Environments Models used for Hardware Certification

NASA JSC Engineering Directorate
Avionic Systems Division
Electronic Design & Manufacturing Branch

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Environments & Models


2. Solar Particle Events – currently use CREME96 October 1989 Event

3. Galactic Cosmic Rays – primarily use Badhwar-O’Neill model, some use of Nymmik 1996 model (as part of the CREME96 tool)
We currently use Ap8 models for environment definition and for hardware rate analyses.

- Biggest issue here – Ap9 appears to be significantly higher than Ap8
  * rates will be higher by about the same factor
- Is the Ap9 data more accurate?
- Our understanding is there is no data in this region.
- Generally not a major issue since
  * Not worried about dose
  * Rates are usually dominated by GCR
NASA Human Spaceflight is focused on Beyond LEO

- Environments of Concern (for both Crew and Hardware)
  - Solar Particle Events
    - A huge driver for crew dose, and hardware soft error rates
  - Galactic Cosmic Radiation
    - Very important for astronaut radiation risk calculations
    - For hardware – the driving environment for single event effects
- What is needed?
  - SPE’s: Ability to define appropriate (more realistic) solar particle events for short duration missions at various times in the solar cycle
  - GCR’s: Updated models to account for more recent satellite data as well as the ability to make predictions anywhere in the heliosphere
  - Updates to include
Really, the Heliosphere is Very Complex (and it's big too, 100 AU)

**solar magnetic field & solar wind features**
- 100 AU
- open & closed field lines
- 22 year cycle starts at solar max (B=0)
- 11 year sunspot cycle starts at solar min
- sun rotation rate depends on latitude
- sunspots start at high lat, move to low
- CME's start low, move high

**GCR’s from Milky Way encounter the heliosphere:**
- the large scale magnetic field carried by steady solar wind
- local field carried by events (SS & CME)
Fokker-Planck equation - governs GCR flow in & out of the Sun's magnetic field (heliosphere = 0 to 100 AU)

Don't let it intimidate you - it's simple. There's 1 time term (It's time dependent), 3 diffusion (k) terms (1 radial and 2 angular, its 3-D), 1 energy loss term (p is momentum) and 1 solar wind (V) term (called drift or convection)

It gives the energy spectrum (flux f vs ion momentum) for each GCR ion

Solve it at every point (ie radius from sun, theta=t, phi=p) in the heliosphere & you know the GCR flux spectrum f(p is momentum, r, theta, phi) everywhere from the sun out to r=100 AU at all times over the solar cycle (sunspots)

You must know the diffusion coefficients (they depend on #sunspots), the solar wind velocity (V=450 km/s) and the constant flux at the outer boundary - the Local Interstellar Spectrum (LIS)

You have to fit these parameters so f matches the GCR measurements from ACE, PAMELA, ...
For each element (like hydrogen, ..., carbon, ... iron) the blue line (flux at 100 AU) is the Local Interstellar Spectrum (LIS) - IT'S CONSTANT - IT'S IN THE MILKY WAY - IT DOESN'T CHANGE

Fokker-Planck solution (green dashed line) matches the GCR measurement (say ACE etc.) at some time at r=1 AU (theta & phi = 0) because we adjusted krr, V, & the LIS

The flux spectrum is lower at 1 AU because the sun's magnetic field modulates the flux as it diffuses inward & it shifts to left due to energy loss
BO Model's Fokker-Planck is easy to solve, It's steady state (left hand side is 0) and 1D (r)

\[ 0 = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial f}{\partial r} \right) + \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 V \right) \frac{\partial}{\partial p^3} (p^3 f) - \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 V f \right) \]

Now, Only 3 terms left

1. diffusion inward depends on Krr - which depends on # sun spots

2. loss of energy as GCR diffuse inward (p is momentum)

3. outward convection (drift) of solar wind (V)

This is Easy to solve using Finite Difference method

However, it cannot be solved by Finite Difference if you add time & another dimension (see chart #7)
Why should we add time and another dimension?

At Solar Max, the Sun's Field "flips" - every 11 years
The GCR peaks (at a - field) & plateaus (at a + field)
Current BO Model **DOES NOT** show the "peaks" & "plateaus"

BO Model of GCR Spectra for every solar cycle (1 to 24)
GCR’s enter along the polar axes when $B$ is + in the Northern Hemisphere (A+)

The "A+" case

$+GCR$ ions

The plateau’s (A+) have a **RAPID** rise because they have immediate access to Earth and they have a **DELAYED** decline because they have a long "exit" path.
& vis-versa GCR's ENTER ALONG THE EQUATOR WHEN B IS - IN THE NORTHERN HEMISPHERE (A-)

CME's start Solar Cycle (at solar min) at Equator and Move to Higher Latitude

So, Pointed cycles (A-) GCR's entering along the equator are IMMEDIATELY modulated
Model & Measured GCR Flux disagree on Pioneer ~ 50 AU Deep in 1990

Model assumes the GCR's are mainly coming from the heliopause at 100 AU

But, after the solar field becomes A+ (1990) many GCR's Reach Pioneer the long way by the sun's poles - "curvature & gradient drift" - and they are more attenuated

BO doesn't model the modulation for GCR's entering along the solar poles