 – 100 keV), (2) single event effects in microelectronics caused by energetic protons and other heavy ions (> 10 MeV), (3) an internal electrostatic discharge (Internal Charging) that results from deep dielectric charging by relativistic electrons (> 500 keV), (4) rapid damage accumulation due to high fluxes of energetic ions (Event Total Dose).

In order to use this data rapidly, a useful connection must be made between the occurrence of a satellite anomaly and the environmental conditions that might have caused it. This means finding the most appropriate environmental drivers for the anomaly. Identifying the right environmental driver involves evaluating the estimated omnidirectional flux levels of the responsible particles at the time leading up to the anomaly occurrence. In terms of the sensor, having sufficient energy channels is key to identifying the correct driver. It has been determined that a factor of 1.8 between adjacent channel centers (1.42 below 100keV) for differential channels is sufficient to reproduce the spectra sufficiently to accurately identify the correct driver. For integral channels, a factor of 1.8 between the midpoints of adjacent channels 90% peak response points will meet the requirement. While it is acknowledged that other conditions, such as illumination, can play a role in space environment anomaly susceptibility, they are beyond the scope of the proposed task.

Sensor accuracy is also key. Without reasonably accurate estimates of the omnidirectional flux, the error of the estimated hazard will grow unacceptably. It has been shown that determining the omnidirectional flux within a factor of four (25% to 400% of the actual flux) is sufficient to drive accurate hazard characterization at this time.

Finally, the environment in which the sensor must operate is generally more extreme than most previous space environment sensors. This is due to the statistical nature of anomalies – extreme environments are most likely to cause anomalies, but the existence of an extreme environment does not guarantee an anomaly. For the purposes of the ECP sensor, the environments to be measured are defined as the Median at the lower bound to the 95th percentile mission-max (95% chance a mission will

[1] O'Brien, T. P., SEAS-GEO: A spacecraft environmental anomalies expert system for geosynchronous orbit, Space Weather, vol 7, S09003, doi:10.129/2009SW000473, 2009.

never see an environment this extreme). Most boundaries are defined using AE9/AP9/SPM v1.3[2], although there are exceptions. Specific details of the boundaries are discussed below.

2 Flux Requirements

This section delineates the flux and channel spacing requirements of the ECP sensor.

2.1 Low-Energy Electron Measurement

The ECP sensor is required to measure the flux from 0.1keV to 5MeV. For the portion below 100keV, we consider that the low-energy electron component.

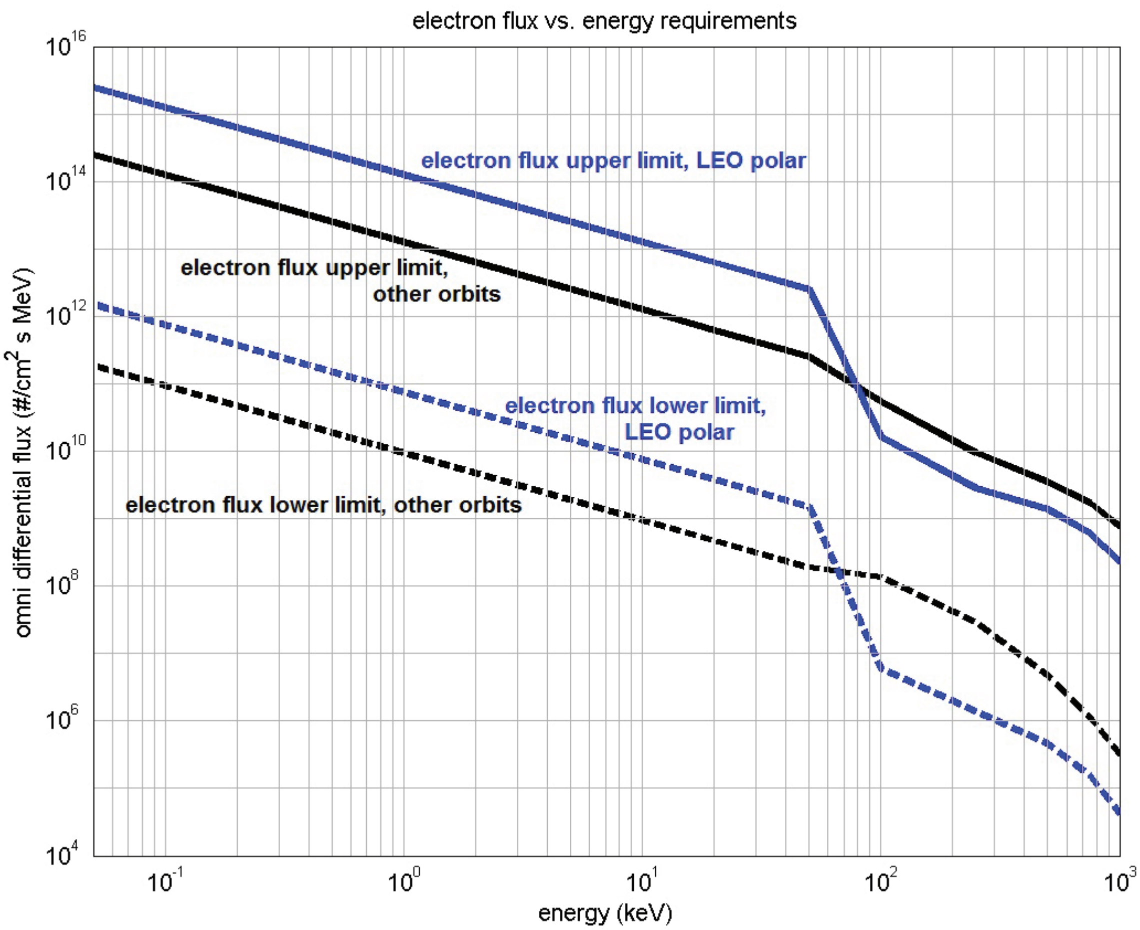

Figure 1: Low-energy electron flux

[2] AE9/AP9/SPM Radiation Environment Model Release Notes, Version 1.30.001," 25 Jan. 2016, on line at AFRL Virtual Distributed Laboratory [https://www.vdl.afrl.af.mil/programs/ae9ap9/files/package/Ae9Ap9_v1_30_001_ReleaseNotes.pdf].

Table 1: Tabulated Low-Energy Electron Flux

Electron Energy (keV)	Orbits other than LEO Polar, upper #/(cm^2 s MeV)	Orbits other than LEO Polar, lower #/(cm^2 s MeV)	LEO Polar, upper #/(cm^2 s MeV)	LEO Polar, lower #/(cm^2 s MeV)
0.05	2.52E+14	1.88E+11	2.52E+15	1.51E+12
0.1	1.26E+14	9.42E+10	1.26E+15	7.54E+11
0.3	4.19E+13	3.14E+10	4.19E+14	2.51E+11
1	1.26E+13	9.42E+09	1.26E+14	7.54E+10
3	4.19E+12	3.14E+09	4.19E+13	2.51E+10
10	1.26E+12	9.42E+08	1.26E+13	7.54E+09
20	6.28E+11	4.71E+08	6.28E+12	3.77E+09
40	3.14E+11	2.36E+08	3.14E+12	1.88E+09
50	2.51E+11	1.88E+08	2.51E+12	1.51E+09
100	5.44E+10	1.35E+08	1.63E+10	6.01E+06

2.2 Low-Energy Electron Flux Limit Basis

The low energy electron flux measurement ranges are idealizations based on several models and data sets. LEO Polar flux upper and lower limits are based on DMSP/SSJ maximum and quiet time observations, respectively. For other orbits, the upper limit is based on a factor of 5 margin above the SPM model 99th percentile and the lower limit on medians from Van Allen Probe/HOPE and LANL GEO/MPA data and the SPM model. It is understood that the range from 40keV to 100keV may be challenging to measure.

2.3 Low-Energy Electron Channel Spacing

Low-energy electron channel spacing should be no more than a factor of 1.42 between adjacent channel centers (or midpoints between 90% response levels for integral channels) to provide sufficient resolution of the spectrum necessary to support anomaly forensics and rapid discrimination of conditions. In the energy range between 0.1keV and 100keV, electron energy channel width should be structured so that the FWHM covers at least 50% of the logarithmic energy range with no individual gap greater than 15% of the total range.

Energy channel spacing is defined for differential channels as the interval between the energies of peak response of successive channels, and for integral channels is the interval between the lowest energies where successive channels reach 90% of their peak response.

2.4 High-Energy Electron Measurement

The ECP sensor is required to measure from 0.1keV to 5MeV. The portion above 100keV is considered the High-Energy electron measurement.

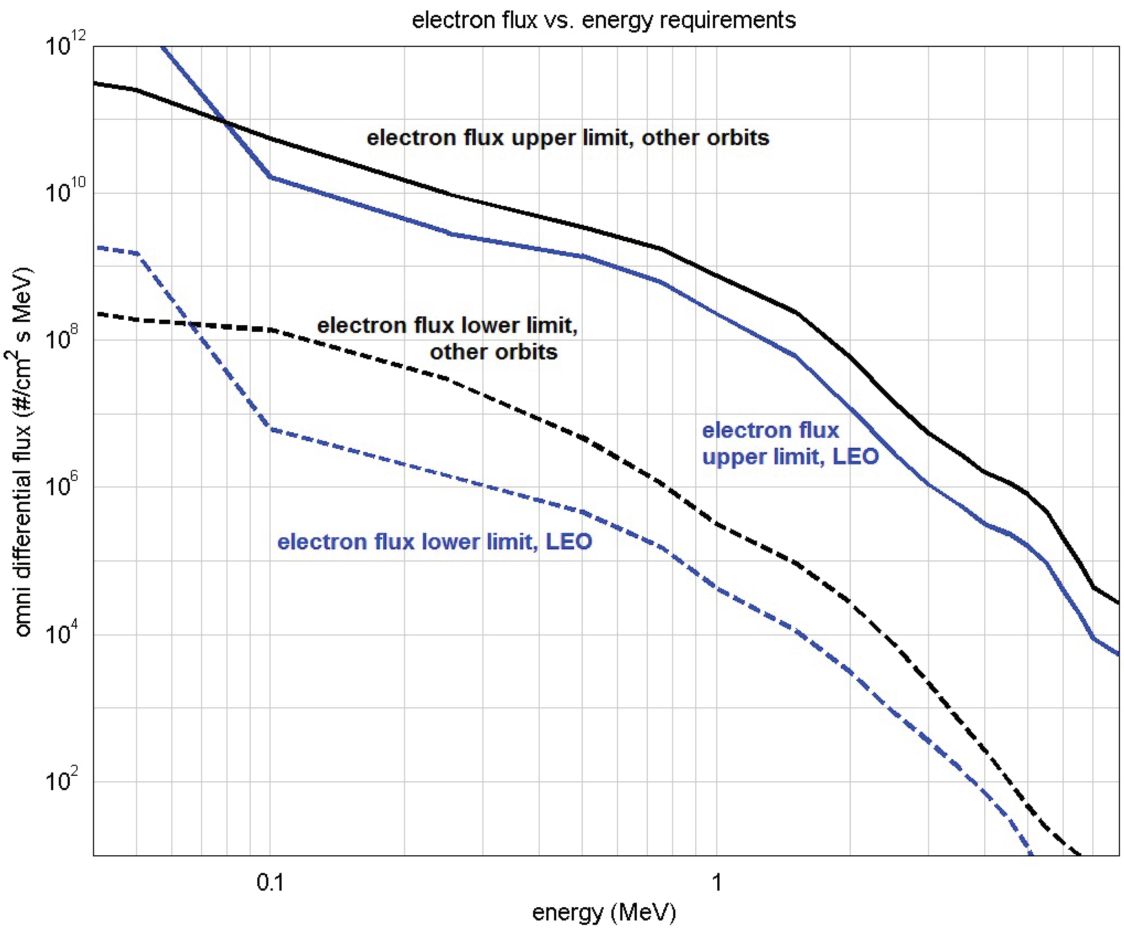

Figure 2:High-Energy Electron Flux

Table 2: Tabulated High-Energy Electron Flux

Electron Energy (keV)	Orbits other than LEO, upper #/(cm^2 s MeV)	Orbits other than LEO, lower #/(cm^2 s MeV)	LEO, upper #/(cm^2 s MeV)	LEO, lower #/(cm^2 s MeV)
100	5.44E+10	1.35E+08	1.63E+10	6.01E+06
250	9.50E+09	2.88E+07	2.85E+09	1.40E+06
500	3.45E+09	4.75E+06	1.38E+09	4.60E+05
750	1.73E+09	1.14E+06	6.06E+08	1.55E+05
1000	7.62E+08	3.16E+05	2.29E+08	4.24E+04
1500	2.45E+08	9.45E+04	6.11E+07	1.15E+04
2000	5.81E+07	2.69E+04	1.16E+07	3.06E+03
2500	1.46E+07	7.44E+03	2.93E+06	8.67E+02
3000	5.36E+06	2.17E+03	1.07E+06	3.51E+02
3500	2.88E+06	6.83E+02	5.76E+05	1.55E+02
4000	1.58E+06	2.66E+02	3.16E+05	6.98E+01
4500	1.18E+06	1.06E+02	2.35E+05	3.26E+01
5000	7.95E+05	4.56E+01	1.59E+05	1.24E+01

2.5 High Energy Electron Flux Limit Basis

The limits are based on AE9/AP9/SPM version 1.30 median (lower) and 95th percentile mission maximum (upper), with a correction to the LEO upper limit applied based on scaling of the other orbit upper limit.

2.6 High Energy Electron Channel Spacing

In order to ensure adequate spectra resolution for rapid anomaly assessment, the channel spacing shall be no more than a factor of 1.8 between adjacent channel centers (or midpoints between 90% response levels for integral channels). For the energy range between 100keV and 5MeV, the channel width for all electron channels shall be FWHM continuous over at least 90% of the logarithmic energy range with no individual gap greater than 5% of that range. Energy channels are defined as in 2.3.

2.7 High-Energy Proton Measurements

The ECP sensor is required to measure the proton flux over the range of 2-100MeV.

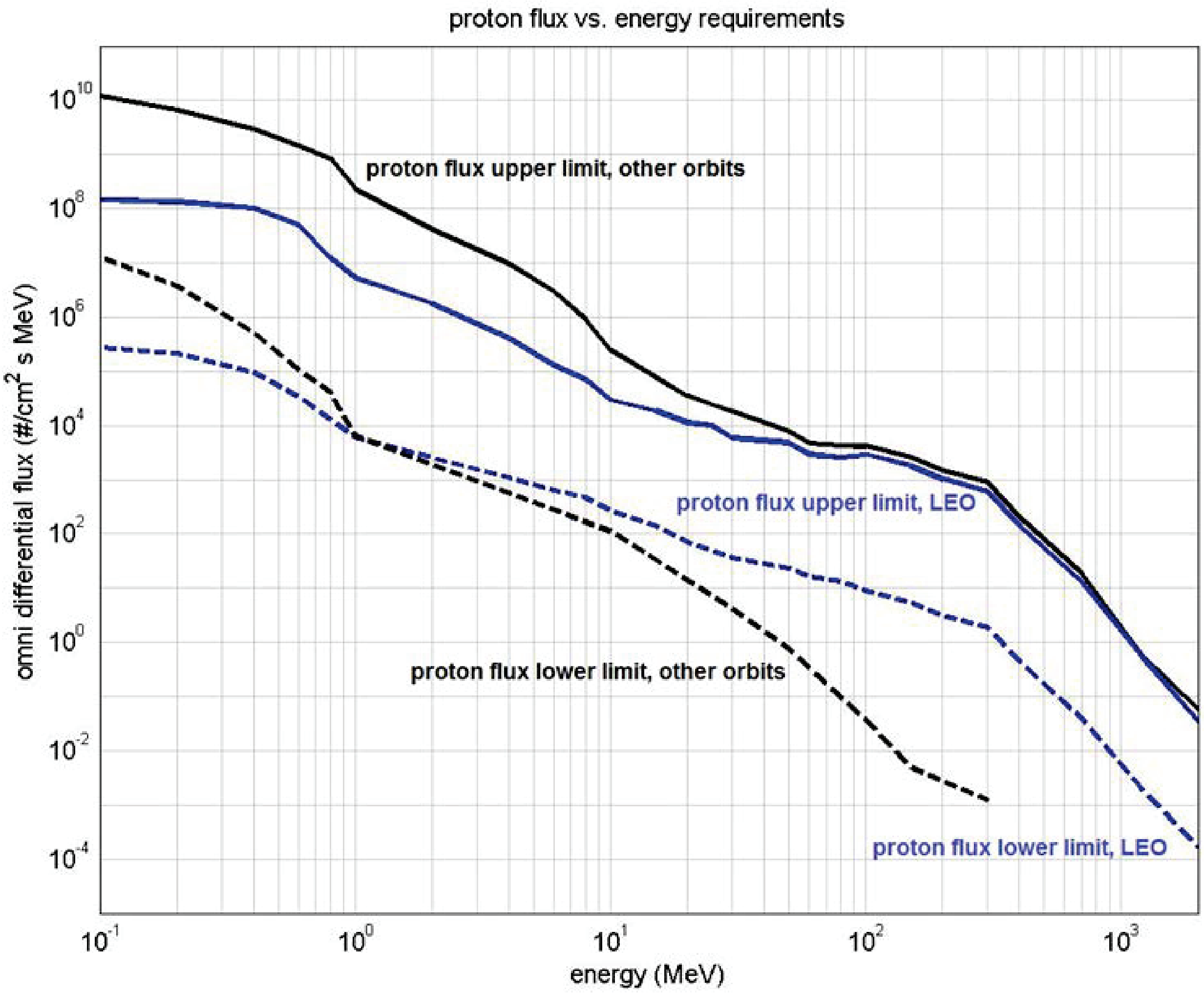

Figure 3: High Energy Proton Flux

Table 3: Tabulated Proton Flux

Proton energy (MeV)	Orbits other than LEO, upper #/(cm^2 s MeV)	Orbits other than LEO, lower #/(cm^2 s MeV)	LEO, upper #/(cm^2 s MeV)	LEO, lower #/(cm^2 s MeV)
2	4.20E+07	1.93E+03	1.77E+06	2.50E+03
3	1.78E+07	9.52E+02	7.46E+05	1.53E+03
4	9.66E+06	5.76E+02	4.05E+05	1.08E+03
6	2.92E+06	2.81E+02	1.28E+05	6.29E+02
8	9.06E+05	1.67E+02	7.09E+04	4.71E+02
10	2.46E+05	1.12E+02	2.96E+04	2.71E+02
15	7.84E+04	3.33E+01	1.85E+04	1.40E+02
20	3.40E+04	1.40E+01	1.13E+04	6.89E+01
25	2.37E+04	7.20E+00	1.00E+04	4.83E+01
30	1.77E+04	4.17E+00	5.87E+03	3.61E+01
50	7.76E+03	7.50E-01	4.80E+03	2.30E+01
60	4.72E+03	3.39E-01	2.91E+03	1.64E+01
80	4.22E+03	9.71E-02	2.59E+03	1.32E+01
100	4.16E+03	3.68E-02	2.87E+03	8.80E+00

2.8 High-Energy Proton Rationale

The upper limit is defined by AE9/AP9/SPM version 1.30 95th percentile mission maximum with a correction at energies >100 MeV using Van Allen Probe data. The lower limit is defined as higher of either the AE9/AP9/SPM median or the median proton spectra from GOES data during solar proton events (defined as time periods above the NOAA warning threshold).

2.9 High-Energy Proton Channel Spacing

In order to ensure adequate spectra resolution for rapid anomaly assessment, the channel spacing shall be no more than a factor of 1.8 between adjacent channel centers (or midpoints between 90% response levels for integral channels). The channel width for all high-energy proton channels shall be FWHM continuous over at least 90% of the logarithmic energy range with no individual gap greater than 5% of the energy range. Energy channels are defined as in 2.3.

3 Other considerations

Considerations beyond sensor performance may drive options. Below are a selection of some of the key additional requirements. It is recommended to discuss any other limiting factors with your program office.

3.1 Sampling Rate

The ECP shall have configurable sampling rates that vary from 1 second to 600 seconds. This is required to handle sampling in all orbits.

3.2 Data Rate

The ECP data rate shall not exceed 1kbps from any sampling rate on orbit. It is anticipated that this will require on-board processing sufficient to condense raw sensor data into processed telemetry.

3.3 Reliability

The reliability shall be ≥80% at the end of 7 years design life and ≥60% at the end of 15 years design life.

3.4 Lifetime

The design lifetime of the final instrument shall be ≥15.5 years for GEO and MEO, and ≥7 years for LEO.

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