Radiation shielding analysis using SPENVIS

D. Heynderickx

DH Consultancy, Leuven, Belgium

Overview

- A quick tour of SPENVIS
  - General functionality
  - Overview of models and tools
  - On-line demonstration
- Currently implemented Jovian environment models
- Ongoing SPENVIS upgrades under the ESA JOREM contract

JOREM models & tools in SPENVIS

- Spacecraft coordinates:
  - Orbit generator produces System III RH coordinate file
  - Upload tool for Orbit Ephemeris Message (OEM) files
    - conversion to System III RH
    - Calculation of Galilean moon positions for body centred trajectories
- JOSE proton, electron and ion (C, O, S) models
- Divine & Garrett plasma models
- SHIELDOSE-J
- Genetic Algorithm (GA) tool
- PLANETOCOSMICS
- DICTAT

Coordinate systems

Ref.	Stand. epoch (d = 0)	d_{2000} (days)	Equinox	Sun		Earth		Jupiter		
				d = 0	d_{2000}	d = 0	d_{2000}	d = 0	d_{2000}	Name
[2], [4]	1957-Jan-1.0	15705.5	B1950	–	–	–	–	Ω = 870.5443169	–	System III (1957.0)
[2], [4]	1965-Jan-1.0	12783.5	B1950	–	–	–	–	Ω = 870.536	–	System III (1965)
[1]	1950-Jan-1.0	18262.5	B1950	α_o = 286 δ_o = 63.8 W = 240.9	α_o = 286 δ_o = 63.8 W = 83.50	α_o = 0 δ_o = 90 ~~W = 99.87~~ W = 9.987	α_o = -0.32 δ_o = 89.72 ~~W = 279.87~~ W = 189.87	α_o = 268 δ_o = 64.5 W = 80.6 Ω = 870.536	α_o = 268 δ_o = 64.50 W = 284.50	System III IAU79
[5]	2000-Jan-1.5	0	J2000	α_o = 286.13 δ_o = 63.87 W = 84.10		α_o = 0 δ_o = 90 W = 190.147		α_o = 268.05 δ_o = 64.49 W = 284.95 Ω = 870.536		IAU88
[6]	2000-Jan-1.5	0	J2000	α_o = 286.13 δ_o = 63.87 W = 84.10		α_o = 0 δ_o = 90 W = 190.147		α_o = 268.05 δ_o = 64.49 W = 284.95 Ω = 870.5366420		IAU2000
[3]	2000-Jan-1.5	0	J2000	α_o = 286.13 δ_o = 63.87 W = 84.10		α_o =0 δ_o =90 W=190.16		α_o = 268.05 δ_o = 64.49 W = 284.95 Ω = 870.536000		JUP_{III}

d_{2000} = Interval in ephemeris days from the standard epoch until 2000-Jan-1.5

Ω = Rotational rate of Jupiter magnetic field (degrees/day)

α_o, δ_o = Equatorial coordinates at specific epoch and equinox (degrees)

[1] Davies M. E. et al, Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites, Celestial Mechanics, 22, 205-230, 1980

[2] Dessler A. J., Appendix B Coordinate Systems, in Physics of the Jovian Magnetosphere, (edited by A. J. Dessler), Cambridge University Press, 1983

[3] Fränz, M., & Harper, D., Heliospheric Coordinate Systems, Planet. Space Sci., 50, 217-233, 2002

[4] Seidelman P. K. & Devine N., Evaluation of Jupiter Longitudes in System III (1965), Geophys. Res. Let., 4, 65-68, 1977

[5] P. K. Seidelmann, et al, IAU/IAG Report, Cel. Mech. Dyn. Astr., 46, 187–204, 1989

[6] P. K. Seidelmann, et al, IAU/IAG Report, Cel. Mech. Dyn. Astr., 82, 83–110, 2002

OEM files

```
CCSDS_OEM_VERS = 1.0
CREATION_DATE  = 2009-06-23T11:43:52
ORIGINATOR     = ESOC/TOS-GFI

COMMENT Orbit data are consistent with planetary ephemeris DE-405

META_START
OBJECT_NAME          = JGO
OBJECT_ID          = 000
CENTER_NAME          = CALLISTO
REF_FRAME          = EME2000
TIME_SYSTEM          = TDB
START_TIME          = 2026-12-24T10:48:57.27103982
STOP_TIME          = 2026-12-24T15:10:22.08000000
INTERPOLATION        = HERMITE
INTERPOLATION_DEGREE = 11
META_STOP

2026-12-24T10:48:57.27103982      11564.900641      -32508.202973      -15148.541239   -1.064965   1.738152   0.803328
2026-12-24T10:59:49.30468679      10869.980283      -31374.016243      -14624.350244   -1.066588   1.740808   0.804555
...
2026-12-24T20:00:48.87199203     -11262.479393       32593.430397       15193.200515   -0.224400   1.974462   0.927185

META_START
OBJECT_NAME          = JGO
OBJECT_ID          = 000
CENTER_NAME          = JUPITER
REF_FRAME          = EME2000
TIME_SYSTEM          = TDB
START_TIME          = 2026-12-24T20:00:48.87199203
STOP_TIME          = 2026-12-28T16:58:22.36825288
INTERPOLATION        = HERMITE
INTERPOLATION_DEGREE = 11
META_STOP

2026-12-24T20:00:48.87199203    -748422.464299   -1537522.702461    -735719.994513   7.318328   -0.909819   -0.320040
2026-12-24T20:17:20.54983801    -741157.124836   -1538412.165530    -736031.228156   7.334243   -0.883943   -0.307609
```

JOSE trapped particle models

- Stand-alone TREP_JOREM for JOSE models
- Produces proton, electron and ion (C, O, S) fluxes in separate files:
  - Full spectra along the trajectory
  - Tables with peak fluxes
  - Integrated integral and differential spectra
- Prototype implementation adapted to new version of JOSE library
- Can run on SAPRE output or uploaded trajectory
- Flux thresholds to be added on interface page
- Implementation of confidence levels with next release of JOSE library

Plasma models

- Divine & Garrett [1983]
- Warm and cold electron and ion populations
- Different regimes of Jovian radial distance
- Will be implemented similar to JOSE models:
  - Model run for each location in trajectory file
  - Outputs: number density and temperature for each species at each location
  - Peak values and trajectory integration (TBD)

SHIELDOSE-2 upgrade

- Generation of new SHIELDOSE database:
  - Extension of electron energy range to >50 MeV
  - Treatment of non-Al shields:
    - Al, Ta, Fe
    - Layered shields (Al+Ta)
    - CW80, Ti
  - New target materials: plastics, epoxy, InGaAs, …
- Same functionality as SHIELDOSE(-2), but extended menu options (shield configuration, target selection)
- Will be available as an alternative for SHIELDOSE(-2)

PLANETOCOSMICS

- Geant4-based application for particle transport (electrons and ions) in magnetic fields of Mercury, Earth, Mars and Jupiter
- Treats nuclear and electromagnetic interactions in the atmospheres and/or planetary surfaces
- Extension to Galilean moon environments:
  - Implementation of magnetic field models (needs coordinate transformations)
  - Moon surface specification
  - Shielding of Jovian fluxes by lunar body
- Adaptation of the PLANETOCOSMICS interface currently under development by BIRA

Genetic algorithm shielding tool

- Uses a genetic algorithm (GA) software package plus Mulassis to help identify optimal shield configurations
- New interface pages in SPENVIS to set up tool configuration and perform test runs
- GA parameters: population size, number of generations, type of mutations
- Material parameters: thickness range, shielding material, shield configuration (slab, sphere)
- Fitness function parameters

$$f = 1 - \left(w_D \frac{TID}{TID_{Max}} + w_N \frac{TNID}{TNID_{Max}} + w_M \frac{Mass}{Mass_{Max}} + w_T \frac{Thickness}{Thickness_{Max}} \right)$$

Deep dielectric charging

- DICTAT tool for analysis of electrostatic discharge risk
- Planar and cylindrical structures: dielectric plus shield
- Dielectric and shield material parameters and configuration
- Current version is intended for use in Earth electron environment
- Electron spectra from internal worst case flux model (FLUMIC) run over trajectory, or spectrum input by user
- For JOREM, trajectory integrated JOSE electron spectrum could be used
- Validity of functions and methods in very high energy environment will need to be validated