Review of the Jovian Trapped Particle Environment Models: Past, Present, and Future

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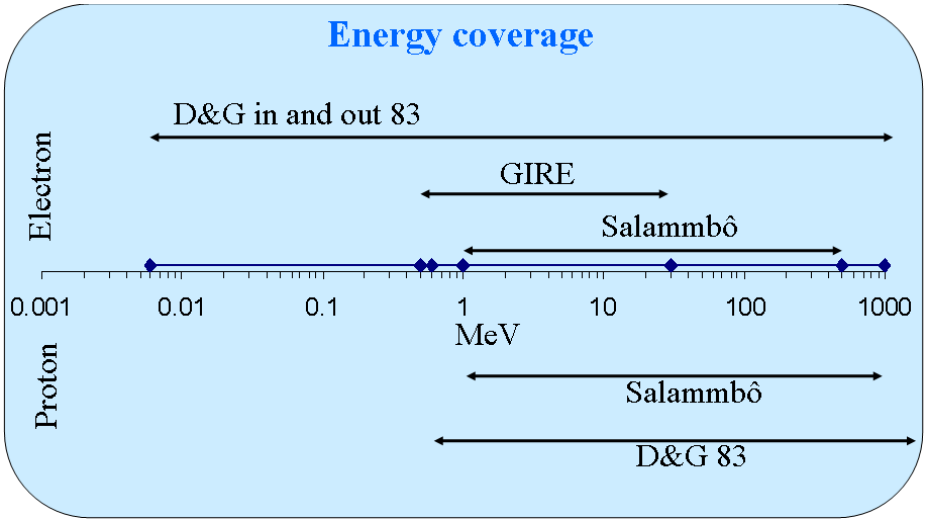
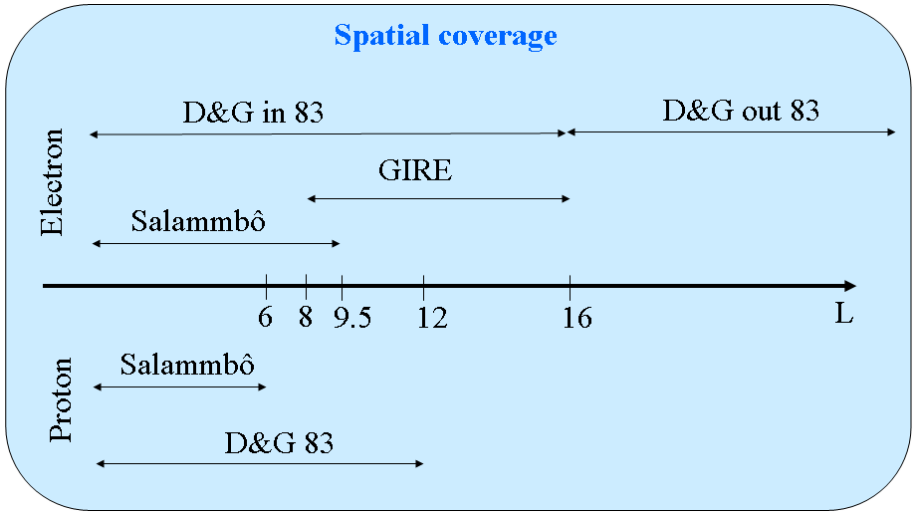
Agenda

- Review available models for
  - Trapped high energy electrons (>0.1 MeV)
  - Trapped high energy protons (>1 MeV)
  - Trapped heavy ions (>1 MeV/nuc)
- Discuss limitations of currently available models
  - Deficiencies
  - Discontinuity
- Discuss on-going efforts to improve or update the models
- Local environments at satellites (e.g., at Europa and Ganymede)
- Summary

Summary of Models Available and Coverage

Courtesy of S. Bourdarie

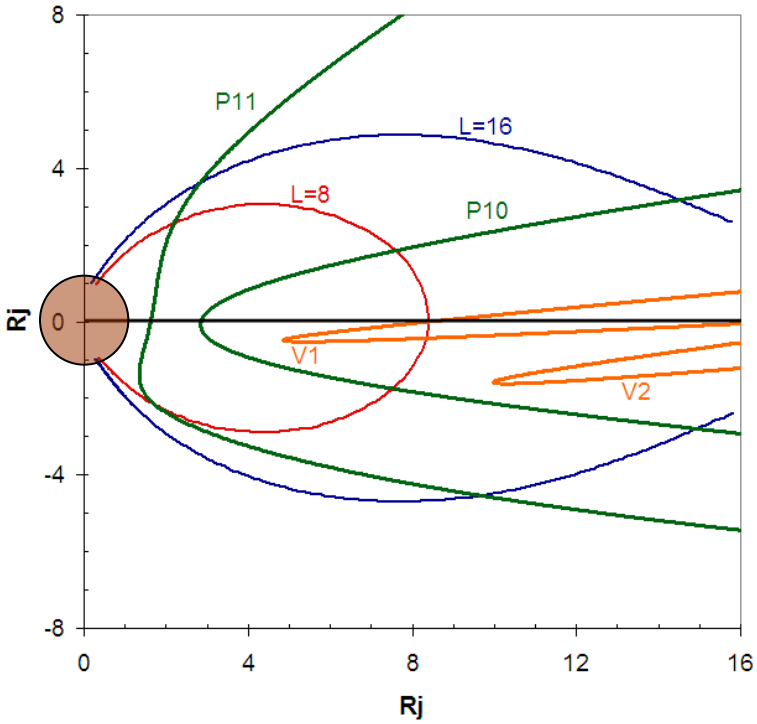




- Heavy ion model
  - See the next talk by H. Garrett, *et al.*:
    - "The Galileo Heavy Ion Environment as Modeled by the HIC Experiment"
  - Also see a poster paper by M. Kokorowski, *et al.*:
    - "Energetic Heavy Ion Depletion Observation Near Europa", SM23B-1607

The Divine Model

- The original Divine model has been 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 and high energy trapped electrons and protons (from ~eV to >100 MeV)

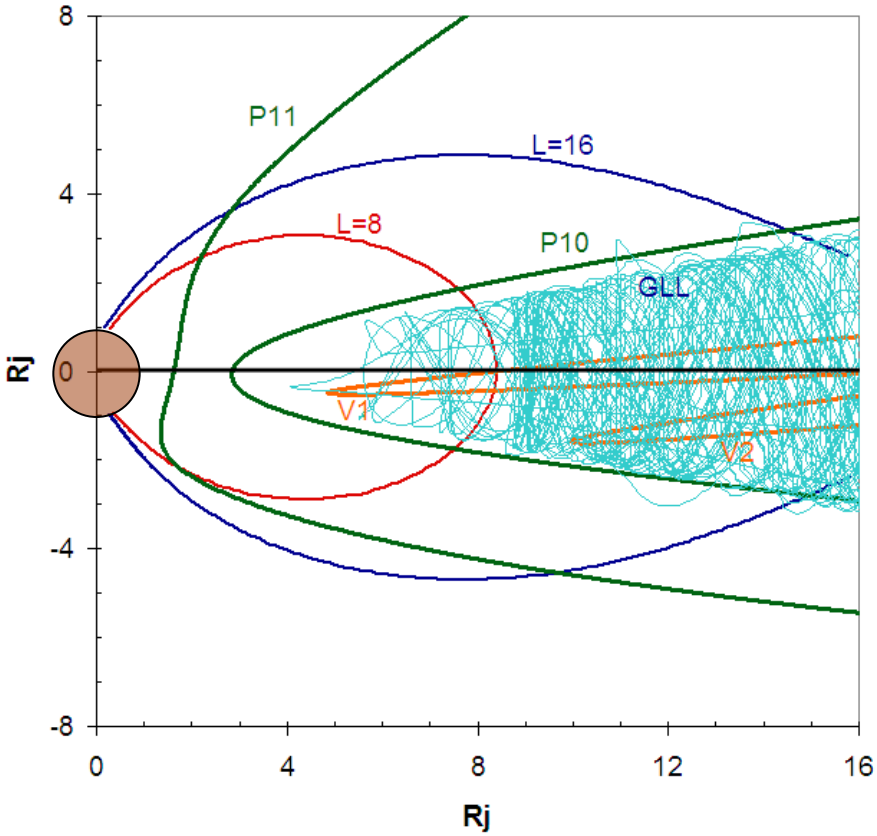


  - The model can provide radiation environment estimates for a wide spatial range (i.e., 1 < Rj < 30 from the equatorial to the pole region) although the model itself was based on the data spatially and temporally limited

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

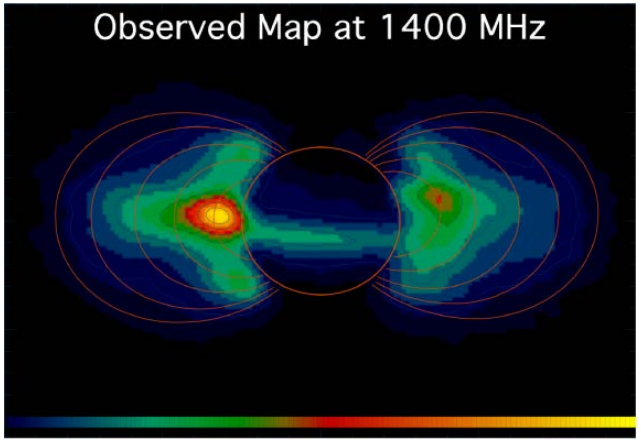


- Assumes Divine pitch angle distributions
- Covers energy range 0.1 MeV to ~30 MeV

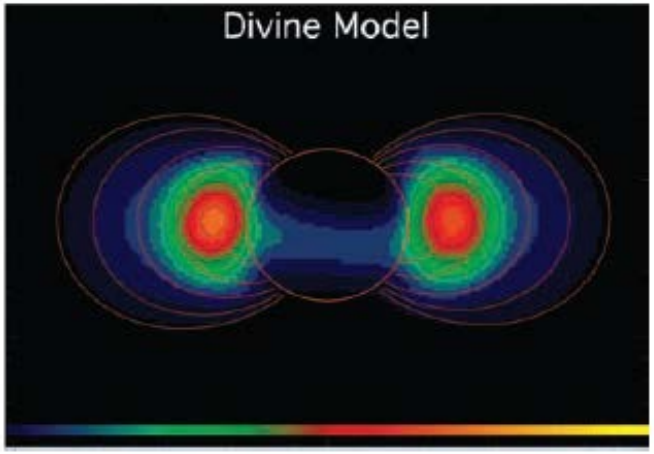
Garrett et al., JPL Publication (2003)

Jun et al., IEEE TNS (2005)

Synchrotron Update

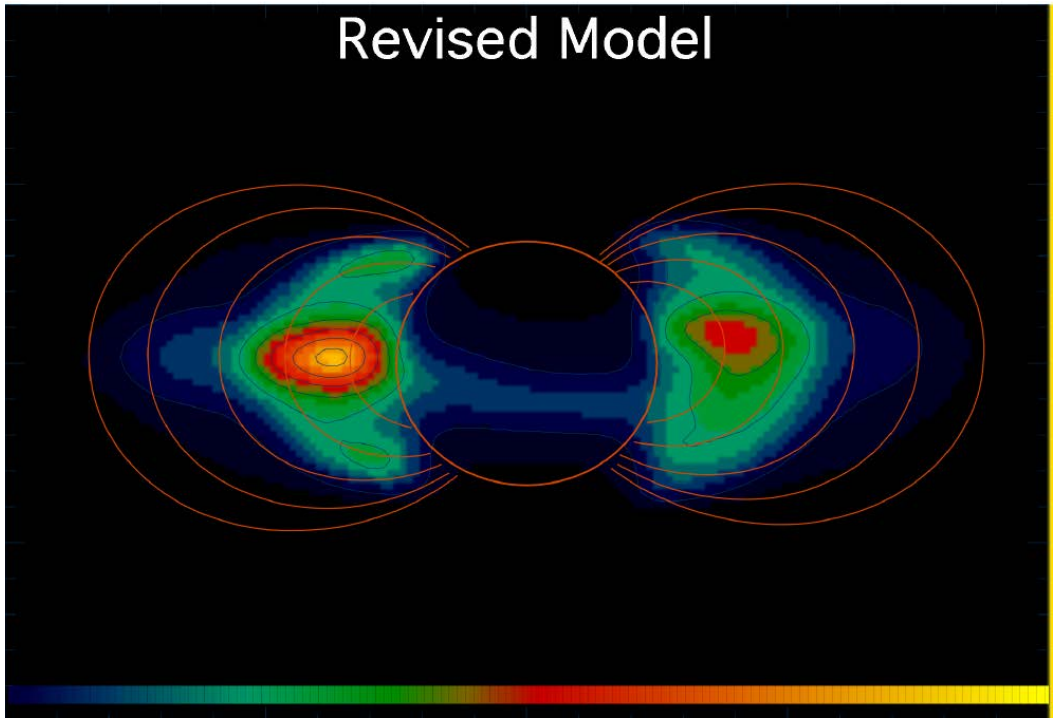


Synchrotron Observations



Synchrotron prediction based on the original Divine Model

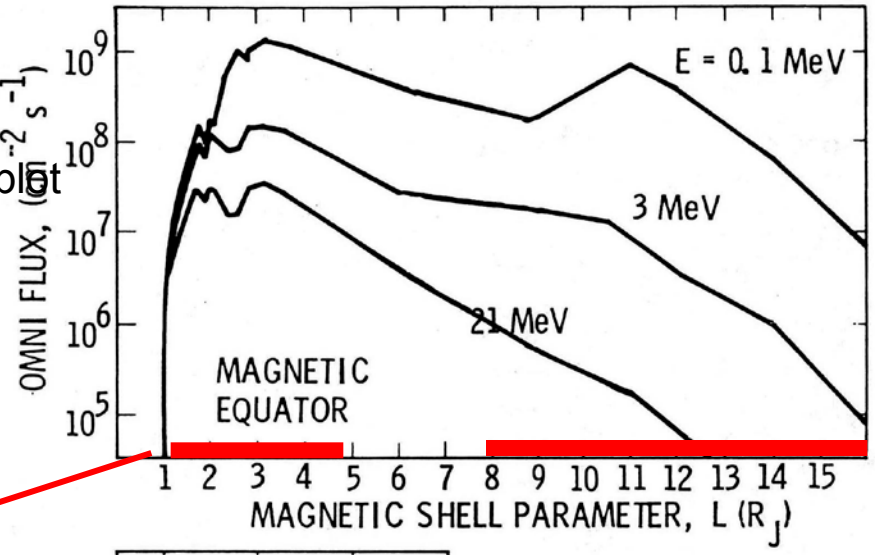
Synchrotron predictions based on update to Divine Model



Garrett et al., GRL (2005)

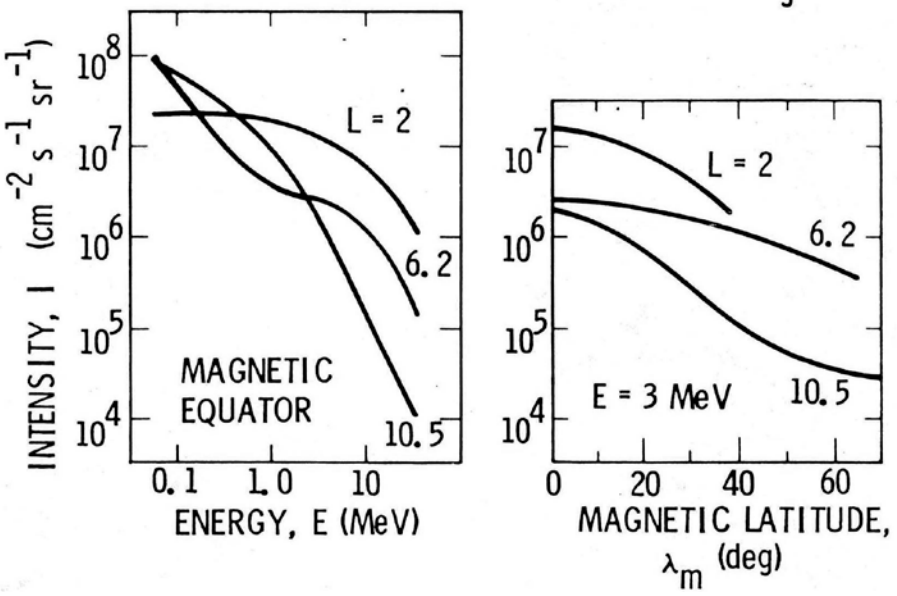
Summary of Spatial Coverage of Electron Models

Note: This is a corrected version of the published plot

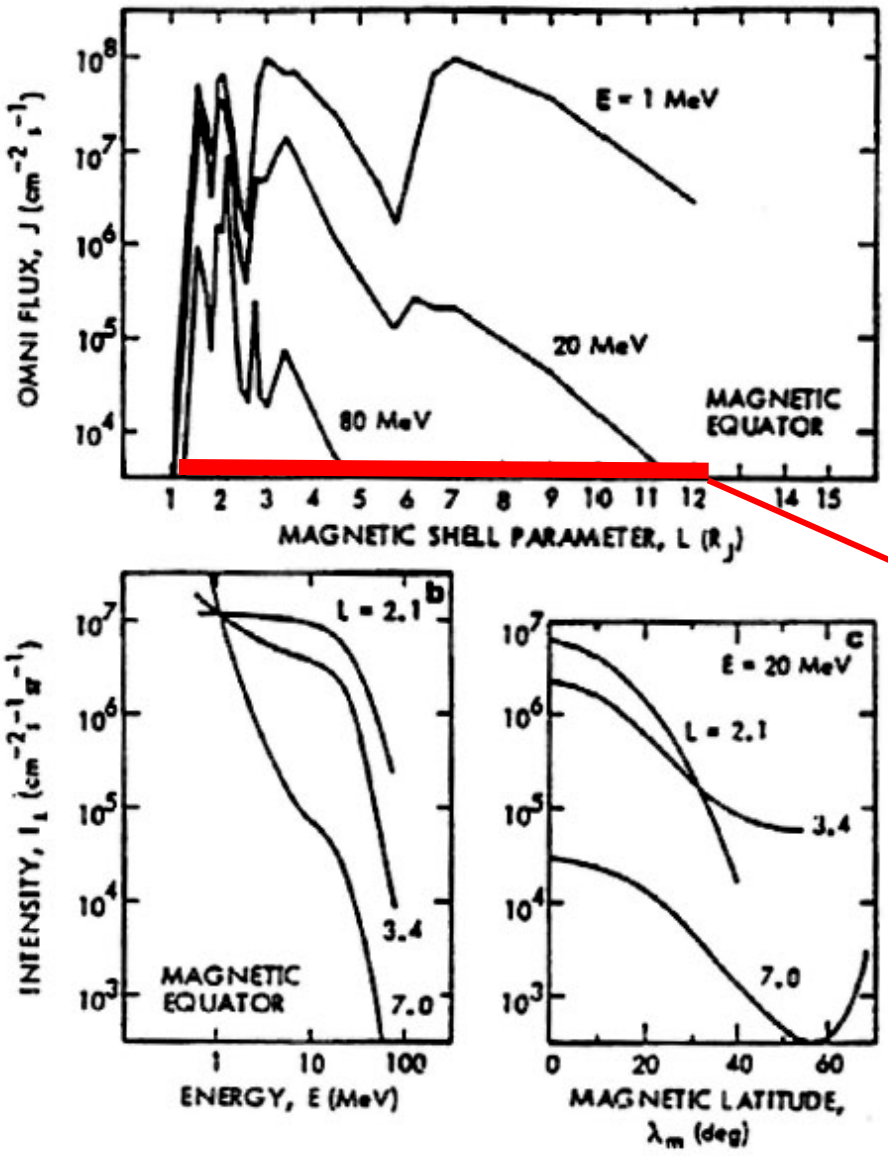


SYNCHROTRON UPDATE

GIRE UPDATE



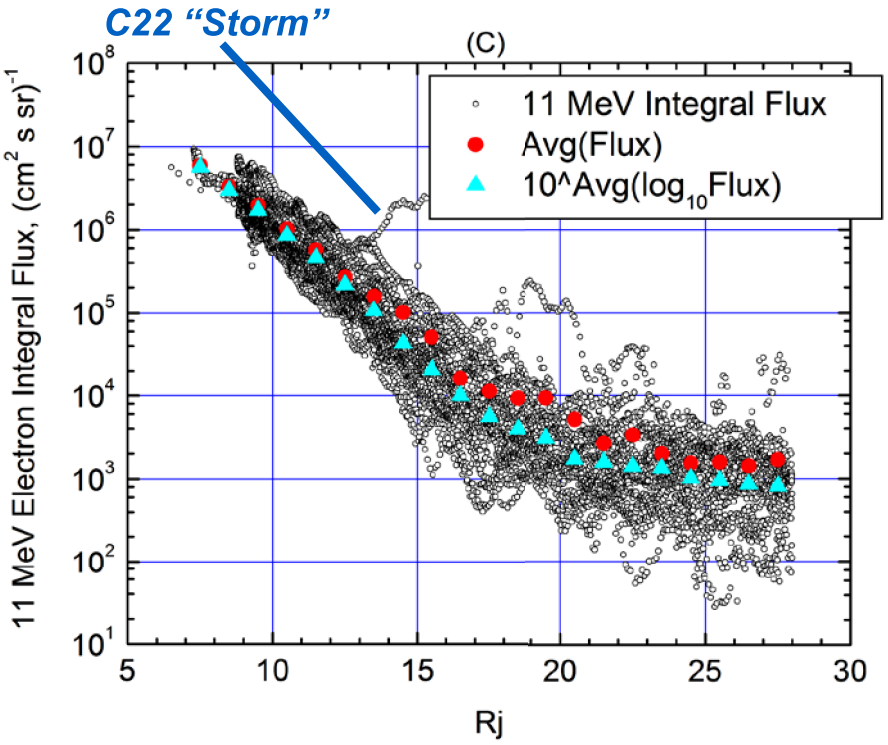
Summary of Spatial Coverage Proton Model



Range of Validity

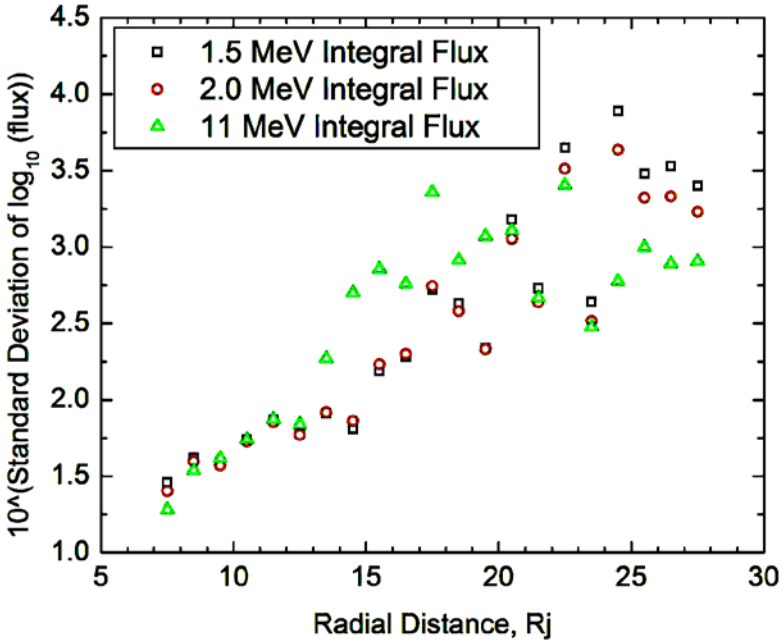
Radial Variation of Trapped Electrons

Variations in EPD 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)

Salammbo Model for Jupiter

- Physical model that considers various processes in the Jovian magnetosphere
- Chronological evolution of Salammbo model (Courtesy of N. Andre)

PhD Thesis of Santos-Costa (ONERA): 1999-2001

- electron for L<6 with D4 B-field model
- Useful for synchrotron mapping

PhD Thesis of Sicard-Piet (ONERA): 2001-2004

- electron for L<9.5 with 0_6 + Khurana
- protons for L<6

JOP/JOE model: 2007

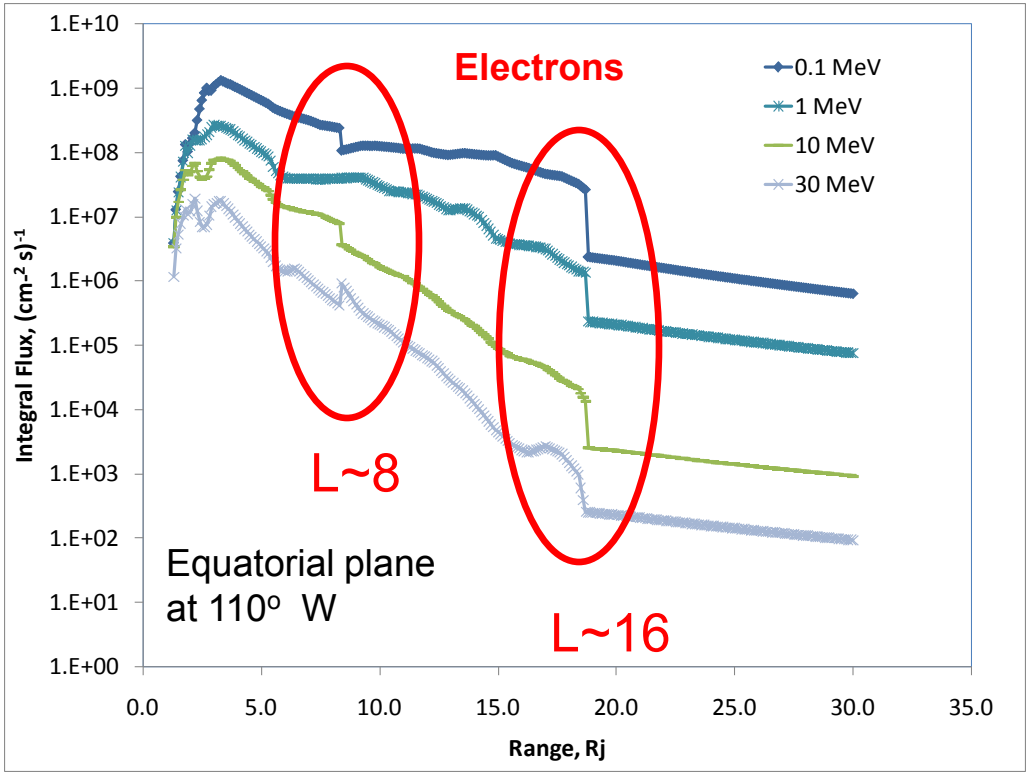
- combined Divine, GIRE, and Salammbo-ONERA models

Santos-Costa : 2003-now

- improved B-field model (0_6+Khurana)
- additional processes included
- approach validated for lower-energy particles
- improved outer boundary condition and bimodal e- pad included in the inner belts (Santos-Costa et al., JGR, 2008)
- Used for estimating synchrotron variability and for identifying key parameters (Santos-Costa, PSS, 2008)

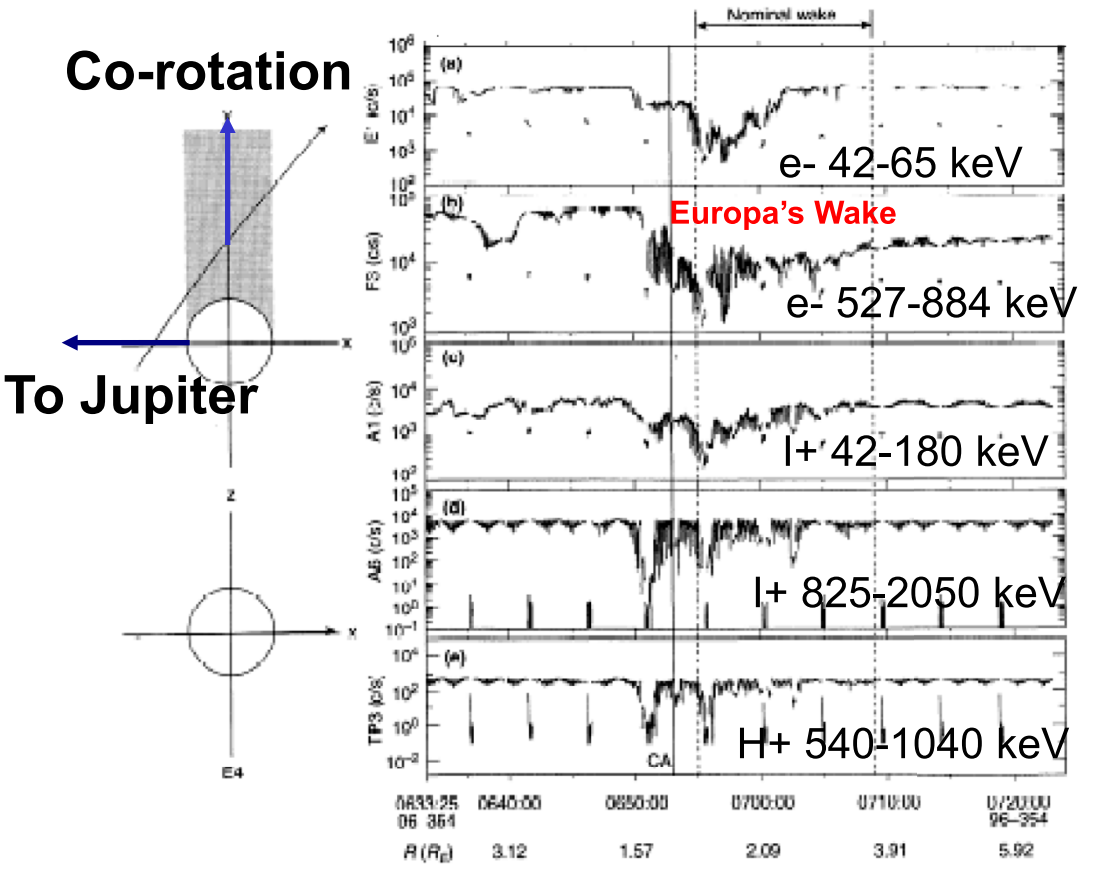
Limitation of Existing Models and On-going Efforts

- Discontinuity at L=8 and L=16 in the Divine-GIRE update → *Will update the model using a consistent magnetic field model*
- Pioneer 20-30 MeV electron data revised since 1983 → *Will re-visit Pioneer high energy electron data*



- Divine's PAD still being used → *Will incorporate Galileo PAD*
- Proton environment limited to L~12 → *Will extend the model to L~30 incorporating Galileo proton data*
- *Will investigate time variations ("storms") and temporal correlation of environment*

Local Radiation Environments at Satellites – Flux Reduction at Europa



EPD observed flux reductions in wake for orbit E4

EPD B1 (1.5-10.5 MeV) Electron Channel

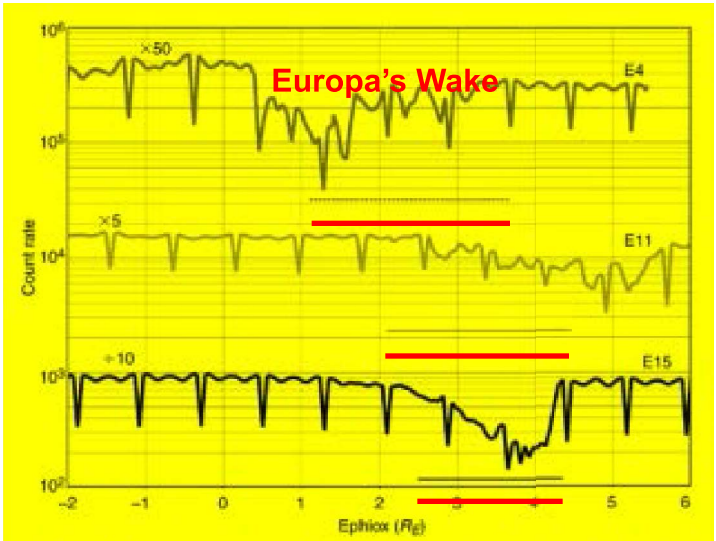
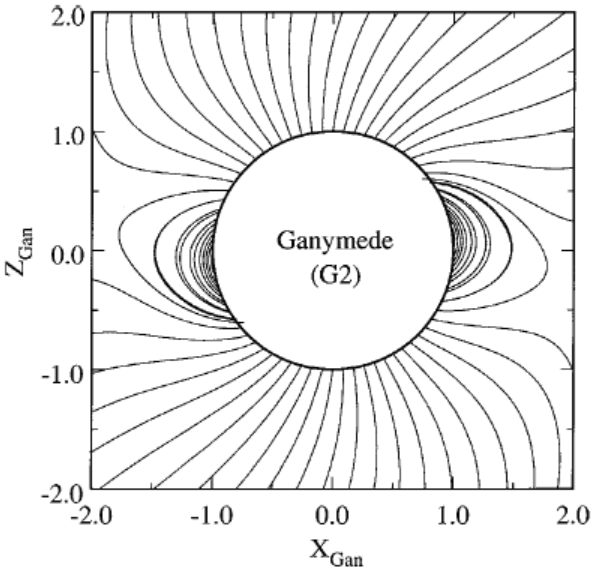


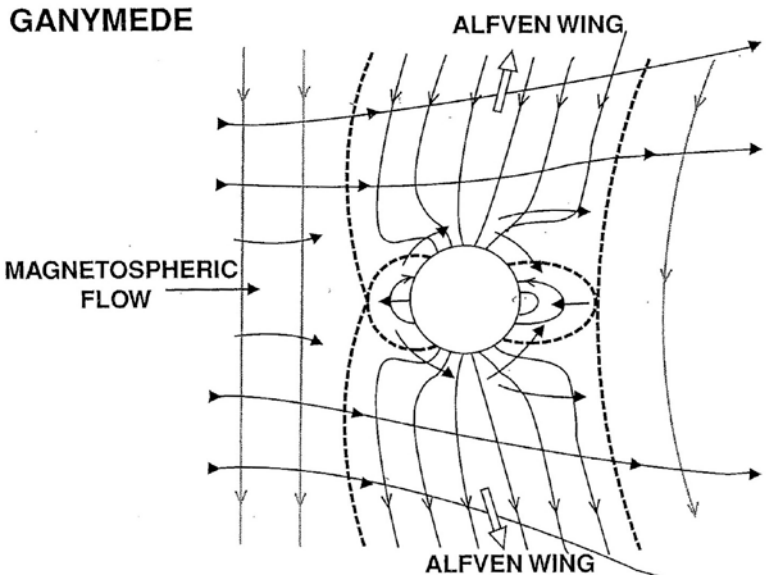
Figure 3. Spin-averaged count rates from the ~1.5–10.5 MeV electron channel on EPD plotted as a function of ephiox, the x-axis of the ephio system. The horizontal lines correspond to the nominal geometric wakes in ephio coordinates.

Paranicas et al., GRL (2007)

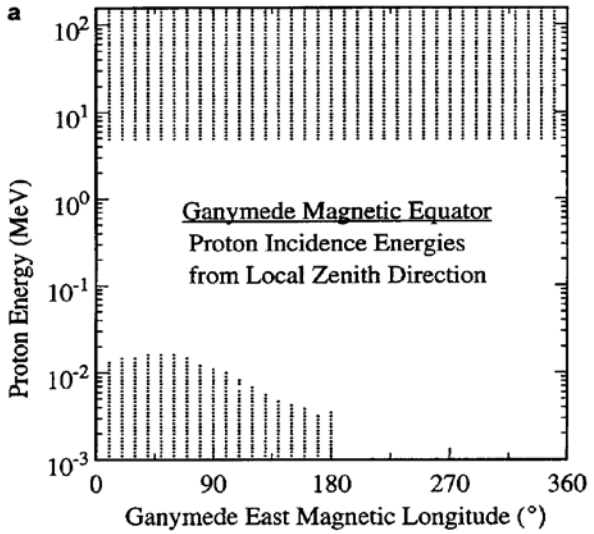
Local Radiation Environments at Satellites – Ganymede's Magnetosphere

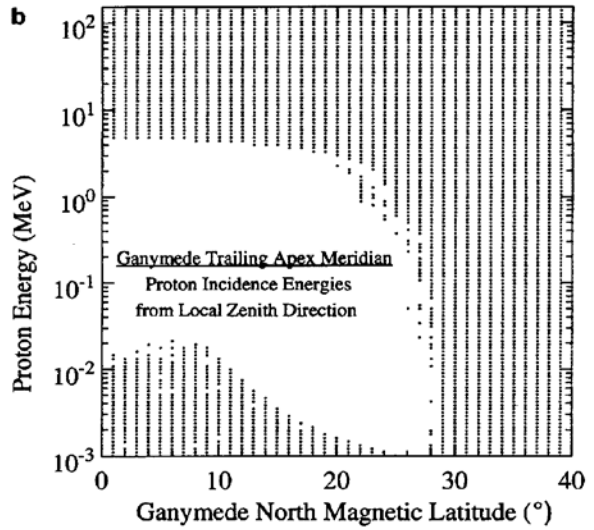


Magnetic field configuration at Ganymede



Magnetic (a) east longitude and (b) north latitude for allowed trajectories incident from zenith onto Ganymede's surface.



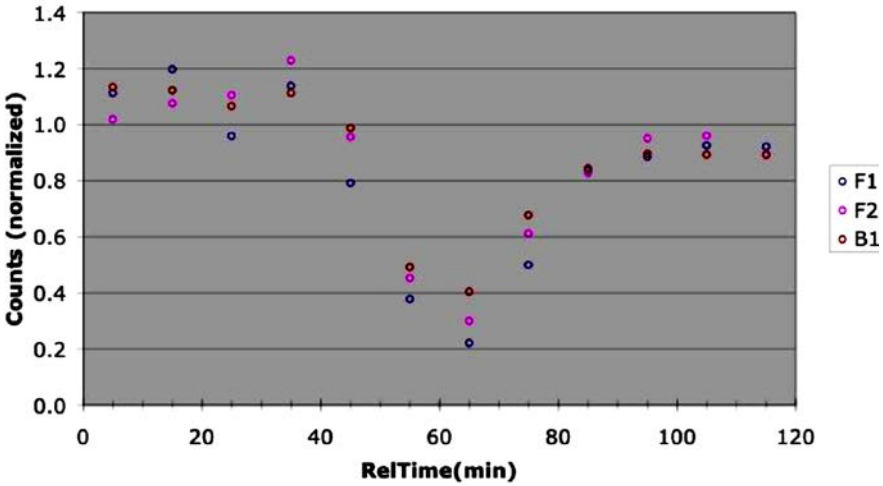


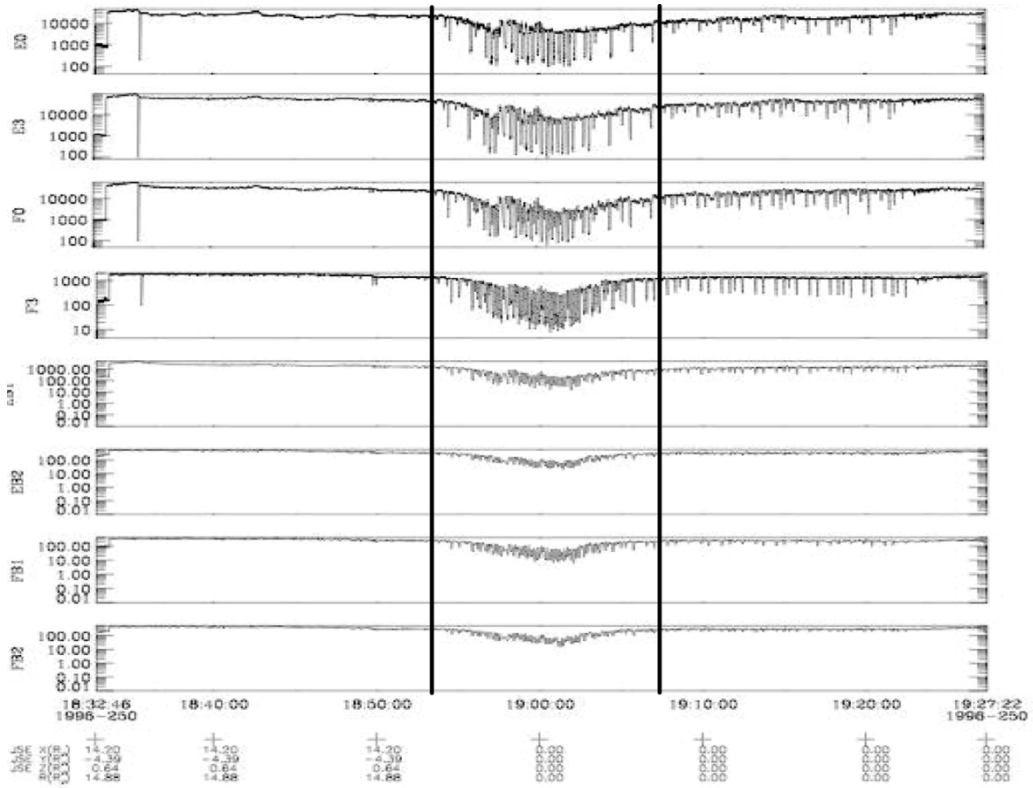
Cooper et al., Icarus (2001)

Local Radiation Environments at Satellites – Flux Reduction at Ganymede

Ganymede Flybys:	
G1	838.0 km (EPD off)
G2	***264.4 km***
G7	3104.9 km
G8	1606.2 km
G28	808.7 km

G2 High F1, F2, B1 Electron Fluxes





G2 Ganymede encounter EPD low-energy channel counts

Local Radiation Environments at Satellites – On-going Efforts

- At Europa, simple shadowing reduction estimates by Pananicas *et al.*, can be improved upon by considerations of energetic charged particle motion near the moon.
- At Ganymede, data show that the internal field stands off the Jovian environment well above the equatorial surface and to high latitudes.
- Plan to use particle tracing in realistic fields (e.g., 3-D global hybrid kinetic simulations) and other considerations (e.g., Störmer's cutoffs) to further refine dose estimate
- Will compare above modeling with existing data from close Galileo flybys of these moons

Summary

- The original Divine model (circa 1983) has provided a good basis for spacecraft radiation design (e.g., Galileo's successful performance)
- The 35 Galileo orbits provided excellent in-situ measurements of the Jovian equatorial radiation environment and has allowed updates to the Divine model:
  - The GIRE model updated the L=8~16 high energy electron environment
  - Synchrotron modeling allowed updating the inner electron radiation environment
  - Statistical models have been developed to allow better risk modeling
  - Modeling of the local lunar environments is underway
- Deficiencies of the existing models have been identified and efforts to improve or update the models are underway at both NASA and ESA

ACKNOWLEDGEMENT

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