MODELING TRAPPED RADIATION—A COMPARATIVE STUDY OF THE TERRESTRIAL, JOVIAN, SATURNIAN, URANIAN, AND NEPTUNIAN RADIATION BELTS

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The Applied Space Environments Conference (ASEC) 2017
15-19 May 2017  Huntsville, AL
OVERVIEW

- Basic Concepts for Trapped Radiation Models
- Planetary Characteristics
- Radiation Belt Models
- Comparisons of Effects
BASIC CONCEPTS FOR TRAPPED RADIATION MODELS

Trapped Radiation Defined in Terms of:
- Flux as a Function of Distance Along Equator (L-Shell)
- Distance along L-Shell from Equator (B-Field at Spacecraft)
Contour plots of >1 MeV electron and >10 MeV proton integral fluxes at Earth. Coordinate system used is geographic at the 0° meridian. Based on AP8 and AE8 solar maximum models.
Jupiter
Contour plots of $>1$ MeV electron and $>10$ MeV proton integral fluxes at Jupiter. Coordinate system used is jovi-centric. Models are based on Divine/GIRE models. Meridian is for System III $110^\circ$ W.
Saturn
Contour plots of $\geq 1$ MeV electron and $\geq 10$ MeV proton integral fluxes at Saturn. Coordinate system used is Saturn-centric. Models are based on Divine/SATRAD models. Meridian is for 0° W.
Trapped Proton Effects on Cassini

Upsets along Cassini orbital traces overlaid on SATRAD >10 MeV proton flux predictions

Forecast:

Lessons Learned: Radiation belt models can predict upsets and drive Ops planning even at Saturn!
Uranus
Contour plots of $\geq 1$ MeV electron and $\geq 5$ MeV proton integral fluxes at Uranus. Plot is for the reference Dipole Coordinates.
Uranian Radiation Belts
Actual Coordinates

Radiation Belt Contours as Viewed by Voyager 2

2.5 MeV Protons

1.0 MeV Electrons

17.24 Hour Planetary Rotation Rate

Uranian Magnetospheric Variations with Rotation**
Neptune
Neptune
**Planetary Characteristics***

<table>
<thead>
<tr>
<th>PHYSICAL PROPERTIES:</th>
<th>Earth</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equatorial radius (km)</td>
<td>6378</td>
<td>71492</td>
<td>60268</td>
<td>25559</td>
<td>24766</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>5.97E+24</td>
<td>1.90E+27</td>
<td>5.68E+26</td>
<td>8.68E+25</td>
<td>1.02E+26</td>
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<tr>
<td>Semi-major axis (AU)</td>
<td>1</td>
<td>5.2</td>
<td>9.54</td>
<td>19.19</td>
<td>30.07</td>
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<tr>
<td>Sidereal day (hr)</td>
<td>23.93</td>
<td>9.89</td>
<td>10.61</td>
<td>17.14</td>
<td>16.7</td>
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<tr>
<td>Dipole tilt (deg)</td>
<td>11.3</td>
<td>9.6</td>
<td>0</td>
<td>58.6</td>
<td>47</td>
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<tr>
<td>Dipole offset (rp)</td>
<td>0.0725</td>
<td>0.131</td>
<td>0.04</td>
<td>0.3</td>
<td>0.55</td>
</tr>
<tr>
<td>Magnetic moment (G-Rp³)</td>
<td>0.305</td>
<td>4.28</td>
<td>0.21</td>
<td>0.228</td>
<td>0.133</td>
</tr>
</tbody>
</table>

*Physical properties of the planets and the Sun. Values are based on the HORIZON system [Giorgini et al., 1996].
Planetary Magnetosphere Comparisons

Bow shock comparisons

\[ \sqrt{y^2 + z^2} (R_N) \]

Earth
Jupiter
Venus
Mars
Uranus
Neptune
Saturn
Venus
Mars
Earth
Saturn
Uranus
Neptune

Courtesy J. Slavin
Planetary Radiation Characteristics

EARTH

SATURN

JUPITER

URANUS

NEPTUNE
Comparative Radiation Belt Doses

<table>
<thead>
<tr>
<th>~Max 1 Mev Electron Flux</th>
<th>~Max Proton Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter: 3x10^8 cm^-2s^-1</td>
<td>Jupiter (10 MeV): 7x10^8 cm^-2s^-1</td>
</tr>
<tr>
<td>Earth: 5x10^6 cm^-2s^-1</td>
<td>Earth (10 MeV): 3x10^5 cm^-2s^-1</td>
</tr>
<tr>
<td>Saturn: 5x10^6 cm^-2s^-1</td>
<td>Saturn (10 MeV): 6x10^4 cm^-2s^-1</td>
</tr>
<tr>
<td>Uranus: 3x10^4 cm^-2s^-1</td>
<td>Uranus (5 MeV): ~10^1 cm^-2s^-1</td>
</tr>
<tr>
<td>Neptune: 10^4 cm^-2s^-1</td>
<td>Neptune (5 MeV): ~10^0 cm^-2s^-1</td>
</tr>
</tbody>
</table>
Comparisons Between Jovian and Terrestrial Radiation Spectra (Inner Radiation Belts)
Conclusions

• The JPL radiation model can be used to estimate radiation and charging effects for interplanetary missions:
  • Total dose versus shielding
  • SEUs due to protons
  • IESD/charging effects on surfaces

• Uranus and Neptune have complex and measurable but fortunately weak belts compared to the other solar planets
  • Although weak, the environment is still sufficient to affect shielding design and parts selection process (e.g., ~ 3 Krad for a 1 year mission behind 100 mils at Uranus)
Uranian Radiation Doses—Voyager 2

Voyager 2 Dose at Uranus

- Photon
- Electrons
- Protons
- Total