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Jovian Radiation Environment Models at JPL

By Insoo Jun

Jet Propulsion Laboratory, California Institute of Technology

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Topics

Background

Divine-Garrett Model

Galileo Interim Radiation Electron (GIRE) Model
- Synchrotron update

GIRE2K

GIRE2p

Heavy Ion Counter (HIC) Model

Statistics

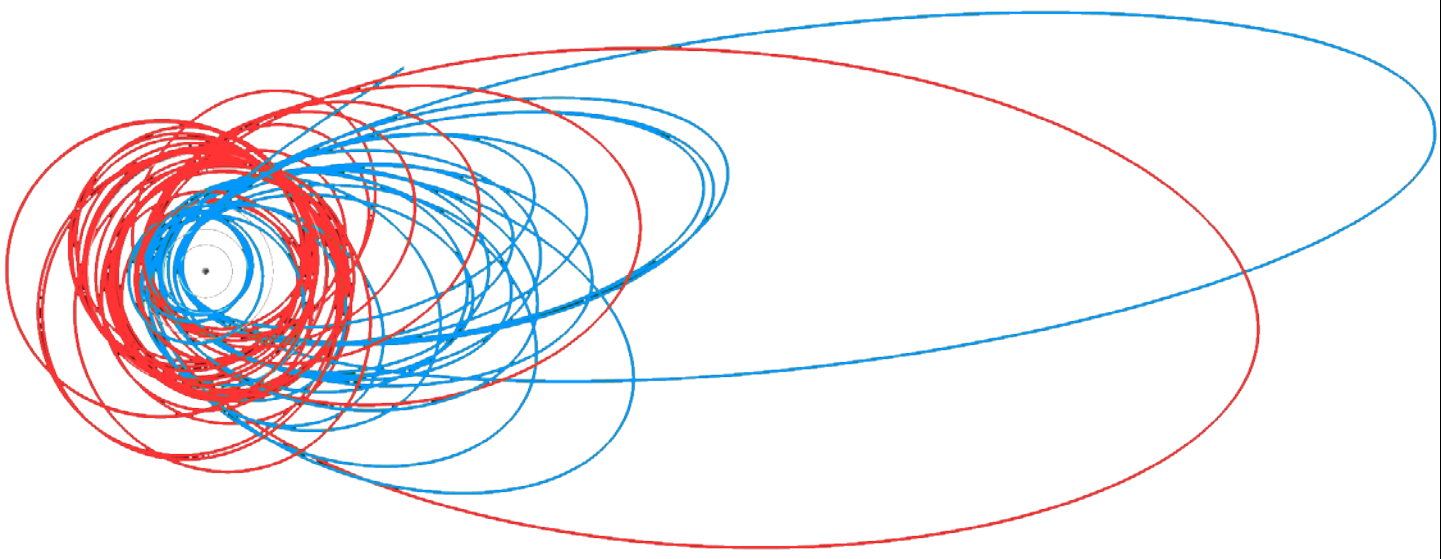
Background

Reducing the uncertainty by understanding and incorporating all data into models has been a focus for over decade

Significant progress has been made using the data from Galileo

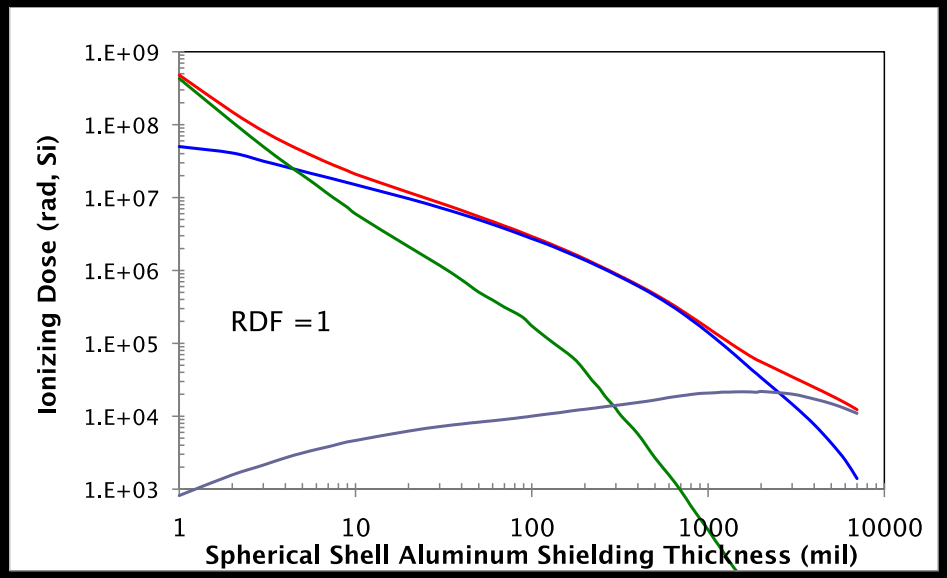
- Electron models
- Proton model
- Heavy ion model
- Plasma model
- Better understanding of temporal behavior
- Statistics

General Radiation Environment Characteristics (1)



Typical orbiter spends ~20% of the Jovian tour duration within 30Rj, but it accounts for >95% of the total dose during the tour → An accurate model of radiation environment within 30Rj is critical

General Radiation Environment Characteristics (2)



Jovian Electrons are the dominating environment consideration for ionizing dose (see chart left), and displacement damage, and charging

Jovian protons are minor contributors to ionizing dose and displacement damage. However, it is important for surface materials such as solar cells

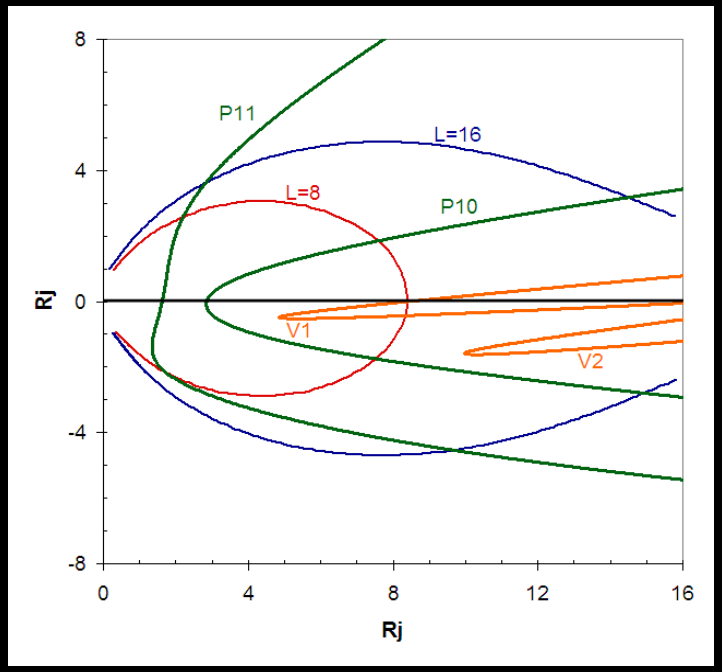
Jovian heavy ions are not important considerations for SEE to shielded electronics -> will be further discussed in later charts

Models for Trapped Particles

The Divine-Garrett Model

The Divine model has been the de-facto standard Jupiter radiation model since 1983:

- It is based on Pioneer and Voyager in-situ data plus Earth-based synchrotron observations
- It includes models for low energy electrons and ions (~eV to ~10 keV) and high energy trapped electrons and protons (from ~100 keV to >100 MeV)
- The model can provide radiation environment estimates for a wide spatial range (i.e., 1 < L < 12 for protons; 1 < Rj < 30 for electrons from the equatorial to the pole region) although the model itself was based on the data spatially and temporally limited



Divine and Garrett, JGR (1983)

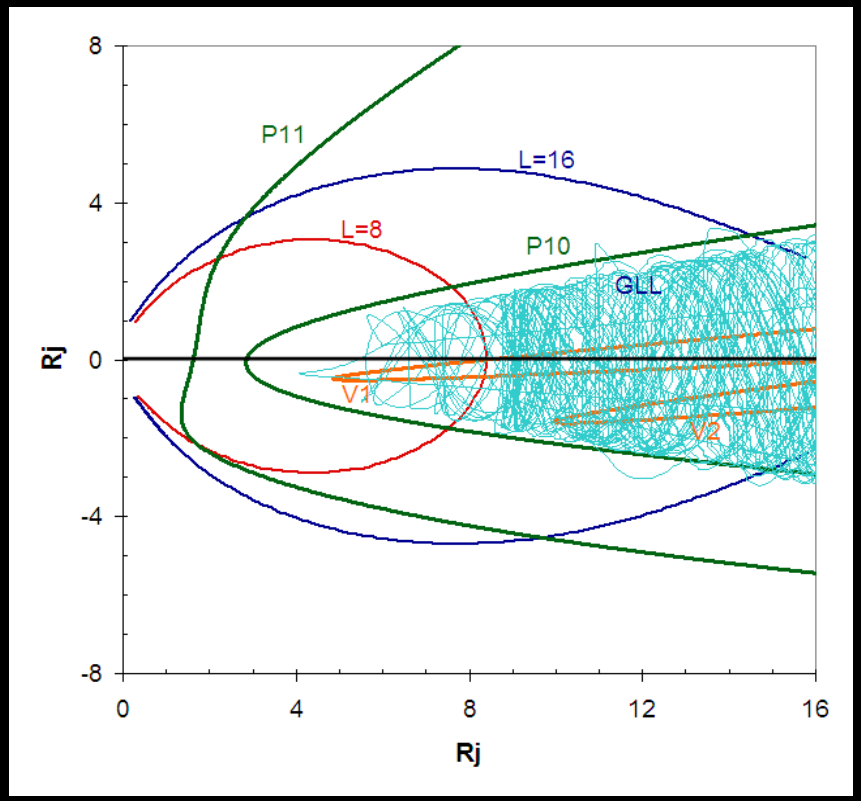
GIRE Update

GIRE is a significant improvement over the Divine's high energy electron model over the range of 8-16 L

Uses in-situ data from 35 Galileo orbits – based primarily on Energetic Particle Detector data (>1 MeV electron channels)

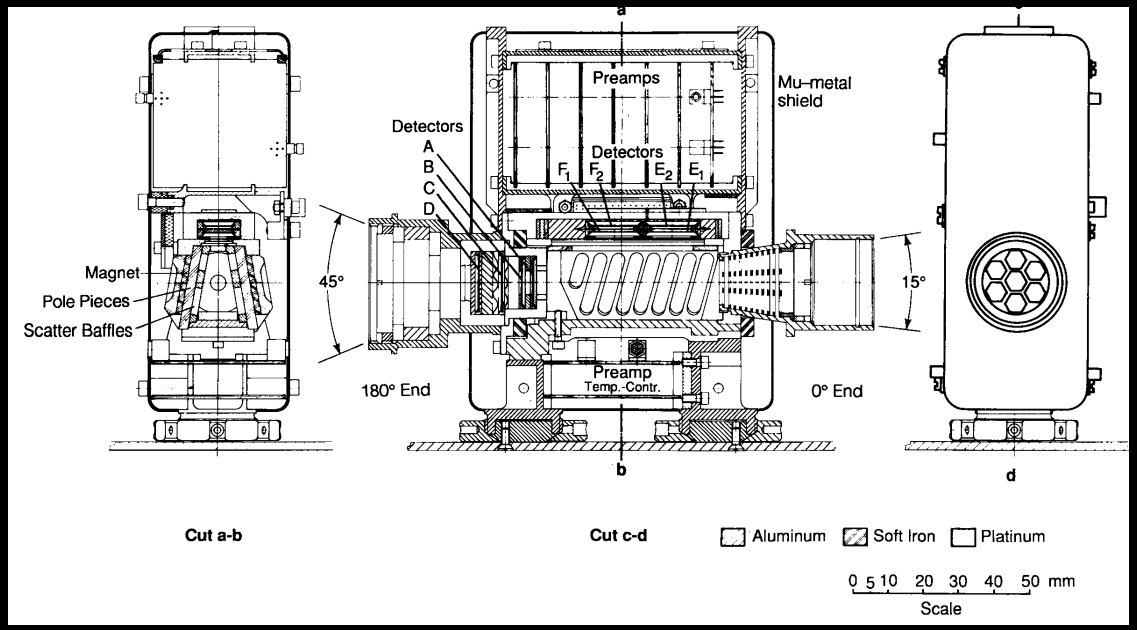
Assumes Divine pitch angle distributions

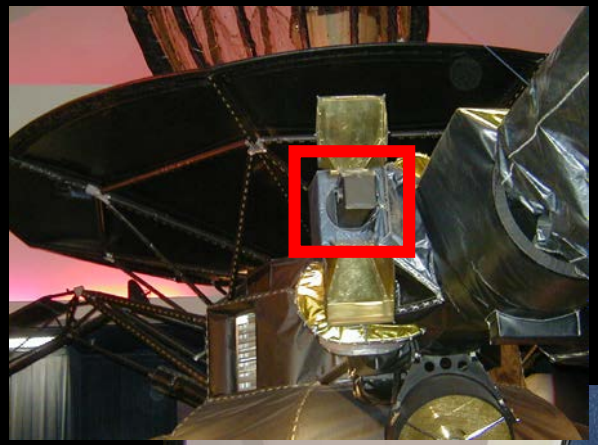
Covers energy range 0.1 MeV to ~30 MeV

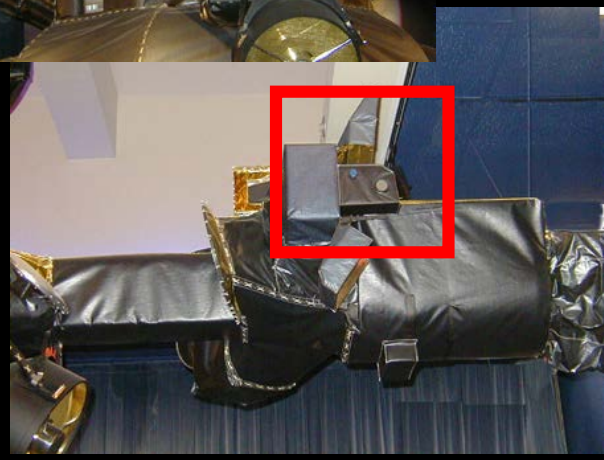


Garrett et al., JPL Publication (2003)
Jun et al., IEEE TNS (2005)

Galileo EPD (LEMMS)





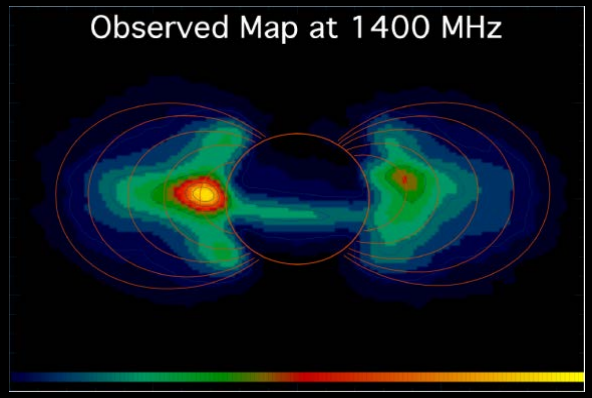


EPD=CMS+LEMMS

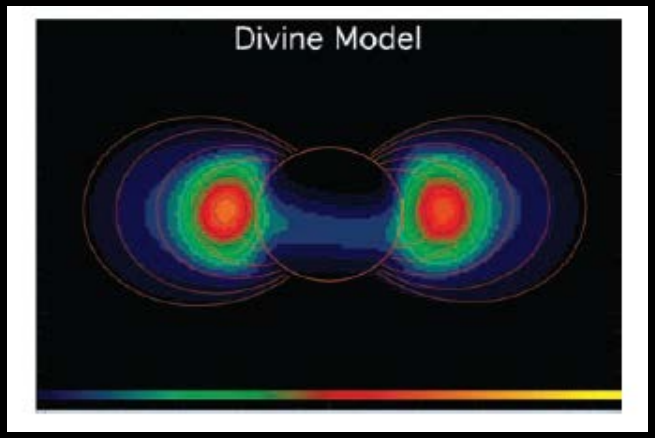
Channel Name	Nominal Energy Range (MeV)
F1	0.174-0.304
F2	0.304-0.527
F3	0.527-0.83
B1	1.5 – 10.5
DC2	>2.0
DC3	>11.0

Synchrotron Update

- Updated the Divine Model in the L<4 region using Earth-based radio observations

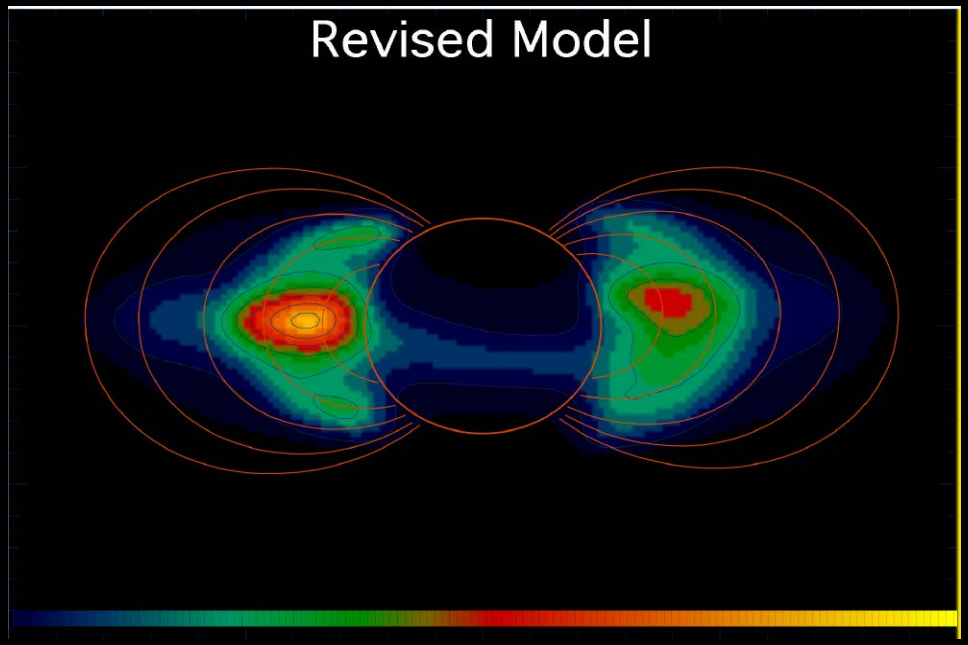


Synchrotron Observations



Synchrotron prediction based on the original Divine Model

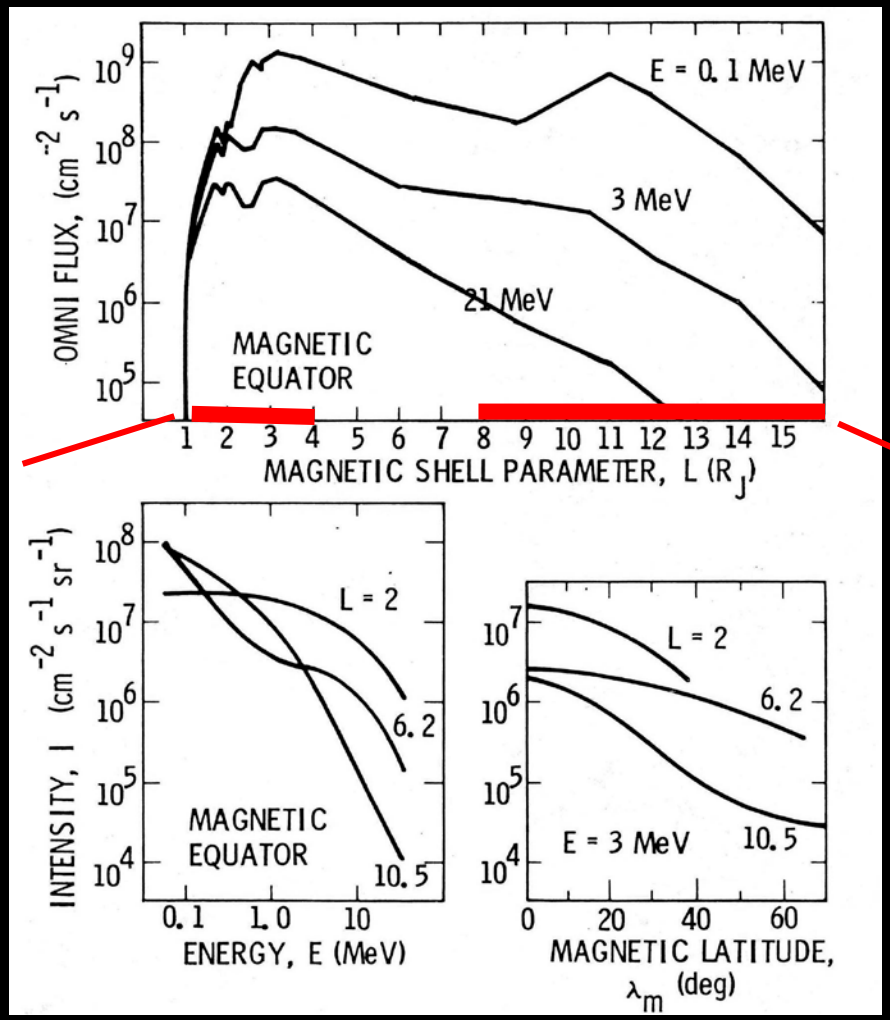
Synchrotron predictions based on update to Divine Model



Garrett et al., GRL (2005)

Spatial Coverage – GIRE model

SYNCHROTRON UPDATE

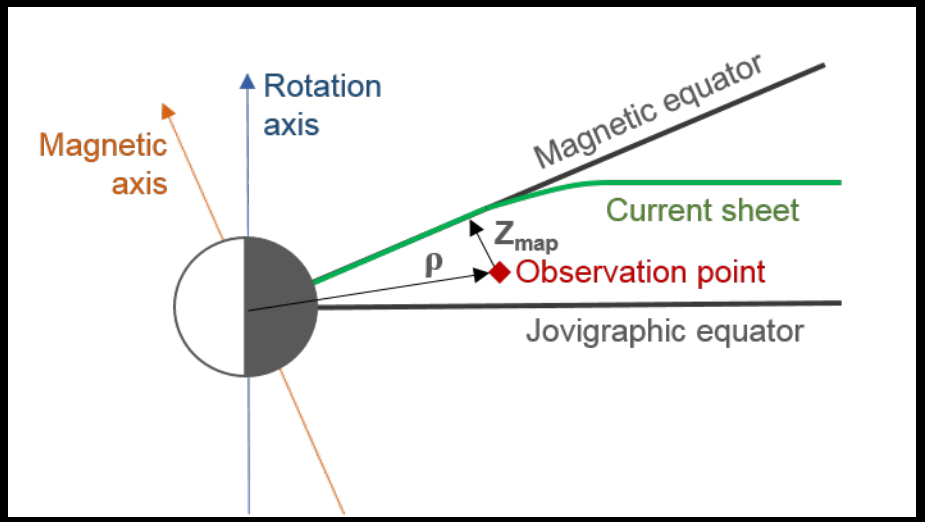


GIRE UPDATE

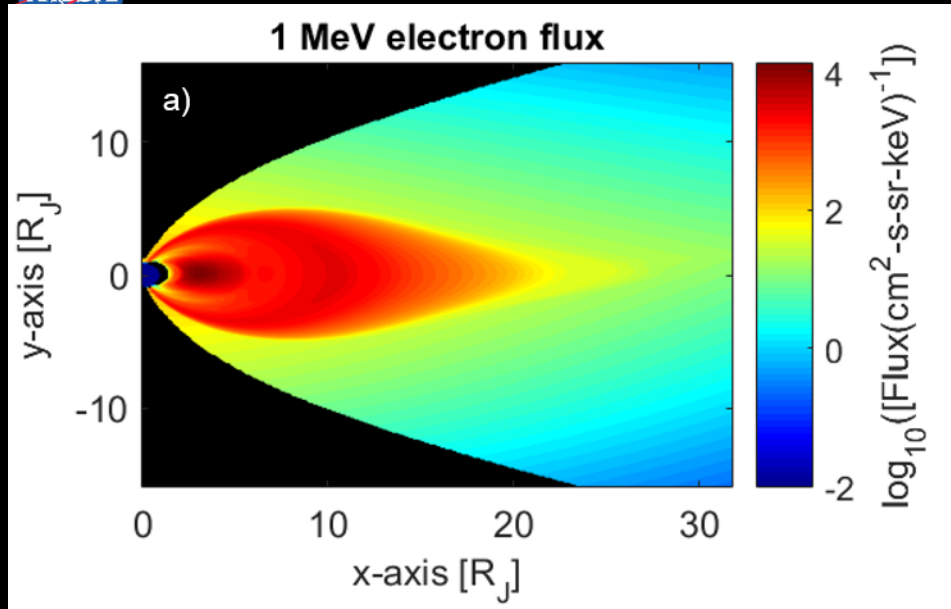
GIRE2K

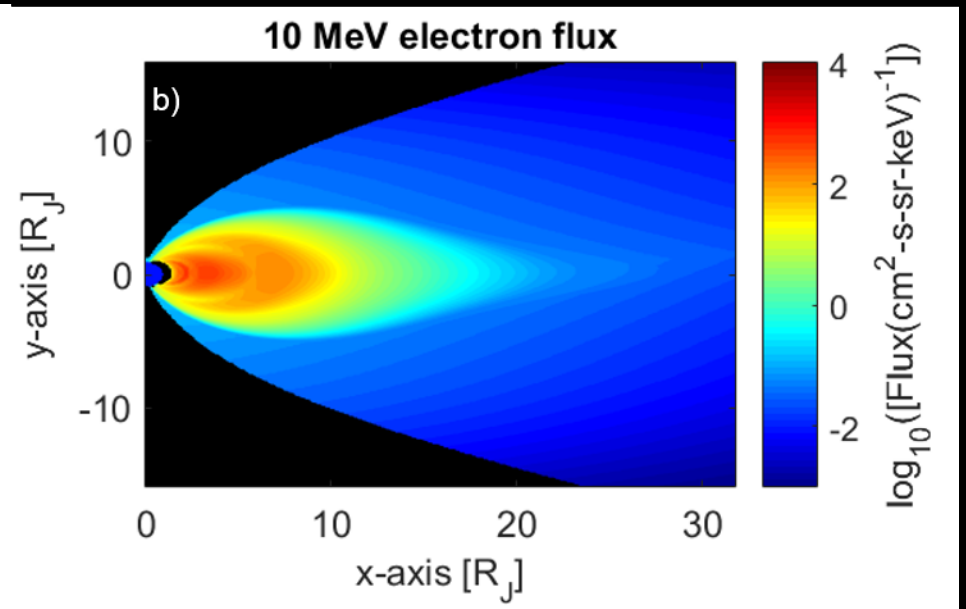
Update to GIRE to include L > 16

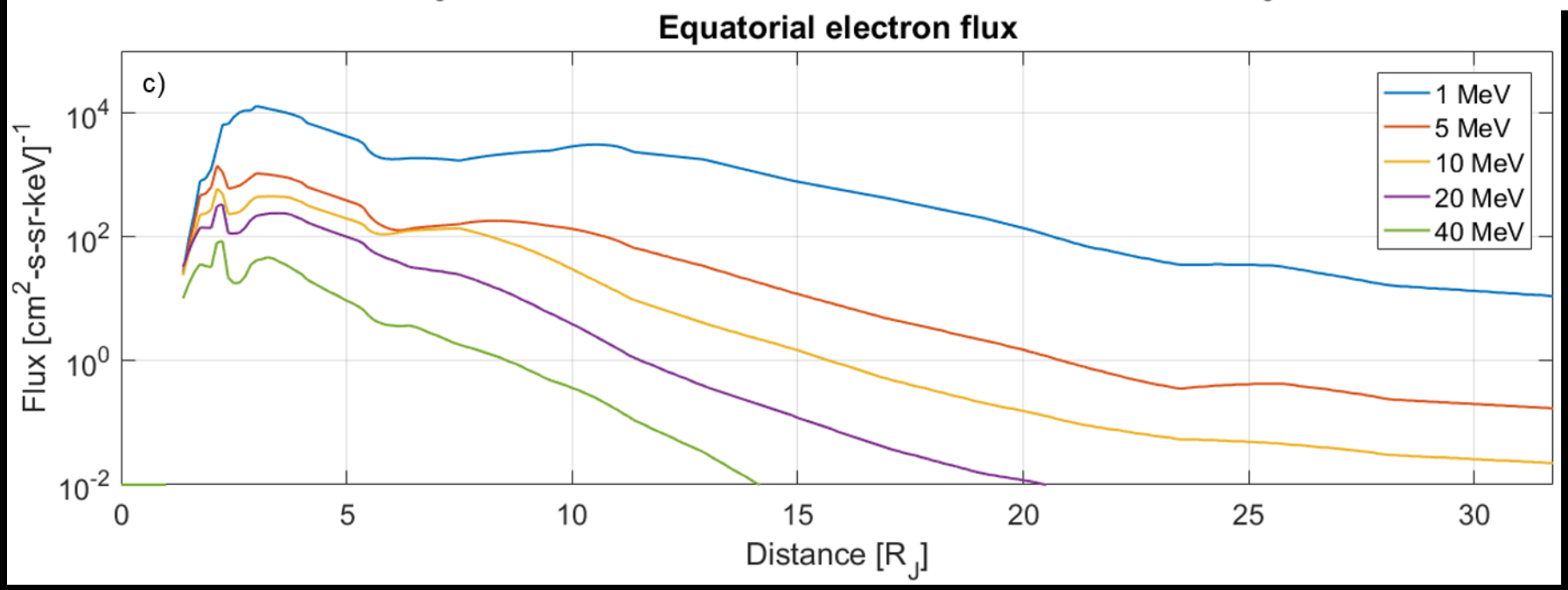
Uses Khurana's magnetic field model for the outer zone



Smoothly connected the inner zone model and the outer zone model


1 MeV electron flux
a)
y-axis [R_J]
x-axis [R_J]
log10([Flux(cm^2-s-sr-keV)^-1])
10
0
-10
0
10
20
30
4
2
0
-2

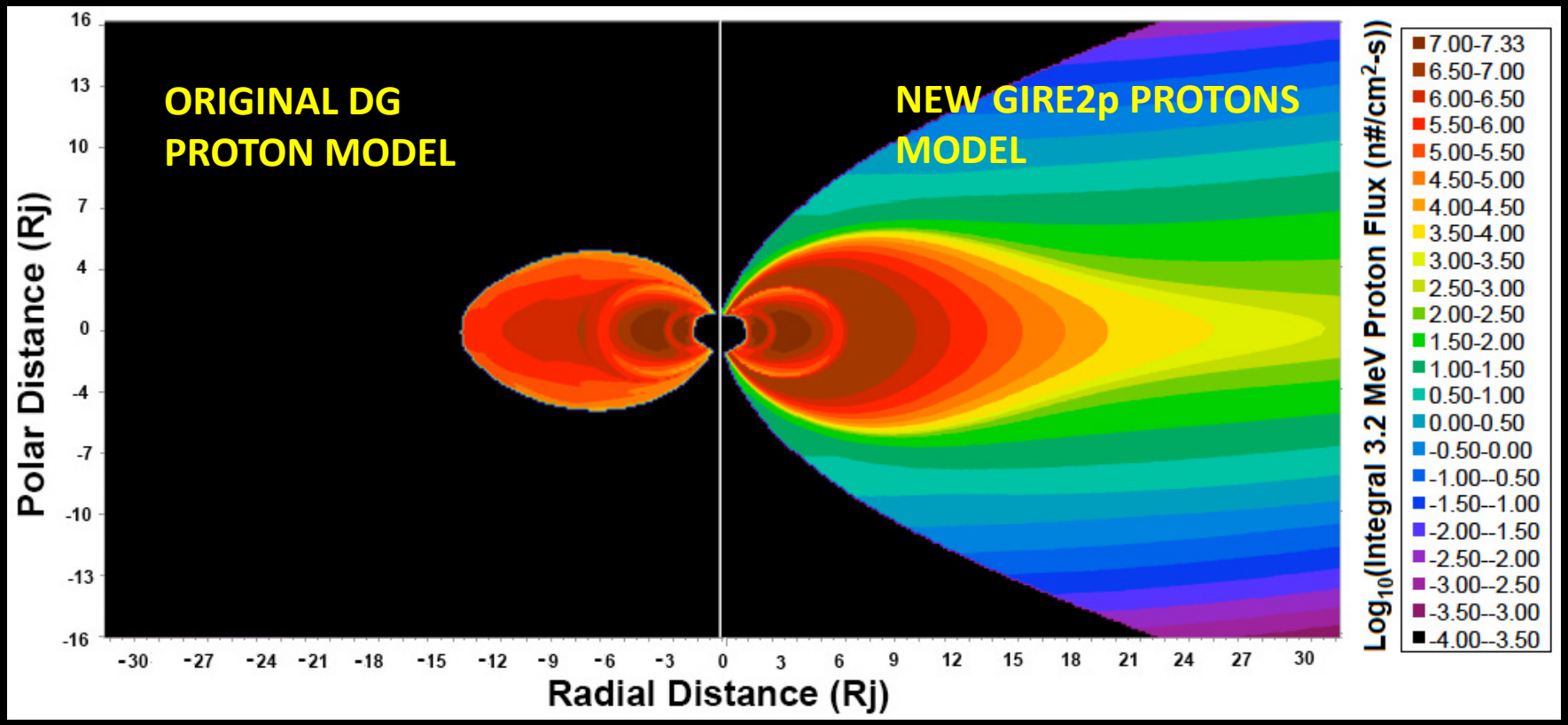

10 MeV electron flux
b)
y-axis [R_J]
x-axis [R_J]
log10([Flux(cm^2-s-sr-keV)^-1])
10
0
-10
0
10
20
30
4
2
0
-2


Equatorial electron flux
c)
Flux [cm^2-s-sr-keV]^-1
Distance [R_J]
10^4
10^2
10^0
10^-2
0
5
10
15
20
25
30
1 MeV
5 MeV
10 MeV
20 MeV
40 MeV

GIRE2p

Update to GIRE2K to include the proton model beyond L=12 based on the EPD proton data

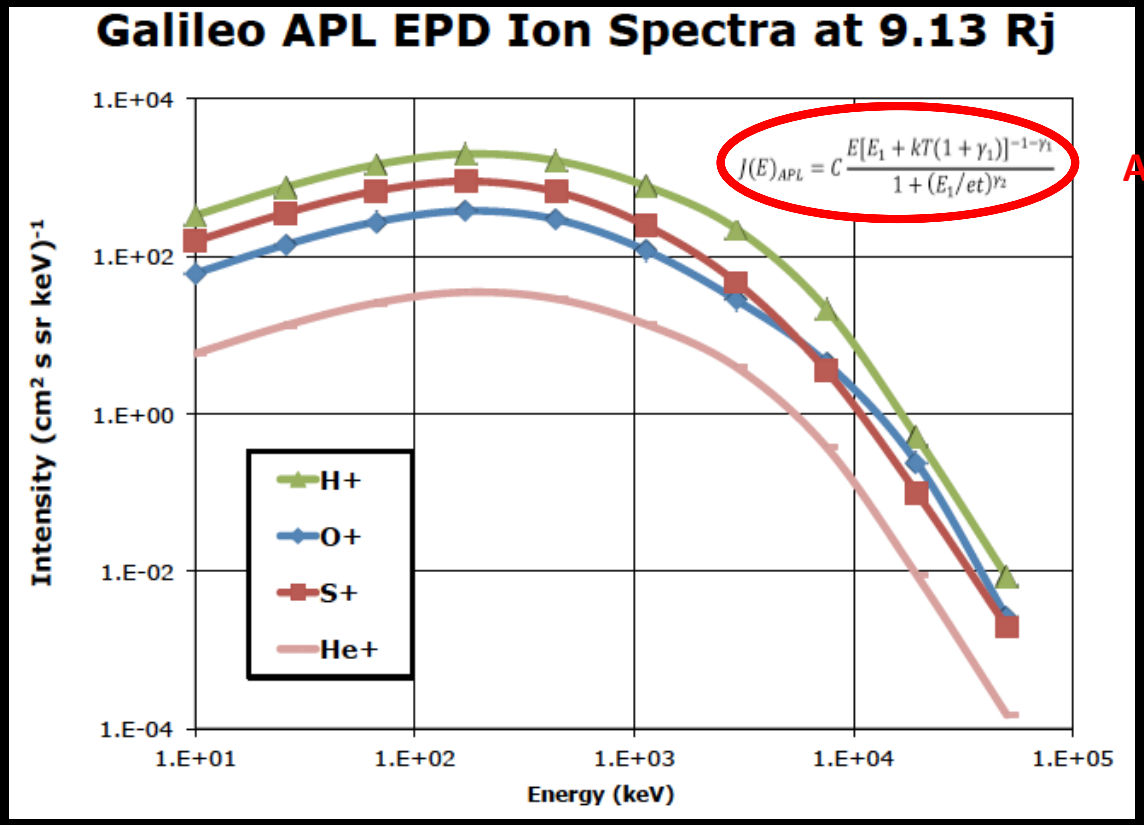
Meridian contours (Log_{10}(Diff Flux)) of GIRE2p:



(A) Original DG model and (B) New GIRE2 model proton integral fluxes (cm^{-2}-s^{-1}) for the 110°W meridian

Galileo EPD Ion Spectra

APL has provided 13 fits to the H^+, O^+, S^+, and He^+ ions between ~50 keV and 50 MeV near the jovian equatorial plane based on their Galileo EPD experiment**



**Mauk, B. H., D. G. Mitchell, R. W. McEntire, C. P. Paranicas, E. C. Roelof, D. J. Williams, S. M. Krimigis, and A. Lagg (2004), "Energetic ion characteristics and neutral gas interactions in Jupiter's magnetosphere," *J. Geophys. Res.*, *109*(A09S12), 24, doi:10.1029/2003JA010270.

Electron Contaminations of the Proton Channels

DC0(17-32 MeV) Geometric Factors

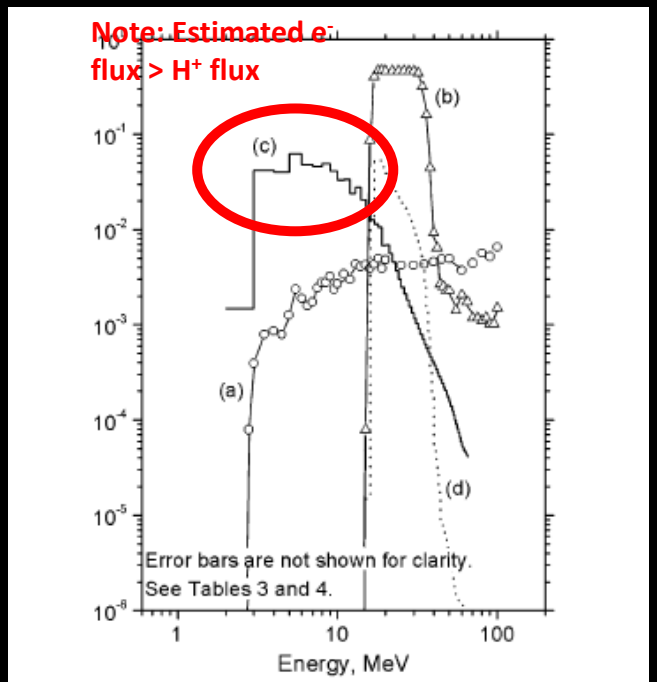


Fig. 7. DC0 channel: (a) *electron* and (b) *proton* geometric factors in cm^2 sr as a function of energy; relative contributions of (c) *electrons* and (d) *protons*, per 1 MeV energy bin, to the total count rates when the $9.2R_j$ electron/proton spectra from the D–G model (Fig. 9) are used for the count rate calculations.

Cross Sections for DC0

Note Comparative Effects of Electrons/Protons

B0(3.2-10.1 MeV) Geometric Factor

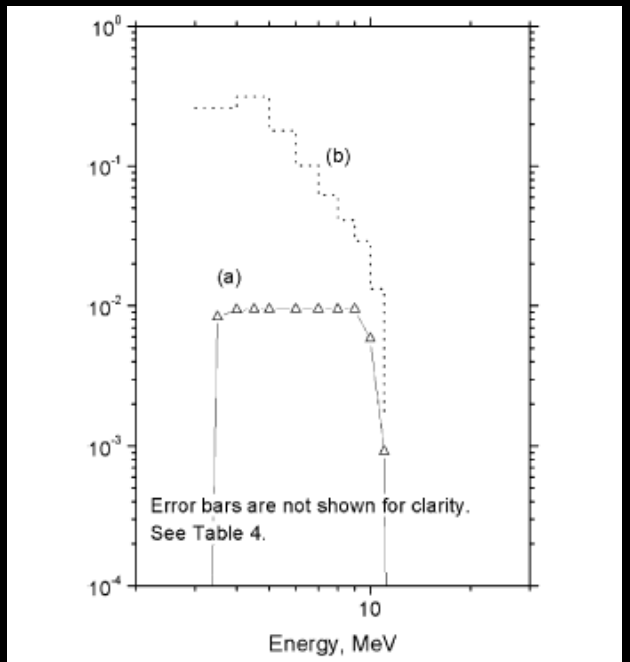
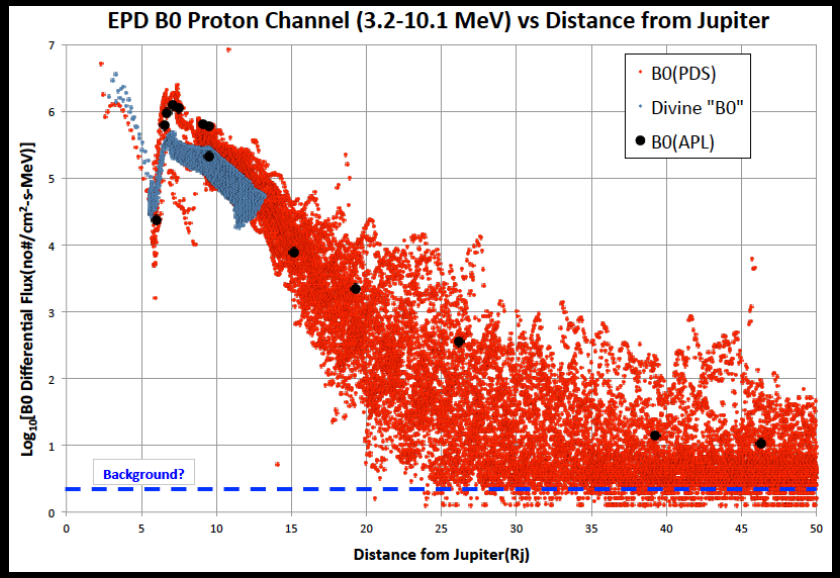


Fig. 6. B0 channel: (a) *proton* geometric factor in cm^2 sr as a function of energy; (b) relative contribution of *protons*, per 1 MeV energy bin, to the total count rate when the $9.2R_j$ proton spectrum from the D–G model (Fig. 9) is used for the count rate calculations. The electron contribution is zero.

"Good" B0 Proton Channel

Reference: Jun, I., J. M. Ratliff, H. B. Garrett, and R. W. McEntire, "Monte Carlo simulations of the Galileo Energetic Particle Detector", Nuc. Instr. and Methods in Phys. Res., A, Vol. 490, 465-475, 2002.

Fitting B0 Protons (3.2 -10.1 MeV)

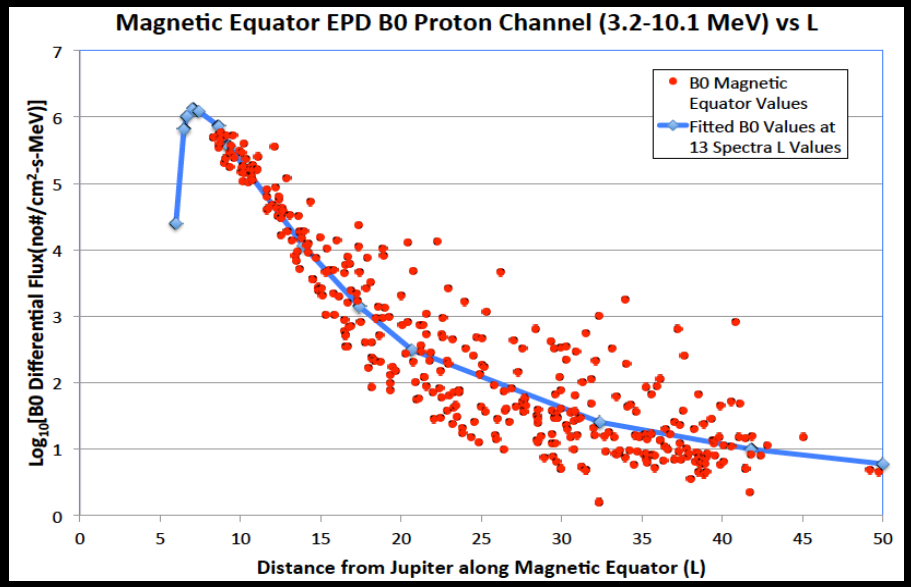


B0 vs Divine and Mauk et al. (2004)

The APL reference energy spectra [Mauk et al., 2004] were multiplied by $(J(B0)_{Eq}/J(B0)_{APL})$ (where $J(B0)_{Eq}$ is given by the equatorial fluxes estimated on the right) to give the proton spectra between 50 keV and 50 MeV at each corresponding equatorial L value.

B0 Fluxes along Magnetic Equator

We start with Galileo EPD spectra fits to H^+, He^+, O^+, and S^+ provided by APL (Mauk e al. 2004)**. For Protons, we "normalize" the spectra to the B0 channel fluxes along magnetic equator.



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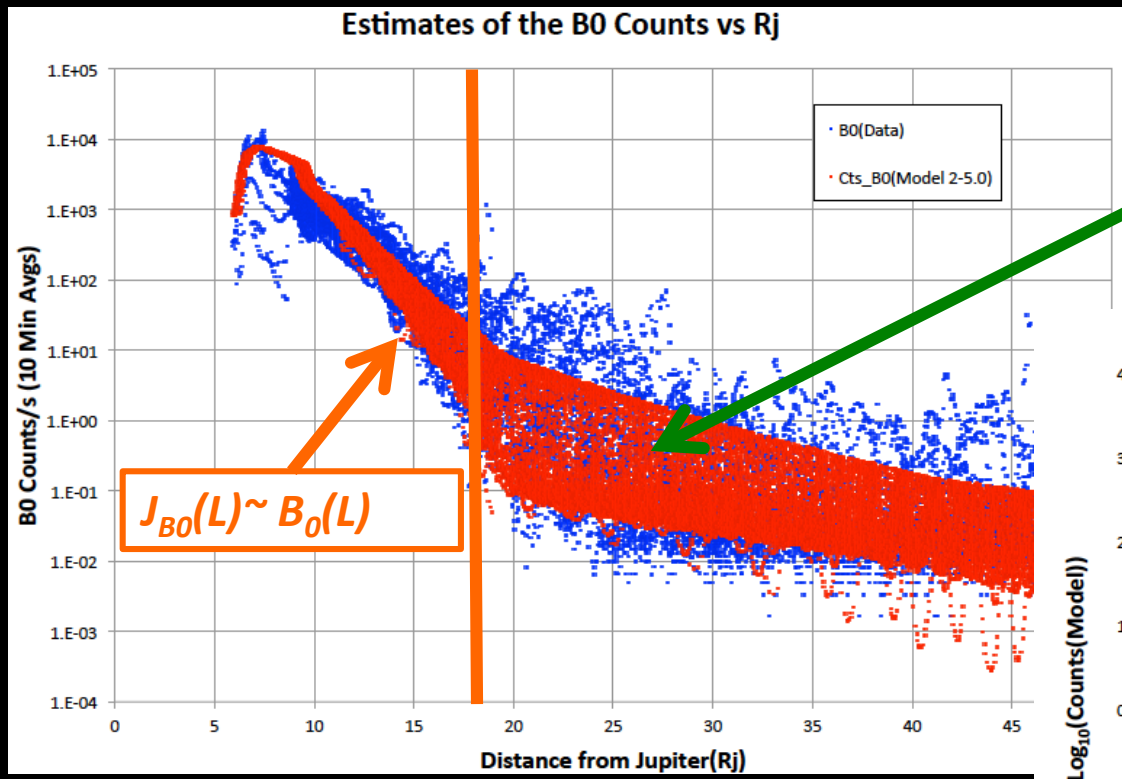
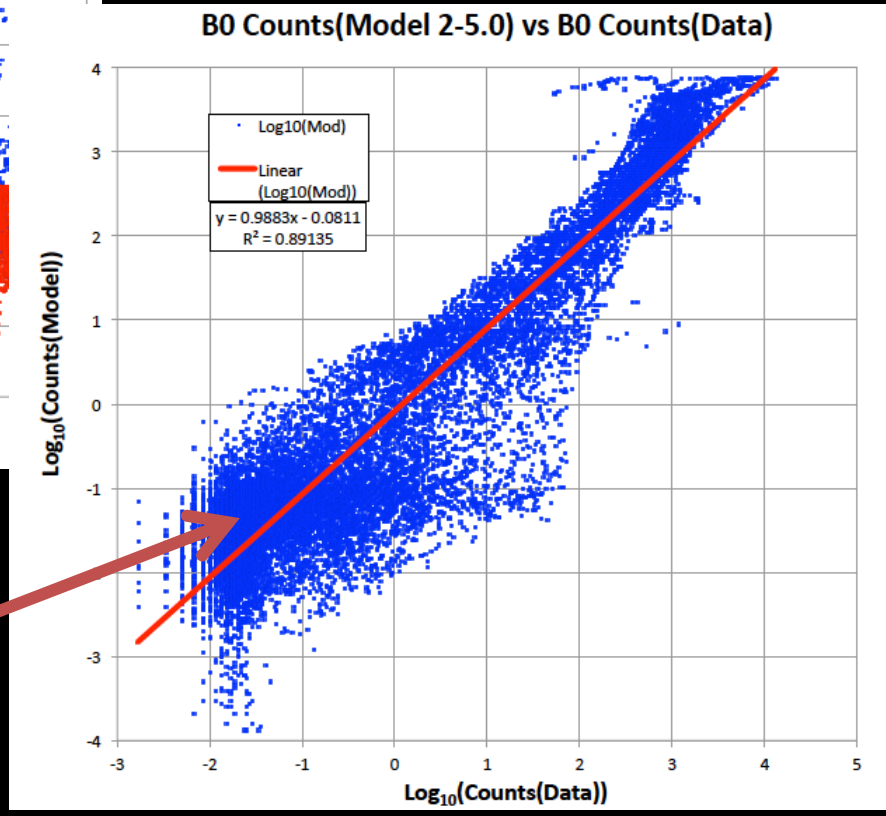
Comparison of EPD B0 Data Cts to Model Cts Predictions



$J_{B0}(L)\sim B_0(L)$

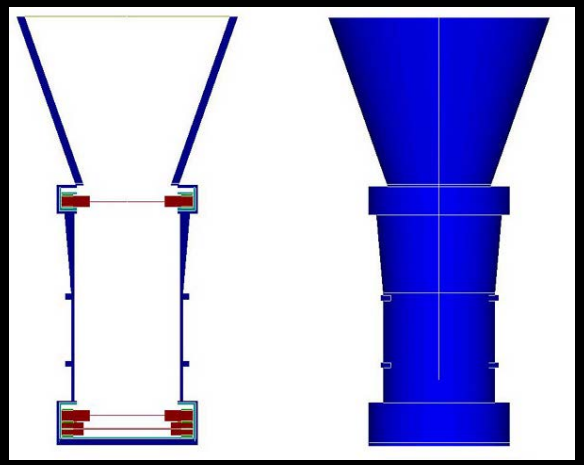
Assume Scale Height Variation of H=5 Rj beyond ~17 Rj:

$$J_{B0}(L,Z_{map})\sim B_0(L)\, e^{(-(Z_{map}/H)^2)}$$



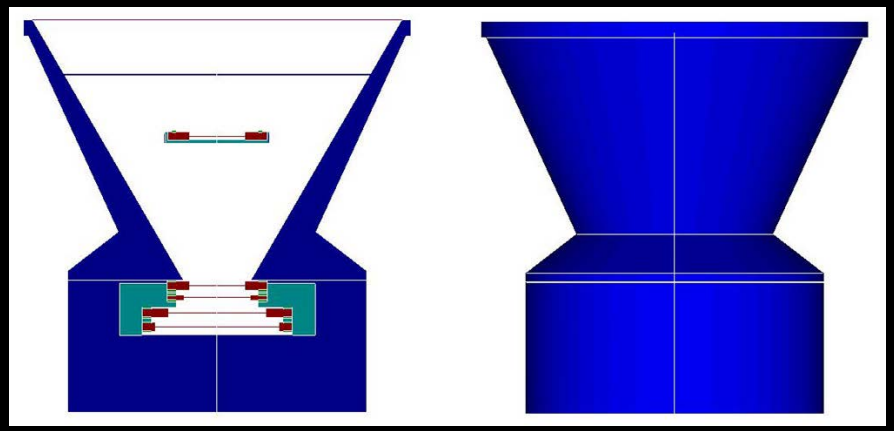
GIRE2P "Cts" ≈ B0 Cts (3.2-10.1 MeV)

Heavy Ion Model – Heavy Ion Counter

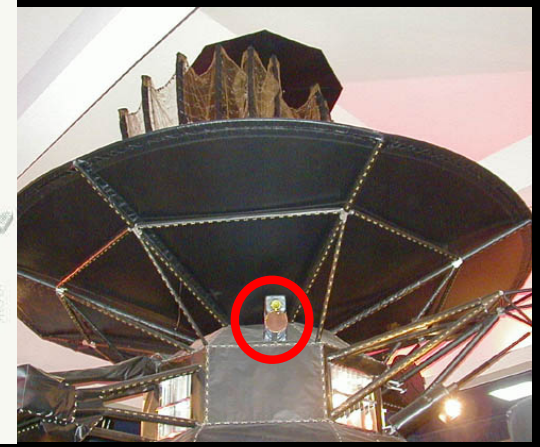


LET B

- Two solid-state dE/dx vs energy Low Energy Telescopes (LET B and LET E).
- Measured ~6 to >200 MeV nucl^{-1}, heavy ions from $_{6}$C to $_{28}$Ni.
- Returned data for all but 2 of the 35 orbits of the Jupiter system from 1995 to 2003.

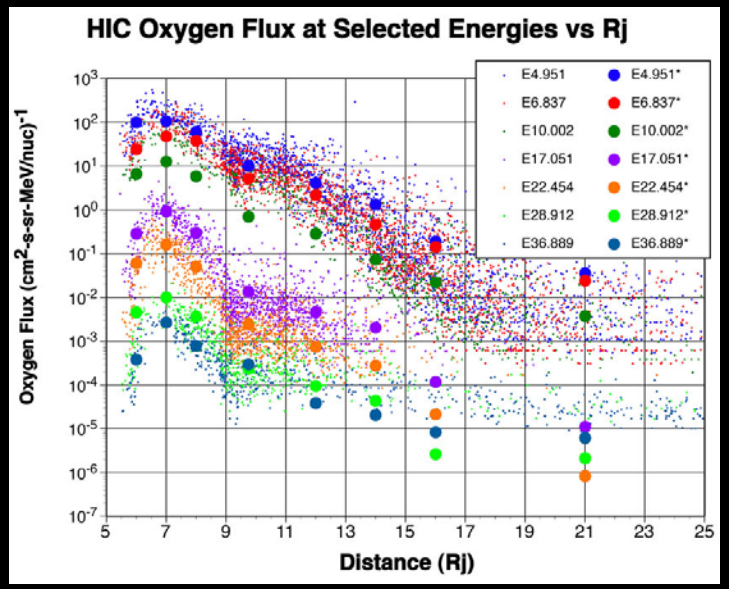


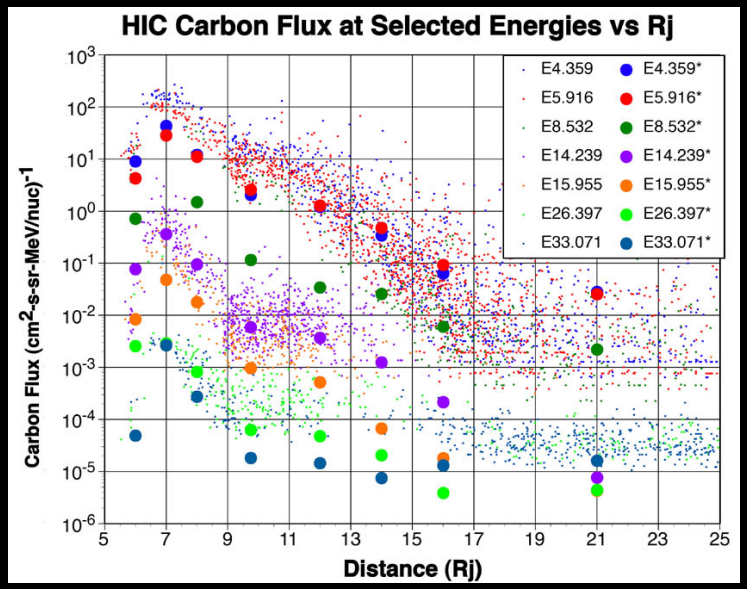
LET E

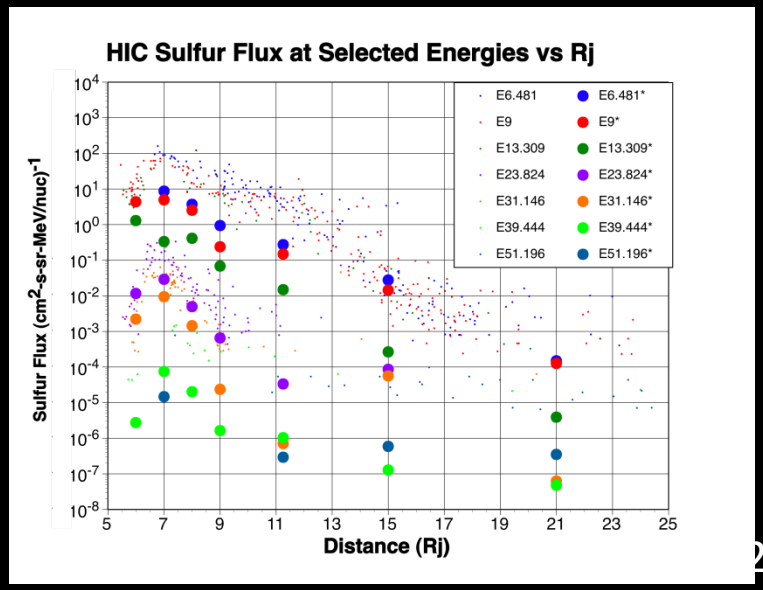


Heavy Ion Counter Observations

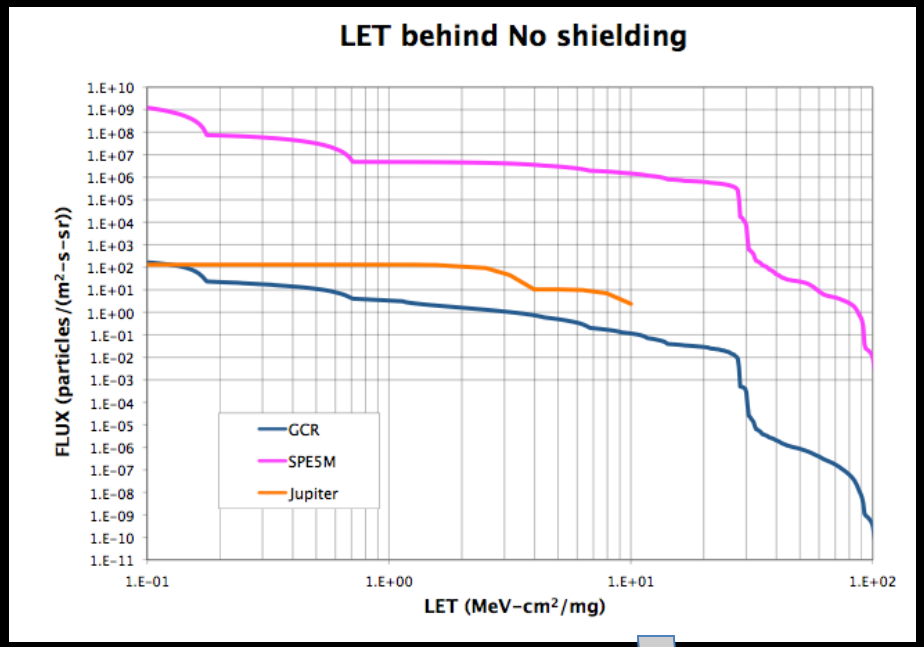
HIC fluxes at selected energies (small symbols; designated "E4.359", etc.) in units of MeV/nuc vs. radial distance. Also plotted are the averages for selected radial intervals and energies (large symbols; designated "E4.359*", etc.).

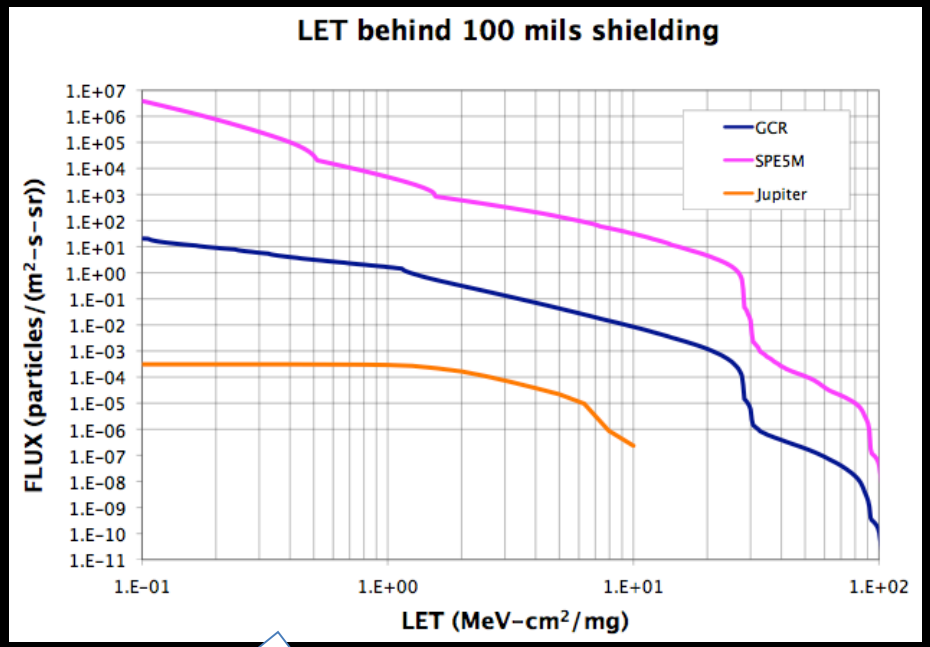






HIC Model Output

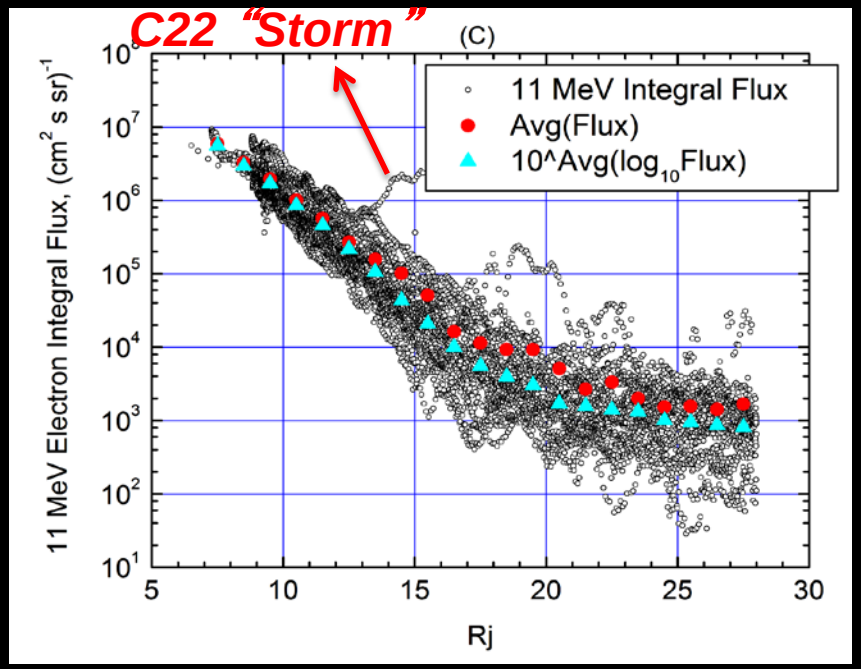




Minimal shielding attenuates the Jovian heavy ion environment to insignificant levels

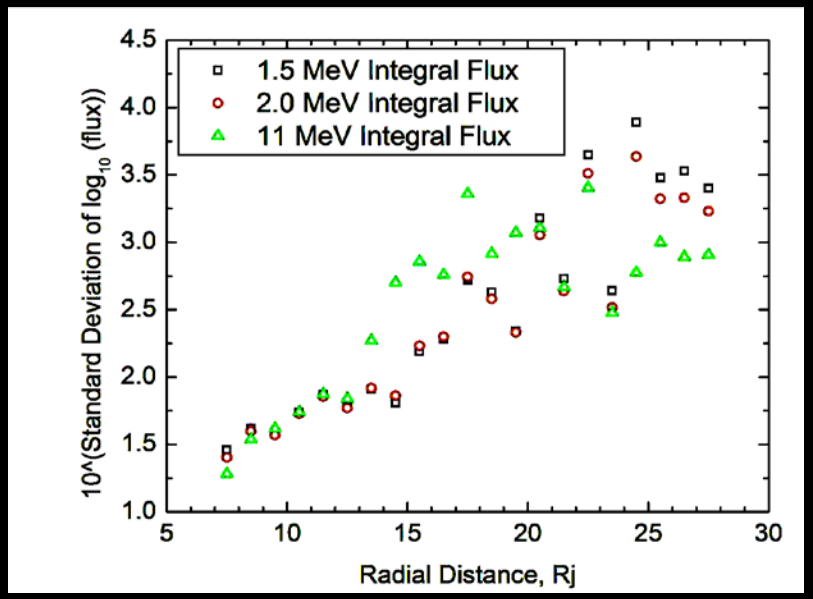
Statistics: Variation of Trapped Electrons

Variations in Energetic Particle Detector Fluxes with distance from Jupiter showing "average" and "storm" variations



Galileo EPD 11 MeV particle fluxes vs radial distance

Examples of log-normal fits to the Galileo electron fluxes



Standard Deviations of Electron Fluxes versus Rj

Jun et al., Icarus (2005)

"Storm" duration appears to be on the order of hours to days, indicating that the "mean" environment is a good representative of the expected long term exposure

Thank You!
Questions?