ESA's Human Interplanetary Exploration Radiation Risk Assessment System (HIERRAS)

Consortium and contract

- DH Consultancy, Leuven, Belgium (Prime): D. Heynderickx
- Kallisto Consultancy Ltd, Farnborough, UK: P. Truscott
- RadMod Research Ltd, Camberley, UK: F. Lei
- DLR, Cologne, Germany: D. Matthiä, T. Berger, M. Wirtz
- Consultants
  - University of Turku, Finland: R. Vainio, O.Raukunen
  - SPARC, Athens, Greece: A. Tsigkanos, I. Sandberg
- ESA Contract No: 4000127129/19/NL/HK
- ESA: P. Jiggens (Technical Officer), S. Clucas, G. Santin

Stakeholder team

- Expert consultation group to provide feedback and testing
- Members: W. Atwell, E.J. Daly, L. Dartnell, H. Evans, A. Fogtman, P. Gonçalvez, M. Giraudo, C. Lobascio, S. McKenna-Lawlor, A. McSweeney, L. Narici, P. Nieminen, G. Reitz, R. Singleterry, U. Straube, M. Vuolo

HIERRAS system overview

- Framework providing access to state of the art models and tools for:
  - Primary radiation environment
    - Spacecraft trajectories
    - Earth radiation belts, Solar energetic particles, galactic cosmic ray, Earth magnetic shielding
  - Particle propagation through layered and full 3D geometries (including Mars soil and atmosphere, GRAPPA)
    - Shielded flux, TID, TNID, LET, …
  - Sector shielding analysis
  - Radiation effects
    - Radiobiological dose, dose-depth curves, SEU rates
- Access to models and tools via command line, Python routine calls or Graphical User Interface (GUI)
- Standardised metadata and message and file exchange json formats
- Validation and verification testing

HI
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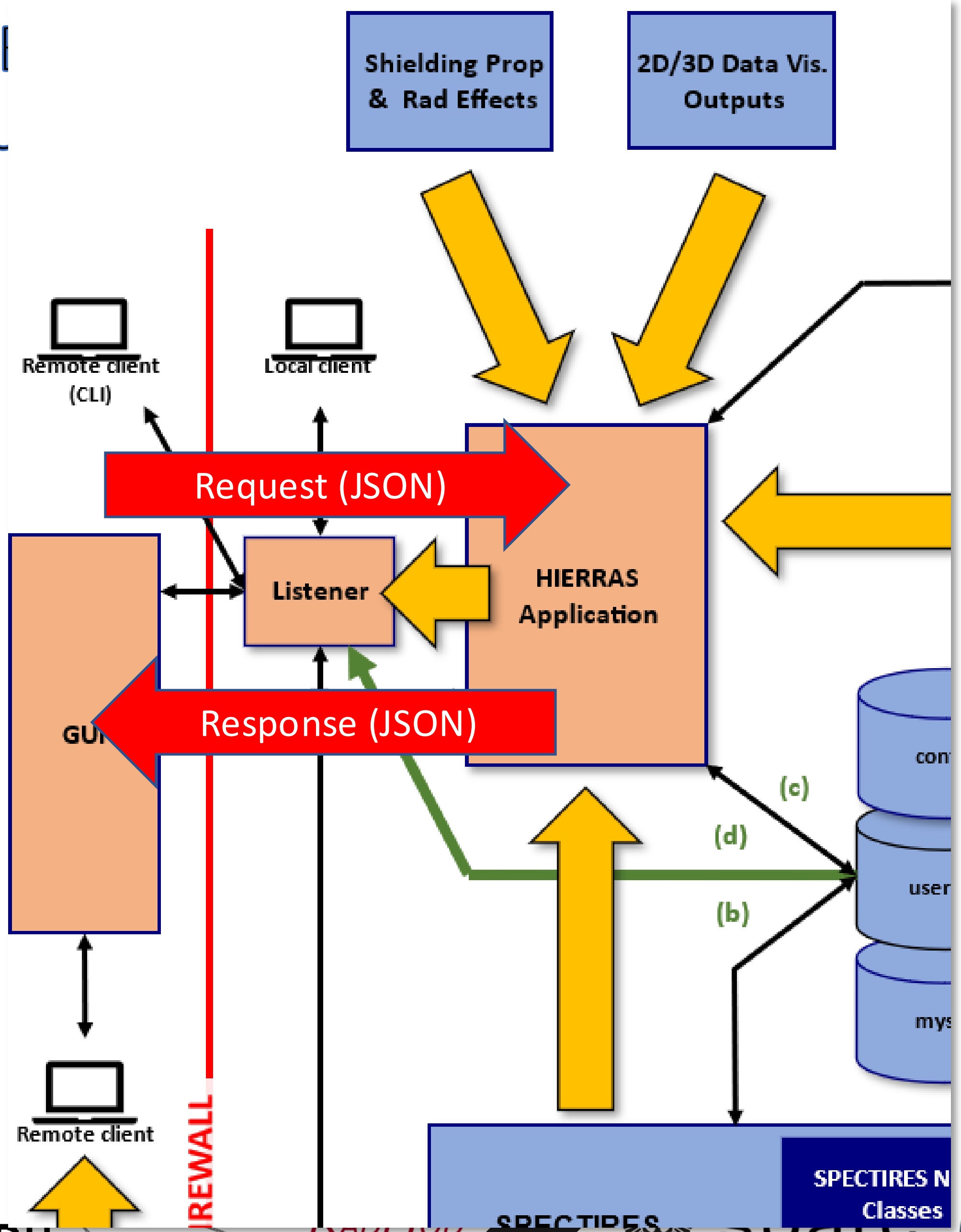
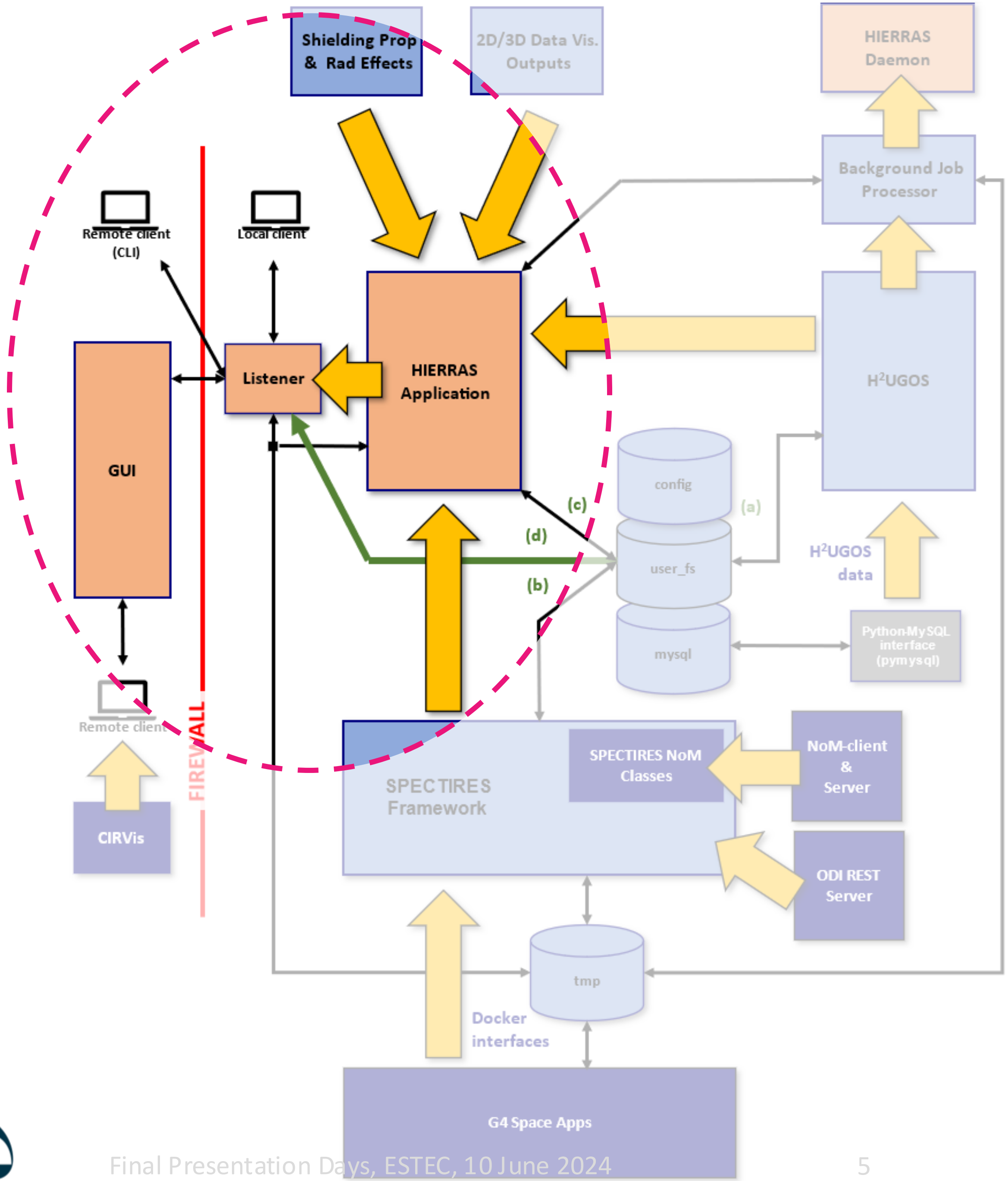


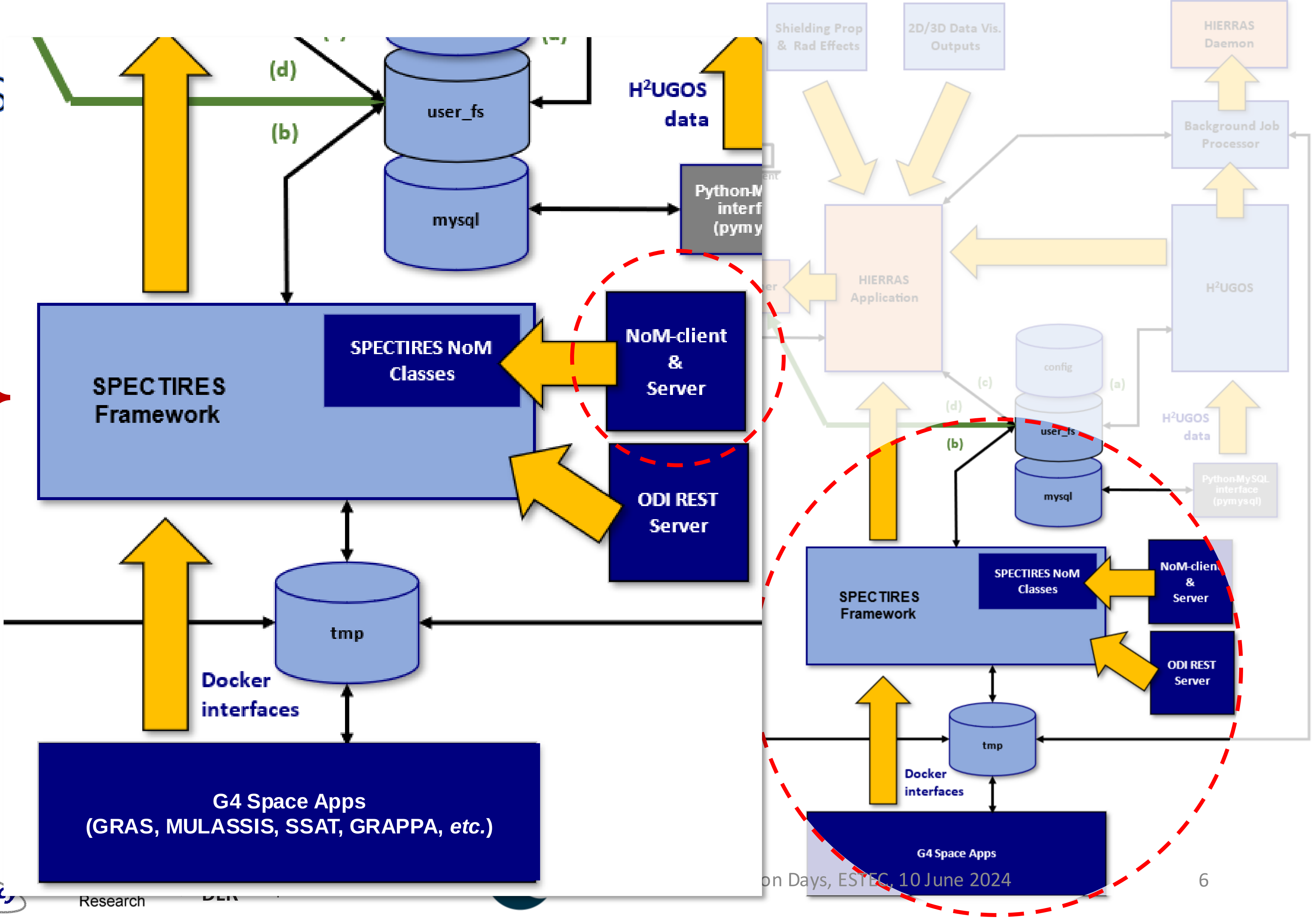
Shielding Prop & Rad Effects
2D/3D Data Vis. Outputs
Remote client (CLI)
Local client
Request (JSON)
Listener
HIERRAS Application
GUI
Response (JSON)
(c)
(d)
(b)
Remote client
FIREWALL
SPECTIRES N Classes



Shielding Prop & Rad Effects
2D/3D Data Vis. Outputs
HIERRAS Daemon
Background Job Processor
Remote client (CLI)
Local client
Listener
HIERRAS Application
GUI
H2UGOS
config
user_fs
mysql
(a)
(b)
(c)
(d)
H2UGOS data
PythonMySQL interface (pymysql)
Remote client
FIREWALL
CIRVis
SPECTIRES Framework
SPECTIRES NoM Classes
NoM-client & Server
ODI REST Server
tmp
Docker interfaces
G4 Space Apps

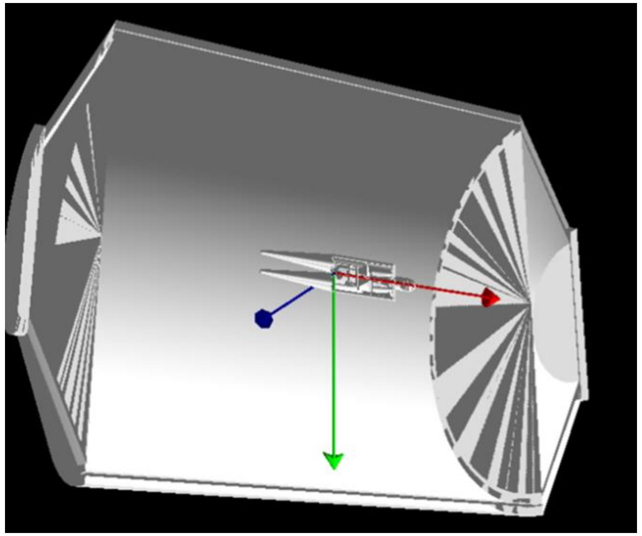
SPECTIRES

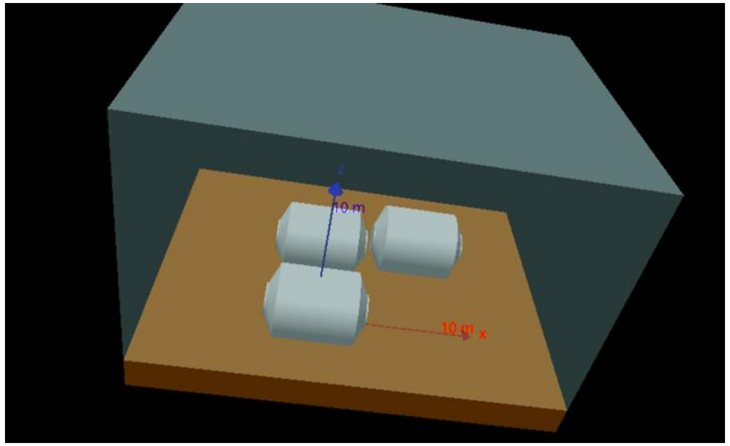
- Trajectory Generators
- Radiation Env Models (GCR, SEP etc)
- Shield Transport Models (+G4 I/F)
- System Effects Analysis Models



Particle Propagation Module (PPM)

- Direct simulation:
  - GRAS (3D),
  - MULASSIS (1D/2D) geometries
- Response Functions (RPF) generation and convolution:
  - GRAS (3D)
  - MULASSIS (1D/2D)
- Tallies:
  - Detector: Particle flux spectra, TID and TNID
  - Phantom: individual organ and full body
  - Maps: Dose_deposited and fluxes
- Sector Shielding Analysis:
  - SSAT (3D)
- Geometry Tools
  - 3D multi-geometry modeller
  - GDML upload and processing
  - 1D/2D shielding configurator
  - Depth configurator for DDC
  - Detector creator
  - Planetary surface (GRAPPA)



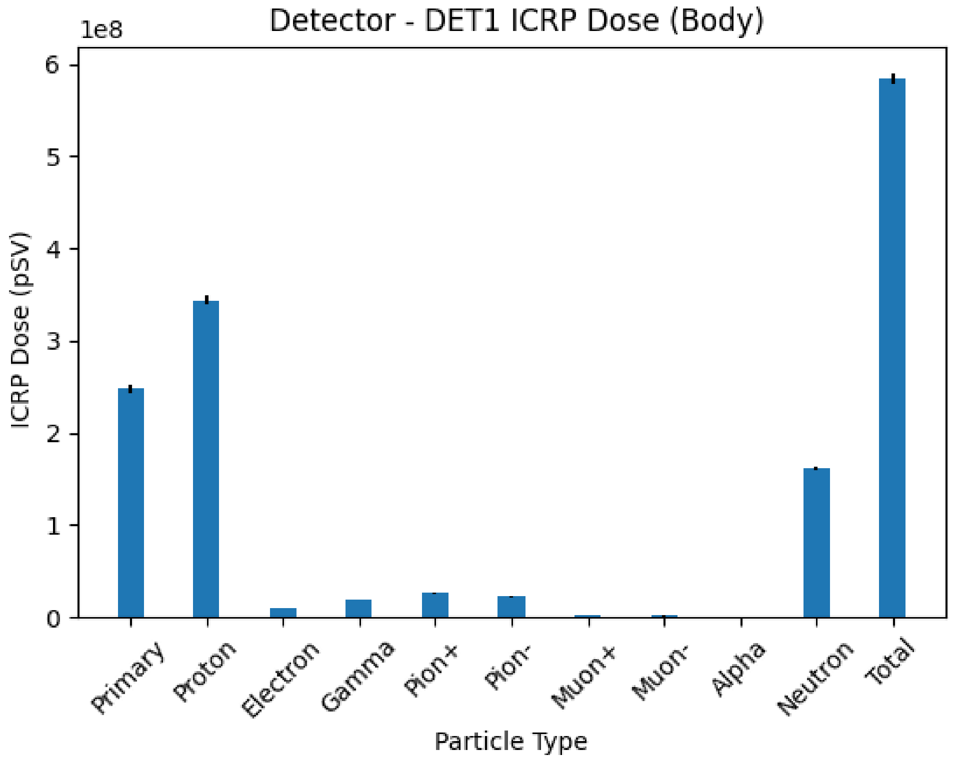


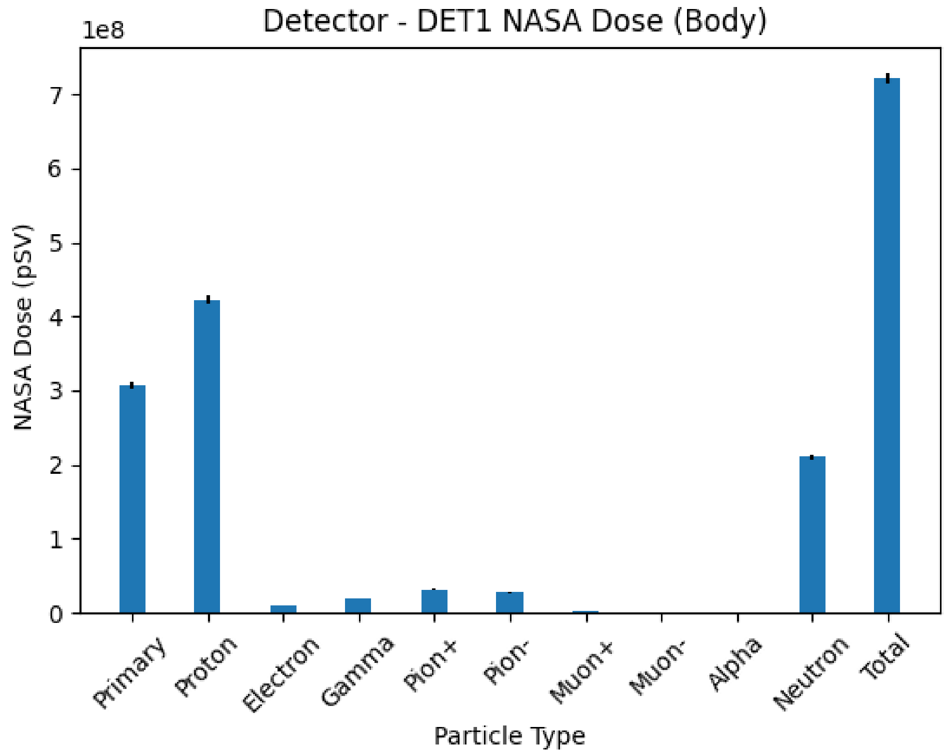
Effects tools module (ETM)

- Biological dose (3D/GRAS)
  - Detector based
    - Full body or RBM, skin, eye lens
    - E_H (ICRP 123), E (ICRP 116), H*(10)
  - Phantom based
    - Full body (E_H, E)
    - Organs (E_H)
  - Map based
    - Full body (E_H, E)
- Biological dose (1D/MULASSIS)
    - E_H (ICRP 123), E (ICRP 116), H*(10)

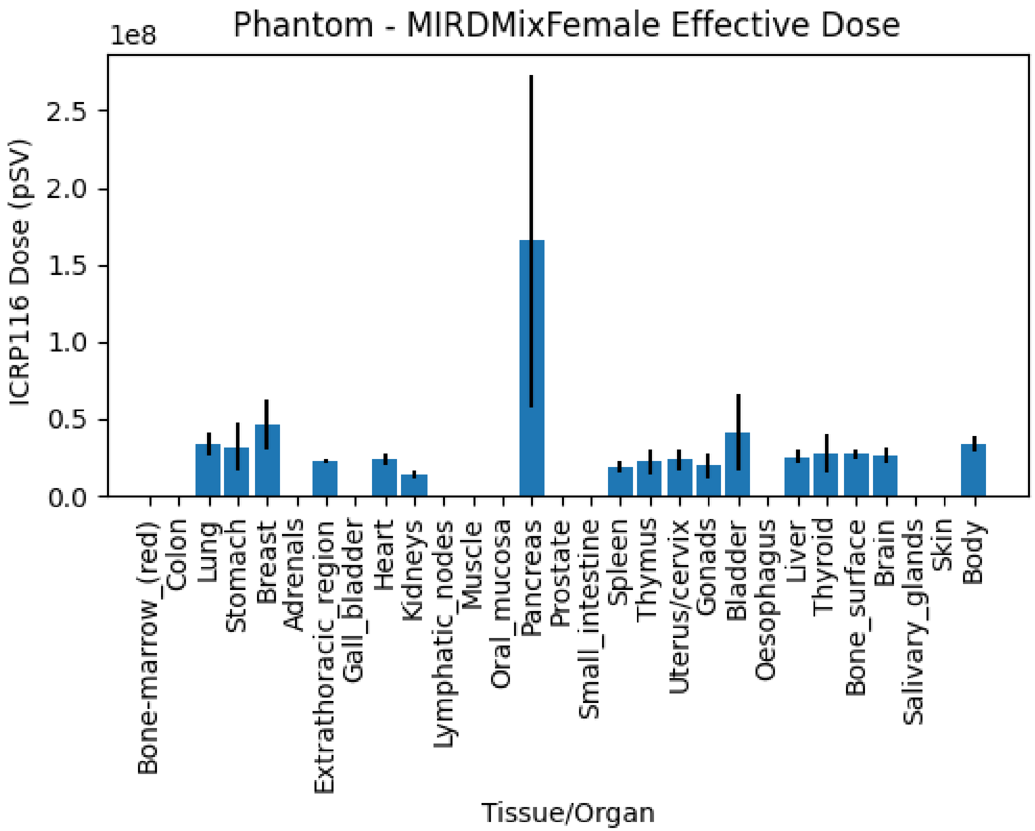
- DDC and Depth-LET Spectra calculator:
  - SD-2Q
  - MULASSIS
- Sector Shielding Doses
  - TID (SHIELDOSE-2Q, MULASSIS)
  - TNID (MULASSIS)
  - Biological (MULASSIS)
- EQFLUX and SHIELDOSE-2Q
- SEU (HI/LET, proton/neutron)
  - 3D Detector (GRAS)
  - 1D Layered shielding (MULASSIS)

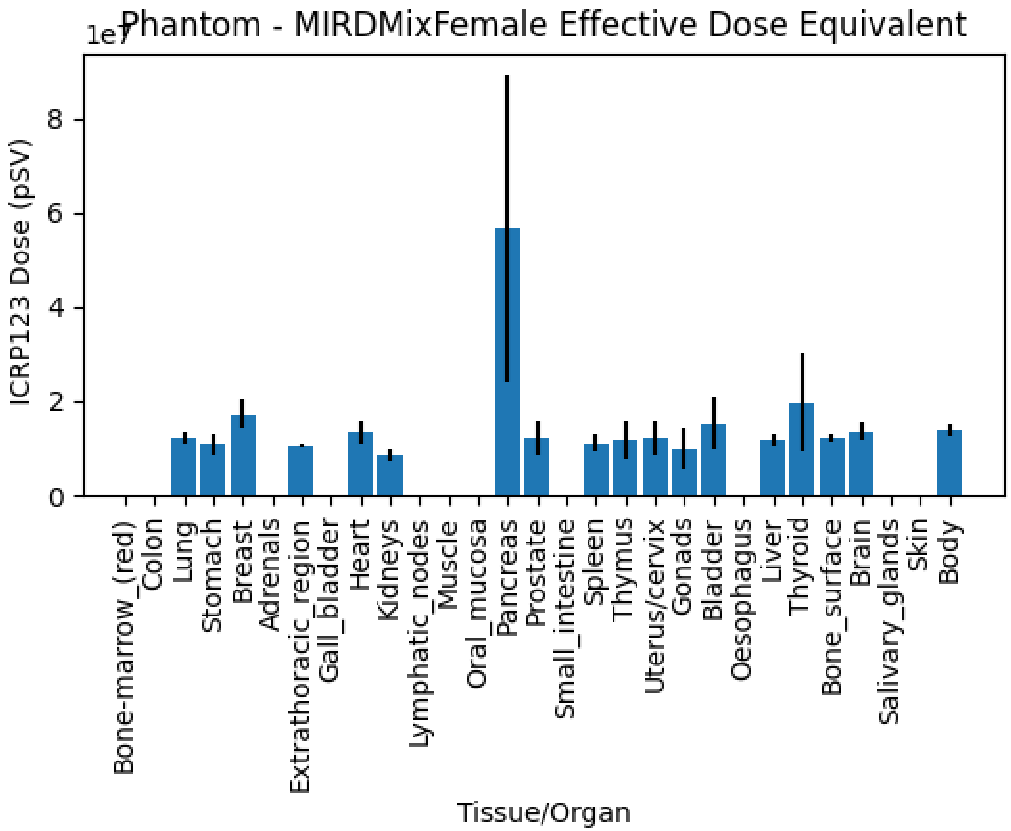
Detector based biological dose



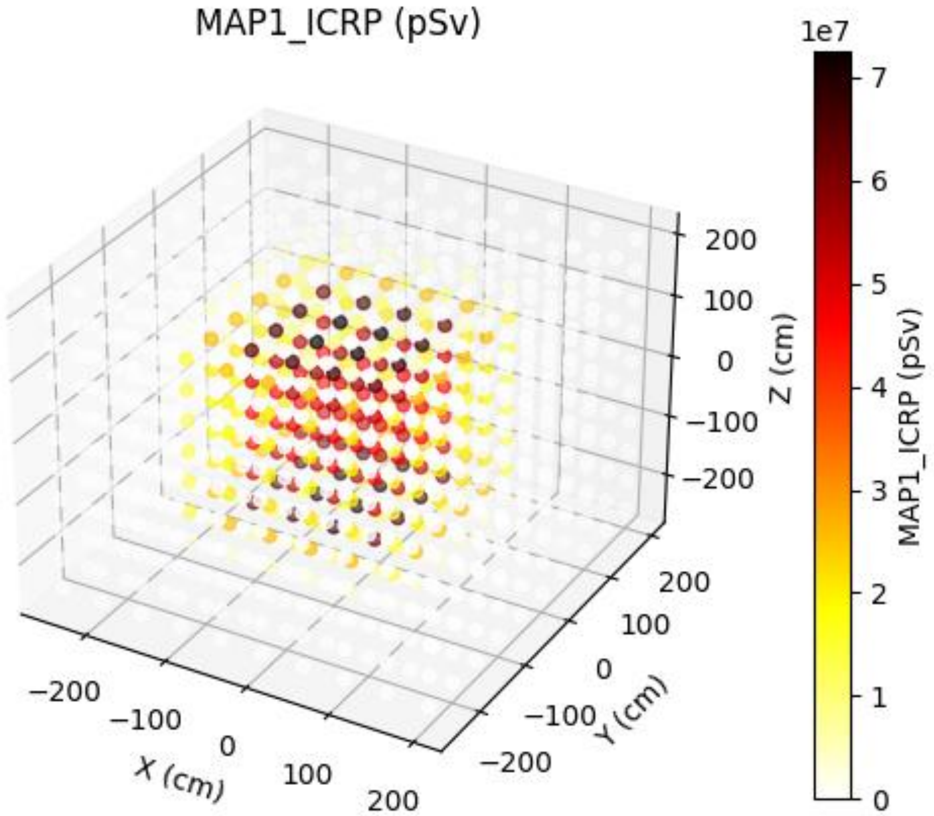


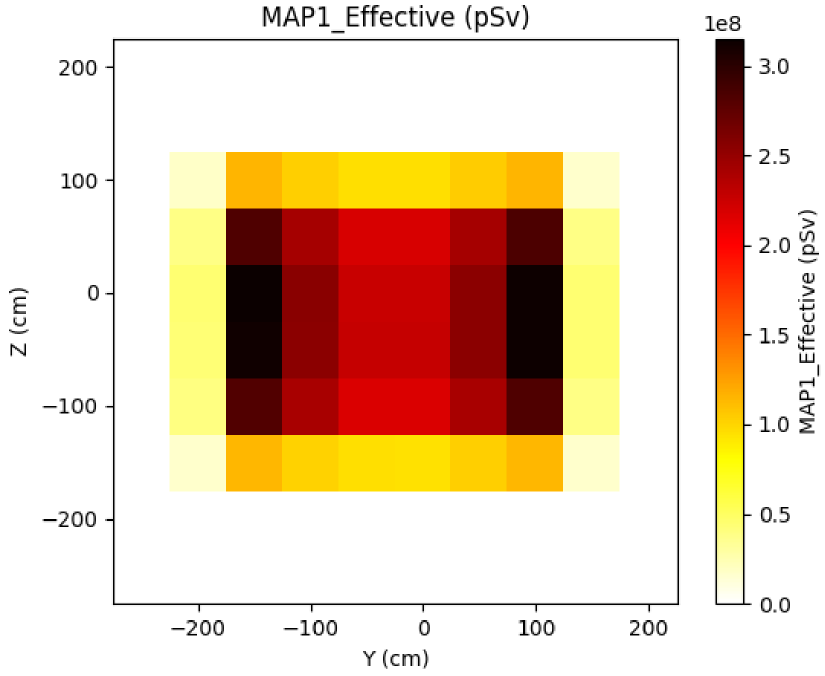
Phantom based biological dose

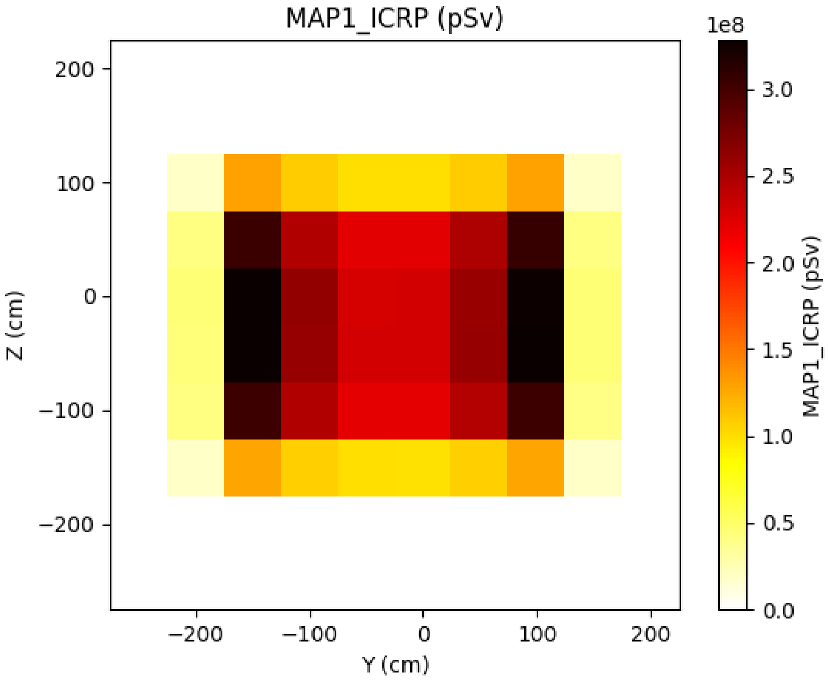




Biological dose maps







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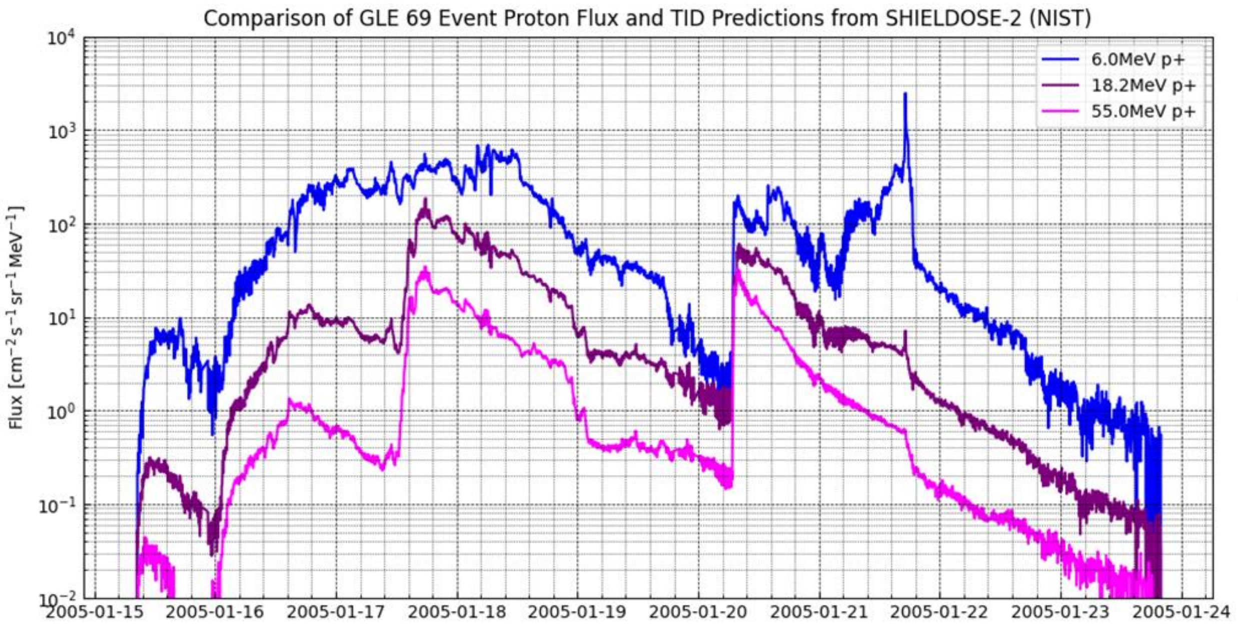
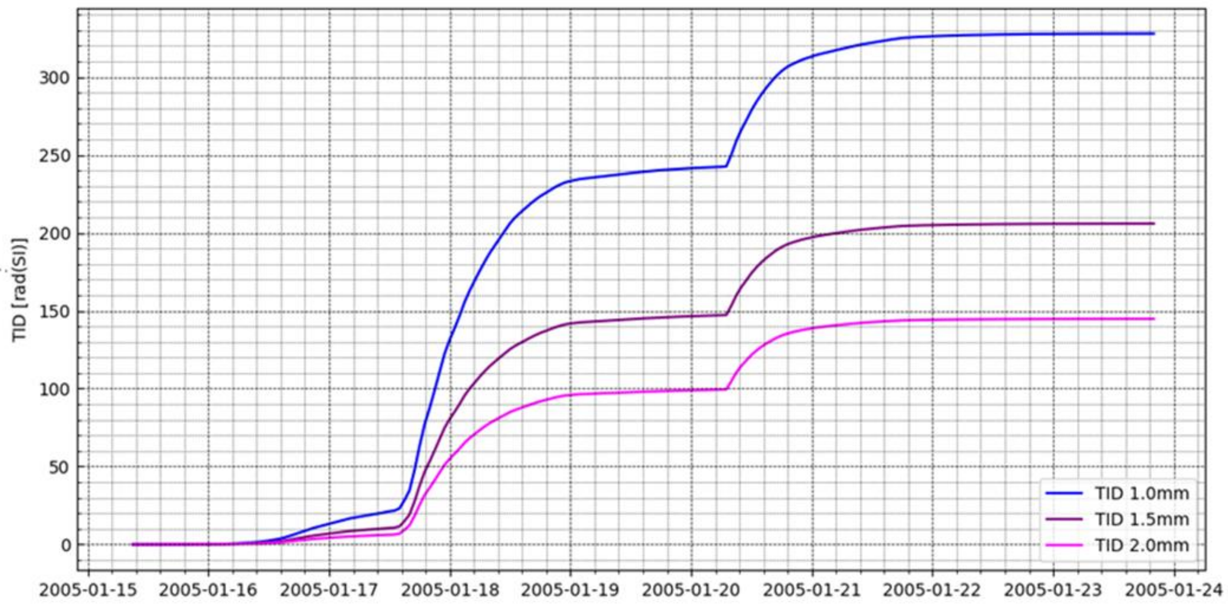
Time series analysis





Test & Verifications

Integrated or system level tests

- APP - backend/cml
  - 7 AdminTest
  - 80 AppTest
  - > 20 SPM Tests
- GUI – frontend/web
  - Selenium IDE

Regression Test

- Generation of reference dataset
- Comparison with reference

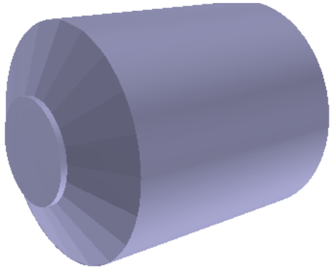
- Test Tools
  - PyTest
  - Coverage
  - Selenium
- Test Report
  - HTML
  - PDF

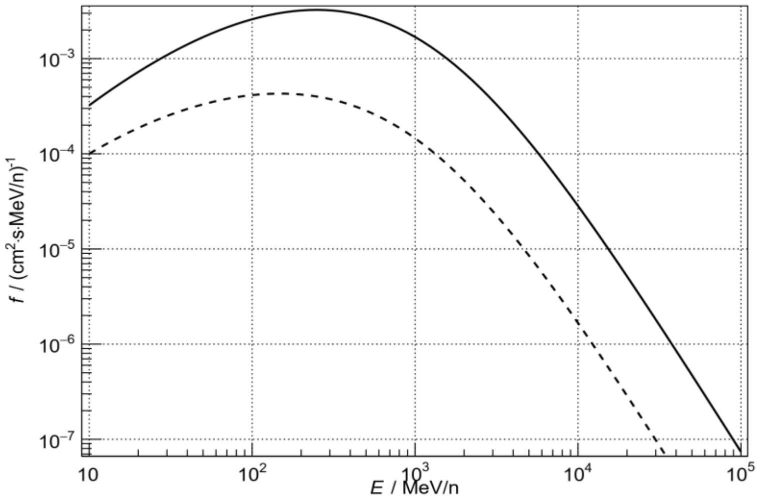
VALIDATION cases

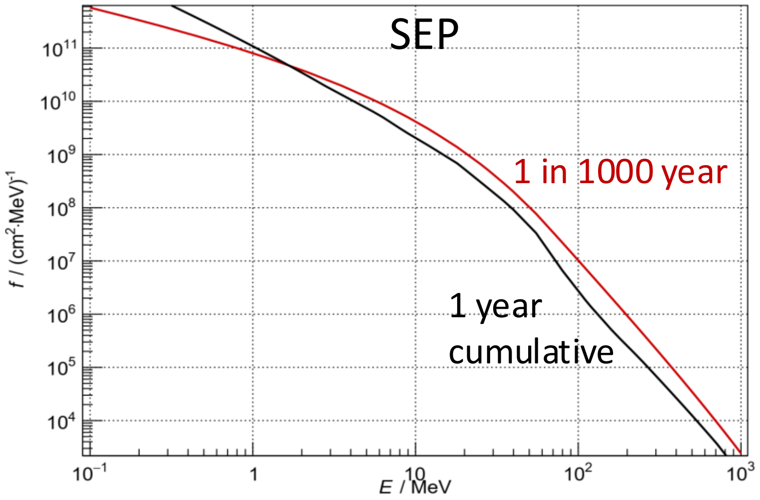
	Scenario	Time	Source	Type of data/endpoint	Reference
HIERRAS/ROSSINI	Interplanetary	Solar max / solar min conditions	GCR/SEP	Particle spectra, Effective Dose Equivalent rate	
DOSIS/DOSIS3D	LEO/ISS	Solar max / solar min conditions	GCR/SAA	Dose rate in silicon	[Berger et al., 2016] [Berger et al., 2017] [Berger et al., 2018]
MATROSHKA	LEO/ISS	26 Feb 2004- 18 Aug 2005	GCR+SAA	Organ absorbed dose rate	[Reitz et al., 2009] https://www.fp7-hamlet.eu/
CRaTER	Moon/surface	Solar max / solar min conditions	GCR	Dose rate in silicon	http://crater-web.sr.unh.edu/ [Schwadron et al., 2018]
MSL-RAD	Mars/surface	Aug 2012 – Jan 2013; 15 Nov 2015 – 15 Jan 2016;	GCR	Dose rate in silicon, dose equivalent rate; H-Fe spectra, E<100-300 MeV/n;	[Ehresmann et al., 2014] [Matthiä et al., 2016] [Ehresmann et al., 2017] [Matthiä et al., 2017]

HIERRAS-ROSSINI inter-comparison

- GCR solar minimum (H-Ni)
- SEP
  - 1 year cumulative fluence
  - 1 in 1000 year
- Cylindrical module, 10 cm Al wall



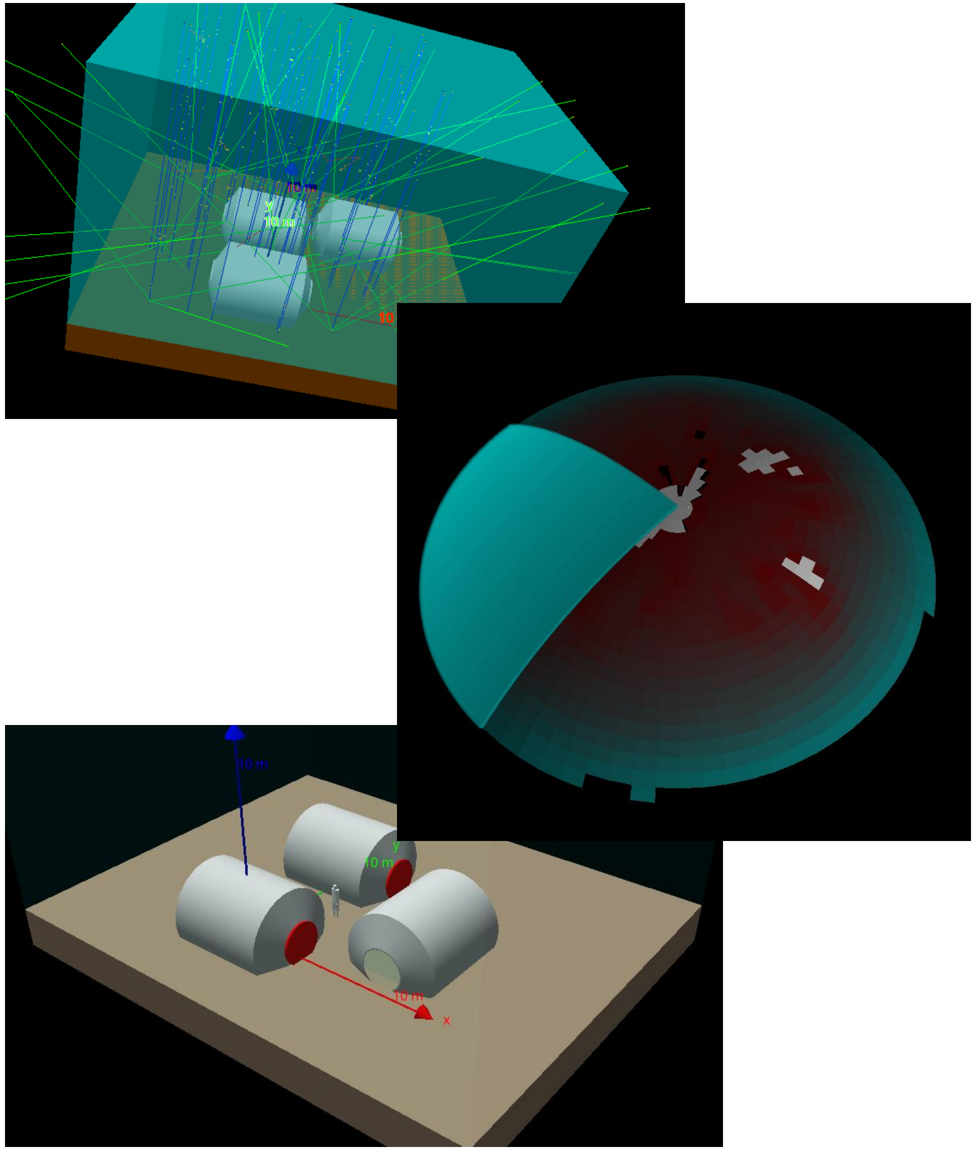




→particle flux inside module

→effective dose equivalent rate (ICRP conversion)

Geant4 Tools Developments from the HIERRAS Project



Pete Truscott and Fan Lei

Kallisto Consultancy Ltd, UK and RadMod Research Ltd, UK

With many thanks to:
ESA: Giovanni Santin, Hugh Evans, Marco Vuolo
G4G Project Team: Mikhail Axiotis and Dimitris Lenis

10th June 2024

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Background

- Human Interplanetary Exploration Radiation Risk Assessment System (HIERRAS) Project:
  - Prime contractor: DH Consultancy
  - Team: Kallisto Consultancy, RadMod Research, DLR, University of Turku, SPARC
  - ESA Contract No: 4000127129/19/NL/HK
- System relies heavily on Geant4-related tools
  - GRA
    - pl
    - sp
    - E
  - SSAT – Sector Shielding Analysis Tool for shielding analysis by ray-tracing
  - MULASSIS – Analysis of different 1D shields
  - GRAPPA – New Mars/Moon geometry generation tool for GRAS
  - CIRVis – GDML geometry interactive visualisation tool
  - g4apps-common – Repository for common classes used by above
  - g4_space_apps - "Dockerization" of Geant4 and these tools

This presentation provides a summary of the changes and current status of these tools

Overall Comments on Status

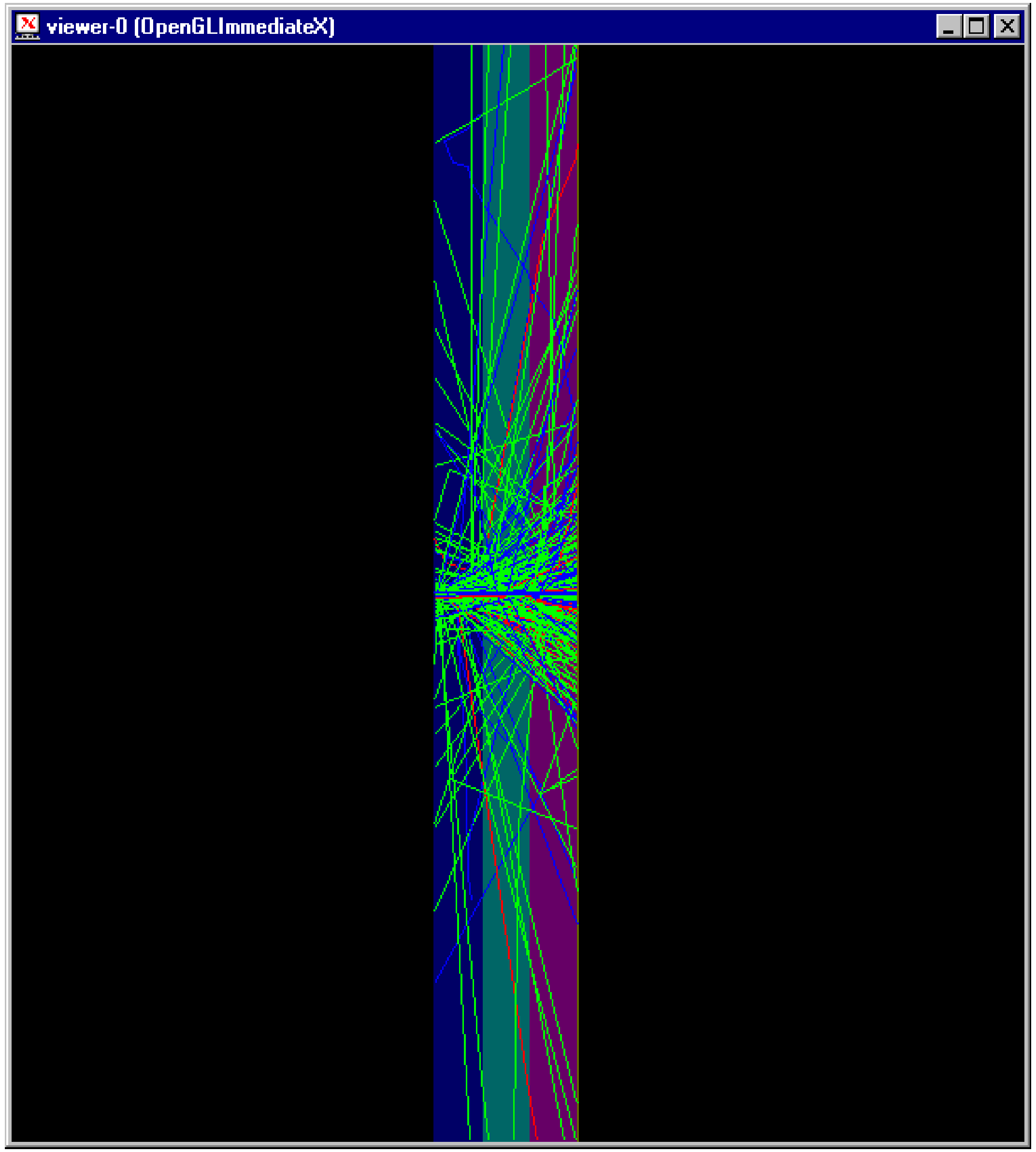
- All applications discussed use Geant4 v10.7 patch 03 – targeted version for HIERRAS
- Work is ongoing under other ESA projects (e.g., G4G) to use G4 v11.x
- Some of the ESA applications also publicly available under different ESSR licence conditions

It is understood that ESA's ultimate objective is to release these G4 applications under an

ESA Open Worldwide license

MULASSIS

- *Multi-Layered Shielding Simulation Software*
- Geant4 application to allow radiation analysis for 1D geometries (slab & sphere)
- Provide SHIELDOSE-type information with the physics of G4
- SPENVIS or standalone versions
- Simple specification of geometry (comprising any materials), source particle, physics, and analysis:
  - TID, DD, fluence, energy-deposition spectra



MULASSIS – Non-Monte Carlo Ion Transportation

- Originally developed under ESA ESHIEM Project as MULASSIS-derived application
- Forms part of MULASSIS v2.0
- Treats 1D multi-layer shielding structures of any material(s)
- Modelling approach:
  - Straight-ahead, continuous slowing-down approximation (CSDA)
  - Attenuation from nuclear interactions treated
  - Only primary is tracked (no secondary particles)
  - Uses Geant4 ion & nuclear physics tables for stopping powers and nuclear inelastic cross-sections
- Outputs fluence, LET spectra, total ionising dose (TID) and non-ionising dose (TNID)

- MULASSIS commands are nearly identical:
  - To run in non-MC mode use command: /nonMC/beamOn instead of /run/beamOn
  - Added commands to allow fine-control of numerical integration processes
    - Recommended that these are not modified
- During HIERRAS improvements made to:
  - Used latest version of MULASSIS as basis of development
  - Non-MC algorithm to improve calculation for thin-shield conditions
  - Overall code-structure for both non-MC and MC parts of MULASSIS
- Set of standard tests and non-MC manual
- *https://essr.esa.int/project/mulassis*
- *https://spitfire.estec.esa.int/Mulassis/ml-v02-00/*
- ESA Open International license Strong Copyleft

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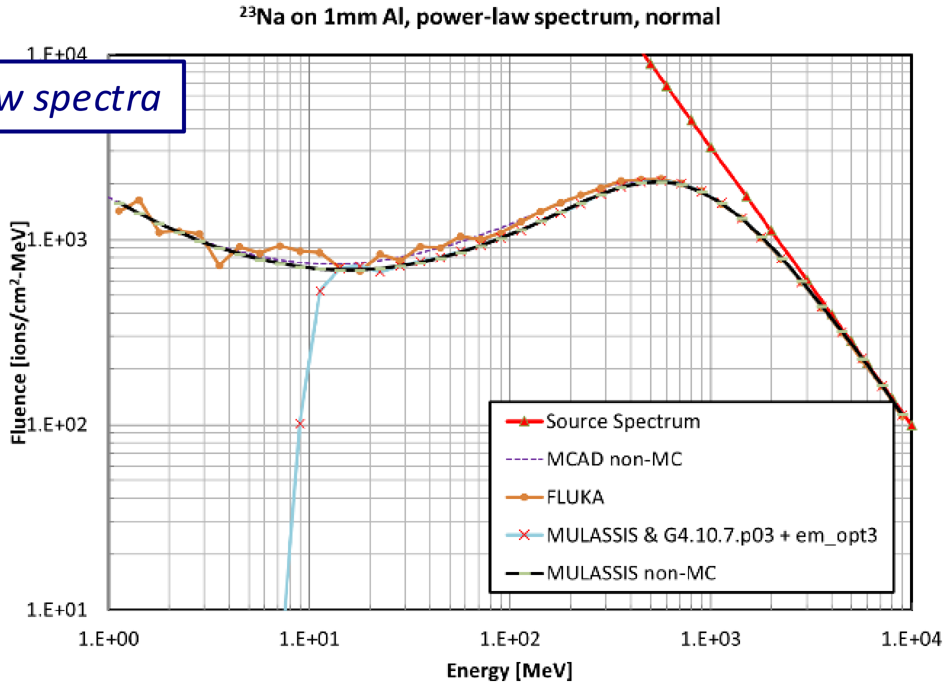
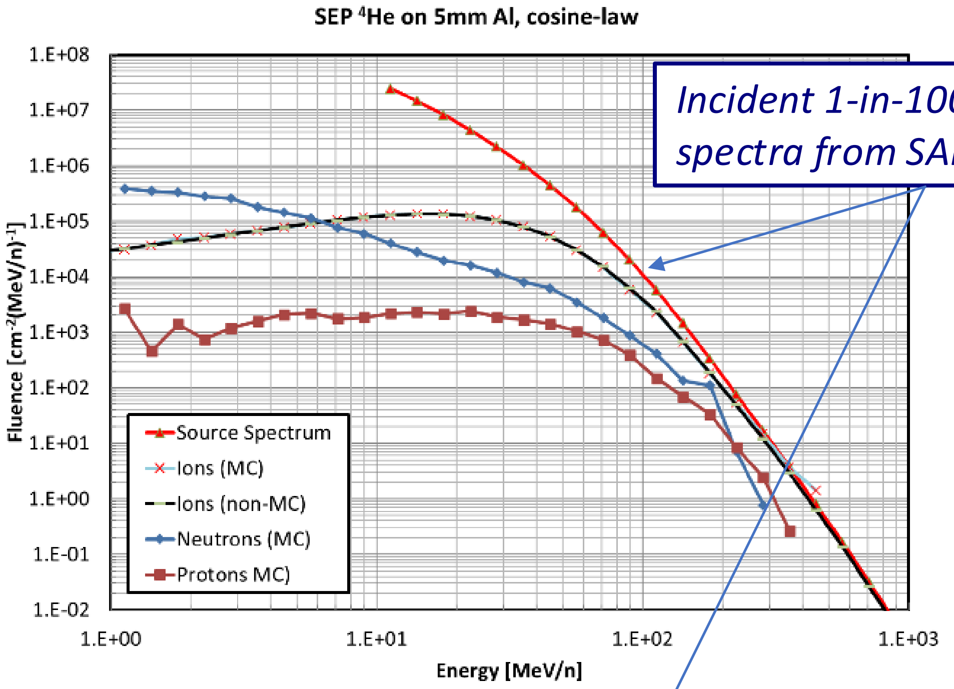
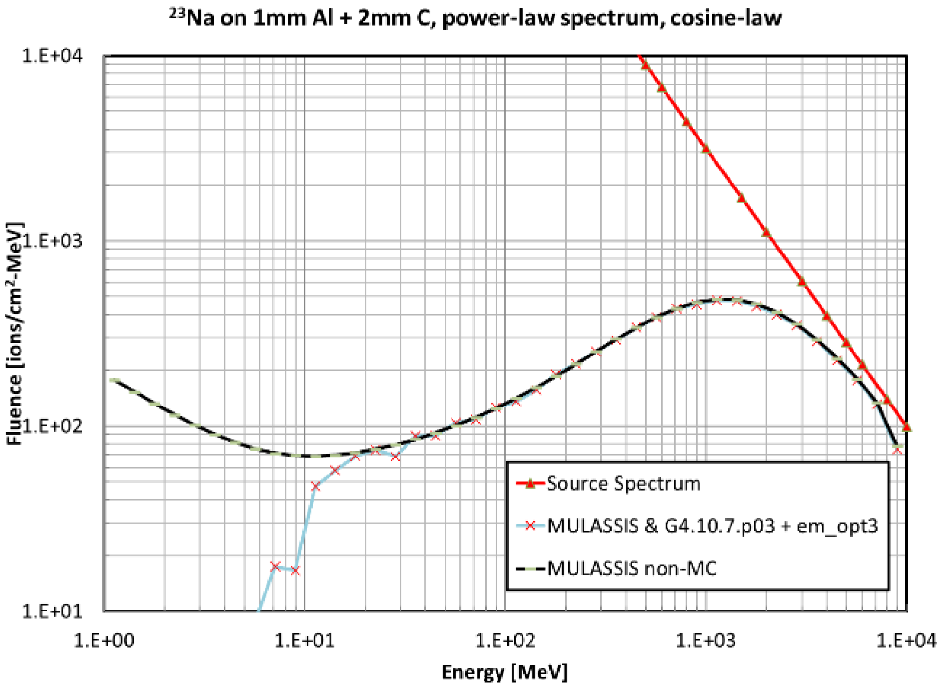
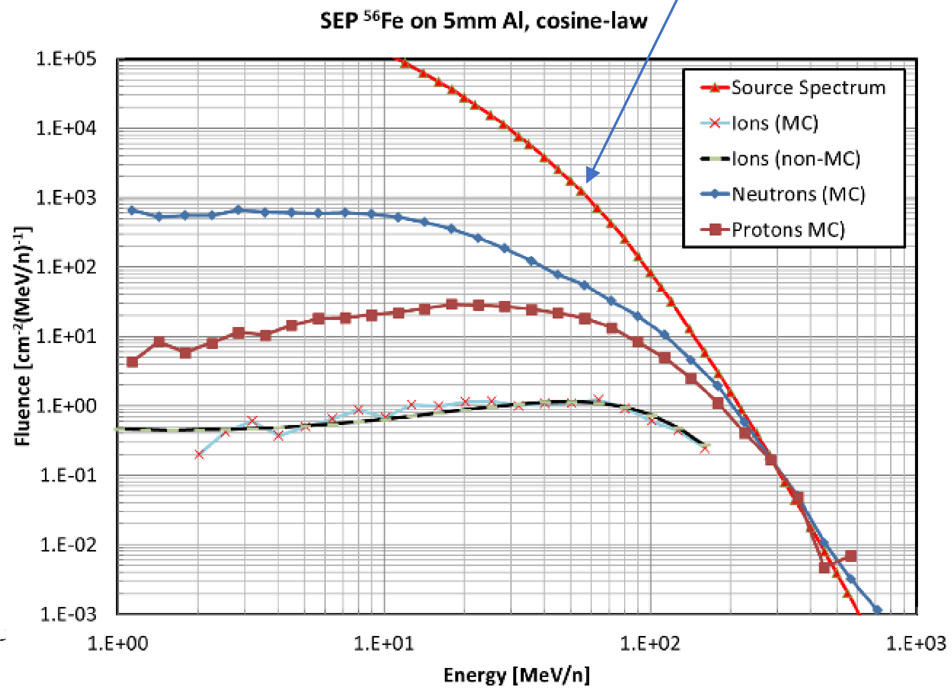
Power law spectra

Incident 1-in-100 year event spectra from SAPPHIRE









Comparison of ionizing energy deposition and TNID in 10 μm Si layer after shield due to 1-in-100 year event spectra from SAPPHIRE

Ion	Target	Edep [MeV/cm²]		TNID [MeV/g]		Additional Information / test-case directories
		(non-MC)	(MC)	(non-MC)	(MC)	
p^+	Al 2mm	1.18×10^8	$1.163\times10^8 \pm 0.001\times10^8$	1.47×10^7	$1.57\times10^7 \pm 0.02\times10^7$	IR_SEP_Al2/1H & MC_SEP_Al2/1H
p^+	Al 5mm	3.15×10^7	$3.07\times10^7 \pm 0.07\times10^7$	4.16×10^6	$4.19\times10^6 \pm 0.03\times10^6$	IR_SEP_Al5/1He & MC_SEP_Al5/1H
^4He	Al 2mm	6.66×10^6	$6.54\times10^6 \pm 0.01\times10^6$	7.68×10^8	$8.3\times10^3 \pm 0.2\times10^3$	IR_SEP_Al2/4He & MC_SEP_Al2/4He
^4He	Al 5mm	1.20×10^6	$1.183\times10^6 \pm 0.004\times10^6$	1.28×10^8	$7.69\times10^3 \pm 0.09\times10^3$	IR_SEP_Al5/4He & MC_SEP_Al5/4He
^{56}Fe	Al 2mm	3.62×10^4	$3.53\times10^4 \pm 0.03\times10^4$	7.17×10^6	$9.3\times10^1 \pm 0.1\times10^1$	IR_SEP_Al2/56Fe & MC_SEP_Al2/56Fe
^{56}Fe	Al 5mm	2.26×10^3	$2.34\times10^3 \pm 0.07\times10^3$	5.00×10^5	$7.04\times10^1 \pm 0.07\times10^1$	IR_SEP_Al5/56Fe & MC_SEP_Al5/56Fe

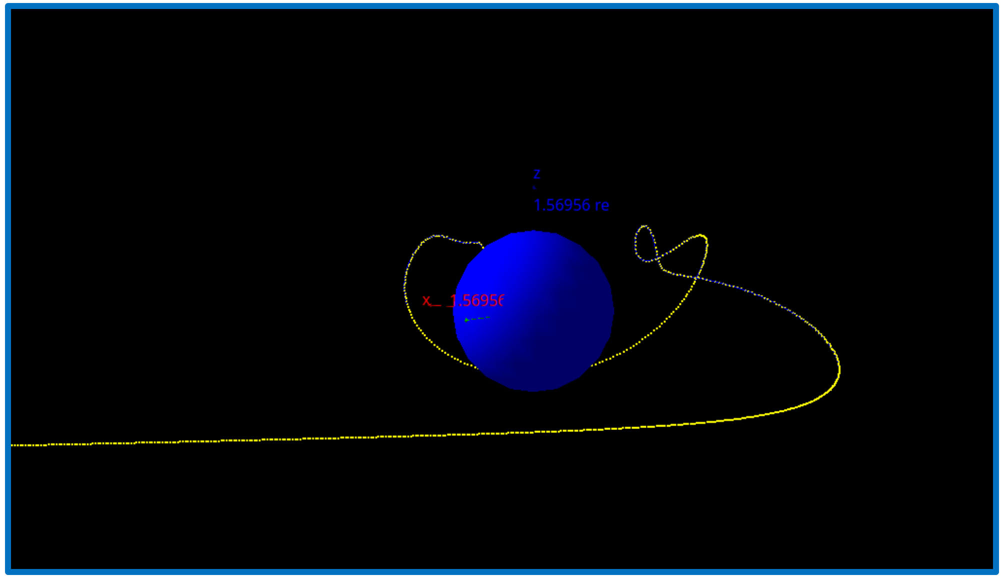
MULASSIS MC results do not include TNID from residual ions $Z\geq2$

Updates to **GRAS** – Treatment of planetary magnetic fields

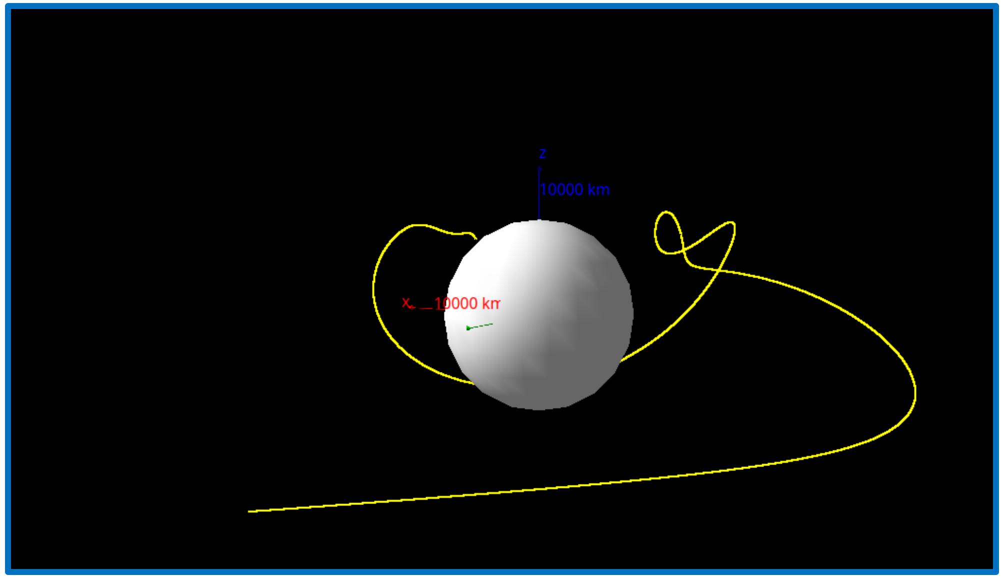
- Originally GRAS allowed users to define B-field on either cartesian or cylindrical set of grid points
- Need to treat magnetic fields relevant to planets, where grid definition in r, θ, and ϕ is more efficient/robust
- Cannot use simple current-loop approximation for field on Mars
- Extensive comparisons have been performed between GRAS simulations for "spherically-grided" planetary-size magnetic fields and MAGNETOCOSMICS runs

3.00 GeV proton, 45°N

MAGNETOCOSMICS Dipole

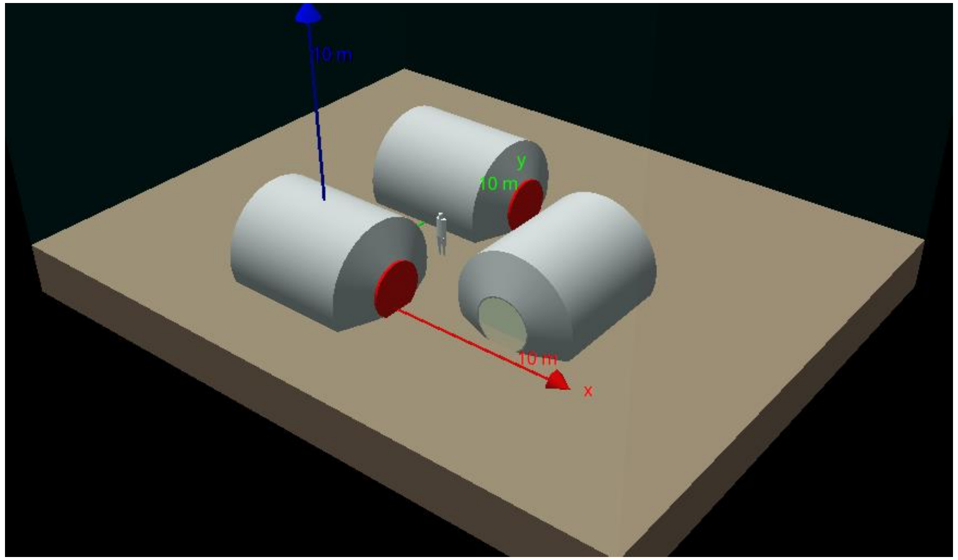


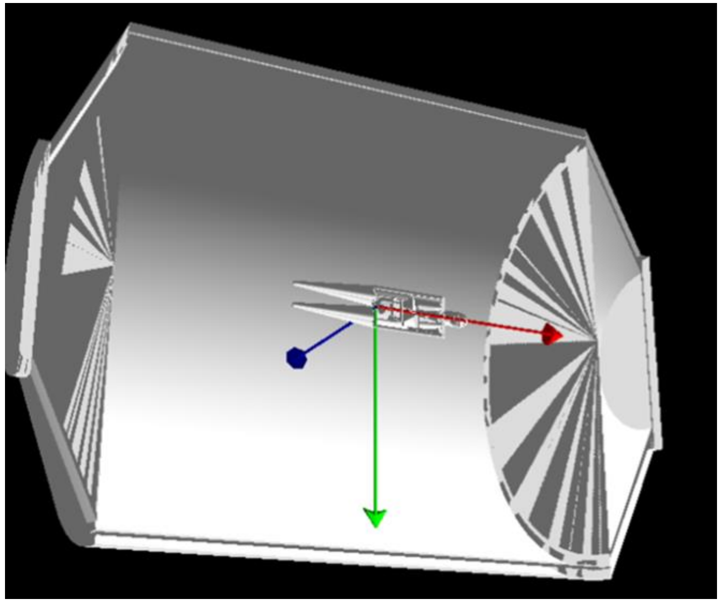
GRAS: Interpolated from gridded dipole



Updates to **GRAS** – Treatment parallel mass world geometries

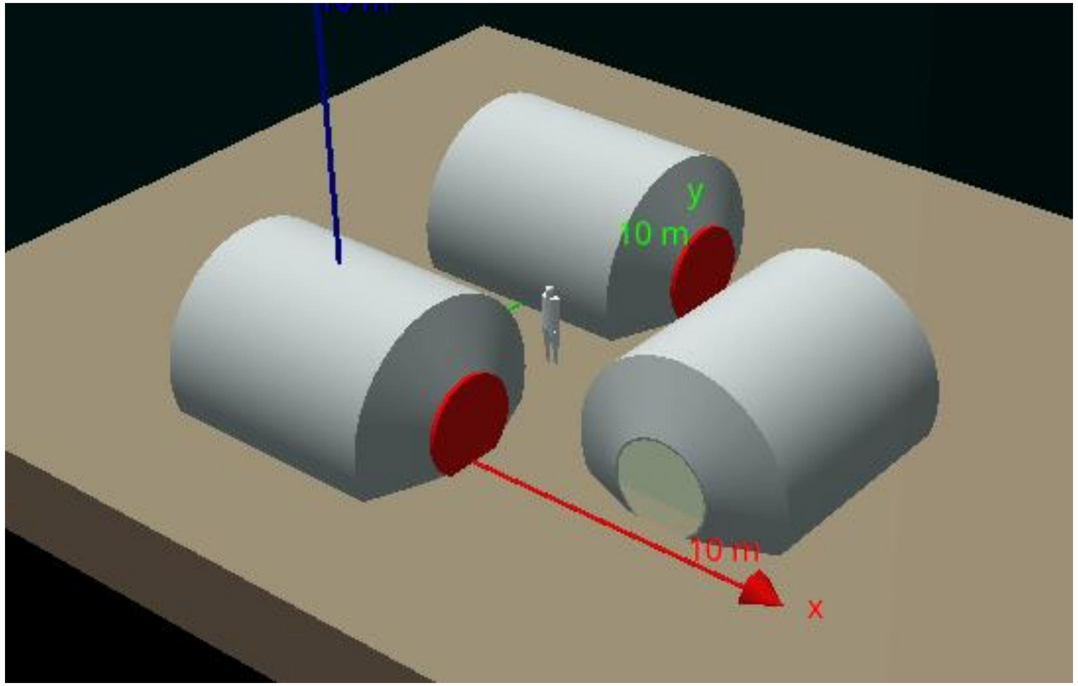
- Combining two GDML files is trivial provided there is no overlapping of more than volume of one file in another
- Many instances where overlapping is desirable if not necessary
  - Traditionally treated by apply Boolean operators to the – not intuitive to the inexpert user
- Parallel mass world feature in Geant4 allows "overlaying" of geometries
  - Volumes in the higher layer will take priority over those in lower





```
/gras/geometry/type multi
/multi/addGDML Mars 0
/multi/gdml/Mars/file MarsSurfaceBox.gdml /multi/gdml/Mars/setup World

/multi/addGDML Hab1 1
/multi/gdml/Hab1/file ColumbusLikeModule_Cyl_2cm.gdml
/multi/gdml/Hab1/translate 0.0 7.0 0.8 m

/multi/addGDML Hab2 1
/multi/gdml/Hab2/file ColumbusLikeModule_Cyl_2cm.gdml
/multi/gdml/Hab2/translate 0.0 0.0 0.8 m

/multi/addGDML Hab3 1
/multi/gdml/Hab3/file ColumbusLikeModule_Cyl_2cm.gdml
multi/gdml/Hab3/translate 7.0 3.5 0.8 m
/multi/gdml/Hab3/rotateZ 90.0 deg

/multi/addGDML Alex 2
/multi/gdml/Alex/file MIRDMale.gdml
/multi/gdml/Alex/translate 0.0 7.0 0.8 m

/multi/addGDML Beth 2
/multi/gdml/Beth/file MIRDFemale.gdml
/multi/gdml/Beth/translate 0.0 0.0 0.8 m
```

```
/multi/addGDML Chris 2
/multi/gdml/Chris/file MIRDMale.gdml
/multi/gdml/Chris/translate 7.0 3.5 0.8 m

/multi/addGDML Doc 2
/multi/gdml/Doc/file MIRDFemale.gdml
/multi/gdml/Doc/translate 2.0 3.5 0.8 m

/multi/instantiateParallelConstructors
```



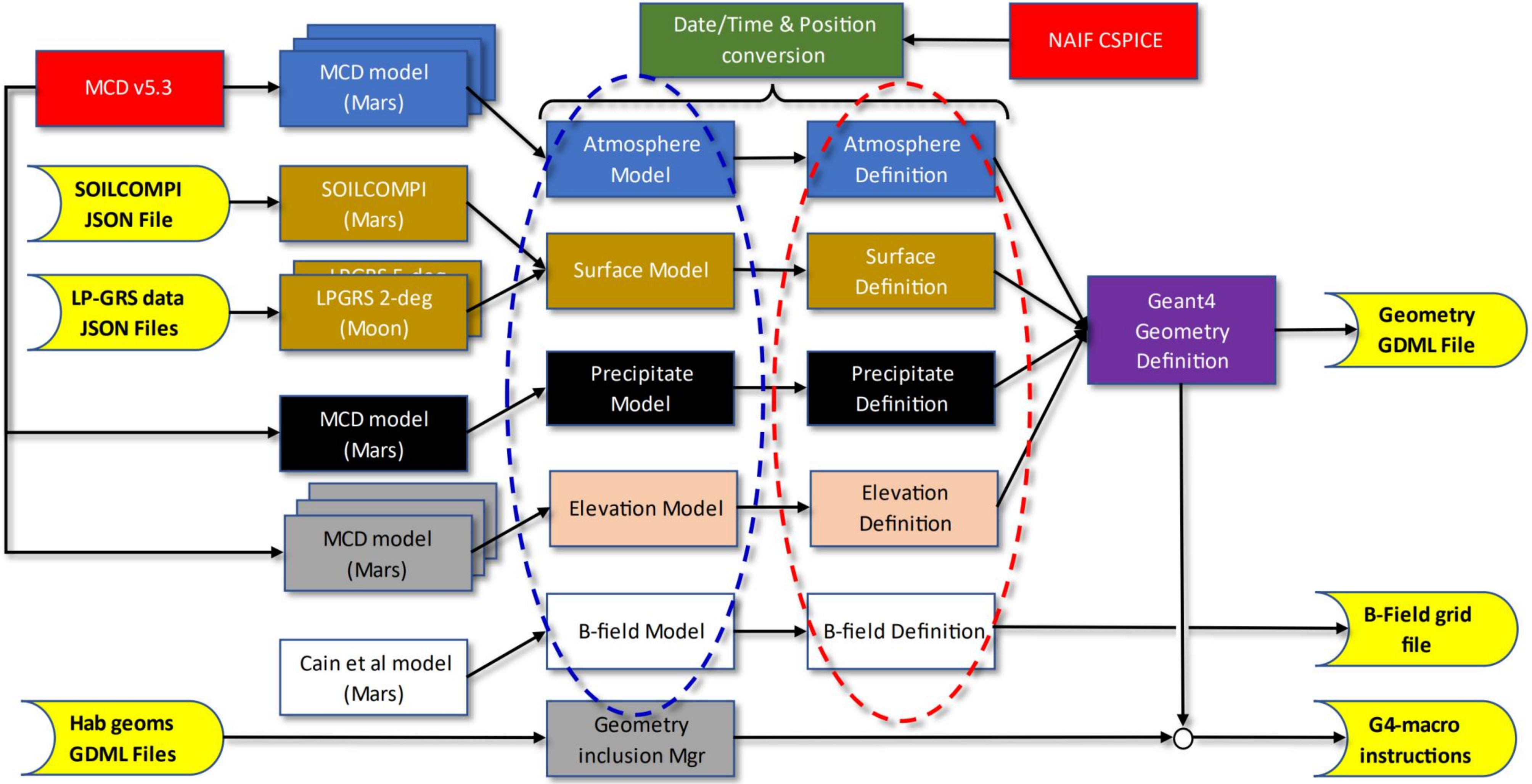
GRAS - Status

- Current release is at v6.0
- Available from ESSR under Open Community license Strong Copy Left
- https://esst.esa.int/project/gras-geant4-radiation-analysis-for-space
- https://spitfire.estec.esa.int/trac/GRAS/

GRAPPA

- ***GRAS Preprocessor for Planetary bodies and Asteroids***
- Creates GDML geometry representations of Mars and Moon so that ESA's GRAS/Geant4 may be used for 3D particle simulation
- Planar and spherical geometries
  - Simple 1D geometries, or
  - 3D geometries with XY (latitude/longitude) dependence
- Can be used at local scales (~ several metres) to planetary scales
- Treatment of:
  - Atmosphere composition and density as function of altitude
  - Soil as function of depth
  - Precipitates (CO_2 & H_2O)
  - Magnetic fields (for Mars)
- Geometry defined based on a user-selected point on Mars/Moon
  - Will be extended to Phobos and Deimos

GRAPPA Functions



GRAPPA Models Currently Implemented

Atmosphere:
- Mars Climate Database (MCD) v5.3
- User defined composition and $\rho(H)$
- User defined fixed composition and H_s

Surface:
- SOILCOMPI based on Mars Odyssey's MGRS; from LIP's dMEREM code (ESA MarsREM Project)
- Lunar Prospector GRS (2-deg) based composition model
- User defined composition and $\rho(H)$

Precipitate:
- Mars Climate Database (MCD) v5.3 for CO_2 & H_2O ice
- User defined composition and $\rho(H)$

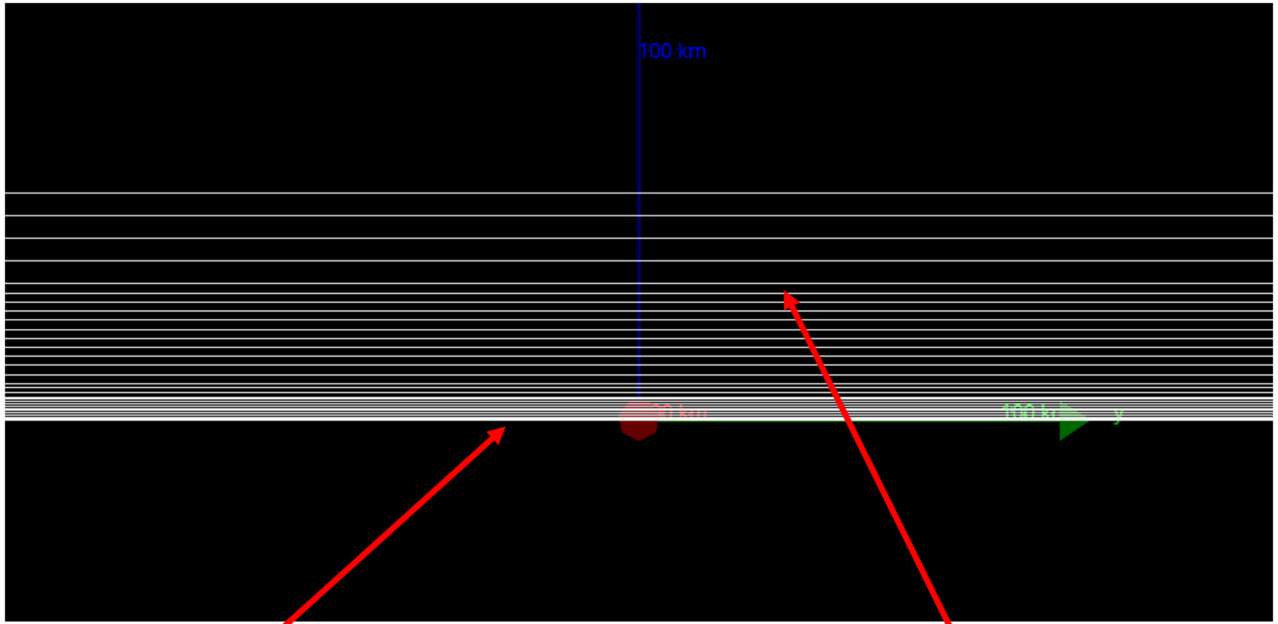
Magnetic Field (crustal models for Mars):
- Cain et al, n=50
- Cain et al, n=90 (2003)
- Purucker et al (2001)
- Alternatively, user-defined field can be added in GRAS simulation

- Software OO-design allows easy extension of GRAPPA to treat additional models
  - Can be interfaced to external software library or data-file based model
- Potential to treat Earth or other planets and moons

Simple Mars Case (Flat geometry)

```
/GRAPPA/setPlanet MARS
/GRAPPA/setReferenceDate 2004 1 4 4 35 0.0
/GRAPPA/setReferencePosition 175.48 -14.57 deg
/GRAPPA/structure/setShape FLAT
/GRAPPA/listPlanet
/GRAPPA/structure/createAtmosphereStructure
/GRAPPA/structure/createSurfaceStructure
/GRAPPA/structure/createElevationStructure
/GRAPPA/preConstructGeometry
/GRAPPA/constructGeometry
/GRAPPA/saveGeometry test_01_00_1_out.gdml
```

```
Solar system body         :                MARS
NAIF SPICE ID for body    :                 499
Date/time           [UTC] : 2004-01-04T04:35:00.00
Date/time ET          [s] :        126462964.184004
MJD 1950             [dy] :        19726.1909719999
Longitude           [deg] :             175.480
Latitude            [deg] :             -14.570
Z-datum type (default)    :    ORIGIN_CELL_GROUND
Models used
Elevation       :                 ZERO
Atmosphere      :        MCD_ATMOSPHERE
Precipitate     :       MCD_PRECIPITATE
Surface         :             SOILCOMPI
Magnetic field  :                (none)
```



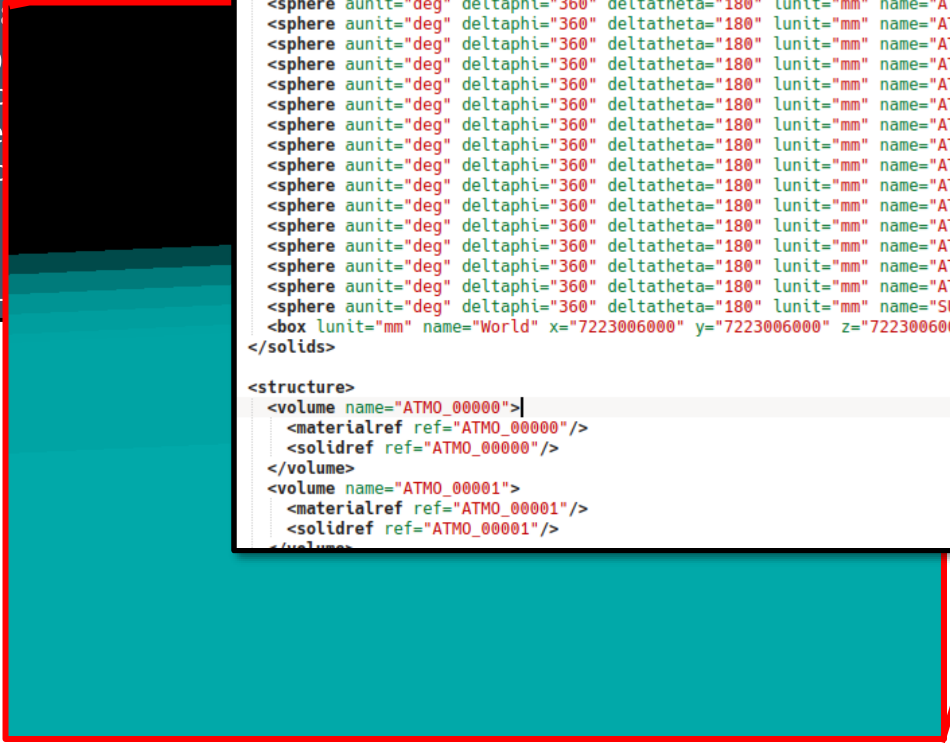
Ground thickness 1m (default)

Atmosphere thickness 50km (default)
Intervals ≅ dMEREM default

Note: To change the atmosphere / surface model etc:
/GRAPPA/structure/setAtmosphereModel <MODEL_NAME>
/GRAPPA/structure/setSurfaceModel <MODEL_NAME>
Etc …

Simple Mars Spherical C

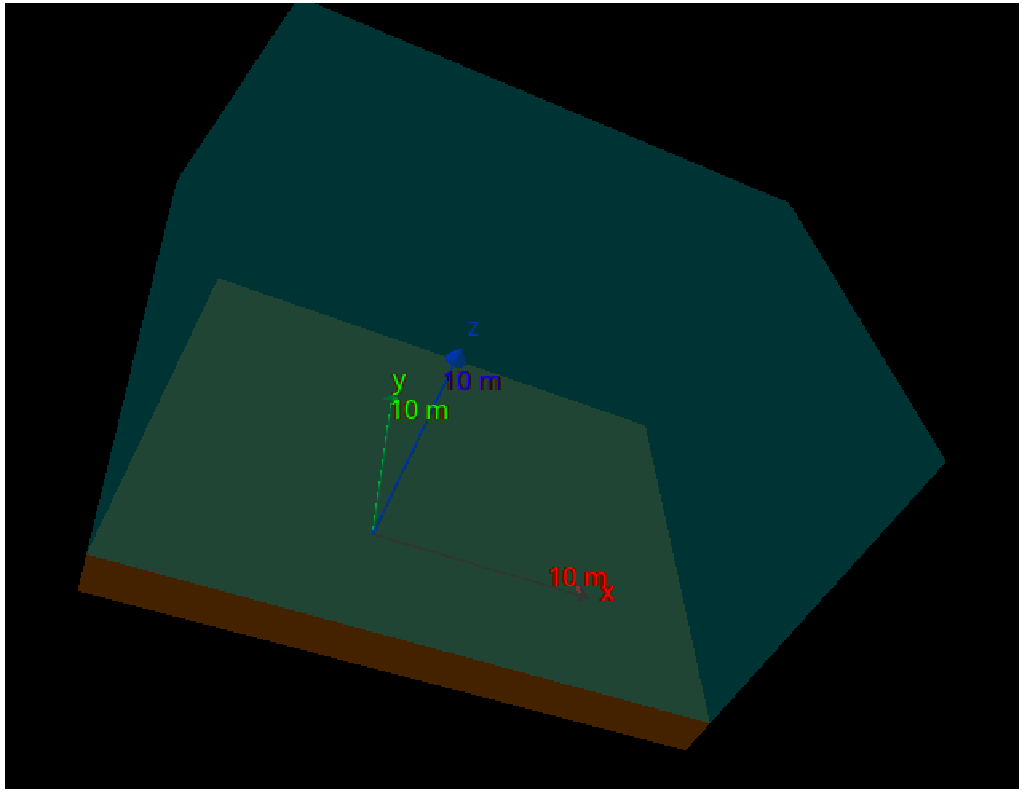
```
/GRAPPA/setPlanet MARS
/GRAPPA/setReferenceDate 2004 1 4 4 35 0.0
/GRAPPA/setReferencePosition 0.0 0.0 deg
/GRAPPA/structure/setShape SPHERE
/GRAPPA/listPlanet
/GRAPPA/atmosphere/setXIntervals -180 180 2 deg
/GRAPPA/atmosphere/setYIntervals -90.0 90.0 2 de
/GRAPPA/surface/setXIntervals -1
/GRAPPA/surface/setYIntervals -9
/GRAPPA/structure/createAtmosp
/GRAPPA/structure/createSurface
/GRAPPA/structure/createElevatic
/GRAPPA/preConstructGeometry
/GRAPPA/constructGeometry
/GRAPPA/saveGeometry test_05_
```



Solid definitions in GDML file for Mars

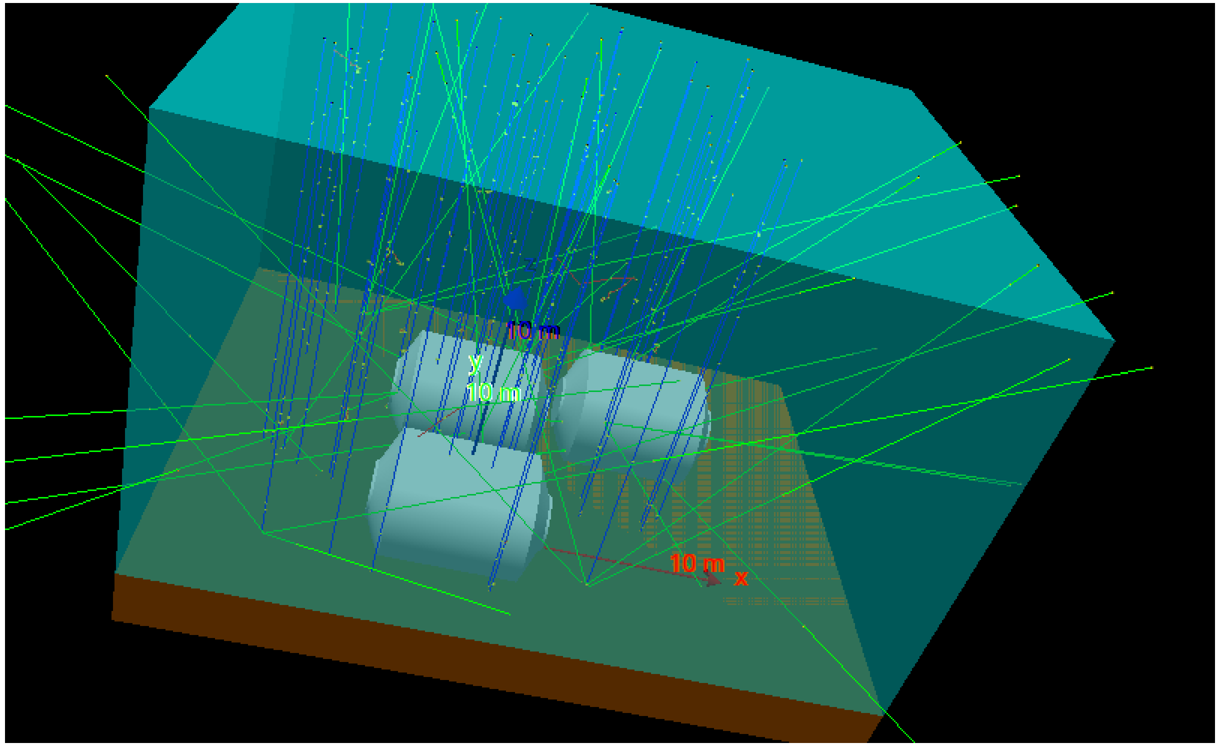
```
<solids>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00000" rmax="3389626666.66667" rmin="3389526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00001" rmax="3389726666.66667" rmin="3389626666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00002" rmax="3390026666.66667" rmin="3389726666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00003" rmax="3390526666.66667" rmin="3390026666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00004" rmax="3391026666.66667" rmin="3390526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00005" rmax="3391526666.66667" rmin="3391026666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00006" rmax="3392026666.66667" rmin="3391526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00007" rmax="3392526666.66667" rmin="3392026666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00008" rmax="3393026666.66667" rmin="3392526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00009" rmax="3393526666.66667" rmin="3393026666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00010" rmax="3394026666.66667" rmin="3393526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00011" rmax="3394526666.66667" rmin="3394026666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00012" rmax="3395526666.66667" rmin="3394526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00013" rmax="3396526666.66667" rmin="3395526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00014" rmax="3397526666.66667" rmin="3396526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00015" rmax="3399526666.66667" rmin="3397526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00016" rmax="3401526666.66667" rmin="3399526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00017" rmax="3403526666.66667" rmin="3401526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00018" rmax="3405526666.66667" rmin="3403526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00019" rmax="3407526666.66667" rmin="3405526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00020" rmax="3409526666.66667" rmin="3407526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00021" rmax="3411526666.66667" rmin="3409526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00022" rmax="3413526666.66667" rmin="3411526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00023" rmax="3415526666.66667" rmin="3413526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00024" rmax="3417526666.66667" rmin="3415526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00025" rmax="3419526666.66667" rmin="3417526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00026" rmax="3424526666.66667" rmin="3419526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00027" rmax="3429526666.66667" rmin="3424526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00028" rmax="3434526666.66667" rmin="3429526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="ATMO_00029" rmax="3439526666.66667" rmin="3434526666.66667" startphi="0" starttheta="0"/>
  <sphere aunit="deg" deltaphi="360" deltatheta="180" lunit="mm" name="SURF_00000" rmax="3389526666.66667" rmin="3389525666.66667" startphi="0" starttheta="0"/>
  <box lunit="mm" name="World" x="7223006000" y="7223006000" z="7223006000"/>
</solids>

<structure>
  <volume name="ATMO_00000">
    <materialref ref="ATMO_00000"/>
    <solidref ref="ATMO_00000"/>
  </volume>
  <volume name="ATMO_00001">
    <materialref ref="ATMO_00001"/>
    <solidref ref="ATMO_00001"/>
```

Mars Case: Local Environment Model & Addition of Mission Equipment

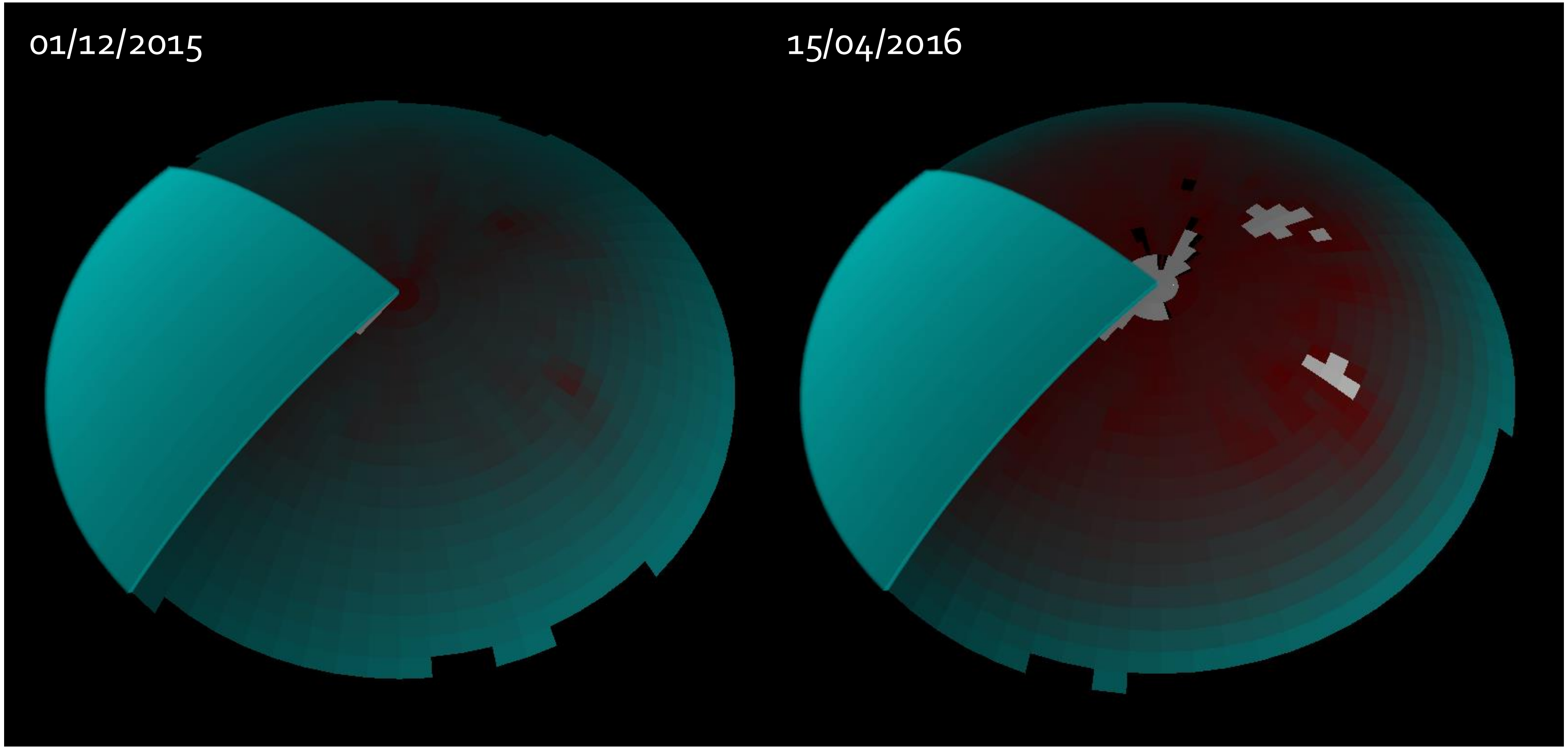


Local environment 25 x 20 x 17 m^3

Local environment with partially-buried habitat modules (additional GDML files) included in GRAS simulation



Spatial Dependence of CO_2 and H_2O Ice (MCD v5.3)

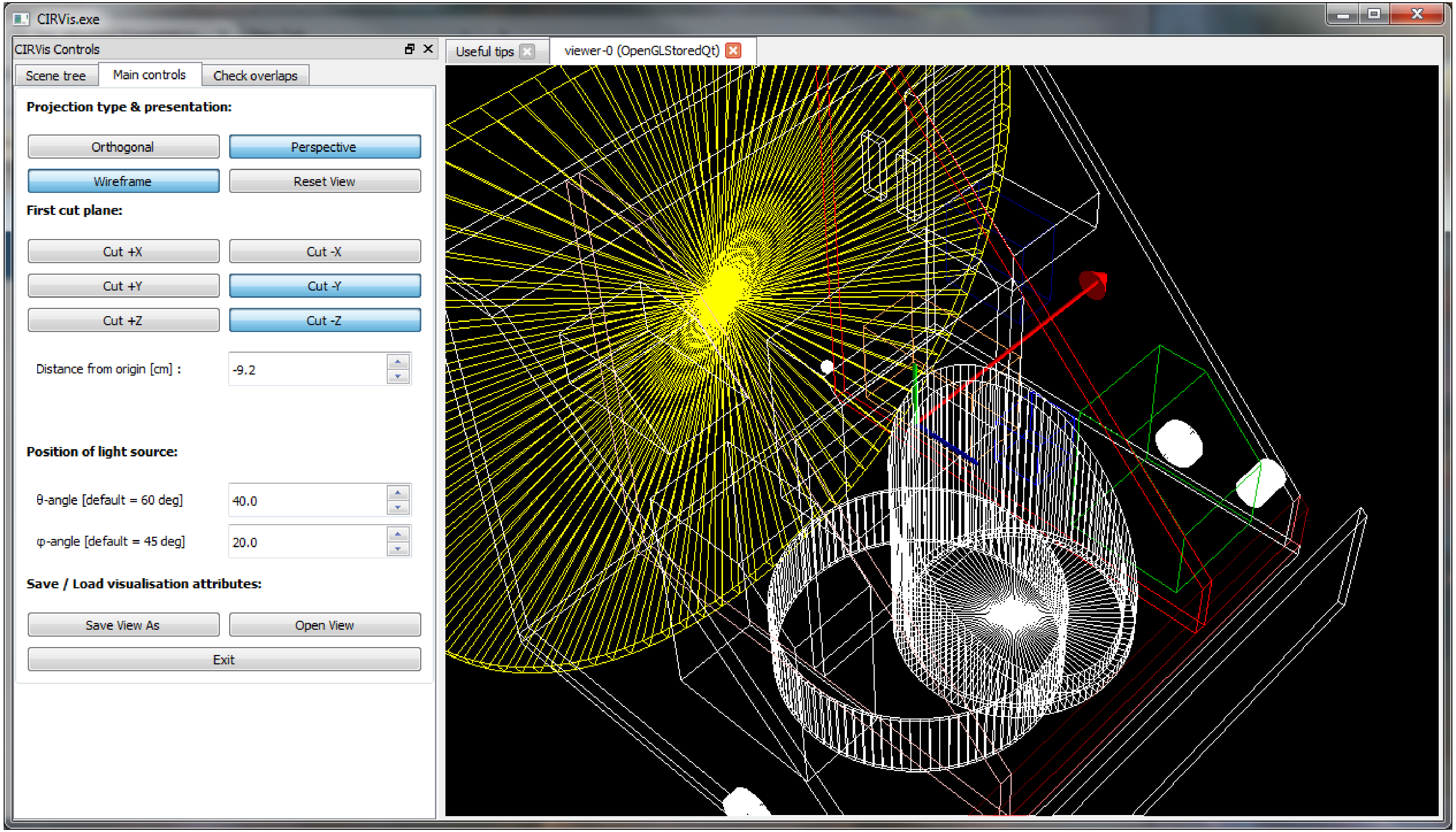


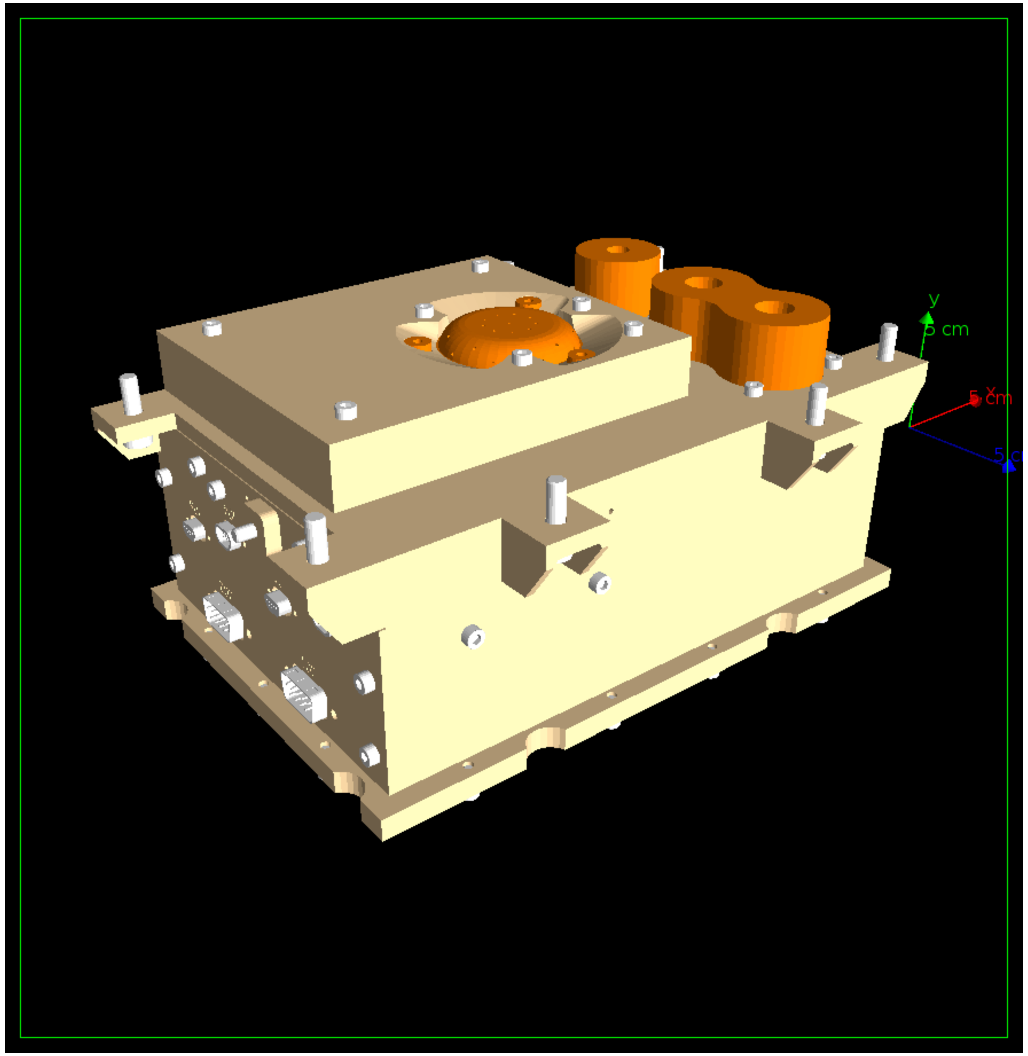
GRAPPA - Status

- Use Geant4 v10.7 patch 03
- Access is currently restricted to the project and agreed parallel project:
- https://space-env-repo.estec.esa.int/hierras/grappa/-_/tree/FAR?ref_type=heads
- Once GRAPPA is formally delivered to ESA, the process to grant Open license can start

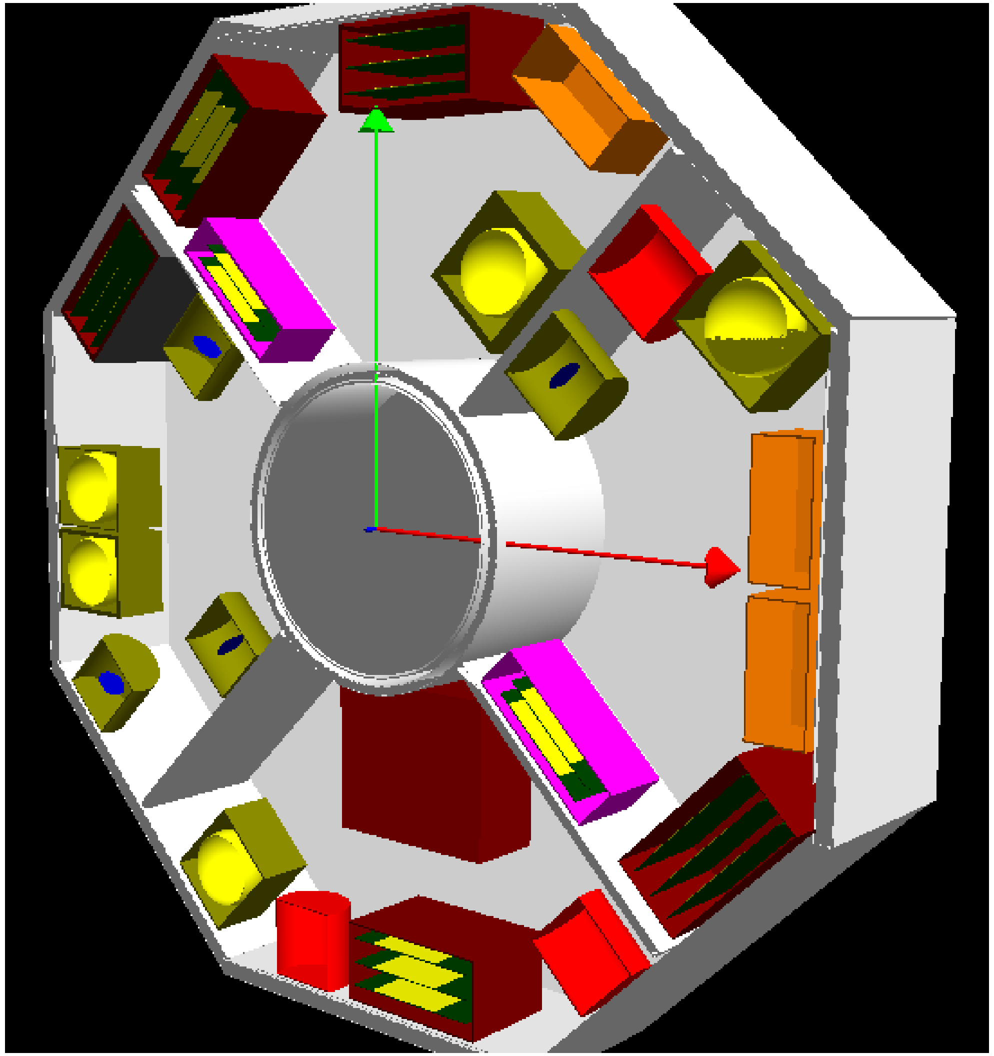
CIRVis – CIRSOS Visualisation Tool

- Developed under ESA CIRSOS Project (4000108668/13/NL/MV)
- Geant4-based application to visualise GDML and Gmsh geometries
- Environment is interactive:
  - Mouse-controlled pan, tilt, zoom, volume select/deselect options
  - Wireframe/solid selection
  - Recolour objects
  - Sectioning of the geometry in different planes
- Performs testing of correct geometry construction
- Extended under HIERRAS Project to:
  - Allow volume colours defined in GDML files to be imported and correctly visualised
  - Treat parallel mass world geometries
  - Use Geant4 v10.7 p03
- Status: Not yet publicly available
- Access is currently restricted to the HIERRAS and CIRSOS projects subject to HIERRAS completion


CIRVis.exe
CIRVis Controls
Scene tree
Main controls
Check overlaps
Projection type & presentation:
Orthogonal
Perspective
Wireframe
Reset View
First cut plane:
Cut +X
Cut -X
Cut +Y
Cut -Y
Cut +Z
Cut -Z
Distance from origin [cm] :
-9.2
Position of light source:
θ-angle [default = 60 deg]
40.0
φ-angle [default = 45 deg]
20.0
Save / Load visualisation attributes:
Save View As
Open View
Exit
Useful tips
viewer-0 (OpenGLStoredQt)



JUICE RADEM Instrument – Geometry courtesy of Patricia Gonçalves, LIP



Representation of general science spacecraft – courtesy of Giovani Santin and Marco Vuolo, ESA

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G4 Apps Common

- Collection of common C++ G4-type classes used within the ESA applications, or potentially may be used in more than just one application
- Classes include:
  - New/extended G4UI command classes to allow:
    - Input vectors of numbers
    - Generation of std::vector of numbers from min, max, n-intervals, units and lin/log scale specification
    - Keyword (case-independent) field-type
  - Treatment of G4vis colours:
    - Add colour XML commands to GDML files (Gabriele Cosmo)
    - Colour-scaler to map RGBA to a physical quantity of a geometry object, such as density, height, dose
    - Standard colour templates (MULASSIS, X11-145, X11-502, BS2660, Pantone)
  - Generation of standard progress report file
  - Standard MaterialManager & MaterialMessenger
  - Extended common units table for space env. analysis

G4 Applications Standard Progress Report Files


```
{
  "Geant4RunProgress"      : {
    "Application"          : "GRAS",
    "Date"                 : "2023-11-28 16:20:37",
    "Processes"            : [
      {
        "PID"              : 497,
        "ProcessTime"      : 13.07,
        "Status"           : "INACTIVE"
      }
    ],
    "TargetValue"          : [ 50],
    "CurrentValue"         : [ 50],
    "PercentageComplete"   : 100
  }
}
```

Dockerization of Geant4 – g4_space_apps
Features

- Installing and maintaining installations of Geant4 can be very problematic for user if they're not experts
- The docker contains:
  - GRAS
  - MULASSIS
  - SSAT
  - CIRVis
  - GRAPPA
  - MAGNETOCOSMICS
- Portable between Linux and Windows
  - Need OS specific batch files, bash scripts or alias commands to help invoke functions
- Status
  - Not currently released
  - Expected Docker build scripts to be available under ESSR Open Worldwide licence

Dockerization of Geant4 – g4_space_apps
Using the docker

Once you have docker image installed on your system, you can execute it in one of two ways:

1. Single docker container for each run:
   - *<HOST_VOL_PATH>* is directory on host system containing the input files, and where output files will be stored
   - For MULASSIS run of macro file myMLRun.g4mac:

     docker run --rm -it -v "<HOST_VOL_PATH>:/opt/g4pub" --name g4exe g4_space_apps mulassis myMLRun.g4mac
   - Or to run GRAS as interactive GUI:

     docker run --rm -it -e DISPLAY=123.45.678.90:0.0 –v "<HOST_VOL_PATH>:/opt/g4pub" --name g4exe g4_space_apps gras
   - Note, it is better to set up local scripts to alias "mulassis", "gras", "ssat" etc to the "docker run …" commands shown above

Dockerization of Geant4 – g4_space_apps
Using the docker

2. Run in server mode:
   - First start the server

     docker run --rm -it -v "<HOST_VOL_PATH>:/opt/g4pub" --name g4exe g4_space_apps server

   - The docker will identify an IP address <*g4_exe_IP*> after the g4_space_apps server is running
   - The issue SSHpass commands to the server docker from the host

     sshpass -p g4user ssh g4user@<g4_exe_IP> 'cd /opt/g4pub/<HOST_SUB_DIR> ; mulassis myMLRun.g4mac'

- Don't use absolute pathnames in input files such as G4 macros; only relative pathnames
- If using Windows CL, use MS-DOS window, not Powershell

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Dockerization of Geant4 – g4_space_apps Build

- Using the geant4_qt5 docker, then build the g4_space_apps docker
  - Build scripts are in:

    https://space-env-repo.estec.esa.int/geant4-space-apps-dockers/g4-space-apps
  - To build with defaults:

    *docker build --no-cache -t g4_space_apps . --build-arg USERID=<YOUR UID> *

    --build-arg PASSWD=<<YOUR PWD>>
  - Defaults are:

    ML_VERSION=tags/ml-v02-00/

    GRAS_VERSION=trunk/gras/

    SSAT_VERSION=trunk/ssat/

    GRAPPA=FAR/

    CIRVIS_VERSION=CDR-TRR

    MAGNETOCOSMICS_VERSION=trunk/magnetocosmics

    ROOT_VERSION=v6.22.08.Linux-ubuntu20-x86_64-gcc9.3

  Users can change versions with command line options in docker build command, as well as exclude some of these