GEANT4 Workshop
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Applications of Geant4 at JPL

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Summary of Geant4 Activities at JPL

- Code comparison studies
- Detector response analysis for Juno spacecraft
- GCR attenuation through Jupiter’s magnetic field

Code Comparison Studies

- NESC space-shielding code evaluation study for the Artemis program
  - Primary objective is to study the applicability of Shieldose2 code for very thin materials
- Wide range of radiation transport tools compared: Shieldose2, MCNP, Geant4, FASTRAD, NOVICE, ITS, and Fluka
- See Insoo Jun’s talk on Thursday afternoon for details

Juno detector response

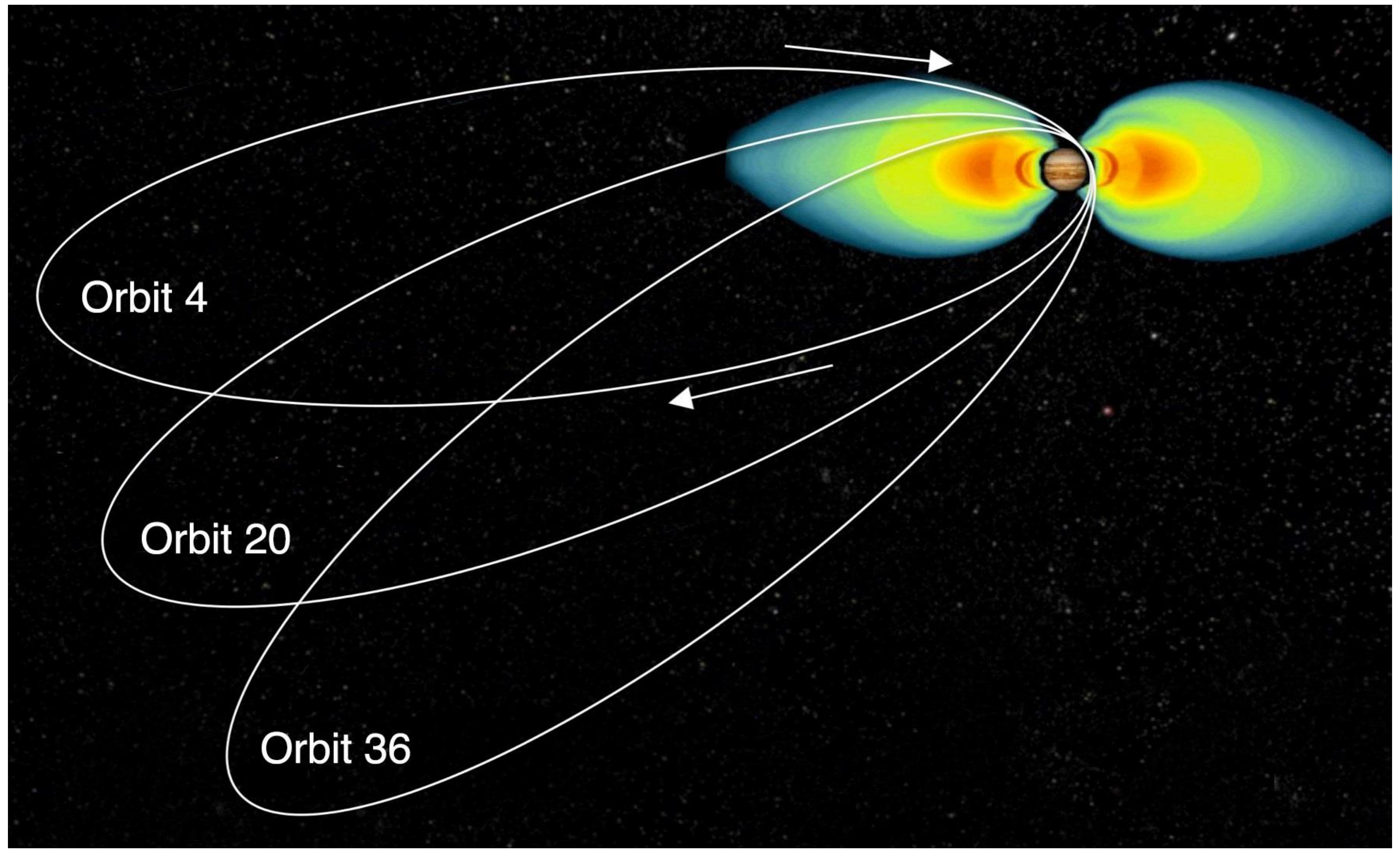
- At JPL, one of the core applications of Geant4 is for understanding detector response to high energy radiation

- In collaboration with UVS and JEDI teams from SwRI and APL, performed Geant4 simulations for several Juno instruments to characterize response to radiation

- The Juno mission aims to study the polar magnetosphere of Jupiter

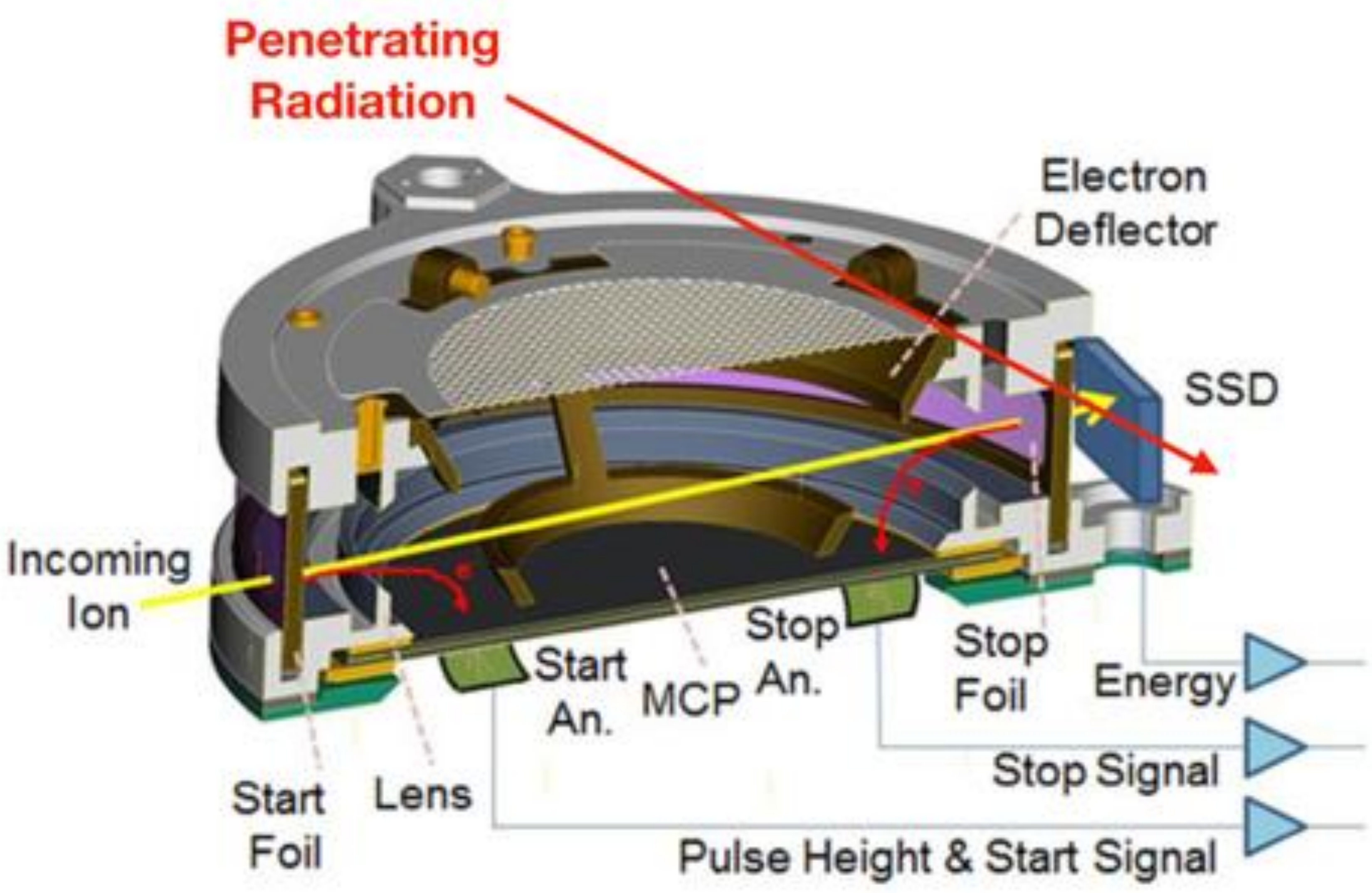
  - Entered orbit around Jupiter in 2016

  - Highly elliptical orbits probe the high latitude region of the Jovian magnetosphere



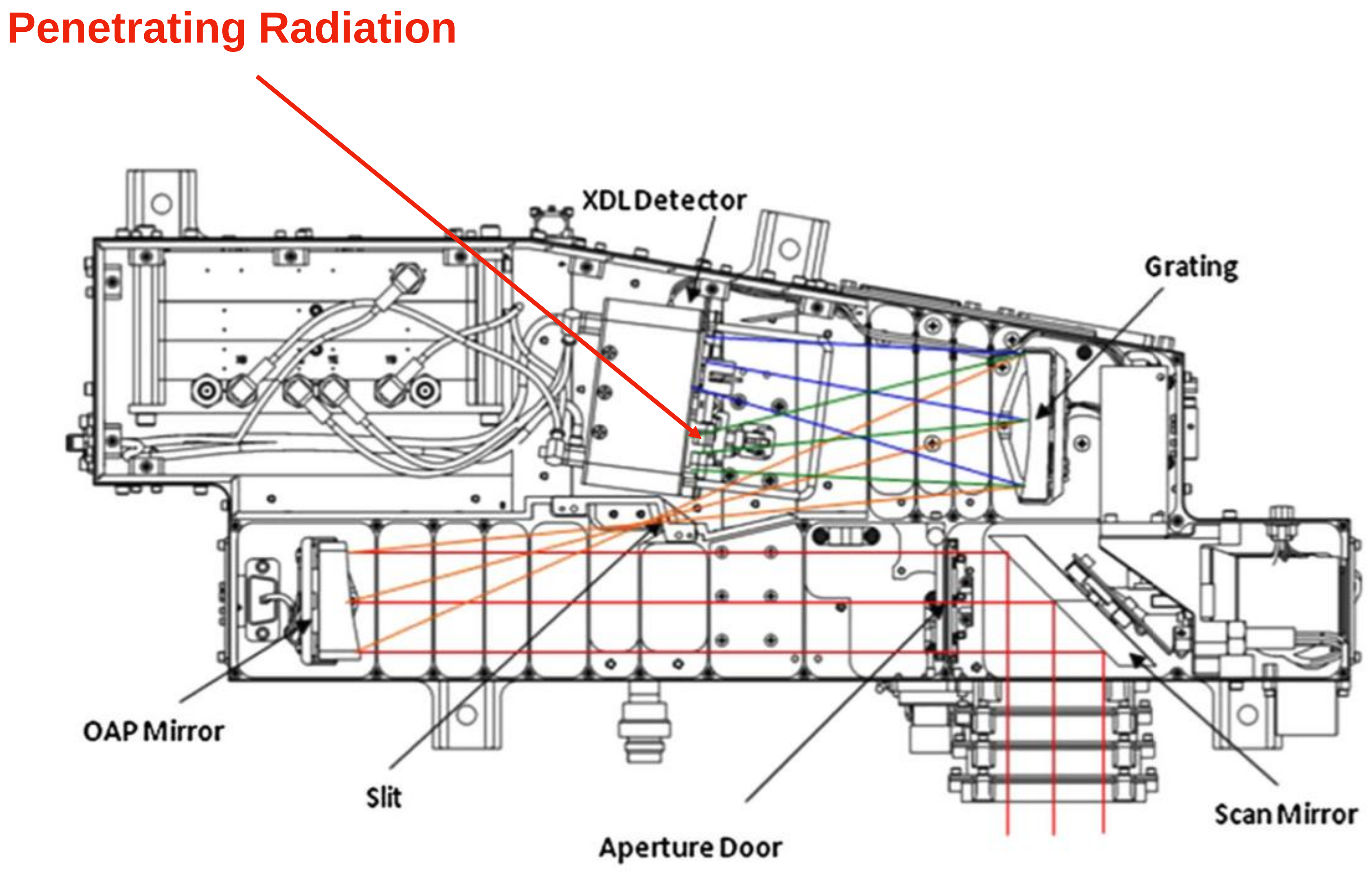
B.X Zhu, JPL; GEANT4 Workshop 2023

Juno Instruments



Mauk, B. H., et al 2013

- JEDI measures both electrons and ions
  - Solid State Detectors (SSDs) are sensitive to electrons up to 1 MeV
  - Penetrating radiation can leave a minimum ionizing signal within the SSDs

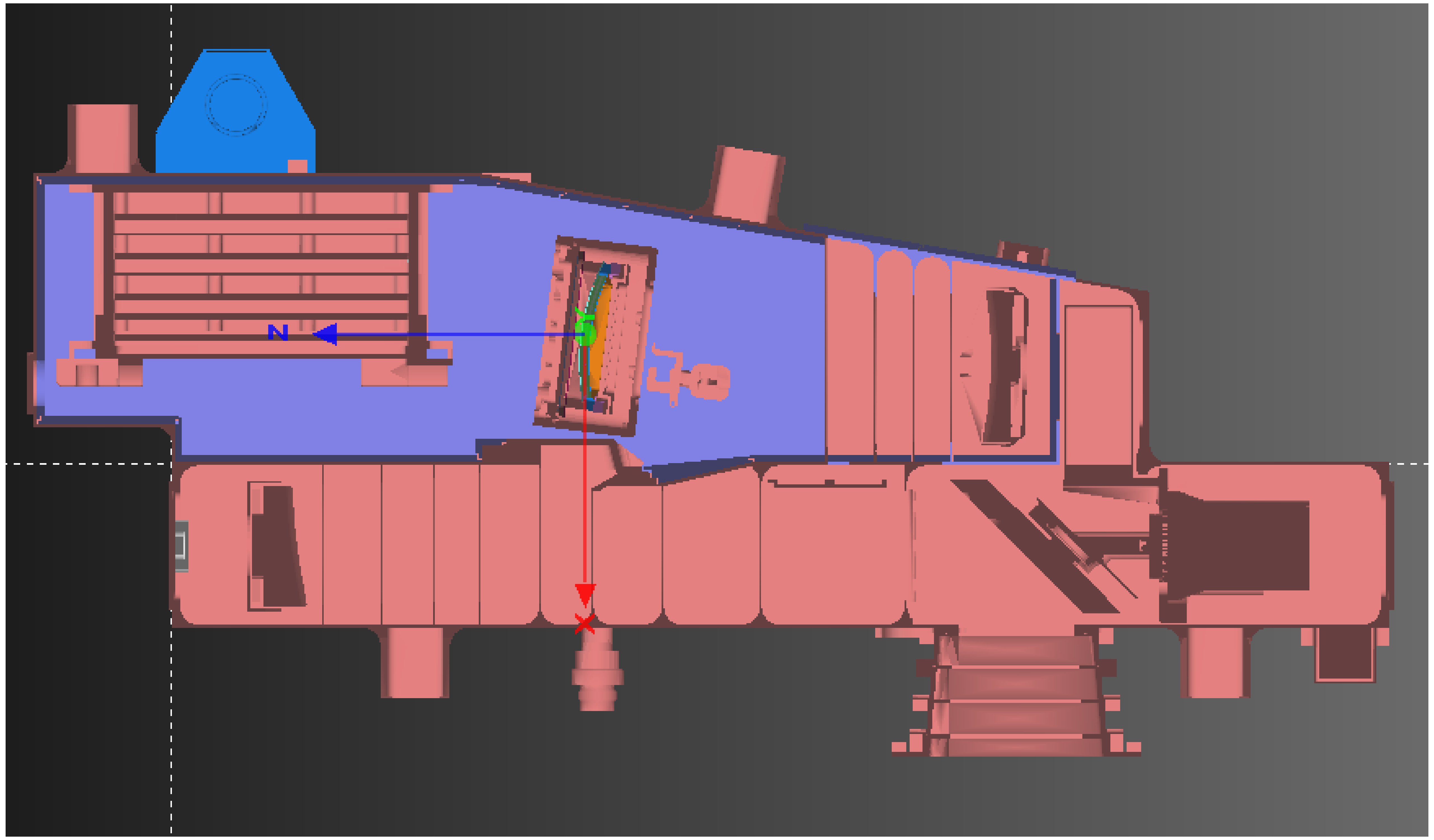


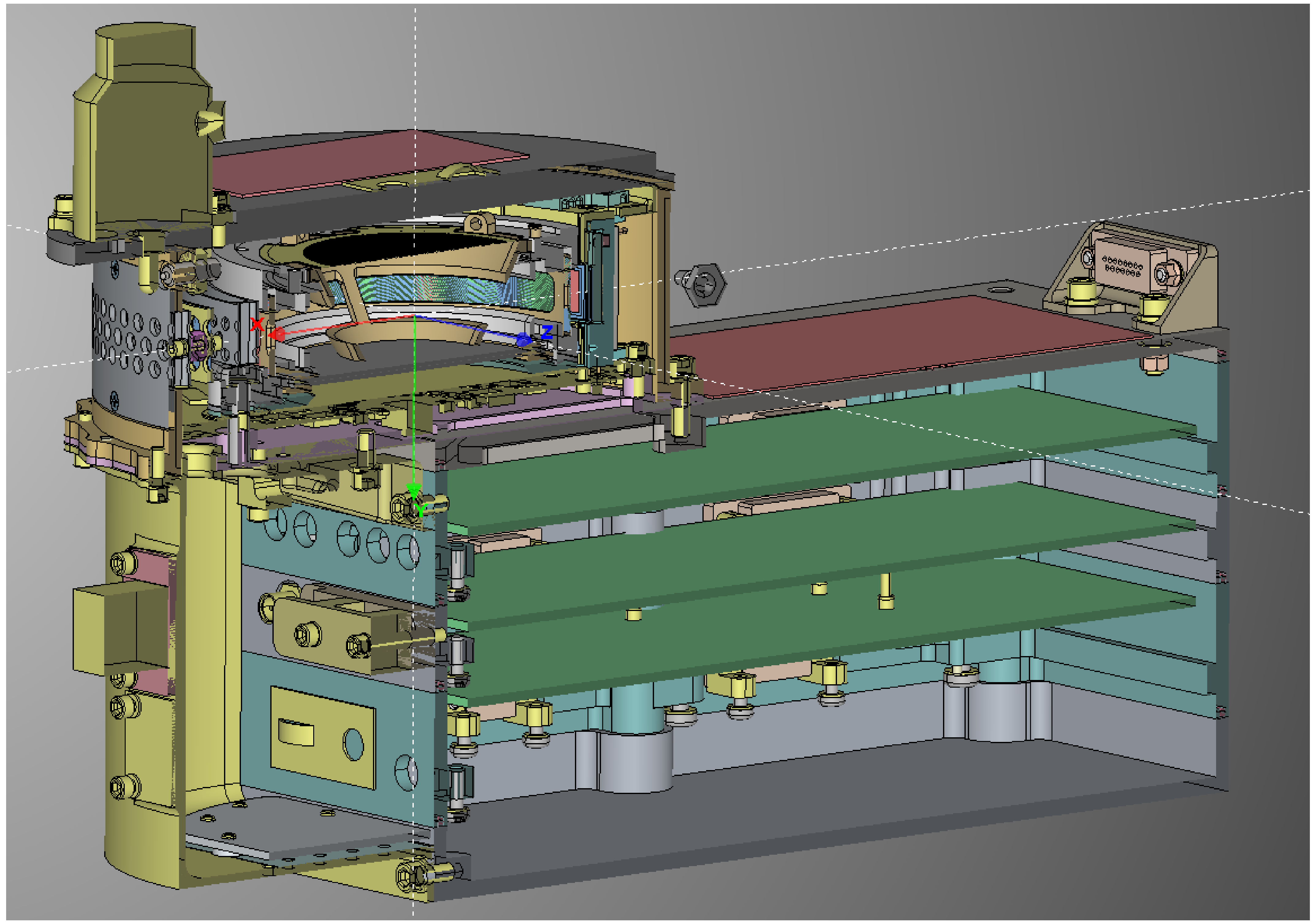
Gladstone, G. R., et al 2017

- UVS uses microchannel plate (MCP) detectors to measure UV photons
  - Complex optical path makes it difficult for electrons to reach the MCP without penetrating shielding
  - Penetrating radiation and UV photons are combined in a count rate

Detector Response Workflow

- Loaded CAD models of instruments using FASTRAD
  - Added materials, exported as GDML for Geant4 simulations
- Simulated mono-energetic electrons and protons in a sphere, using cosine-law angular distribution





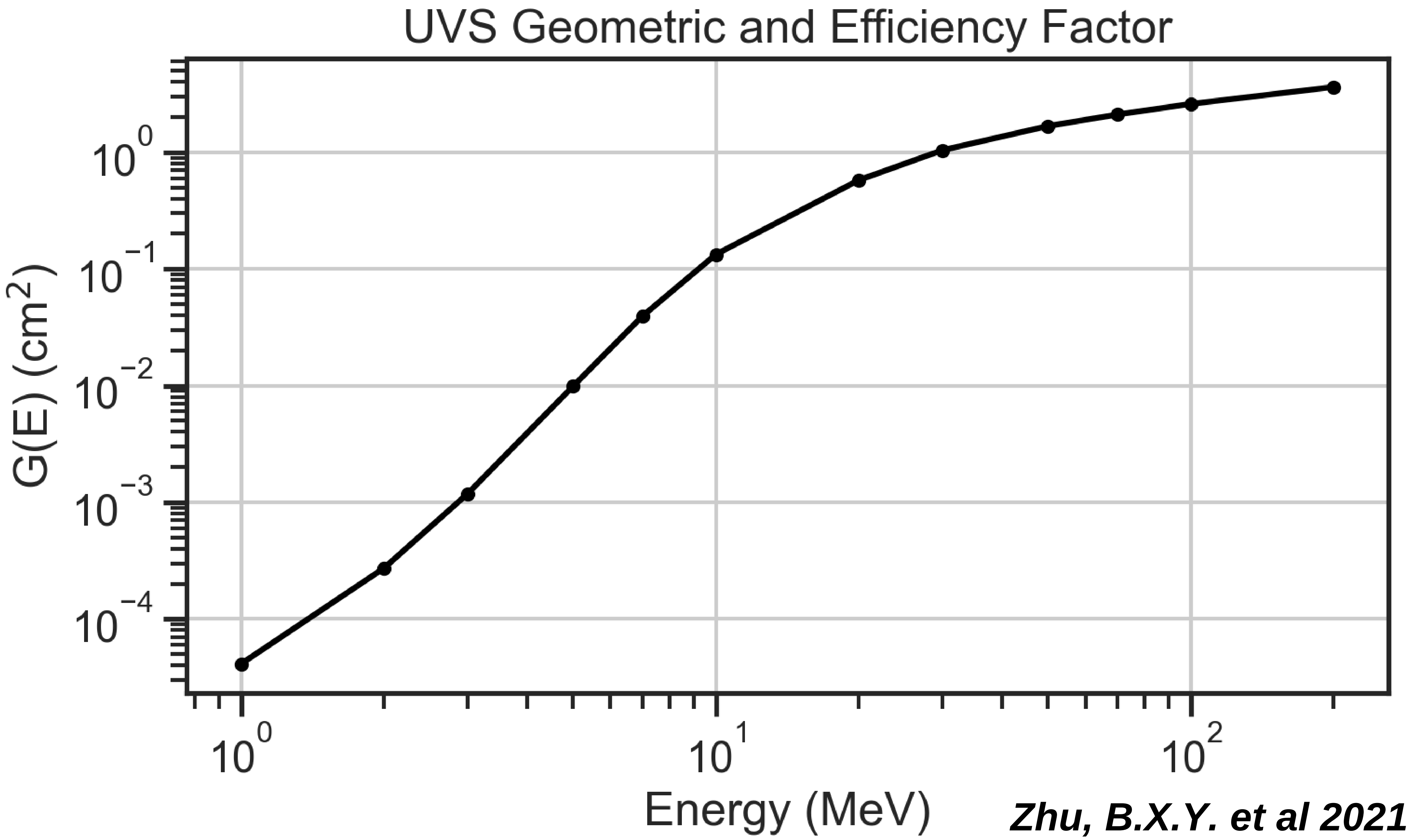
B.X Zhu, JPL; GEANT4 Workshop 2023

Geometric Factor Calculation

- We calculated the omnidirectional geometric factor for UVS and the incidence-angle-dependent geometric factor for JEDI

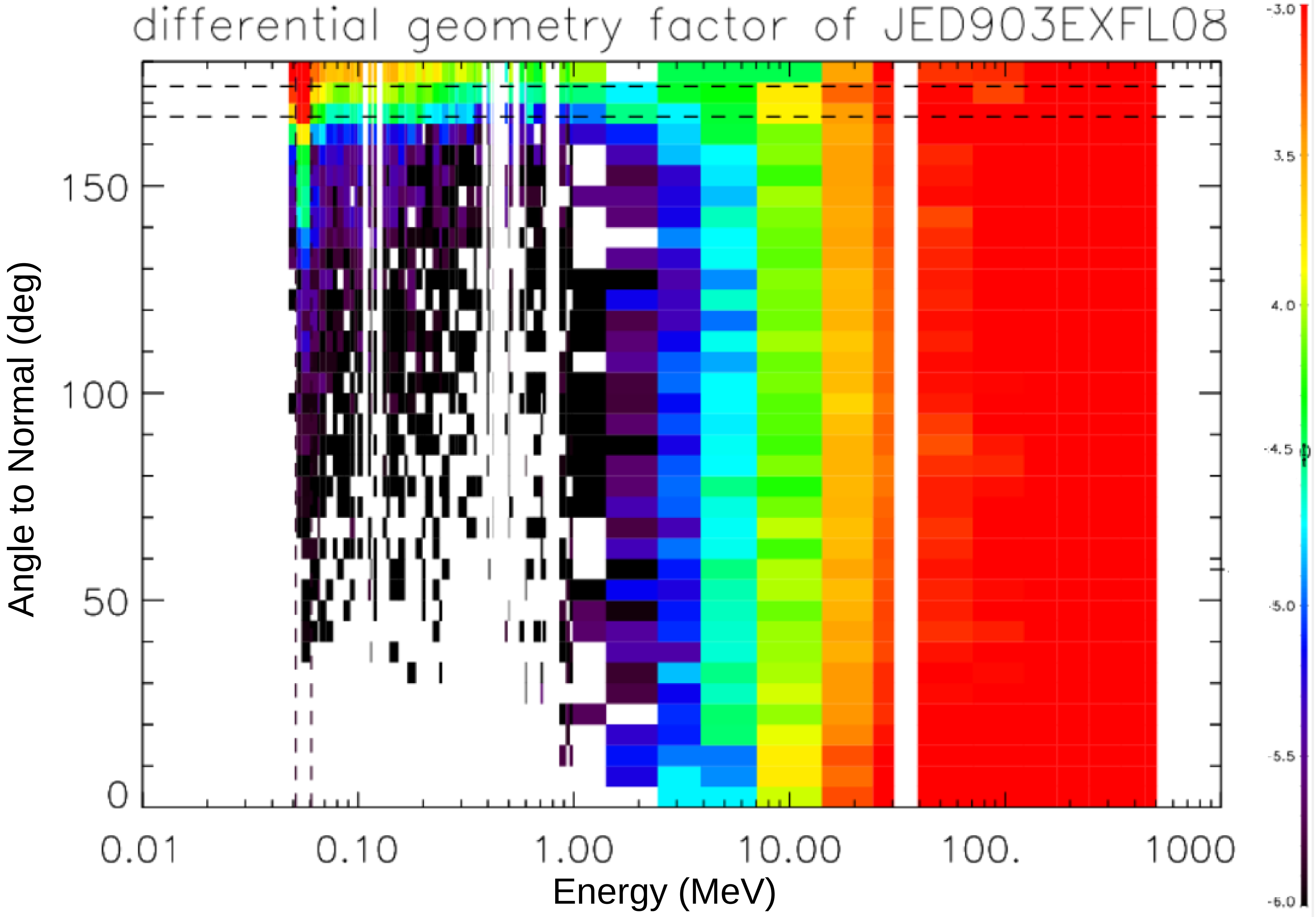
$$C_{JEDI} = \int_0^{\pi} d\theta \int_0^{2\pi} d\phi \int_0^{\infty} j(E) g_d(E,\theta) sin(\theta) dE$$

$$C = \int_0^{\infty} G(E) j(E) dE \approx H \int_{E_t}^{\infty} j(E) dE$$



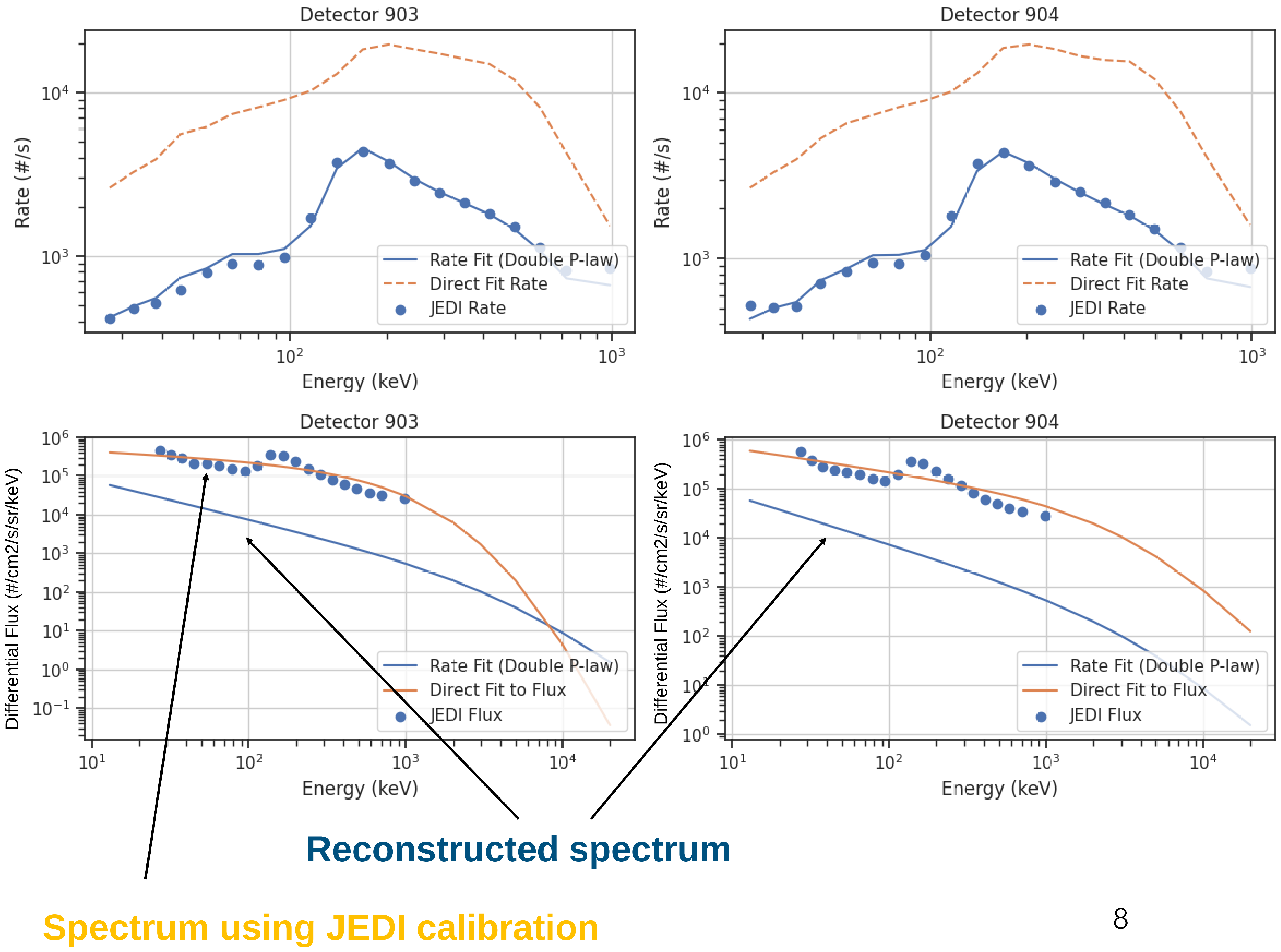
Zhu, B.X.Y. et al 2021

From P. Kollmann



Reconstructing Energy Electron Spectra

$$C_{JEDI} = \int_0^{\pi} d\theta \int_0^{2\pi} d\phi \int_0^{\infty} j(E) g_d(E,\theta) sin(\theta) dE$$



- An application of the geometric factor is to use them in combination with JEDI's measured count rate to reconstruct the electron differential spectrum j(E) beyond JEDI's sensitive energy range
- Assuming a double power-law spectral shape for j(E), we calculate the expected count rate from it, and then optimize the spectral parameters by minimizing between predicted and measured count rates
- Preliminary example spectrum shows a lower intensity compared to the conventional calibration from JEDI, since differential flux spectrum extends to higher energy
- Study is in progress, working to process Perijoves 1 through 24 and 45 (Europa flyby)

GCR Attenuation at Jupiter

- Single Event Effects (SEE) produced by GCRs can cause a variety of problems for spacecraft electronics
- Jupiter’s strong magnetic field can deflect the GCR flux, reducing the total flux a spacecraft may see during a mission
- Used magnetic field and particle tracking capability in Geant4 to study the GCR penetration into Jupiter’s magnetic field
- Work primarily performed by J. Hensley (now at Georgia Tech)

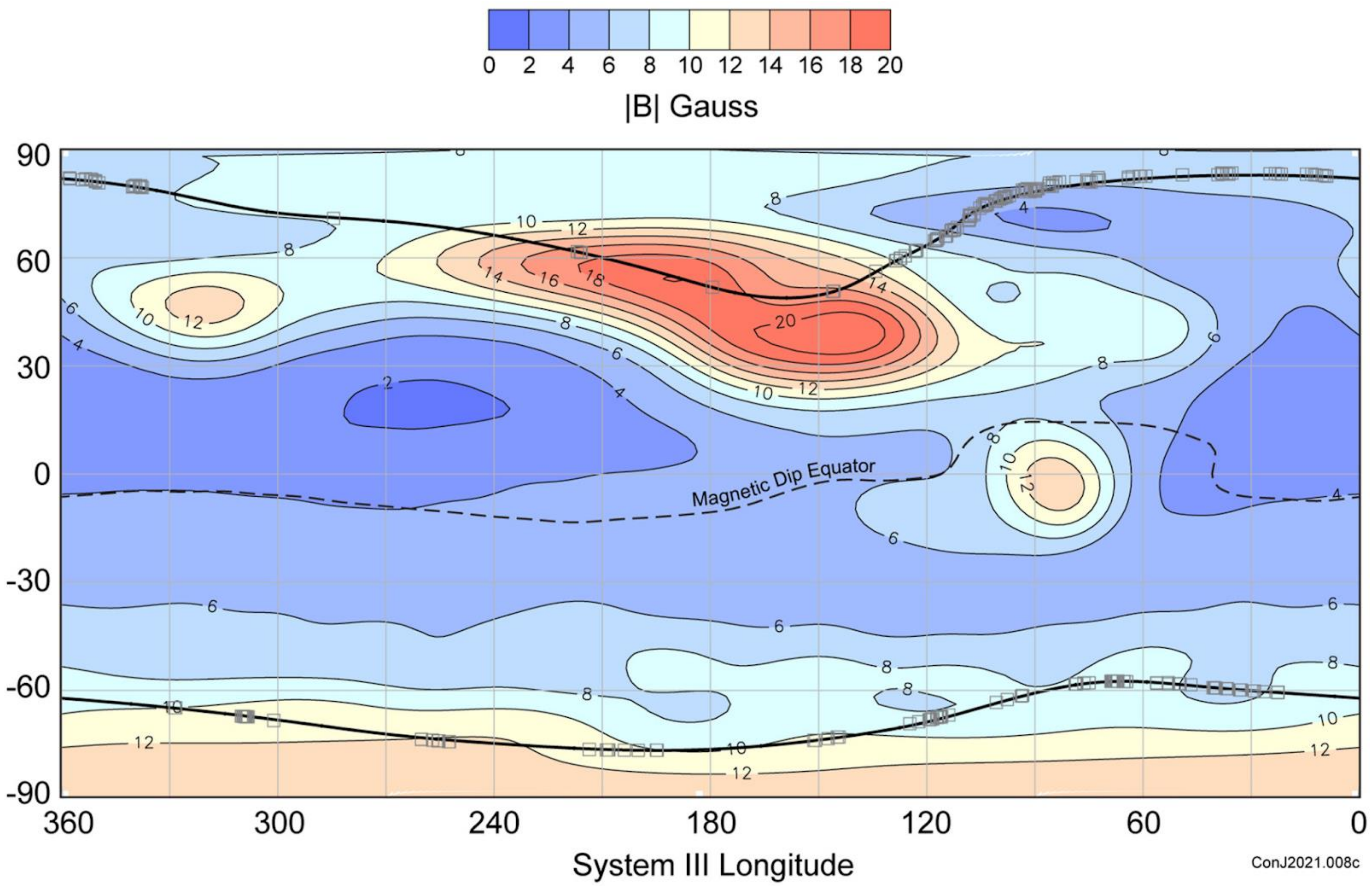
Jupiter Magnetic Field Model

- Latest model of Jupiter’s magnetic field based on data from Juno’s primary mission (33 orbits)

- Model described by a spherical harmonic expansion with Schmidt coefficients to order 18

- Model includes the addition of a current sheet extending from 7 Rj to 51 Rj. New model for current sheet obtained from Juno’s first 24 orbits

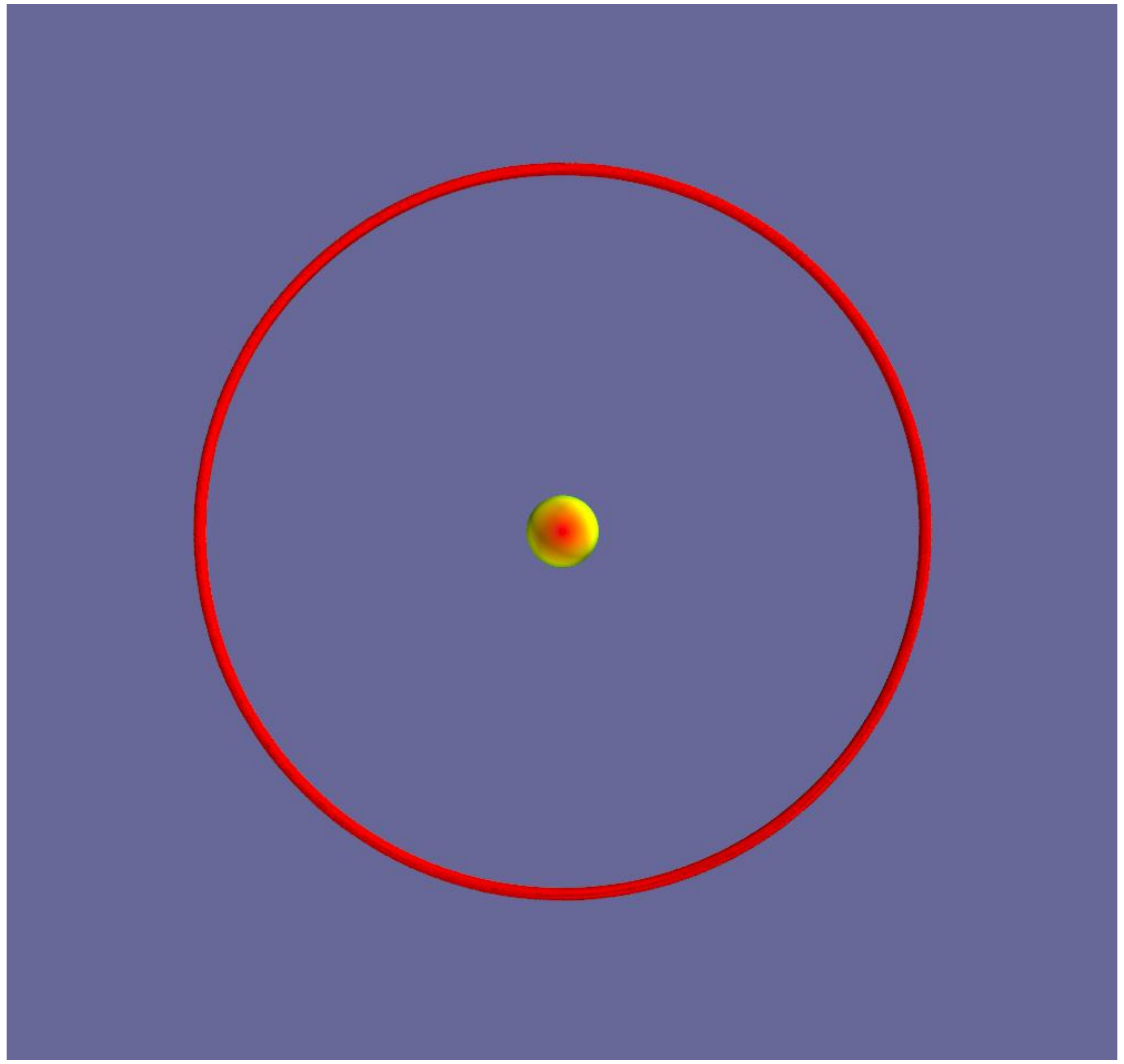
- ~11° longitudinal resolution in data for new model

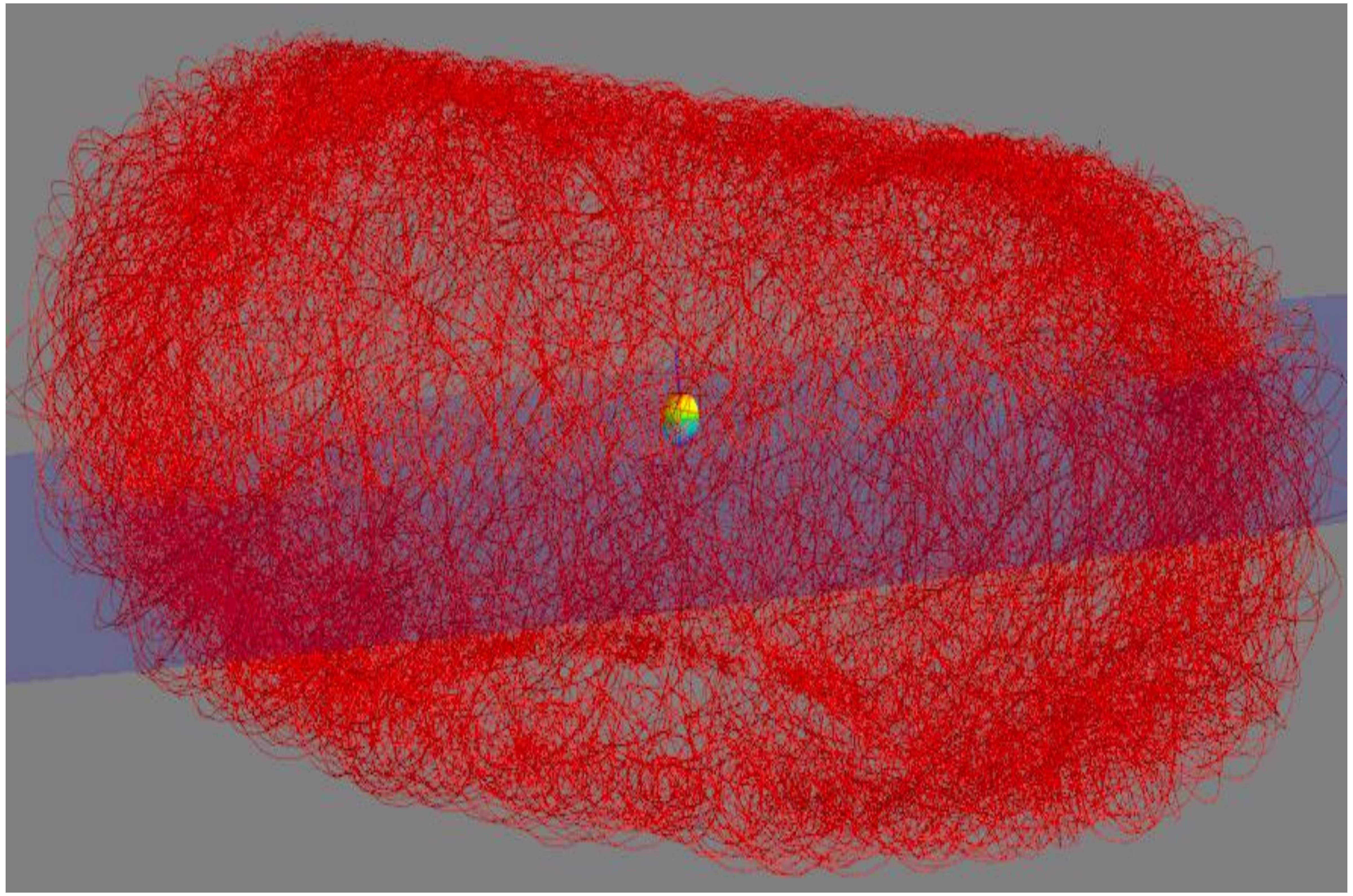


Connerney, J. E. et al 2022

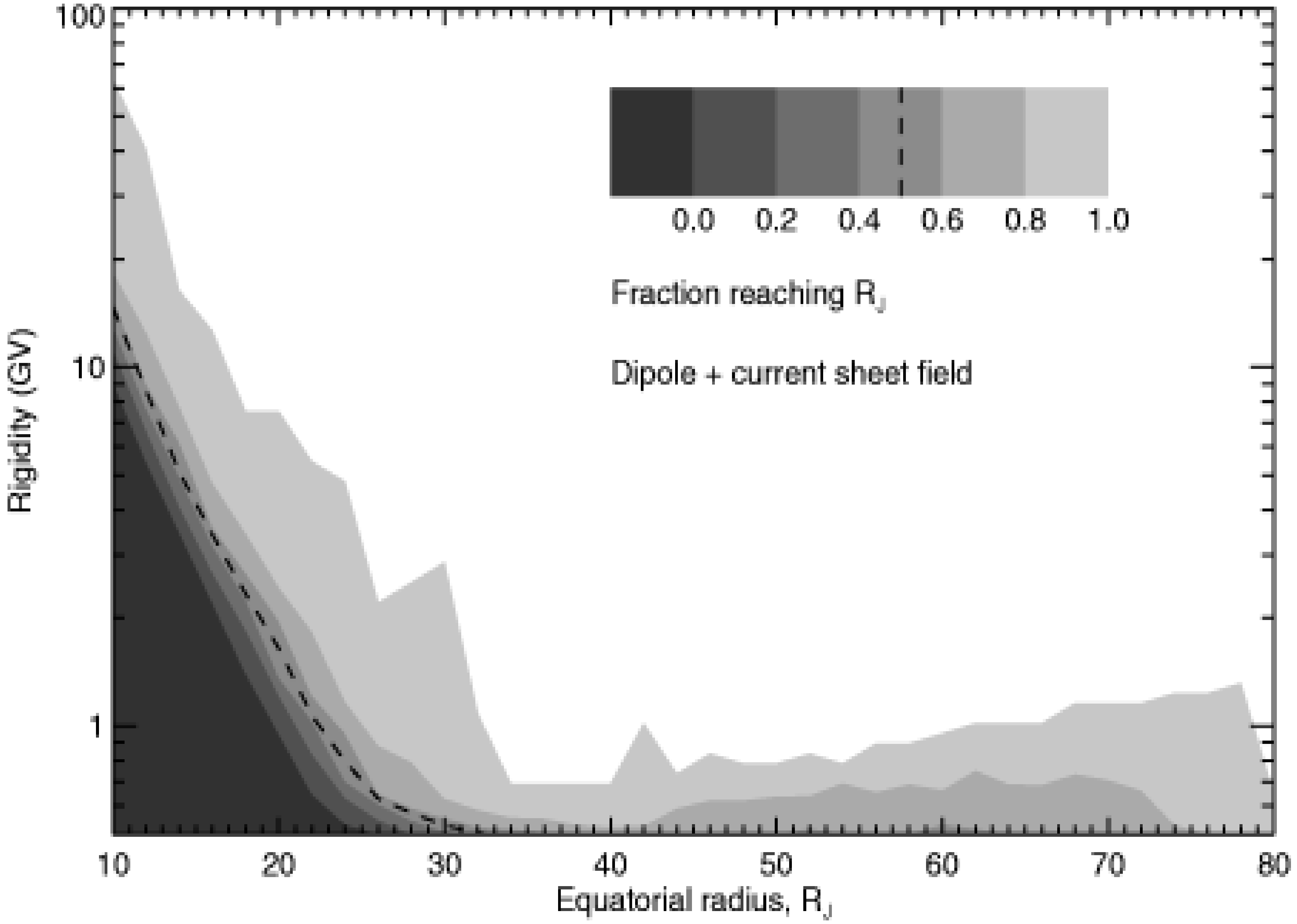
Geant4 particle trajectory simulations

- First performed sanity check of particle trajectory in magnetic field using dipole magnetic field to simulate protons in a circular trajectory
- Then implemented JRM33 model to simulate trapped proton trajectory

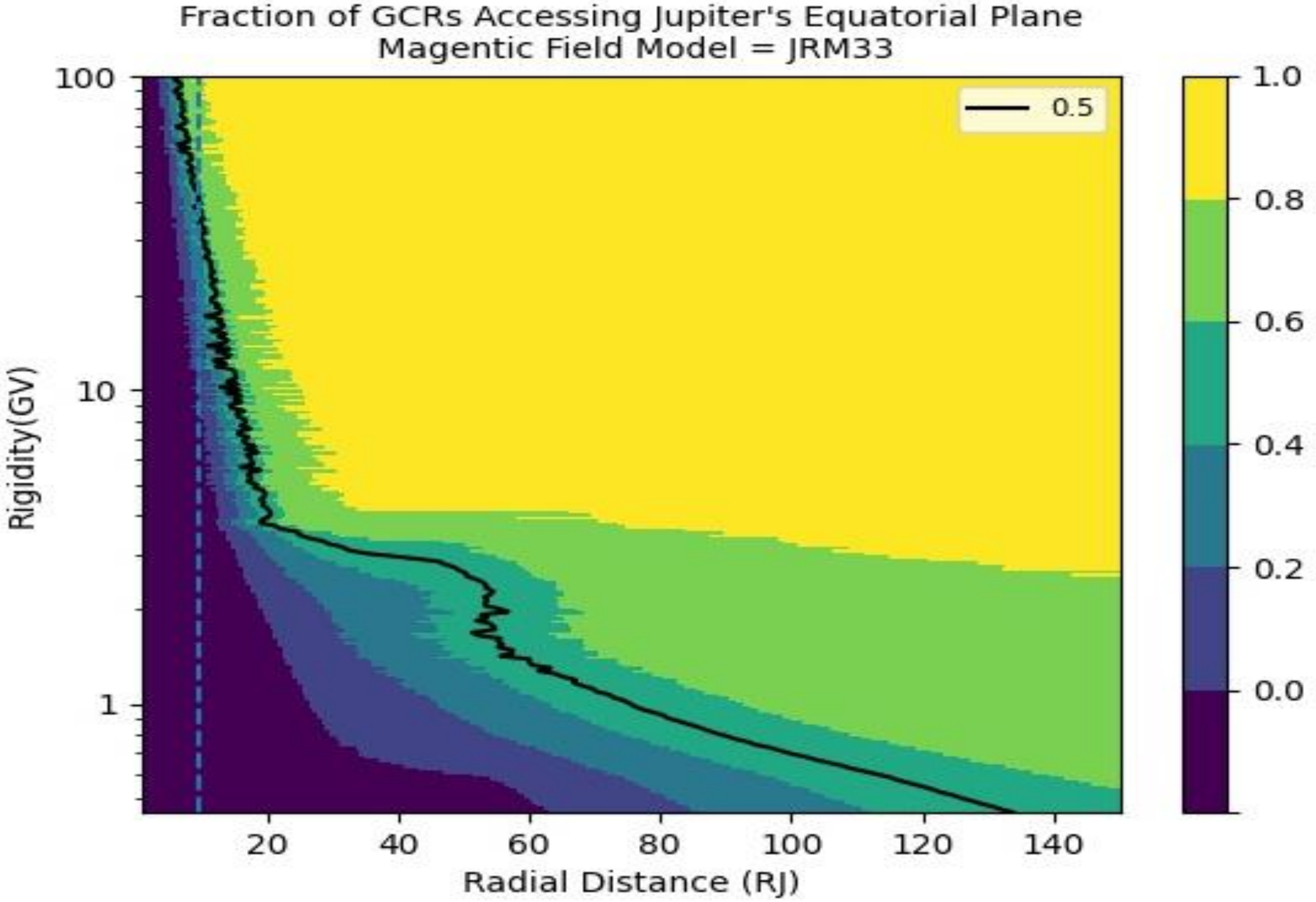




GCR attenuation factor



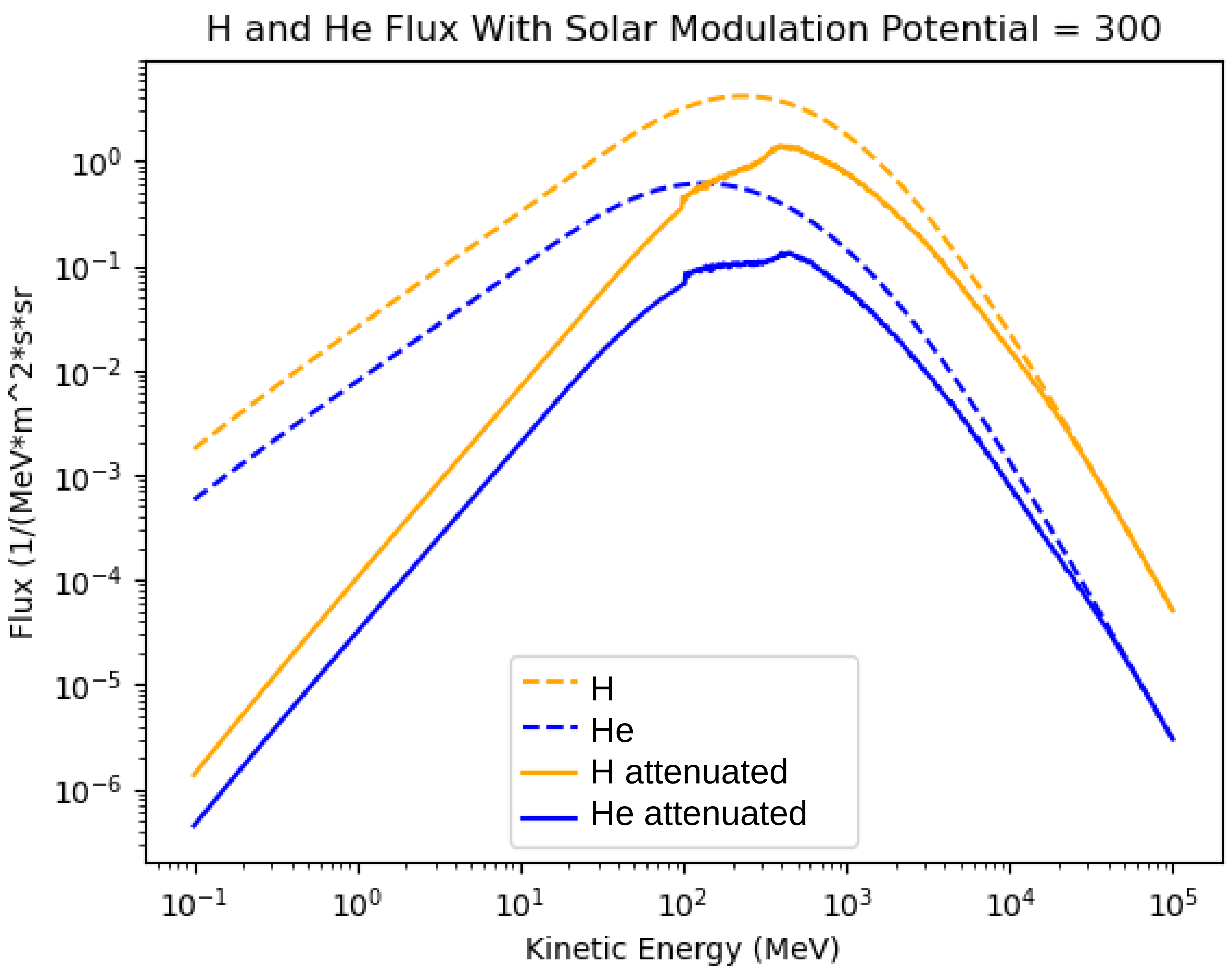
Selesnick, R. (2002)



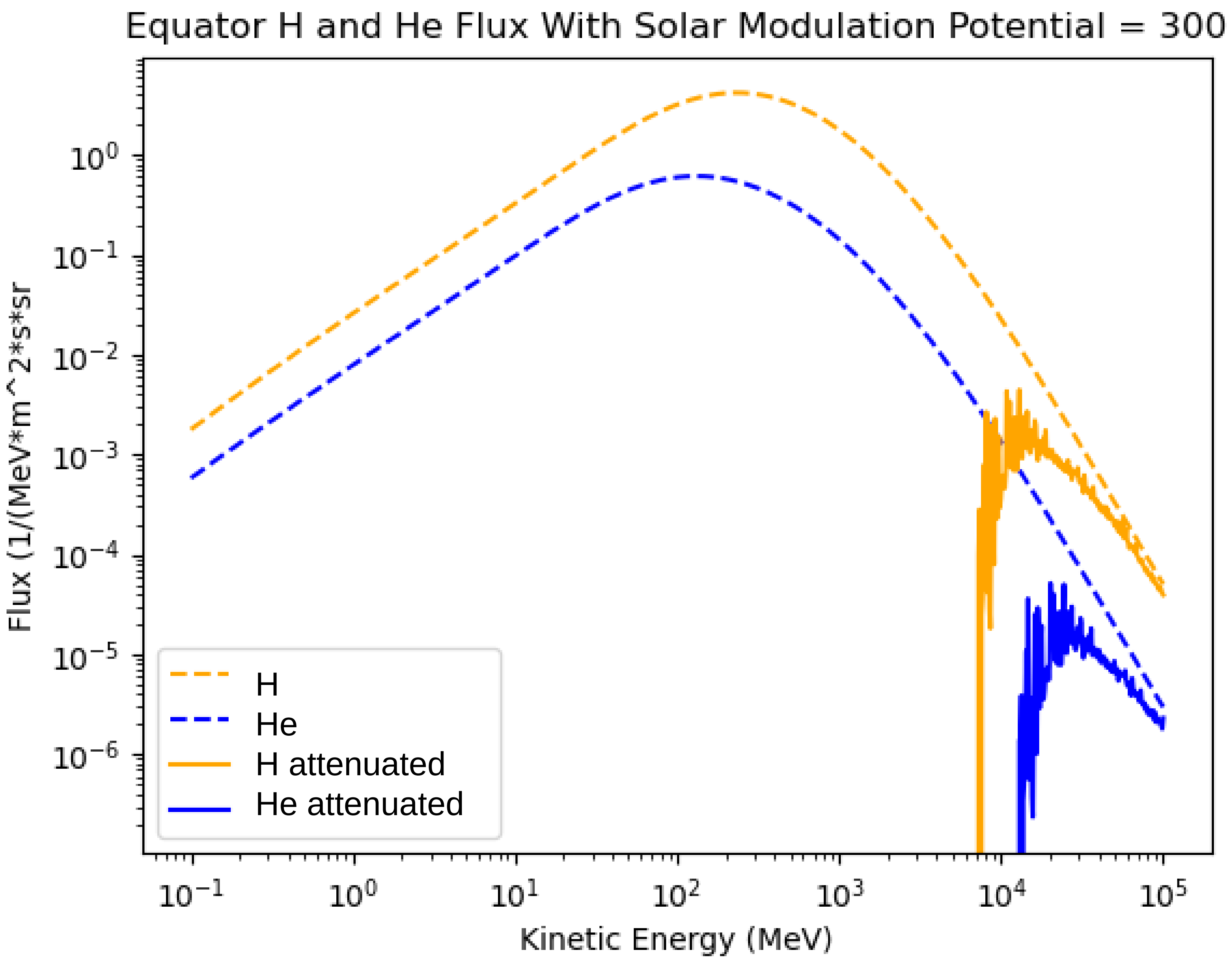
- Simulated 0.1 – 100,000 MeV protons generated using cosine-law angular distribution on sphere with radius 150 Rj
- Recorded the minimum radial distance along a particle's trajectory for each simulated proton
- Comparisons of the JRM33 model to the dipole + current sheet model shows higher attenuation at the equator

Attenuated GCR Fluxes

Average over Jovian system <10Rj



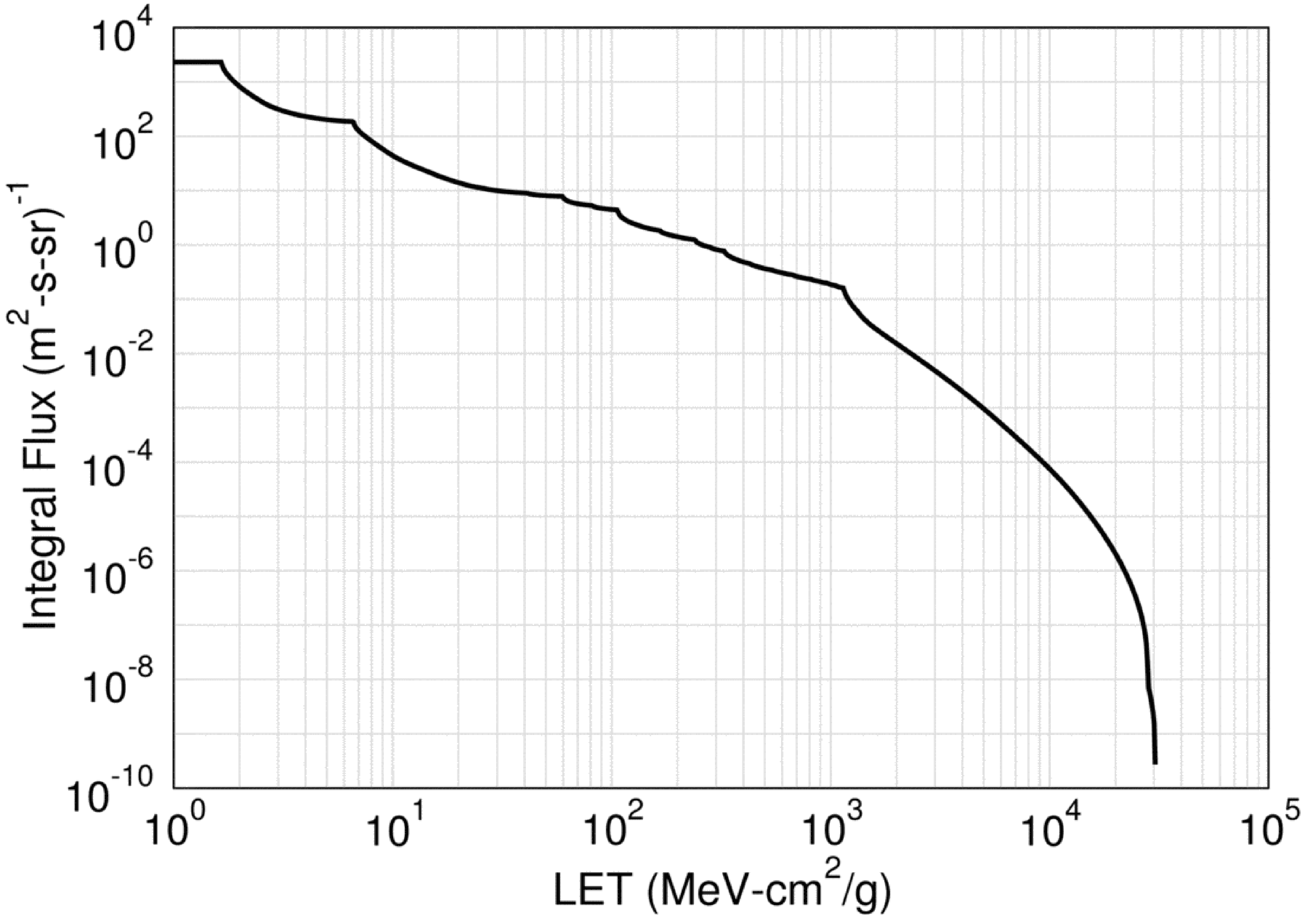
Equatorial plane <10Rj



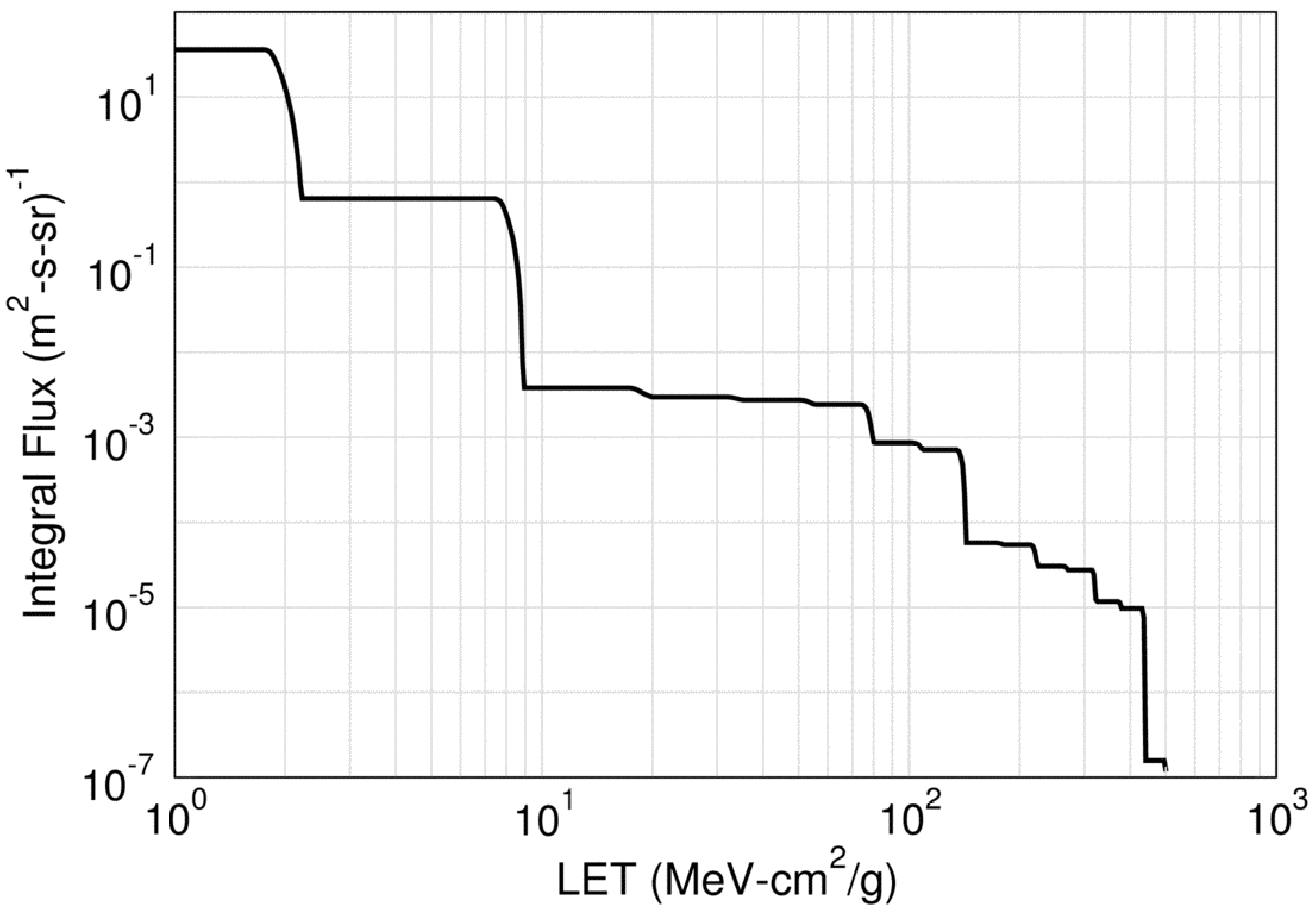
- Applied attenuation factor to GCR fluxes estimations from Badhwar-O'Neill 2020 GCR model (Slaba, T.C et al 2020)
- Flux of low rigidity particles is largely blocked in the equatorial plane at radial distances <10 Rj

LET spectrum

Average over Jovian system <10Rj



Equatorial plane <10Rj



- Used CREME96 to calculate the LET spectrum
- LET spectrum between 9-10 Rj can be used to estimate SEE rates for Europa mission such as Europa Clipper

Summary

- Variety of ongoing activities at JPL using Geant4:
    - Dose comparison studies
    - Detector response simulations
    - Magnetic field particle transport

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jpl.nasa.gov