GALILEO MEASUREMENTS OF THE JOVIAN ELECTRON RADIATION ENVIRONMENT

H.B. Garrett (1), I. Jun (1), J.M. Ratliff (1), R.W. Evans (2), G.A. Clough (3), R.W. McEntire (4)
(1) Jet Propulsion Laboratory, California Institute of Technology, (2) Gibbel Corp., Montrose, CA
(3) Bates College, Lewiston, ME (4) Applied Physics Laboratory, Johns Hopkins University.
[henry.garrett@jpl.nasa.gov]

The Galileo spacecraft Energetic Particle Detector (EPD) has been used to map Jupiter's trapped electron radiation in the jovian equatorial plane for the range 8 to 16 Jupiter radii (1 jovian radius = 71,400 km). The electron count rates from the instrument were averaged into 10-minute intervals over the energy range ~0.2 MeV to 11 MeV to form an extensive database of observations of the jovian radiation belts between Jupiter orbit insertion (JOI) in 1995 and end of mission in 2003. These data were then used to provide differential flux estimates in the jovian equatorial plane as a function of radial distance (organized by magnetic L-shell position). These estimates provide the basis for an omni-directional, equatorial model of the jovian electron radiation environment. The comparison of these results with the original Divine model of jovian electron radiation and their implications for missions to Jupiter will be discussed. In particular, it was found that the electron dose predictions for a representative mission to Europa were about a factor of 2 lower than the Divine model estimates over the range of 100 to 1000 mils (2.54 to 25.4 mm) of aluminum shielding, but exceeded the Divine model by about 50% for thicker shielding for the assumed Europa orbiter trajectories. The findings are a significant step forward in understanding jovian electron radiation and represent a valuable tool for estimating the radiation environment to which jovian science and engineering hardware will be exposed.

KEY WORDS: Jupiter, Radiation Models, Radiation Belts, Galileo Spacecraft, Europa, High Energy Electrons, Trapped Particles, Space Radiation

GALILEO INTERIM RADIATION ELECTRON MODEL

H. B. Garrett[a], I. Jun[a], J. M. Ratliff[a],
R. W. Evans[b], G.A. Clough[c],
and R. W. McEntire[d]

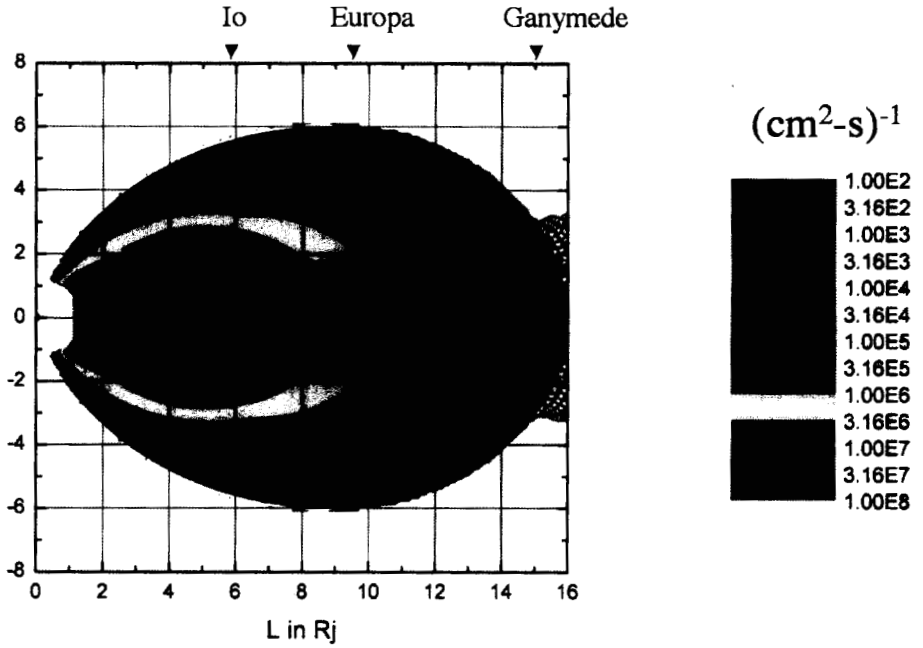
[a]*Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109*
[b]Gibbel Corp., 2550 Honolulu Blvd., Montrose, CA 91020
[c]Bates College, Lewiston, Maine 04240
[d]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland 20723

Galileo Interim Radiation Electron Model JPL

AGENDA

- APL/JHU ENERGETIC PARTICLE DETECTOR
- OMNI-DIRECTIONAL, EQUATORIAL FLUX MODEL
- GIRE FLUX MODEL
- CONCLUSIONS

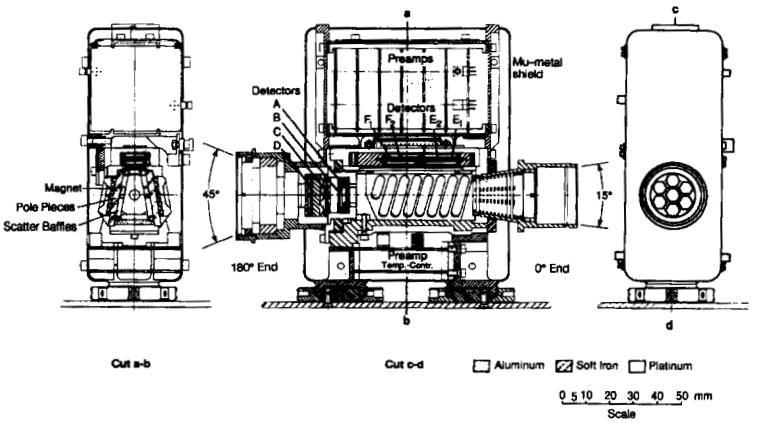
Galileo Interim Radiation Electron Model JPL

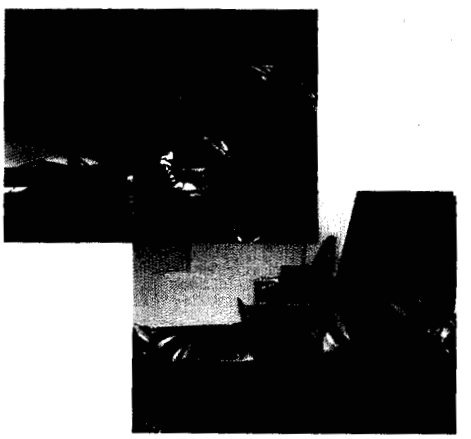


Distribution DG model 10 MeV electron integral flux, overlaid with the Galileo Trajectory

Galileo Interim Radiation Electron Model JPL

APL/JHU ENERGETIC PARTICLE DETECTOR



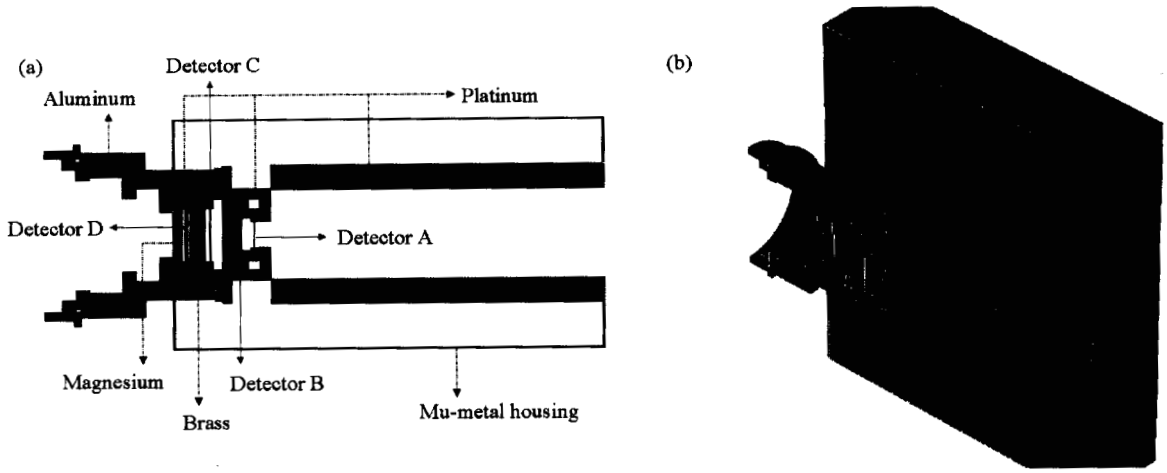


Channel Name	Species	Nominal Energy Range (MeV)	Channel Logic
B0	Z=1	3.20-10.1	A7 B1 NC2
B1	Electrons	1.5-10.5	A2 NA4 B1 NB2 NC2
DC0	Z≥1	14.5-33.5	NB1 D2 NC1
DC1	Z≥1	51-59	NB1 C2 D1
DC2	Electrons	≥2	NB1 D1 ND2
DC3	Electrons	≥11	NB1 C1 NC2 D1

Description of the LEMMS high energy electron and protons channels (Williams et al., 1992).

Galileo Interim Radiation Electron Model JPL

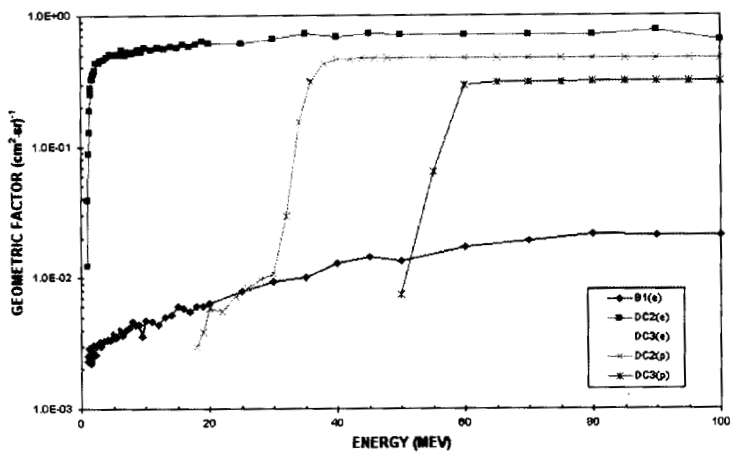
APL/JHU ENERGETIC PARTICLE DETECTOR



LEMMS modeling used in the MCNP/MCNPX simulations:
(a) Cross sectional view and (b) Iso-view

Galileo Interim Radiation Electron Model JPL

GEOMETRIC FACTORS



$$(cts/s)_{APL} = \int_0^\infty \frac{dI(E)}{dE} G(E)\cdot dE = J_0 \int_0^\infty \left(E_i/E_0\right)^{-X} G(E)\cdot dE \cong J_0 \sum_{i=1}^{\infty} \left(E_i/E_0\right)^{-X} G(E_i)\cdot \Delta E_i$$

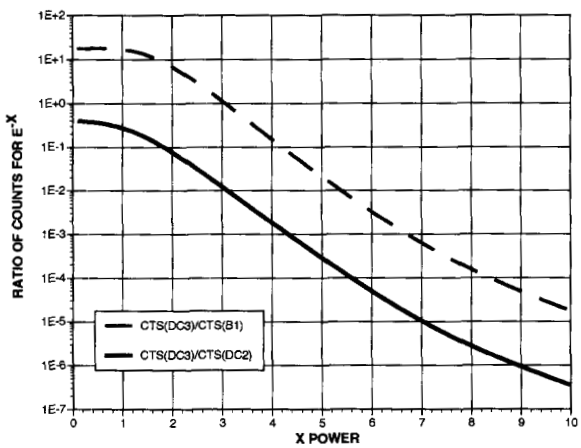
Where:

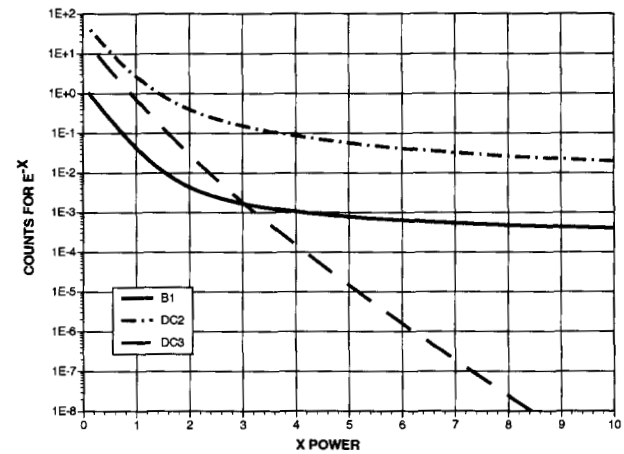
E_i = Energy steps (E_i = 1 MeV here)
E_0 = 1 MeV
$(cts/s)_{APL}$ = Counts per second from EPD channels (B1, DC2, DC3)
$I(E_i)$ = Integral electron flux at E_i
$\frac{dI(E_i)}{dE}$ = $J(E_i)$ = Differential electron flux at E_i
$J(E_i)$ = $J_0\,(E_i/E_0)^{-x}$ (units of (cm²-s-sr-MeV)⁻¹)
$G(E_i)$ = Geometric factor at E_i

Galileo Interim Radiation Electron Model JPL

COUNT RATE TO FLUX CONVERSION

$$J(E) \sim J_0(E/E_o)^{-X}$$



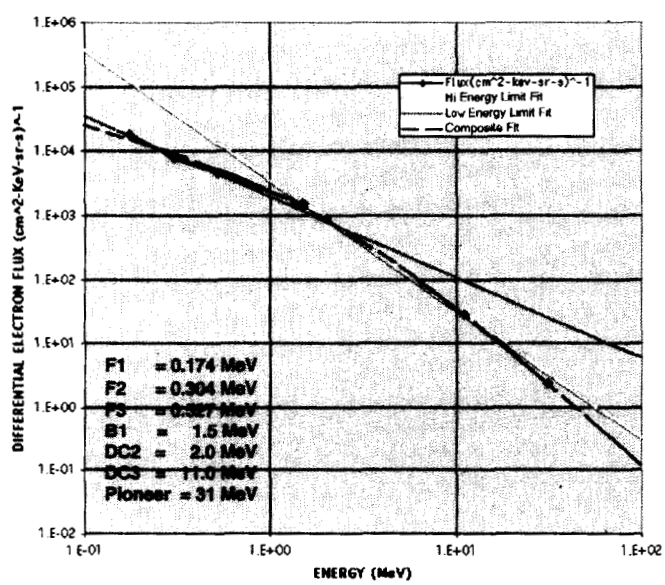


[Cnts(DC3)/Cnts(B1)] ---> X
[Cnts(DC3)/Cnts(DC2)]

J_0 = [Obs Cnts]/[Pred Cnts from X]

Galileo Interim Radiation Electron Model JPL

SPECTRAL FITTING PROCEDURE



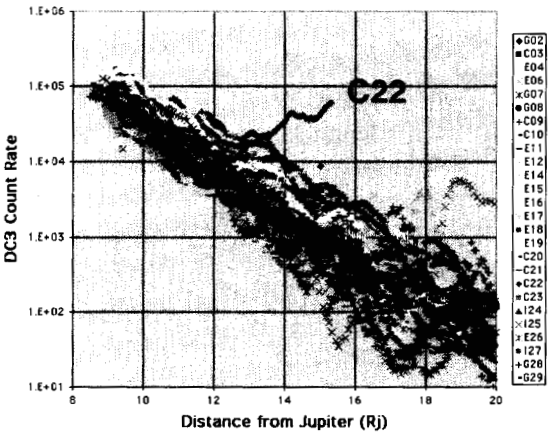
$$F(E) = J_o E^{-A}(1 + \frac{E}{E_o})^{-B}$$

Where:

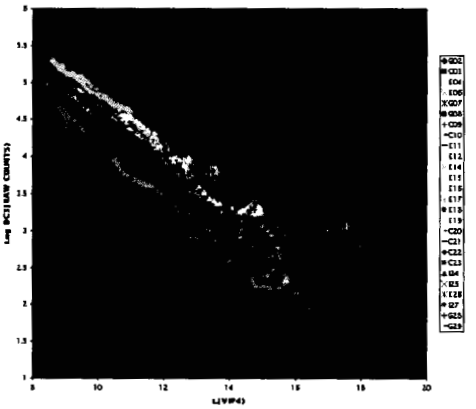
- **F = Differential electron flux as function of E**
- **E = Electron energy (MeV)**
- **J_o= Constant (roughly differential flux at E = 1 MeV)**
- **A = Constant (approximately power law index for low energy component)**
- **B = Constant (A+B is approximately power law index for high energy component)**
- **E_o= Constant (approximately breakpoint energy between low and high energy spectra)**

Galileo Interim Radiation Electron Model JPL

RADIAL VS L-SHELL ORBITAL VARIATIONS



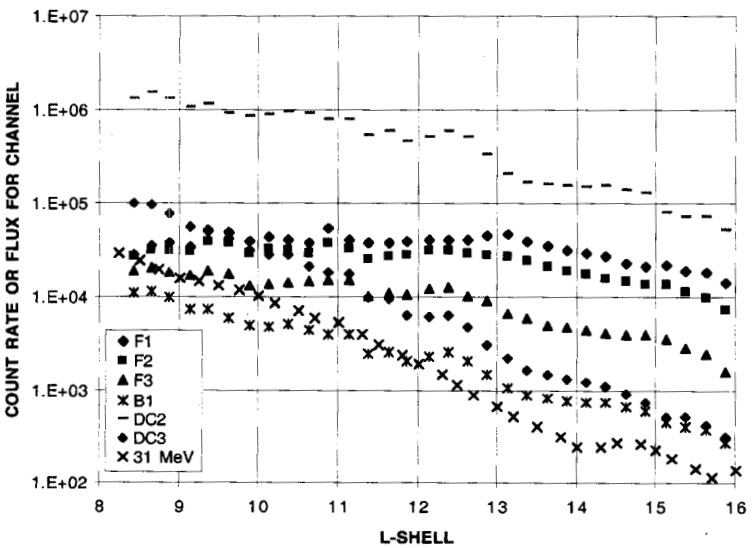
DC3(11 MeV) Count Rates vs Rj
Orbits G02-G29



DC3(11 MeV) Count Rates vs L
Orbits G02-G29

Galileo Interim Radiation Electron Model JPL

EPD COUNT RATE* AVERAGES VS L-SHELL

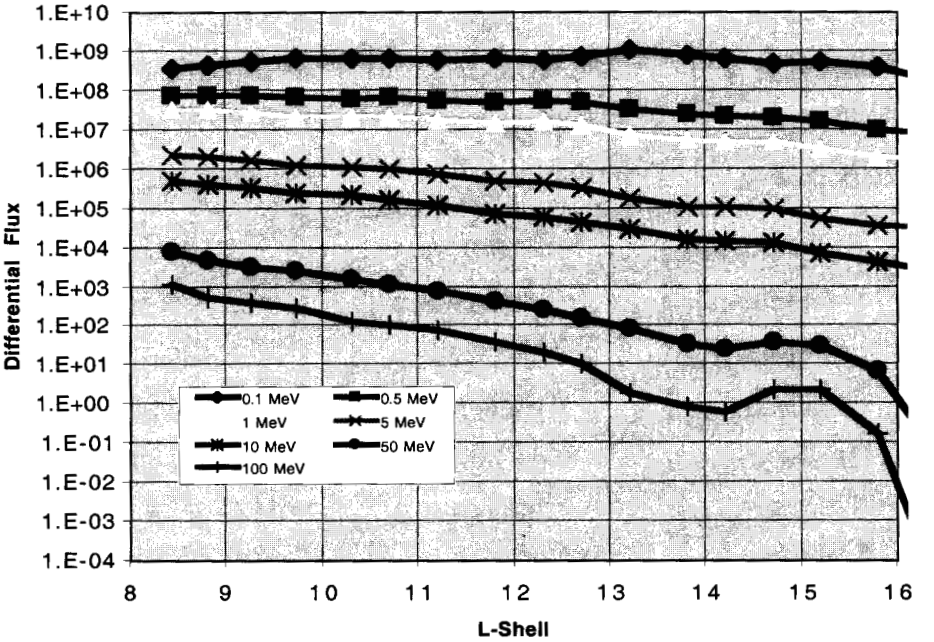


F1 = 0.174 MeV
F2 = 0.304 MeV
F3 = 0.527 MeV
B1 = 1.5 MeV
DC2 = 2.0 MeV
DC3 = 11.0 MeV
Pioneer = 31 MeV

*31 MeV Channel is Omni-Directional Flux

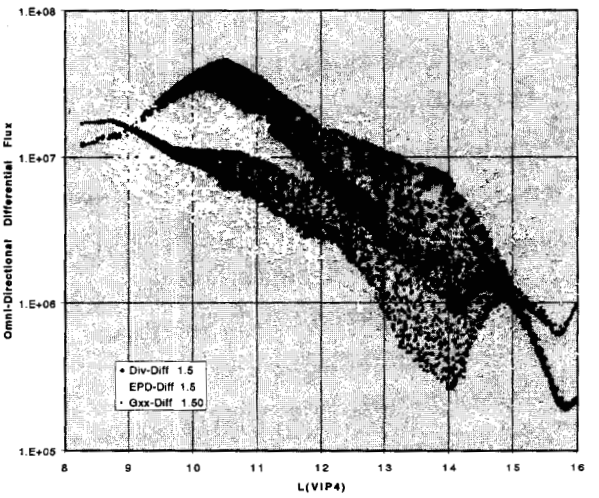
Galileo Interim Radiation Electron Model JPL

EPD OMNI-DIRECTIONAL ELECTRON MODEL FOR THE EQUATORIAL PLANE

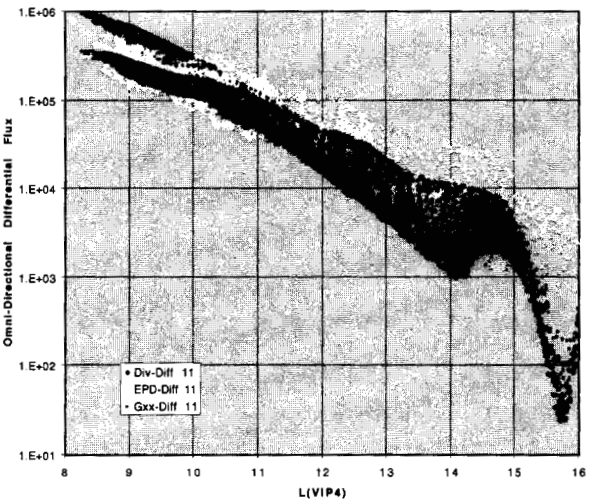


*Units = $(cm^2\ s\ MeV)^{-1}$

Galileo Interim Radiation Electron Model JPL



1.5 MeV ELECTRONS



11 MeV ELECTRONS

Blue = Divine; Pink = GIRE; Yellow = EPD Fits

Divine Model Estimates vs GIRE Estimates

Galileo Interim Radiation Electron Model JPL

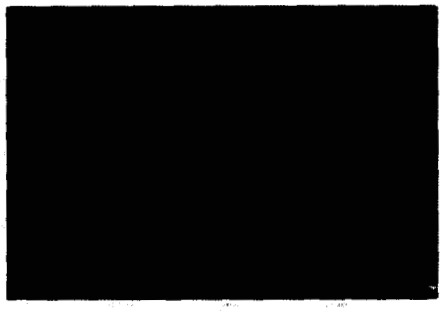
CONCLUSIONS

- APL EPD 1-11 MEV ELECTRON DATA CONVERTED INTO FLUX ESTIMATES USING MODELED GEOMETRIC CROSS SECTIONS
- AVERAGE FLUXES FOR L = 8-16 FIT WITH CONTINUOUS SPECTRUM FOR ENERGIES 0.174-31MEV (EPD OMNI-DIRECTIONAL EQUATORIAL MODEL)
- DIVINE MODEL PITCH ANGLE VARIATIONS COMBINED WITH EPD MODEL TO GIVE GIRE MODEL FOR L=8-16
- COMPUTER MODEL AND REPORT ARE AT:

http://www.openchannelfoundation.org

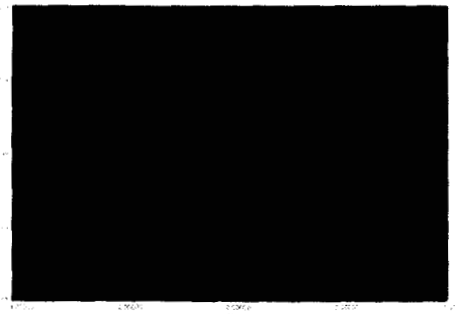
Galileo Interim Radiation Electron Model JPL

The Next Step:



Original Synchrotron data plot....

Original Divine Model with high latitude pitch angle "cut"



Divine Model Fit—includes thin disk component between 2 and 4 L plus high latitude field aligned component.

Disk Component:

$1<L<4$

$Flux' = Fux(Divine) \times [.8+3 \times SIN^{40}(\alpha)]$

High Latitude Field Aligned Component:

$L<2$ and $\alpha<\alpha_c$

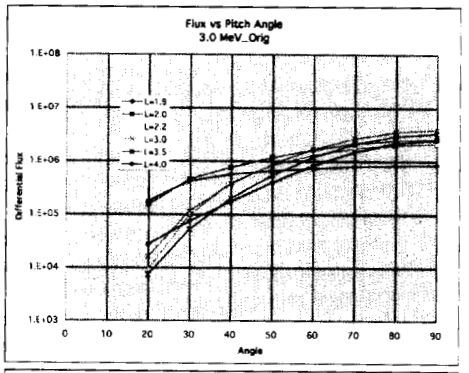
$Flux'' = 0$

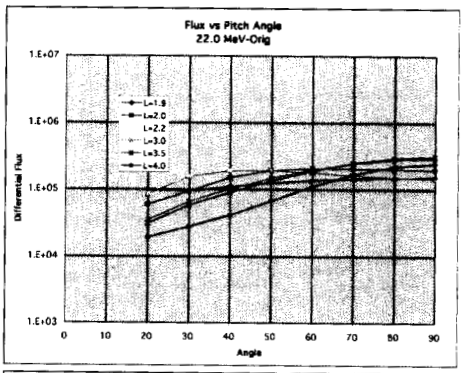
$2<L<4$

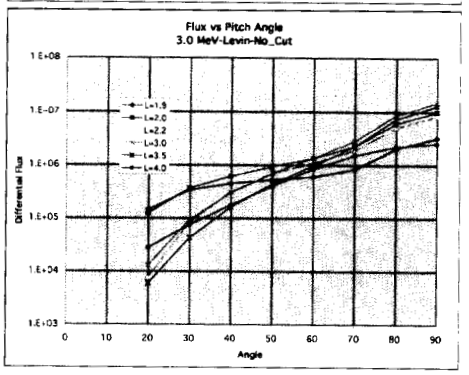
$Flux'' = 0.6*Flux'/SIN^3(\alpha)$

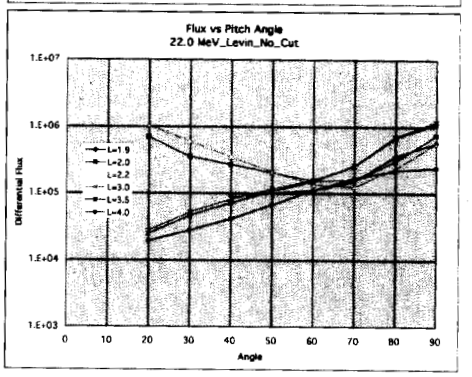
Galileo Interim Radiation Electron Model JPL

Pitch angles for original Divine and Synchrotron Fit









***At 22 MeV, both include high latitude components**