National Aeronautics & Space Administration

Johnson Space Center

Environments Models used for Hardware Certification

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

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and Science Applications Workshop
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Environments & Models

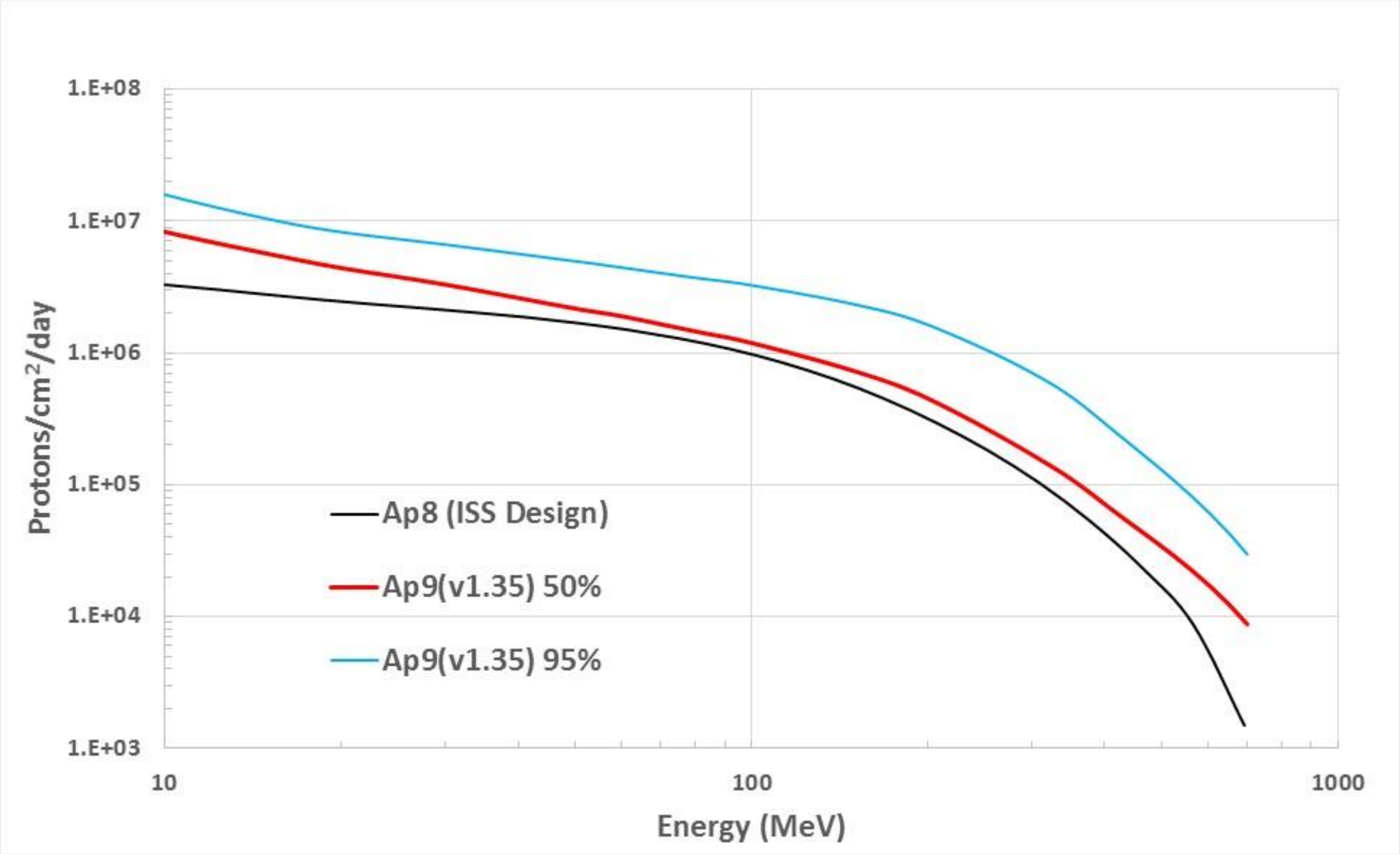
1. LEO – trapped protons – currently using Ap8, evaluating Ap9

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)

500 km x 500 km 51.6° ISS Design Orbit

LEO Missions



- 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

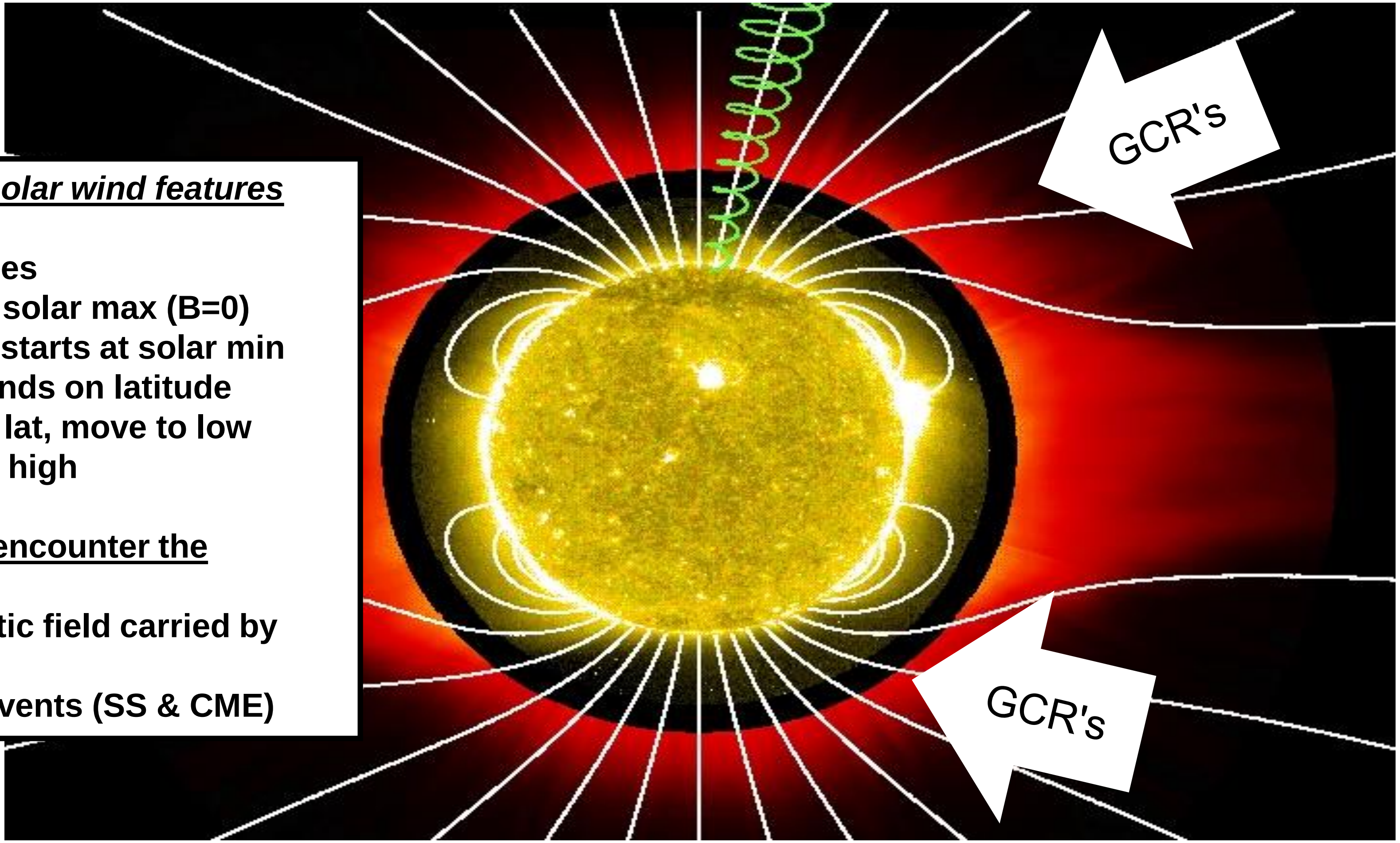
NASA Human Spaceflight is focused on Beyond LEO

- 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 - time dependent and 3-D

$$\frac{\partial f}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \kappa_{rr}\frac{\partial f}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\kappa_{\theta\theta}\sin\theta\frac{\partial f}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial}{\partial \phi} \cdot \left(\kappa_{\phi\phi}\frac{\partial f}{\partial \phi}\right) + \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 V)\frac{\partial}{\partial p^3}(p^3 f) - \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 V f)$$

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)

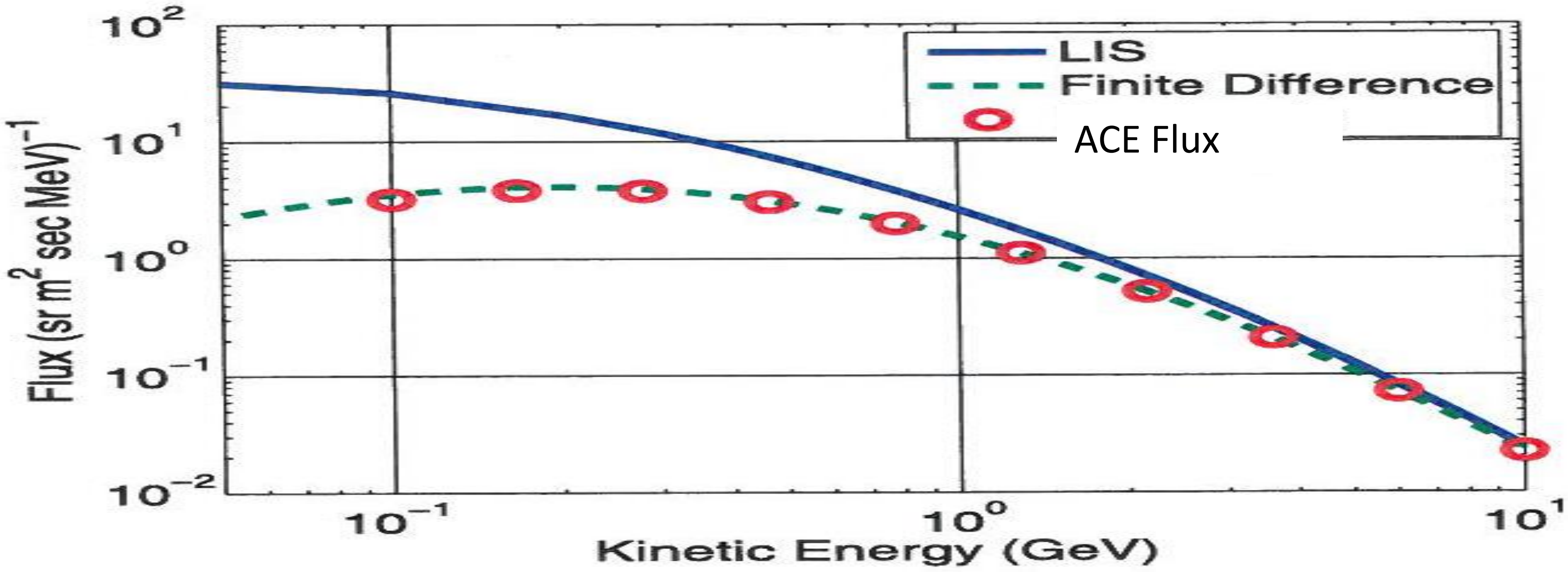
You have to fit these parameters so f matches the GCR measurements from ACE, PAMELA, …

FOKKER-PLANCK ACCOUNTS FOR FLUX REDUCTION DUE TO SOLAR MODULATION

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)

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

<u>Now, Only 3 terms left</u>

1. diffusion inward depends on Krr - which depends on <u># sun spots</u>

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

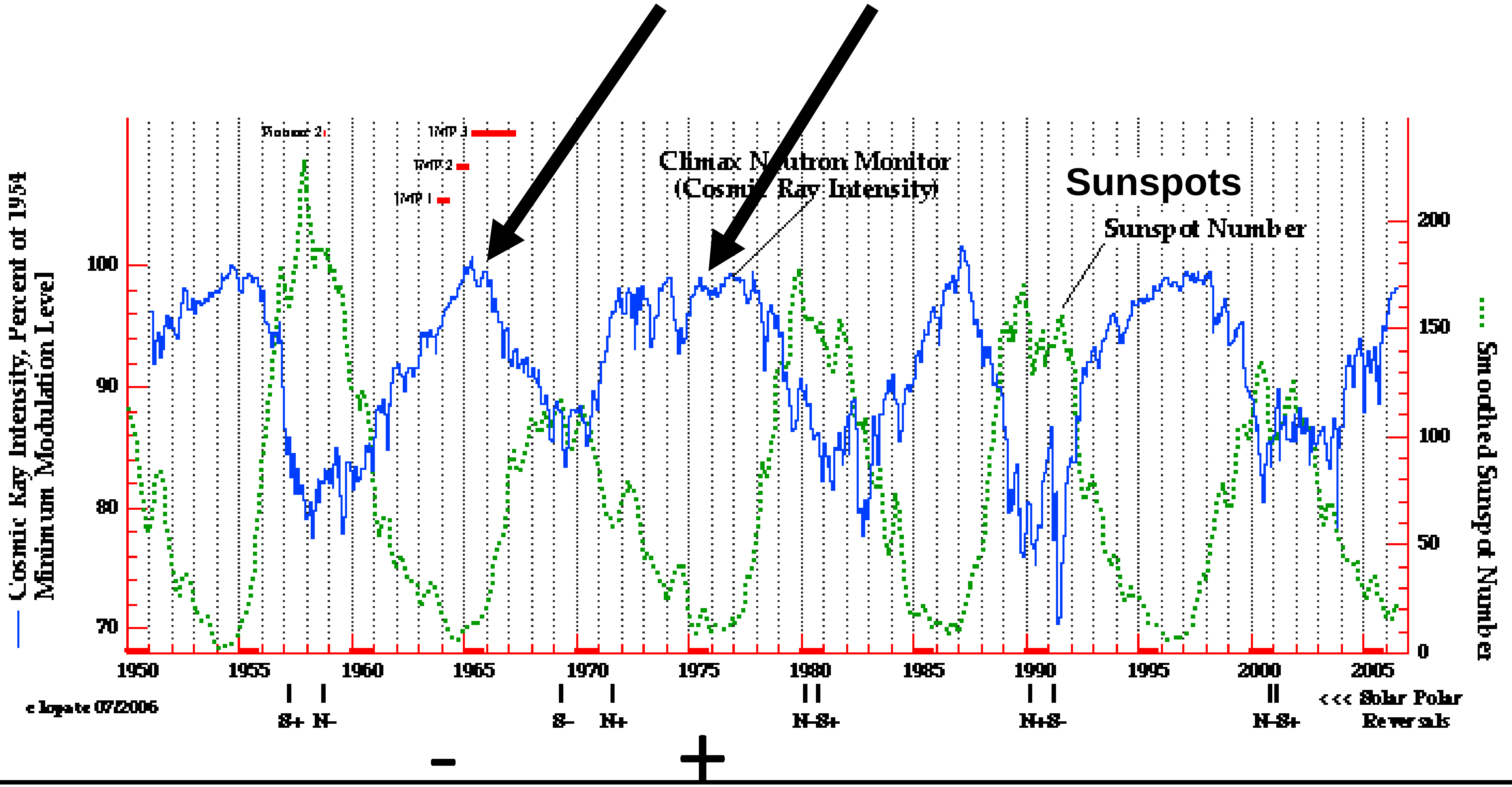
3. outward convection (drift) of solar wind (V)

This is <u>Easy</u> to solve using <u>Finite Difference method</u>

However, it <u>cannot be</u> to solved by <u>Finite Difference</u> if you <u>add time & another dimension</u> (see chart #7)

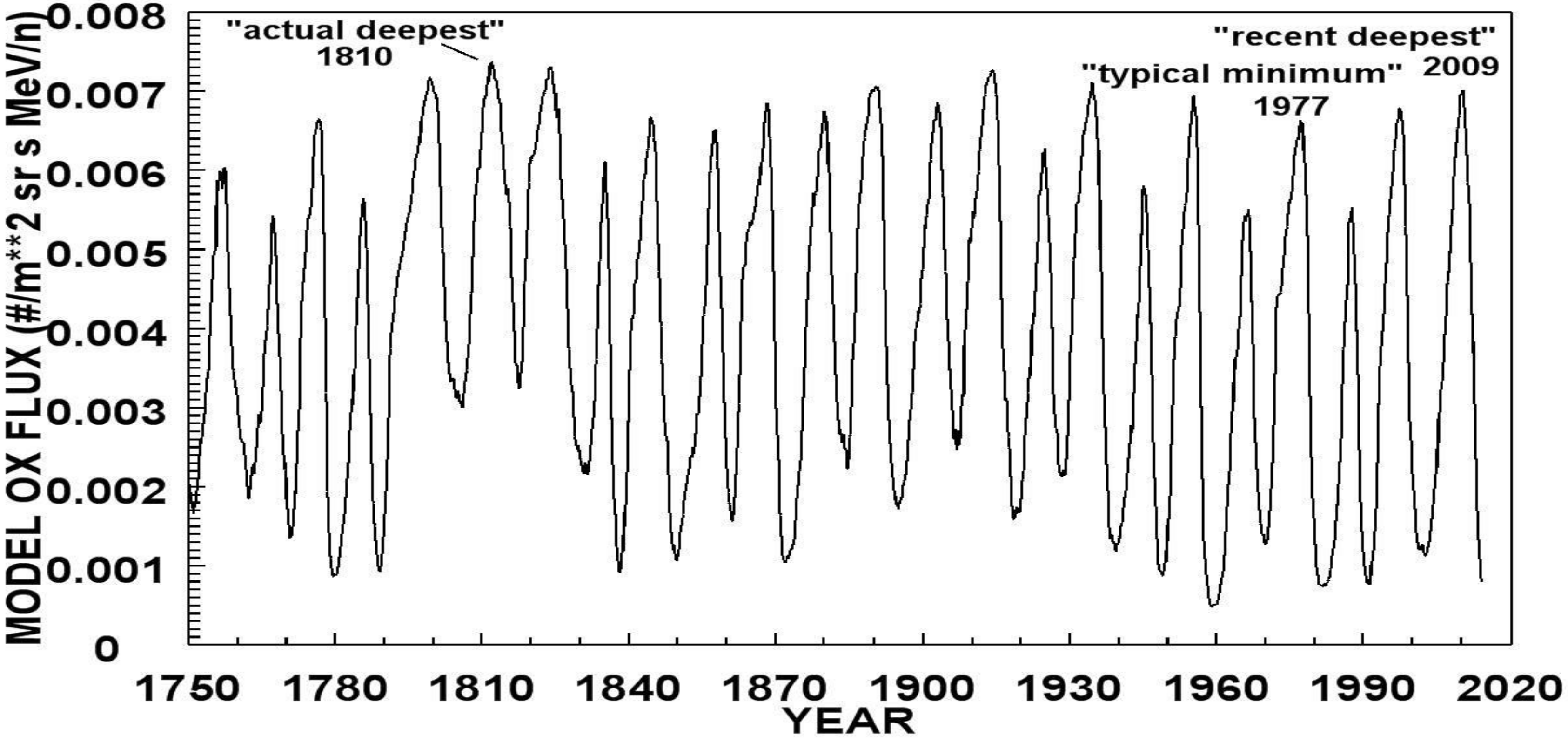
Why should we add time and another dimension?

At Solar Max, the Sun's Field "flips" - every 11 years
The GCR peaks (at a - field) & plateaus (at a + field)

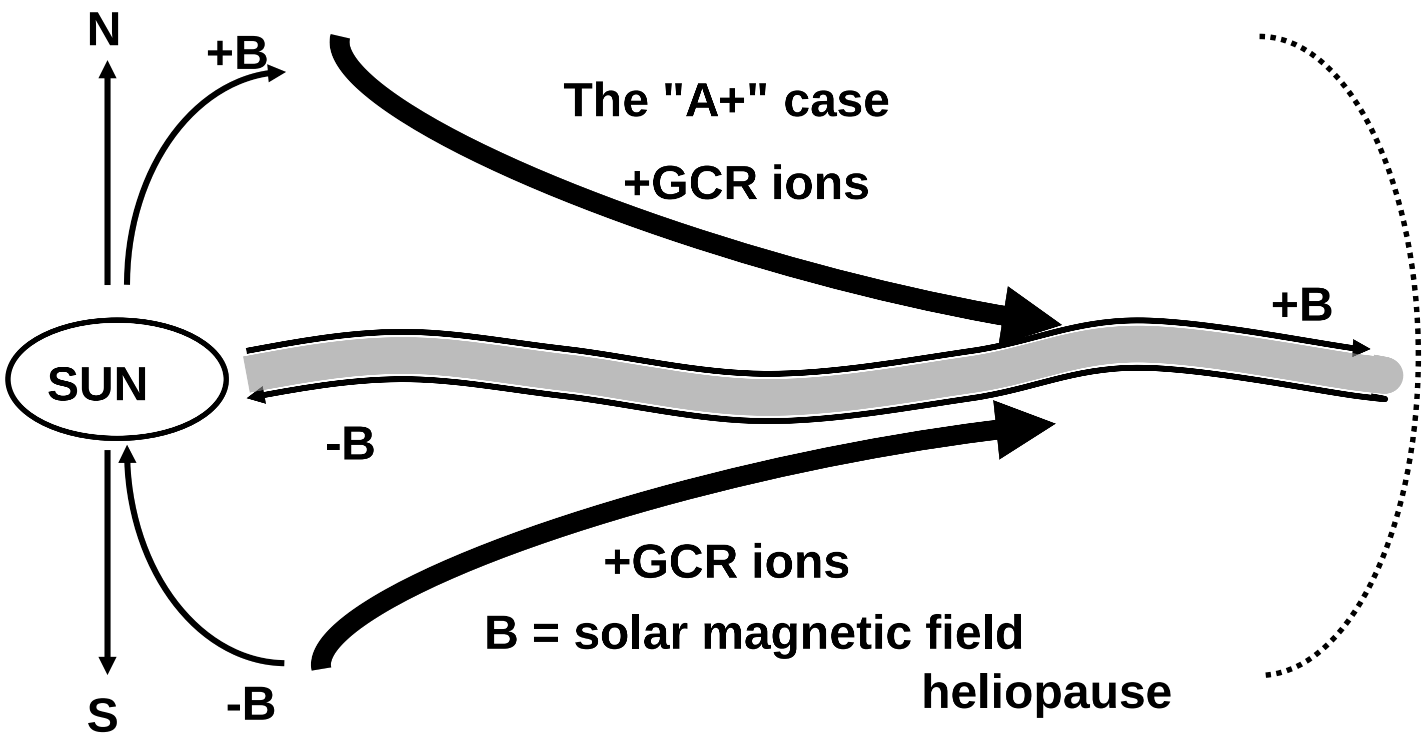


Current BO Model DOES NOT show the "peaks" & "plateaus"

BO Model of GCR Spectra for every solar cycle (1 to 24)



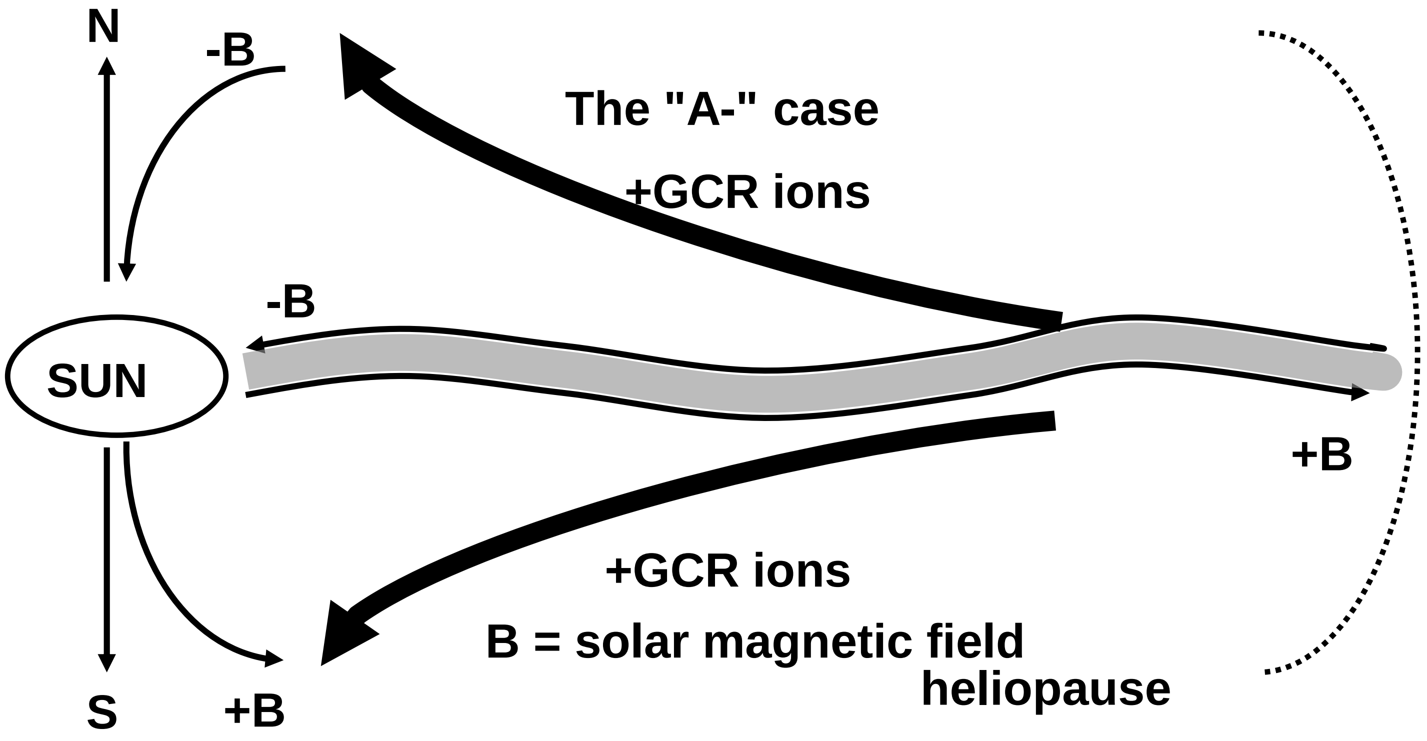
GCR's ENTER ALONG THE POLAR AXES WHEN B IS + IN THE NORTHERN HEMISPHERE (A+)



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 - INTHE NORTHERN HEMISPHERE (A-)

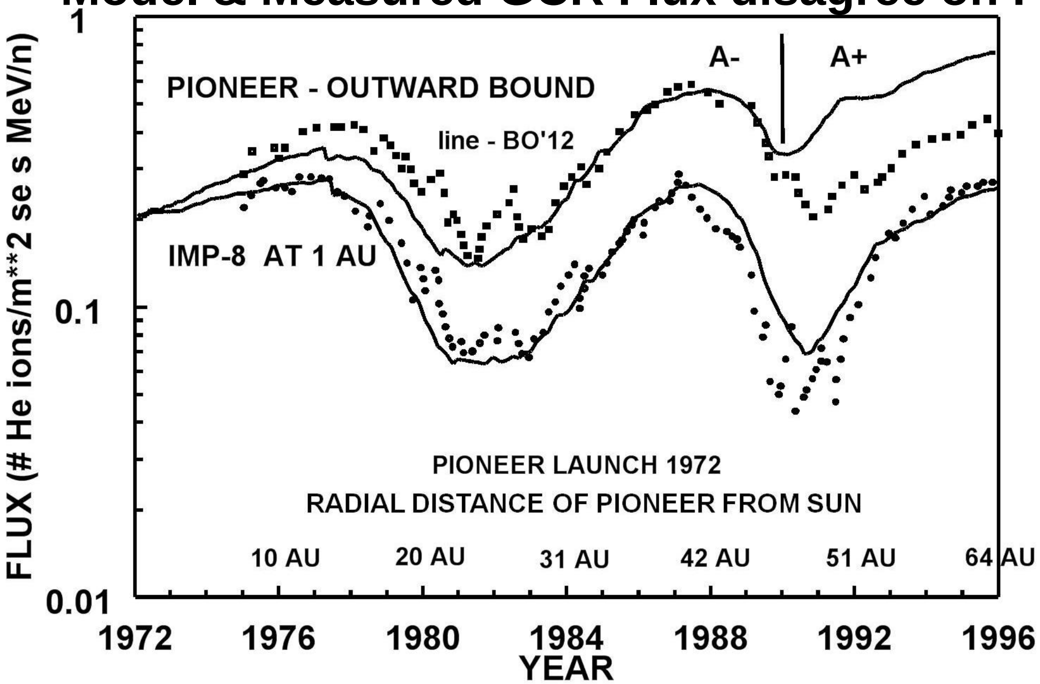


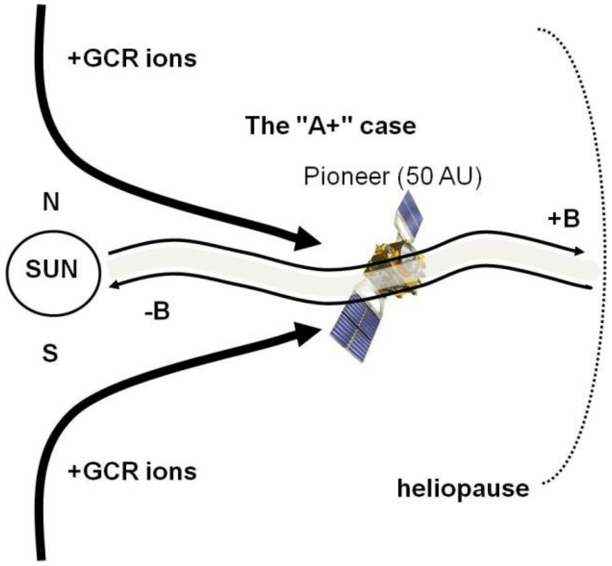
CME's start Solar Cycle (at solar min) at Equator and Move to Higher Latitude

So, Pointed cycles (A-) GCR's entering along the equator are **IMMEDIATELY** modulated

Just more proof we need "curvature & gradient drift"

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