DICTAT Update for Jovian Missions

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Jovian Environment

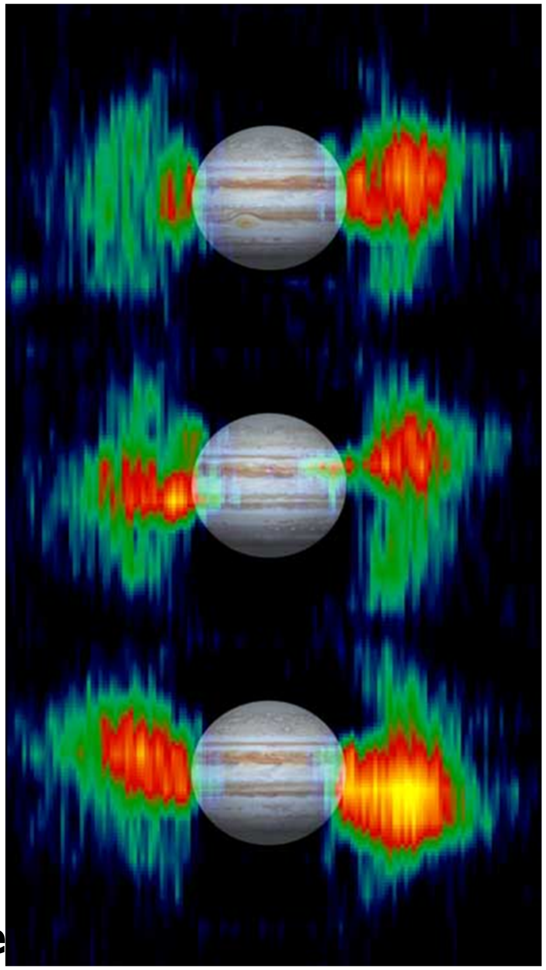
Earth-like magnetic field structure

1. Stronger magnetic field
2. Larger magnetosphere
3. More intense radiation belts
4. Harder radiation belt electron spectrum

Galilean moons orbit inside the magnetosphere

Proposed Laplace mission

1. Candidate in ESA's Cosmic Vision
2. To visit Jupiter/Callisto/Ganymede/(Europa)
3. Radiation effects are crucial factor
   - Dose effects
   - Internal charging effects

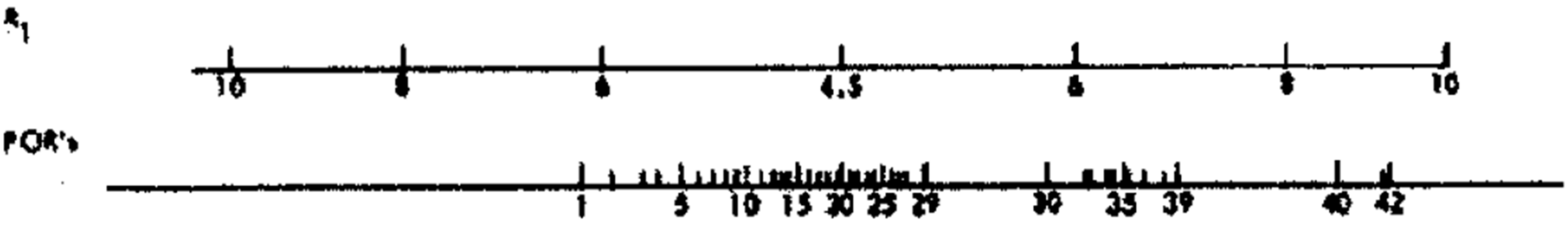


NASA/JPL Cassini μ-wave measurement

Internal Charging

This is a familiar cause of upsets and damage on terrestrial spacecraft.

Voyager-1 experienced 42 anomalies during Jovian fly-by in 1977 [Leung et al 1986]

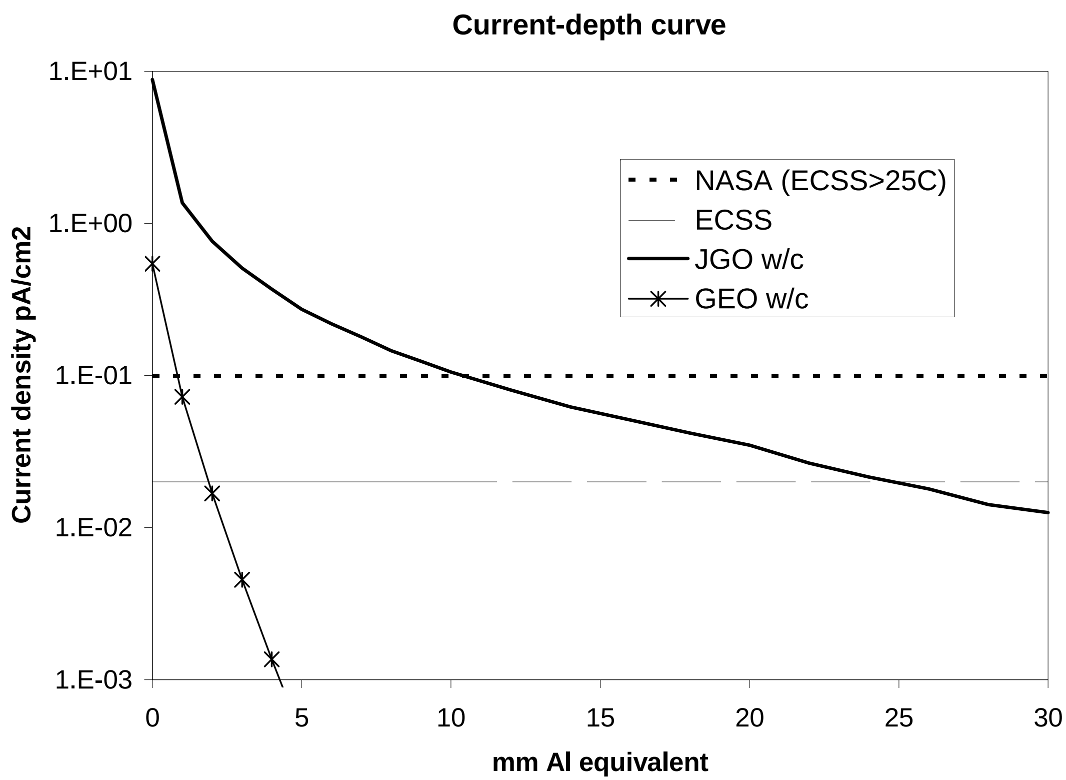


Jupiter Galileo probe instruments also had anomalies for which internal charging ESD is the likely cause [Fieseler et al 2002]

Critical Charging Currents

Critical charging currents

1. 0.1pA/cm2
   - NASA-HDBK-4002
   - ECSS-E-ST-20-06C (>25ºC)
2. 0.02pA/cm2
   - ECSS-E-ST-20-06C (<25ºC)



Shielding to below critical charging current is difficult around Jupiter.

Need to show that the internal charging level is acceptable by simulation.

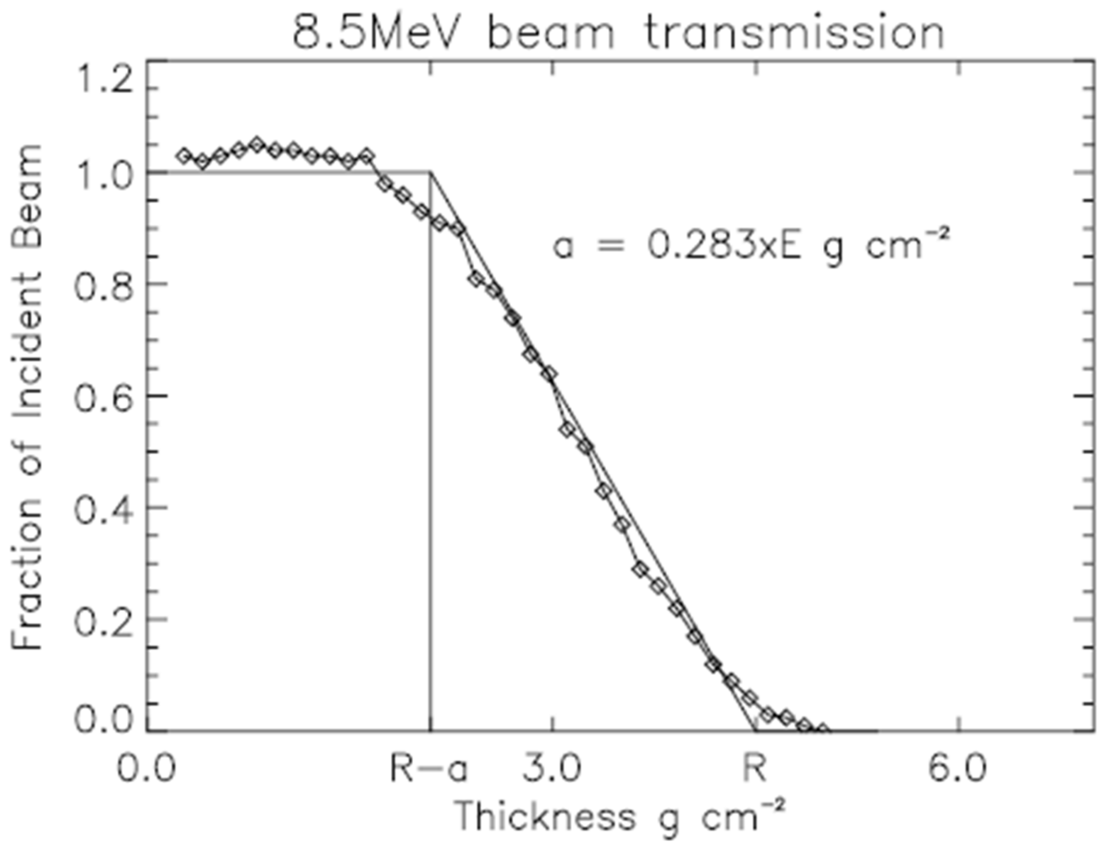
Internal Charging Simulation

Internal charging assessment is part of the spacecraft design process

Dielectric Internal Charging Threat Assessment Tool (DICTAT)

- Accessible via SPENVIS (www.spenvis.oma.be), or stand-alone
- 1-d analytical code
- Planar or cylindrical geometry
- Models:
    - Electron transport and deposition
    - Dose-rate
    - Conductive flow
    - Conductivity variation with temperature, dose-rate and electric field
- Currently version 3 available

Range 'R' and straggle distance 'a'



Calculation of deposited charge

DICTATv3 calculates deposited charge based on Range and straggle

- Range formula of [Weber 1964], valid for Al up to 10MeV
- Straggle formula of [Sorensen 1996]
- assumes all materials can be equated to Aluminium

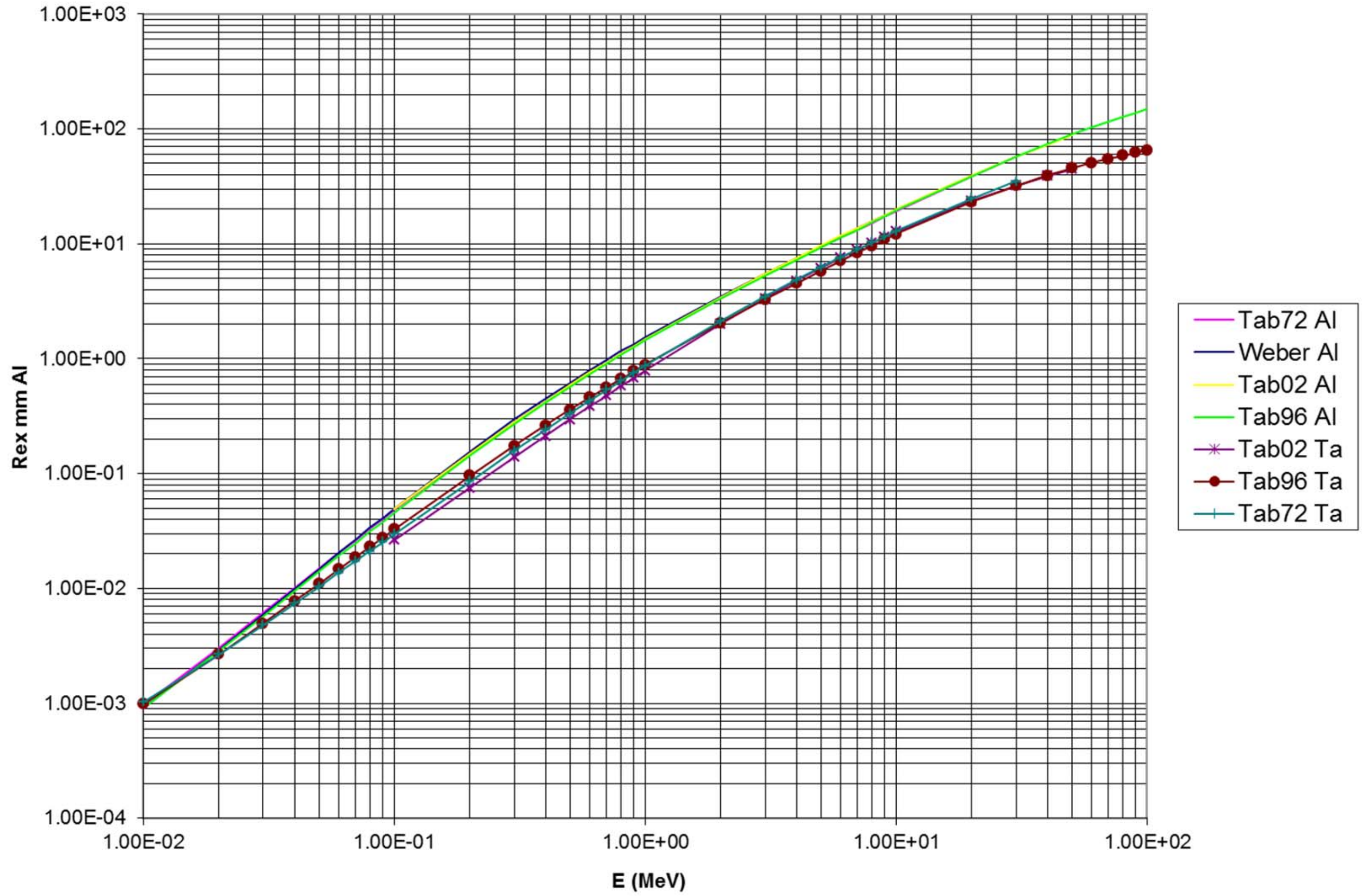
At Jupiter

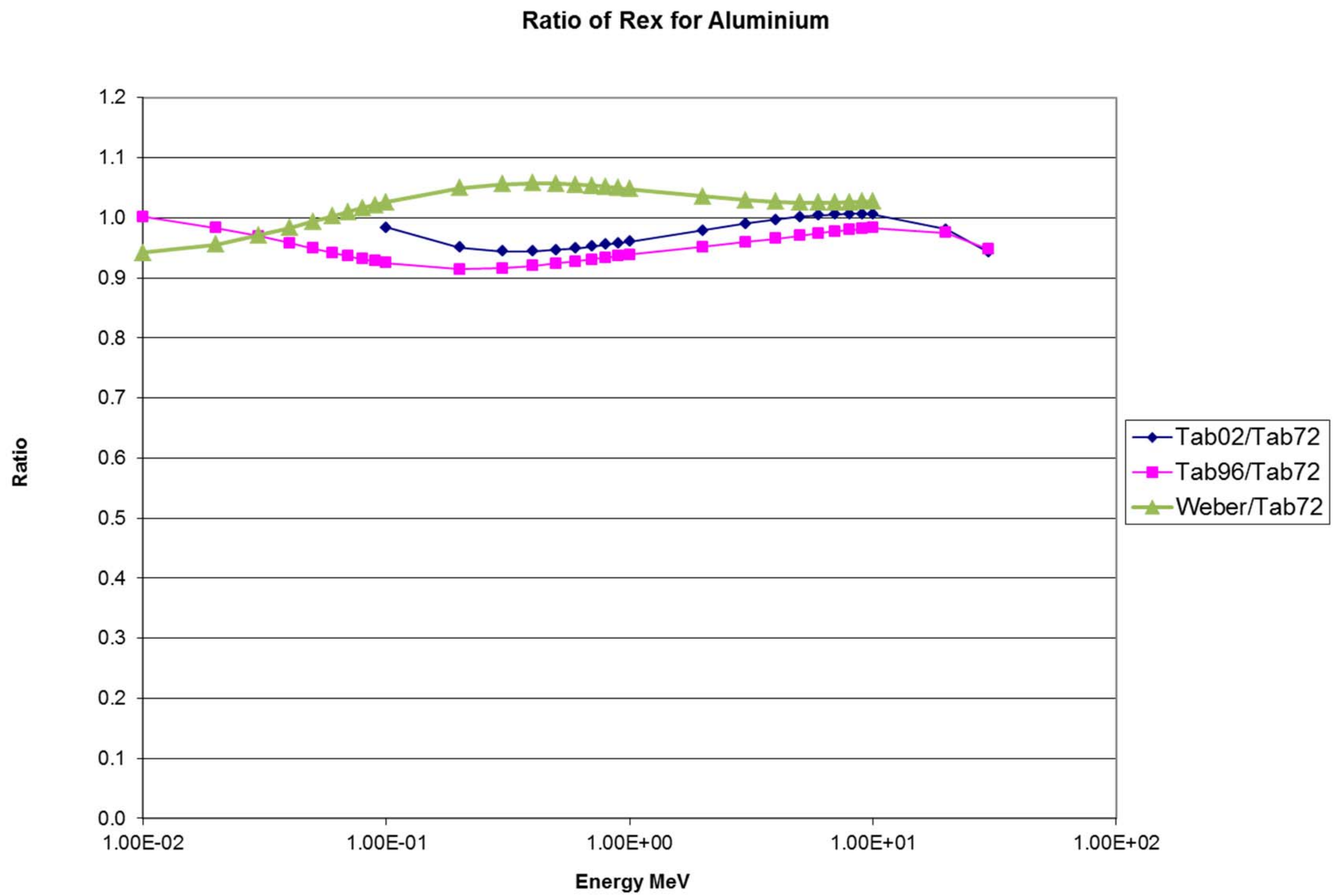
- We need to simulate higher energy electrons (up to 30MeV)
- We need to model Tantalum

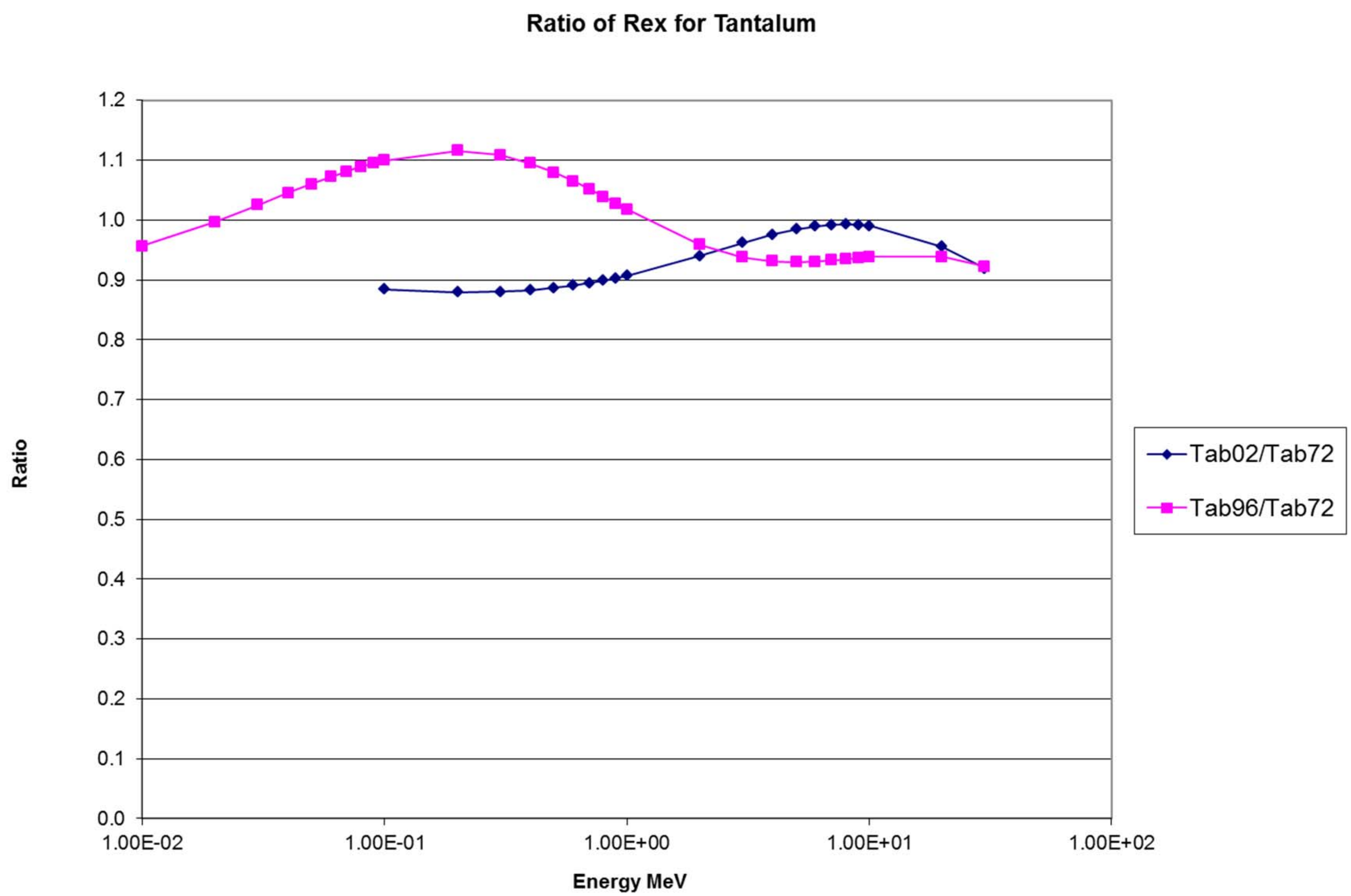
Tabata's work on Range.

[Tabata, Ito & Okabe, 1972]	Experimental fit	0.3keV to 30MeV
[Tabata, Andreo & Shinoda, 1996]	Monte Carlo and experimental fit	1keV to 100MeV
[Tabata, Moskvin, Andreo, Lazurik & Rogov, 2002]	Monte Carlo fit	100keV to 50MeV

Range calculation




Ratio of Rex for Aluminium
Ratio
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Energy MeV
Tab02/Tab72
Tab96/Tab72
Weber/Tab72

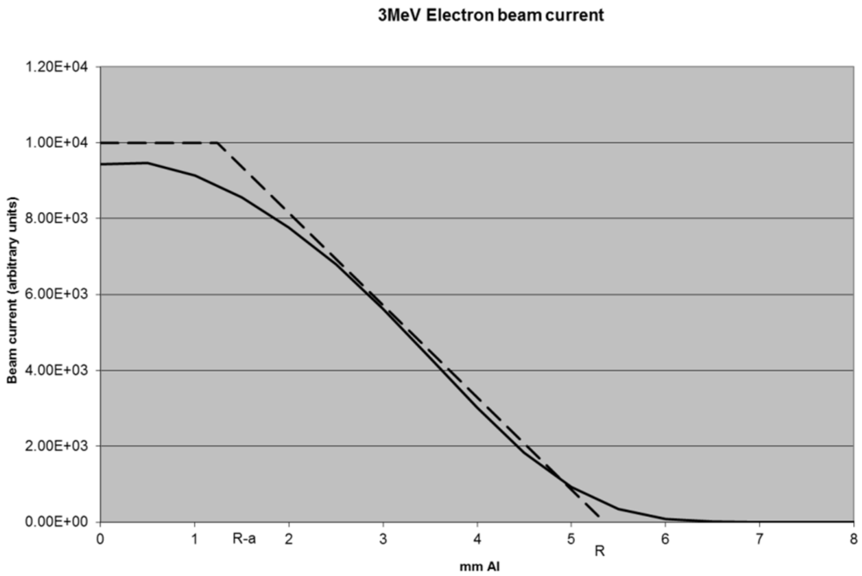


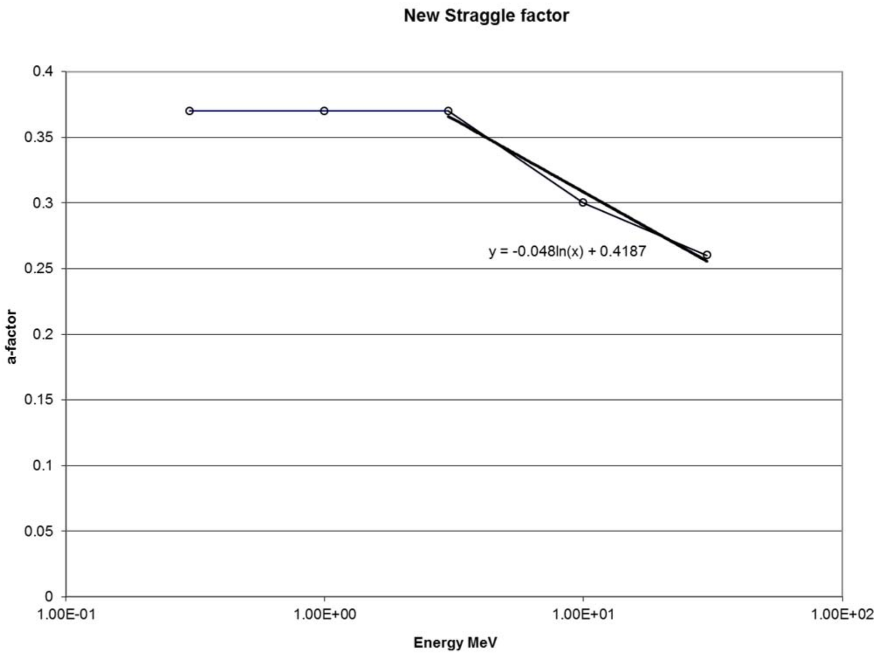
Ratio of Rex for Tantalum
Ratio
Energy MeV
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.00E-02
1.00E-01
1.00E+00
1.00E+01
1.00E+02
Tab02/Tab72
Tab96/Tab72

Calculation of deposited charge

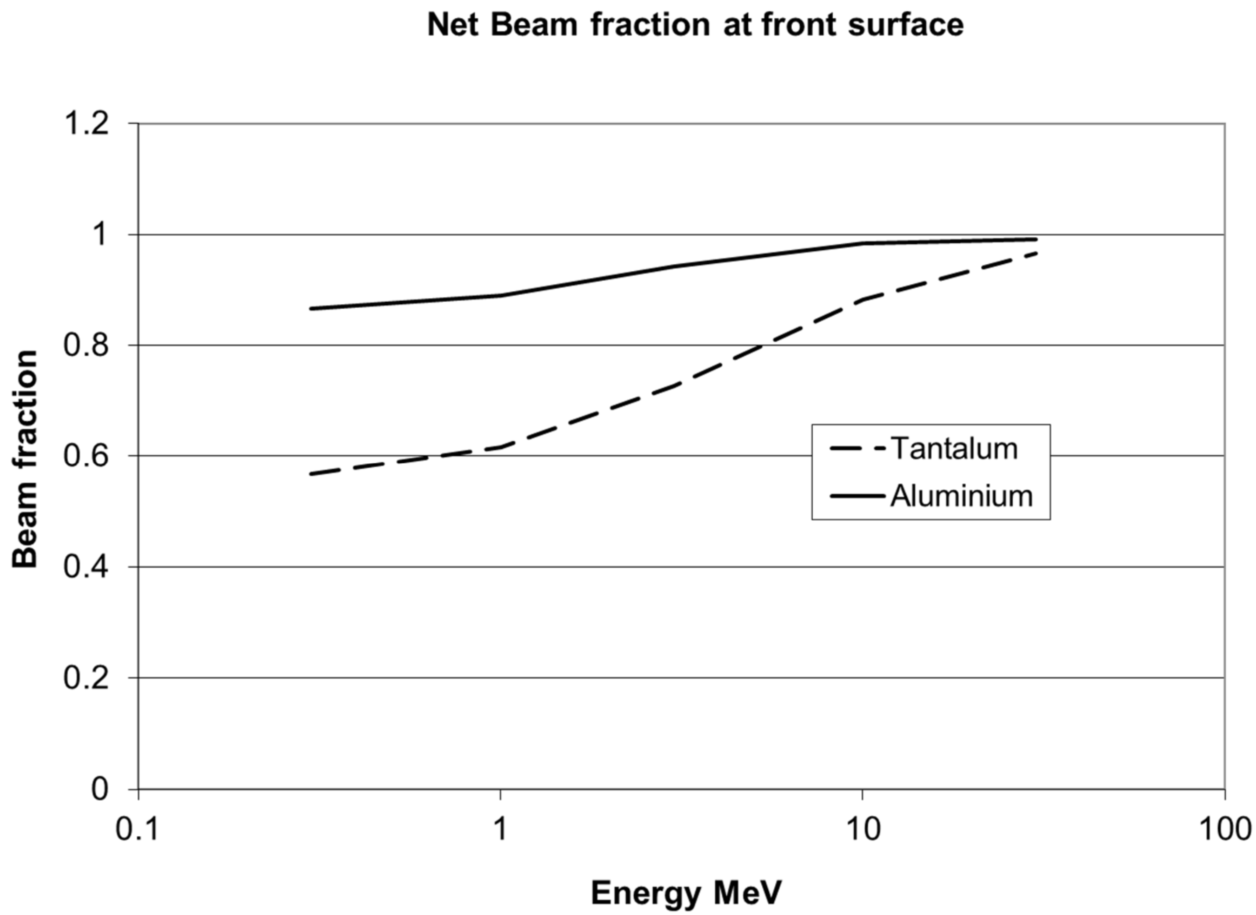
DICTATv4 also uses Range and straggle

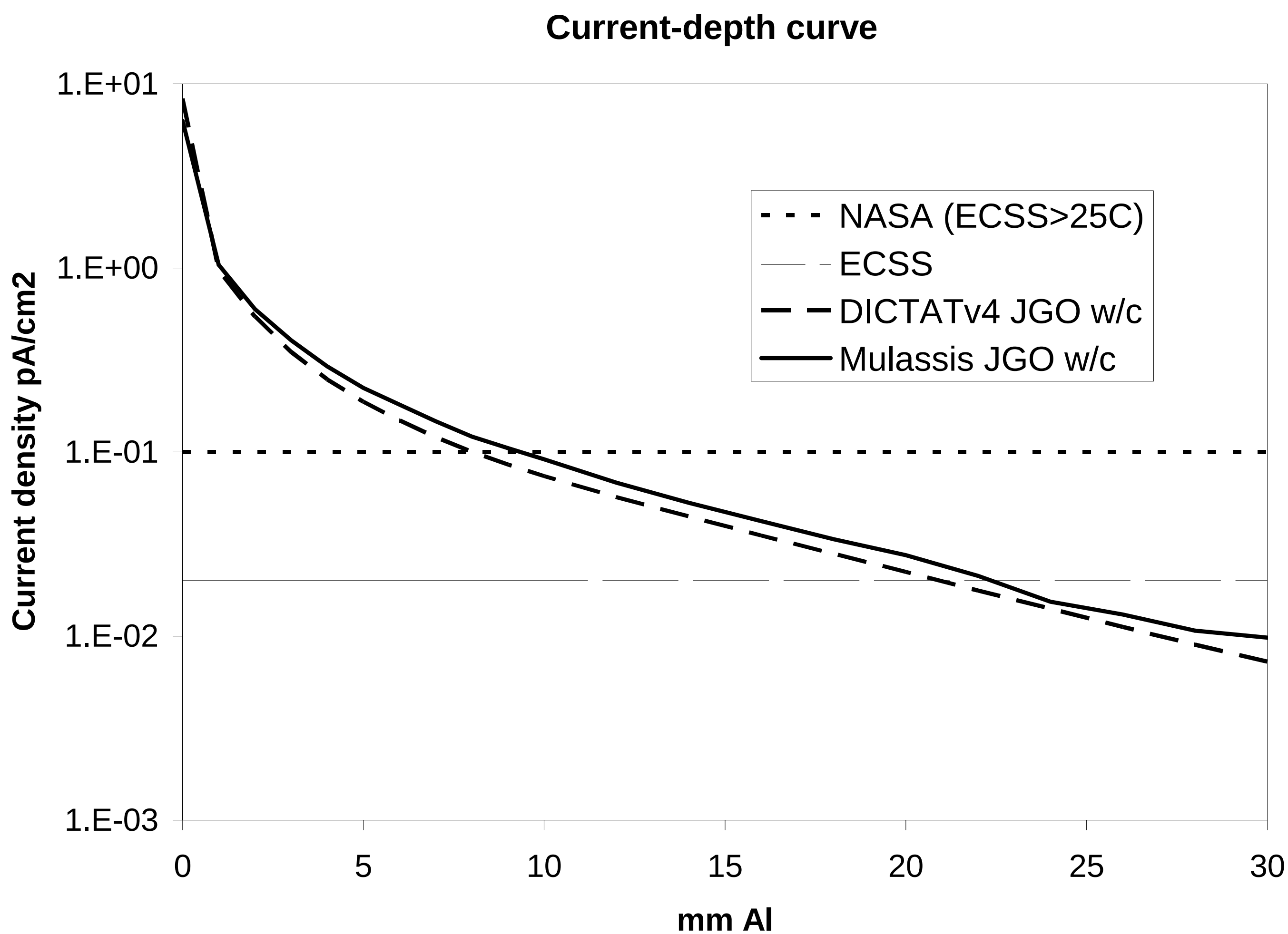
- Range formula of [Tabata, Ito & Okabe, 1972]
- Applicable to a wide range of materials (Z=6-92)
- New straggle formula fitted to net current

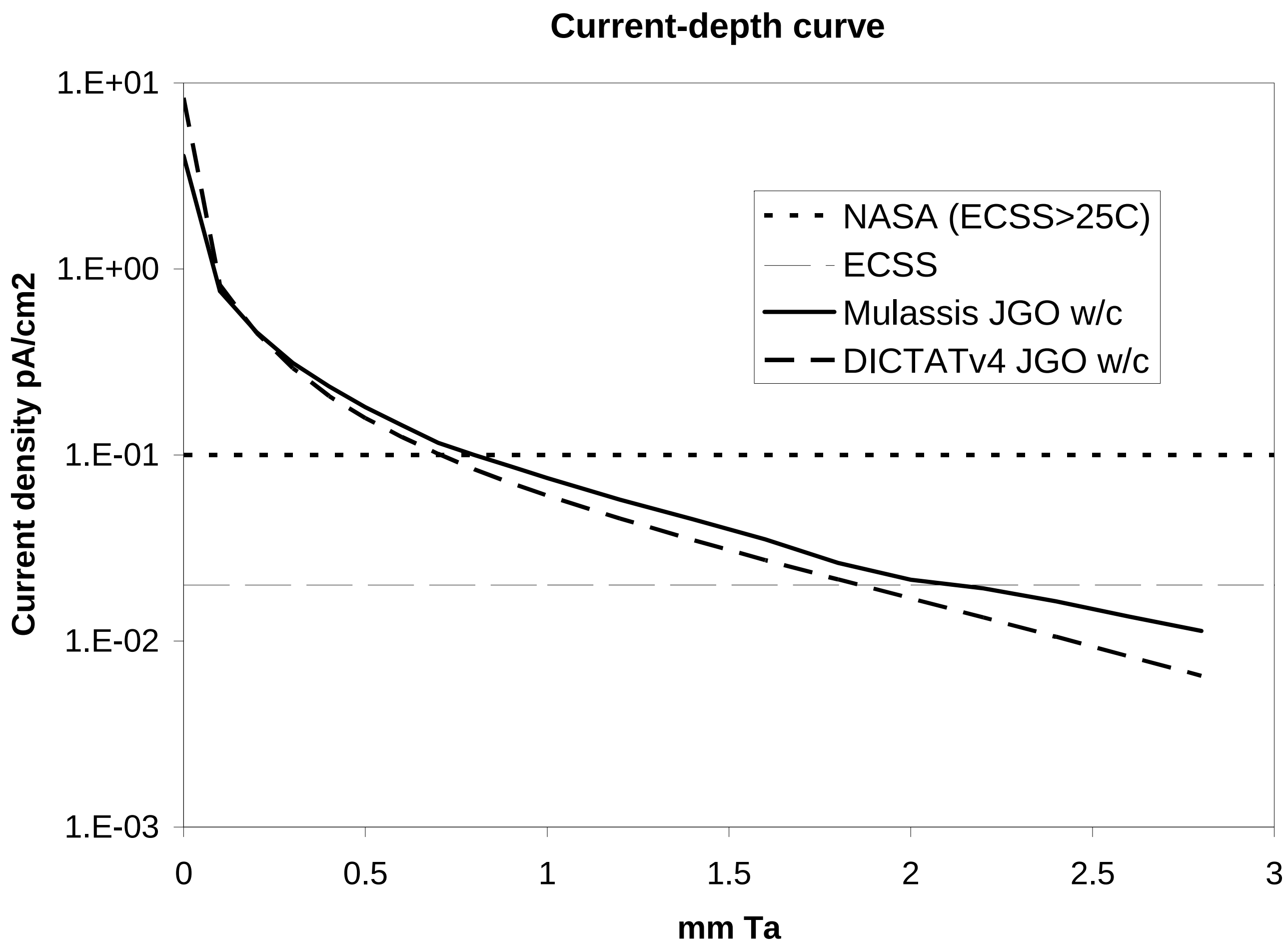




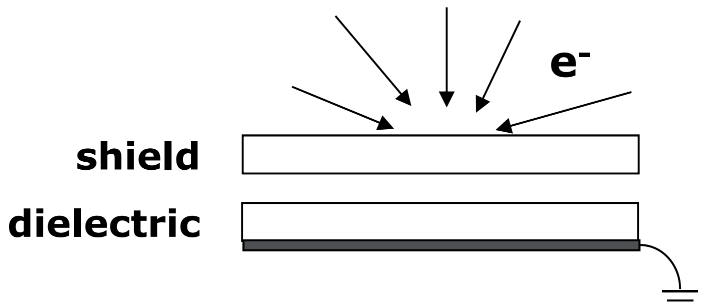
Loss of electrons from front surface




Current-depth curve
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
Current density pA/cm2
0
5
10
15
20
25
30
mm Al
NASA (ECSS>25C)
ECSS
DICTATv4 JGO w/c
Mulassis JGO w/c


Current-depth curve
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
Current density pA/cm2
0
0.5
1
1.5
2
2.5
3
mm Ta
NASA (ECSS>25C)
ECSS
Mulassis JGO w/c
DICTATv4 JGO w/c

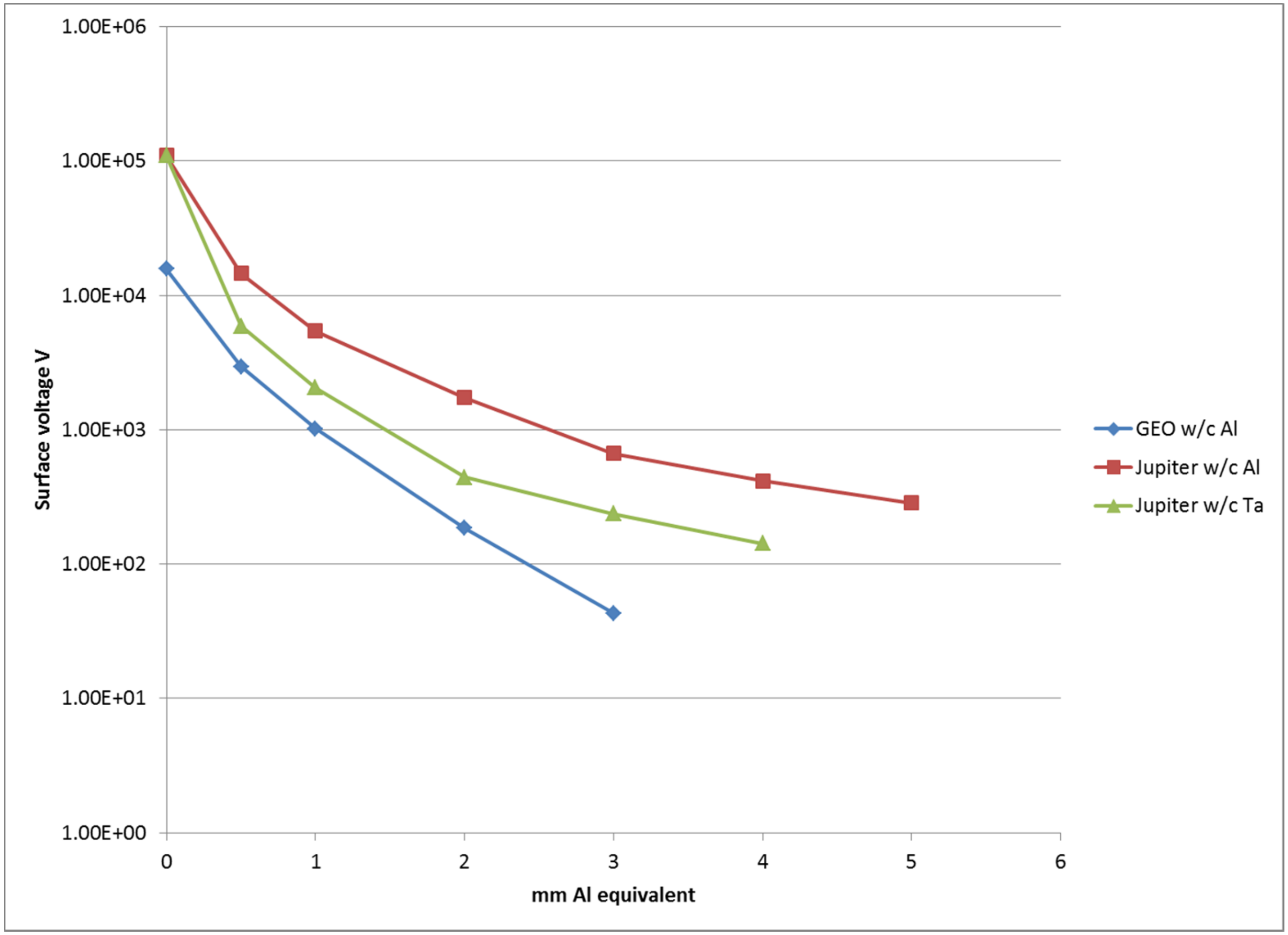
Example run



Material	Density (g/cm^3)	Dark conductivity (Ω^{-1} m^{-1})	Dielectric constant	K_p (Ω^{-1} m^{-1} rad$^{-\Delta}$ s^{-1})	Δ	Ea (eV)
FR4 1mm 0°C	1.94	1.E-18	4	1.E-15	0.75	1.7

$$\sigma = k_p \dot{D}^{\Delta}$$

$$\sigma = \frac{const.}{kT} \exp\left(-\frac{E_A}{kT}\right)$$



1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
Surface voltage V
0
1
2
3
4
5
6
mm Al equivalent
GEO w/c Al
Jupiter w/c Al
Jupiter w/c Ta

Conclusion

1. Shielding to reduce charging current to below critical current levels is difficult around Jupiter.
2. We can make a reasonable quantitative assessment of whether the internal charging level is acceptable by simulation using DICTATv4
3. From examination of simple example cases:
    - Worst case Jovian environment is more severe than terrestrial GEO
    - Shielding of a few mm Al is required
    - Ta is more effective than Al

THE END