Calculation of Radiation Exposure Levels in Low Earth Orbit and Beyond

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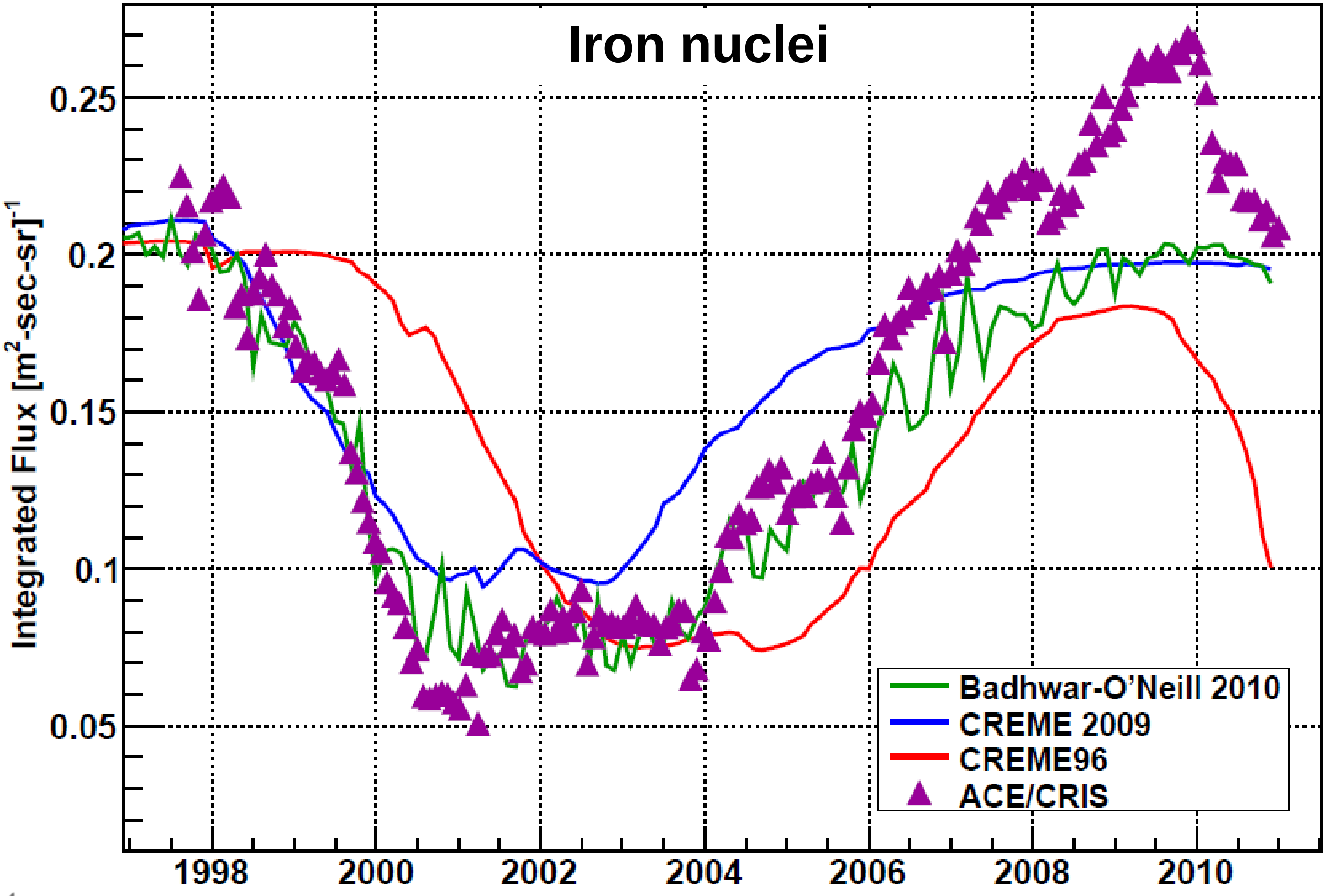
Motivation: GCR model behaviour

A. I. Mrigakshi, D. Matthiä, T. Berger, G. Reitz, R. Wimmer-Schweingruber, Assessment of galactic cosmic ray models, JGR, 2012



Outline

- GCR model

- Comparison to data / ISO model / Badhwar-O‘Neill 2010 model

- Estimates of the radiation exposure
    - Interplanetary space
    - Lunar surface
    - ISS orbit
        - MATROSHKA-1
        - Solar minimum / DOSIS / DOSIS 3D

DLR GCR model

- GCR model developed at DLR based on ISO model for particles ranging from 1≤Z≤28 and for periods from 1964

- ISO model, based on sun spot number:

$$\phi_i(R,t) = \frac{C_i \beta^{\alpha_i}}{R^{\gamma_i}} \left[\frac{R}{R + R_0(R,t)}\right]^{\Delta_i(R,t)}$$

- New Model:

$$\phi_i(R,t) = \frac{C_i \beta^{\alpha_i}}{R^{\gamma_i}} \left[\frac{R}{R + \left(0.37 + 3\cdot 10^{-4} \cdot W(t)^{1.45}\right)}\right]^{b\cdot W(t)+c}$$

Solar modulation parameter *W* derived by fitting carbon measurements from ACE and Oulu neutron monitor count rates

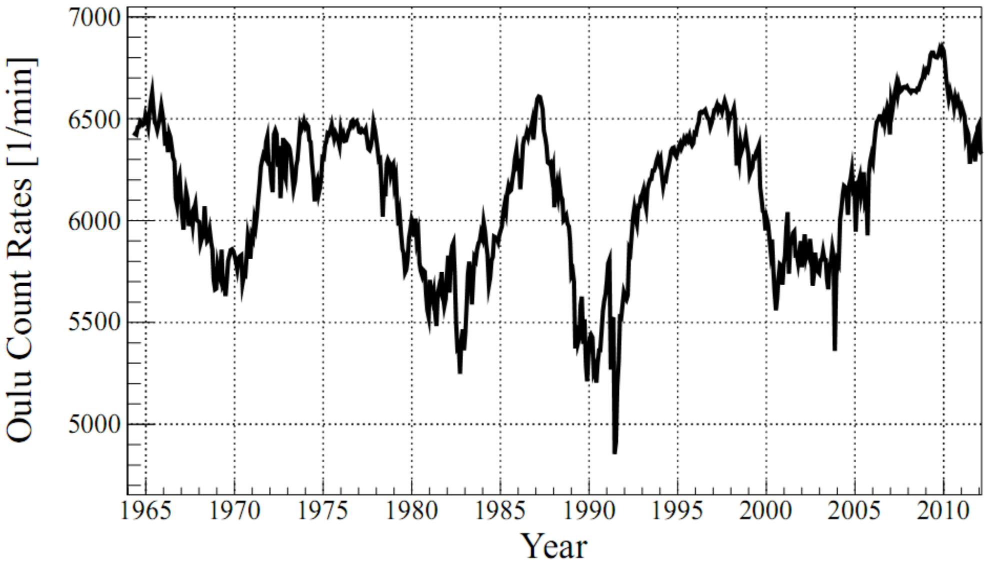
Matthiä, D., Berger, T., Mrigakshi A. , T., Reitz G., A Ready-to-Use Galactic Cosmic Ray Model, submitted to Advances in Space Research (Under Review)

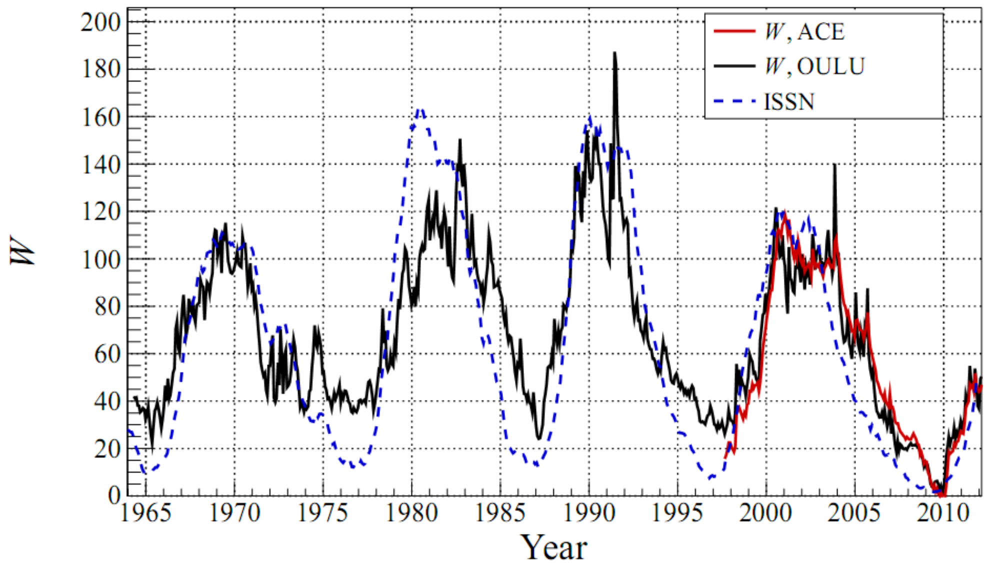
DLR GCR model

- Modulation is quantified by parameter *W*

D.Matthiae , T.Berger, A. Mrigakshi, G. Reitz, A Ready-to-Use Galactic Cosmic Ray Model, submitted to ASR

GCR intensity measured by Oulu neutron monitor



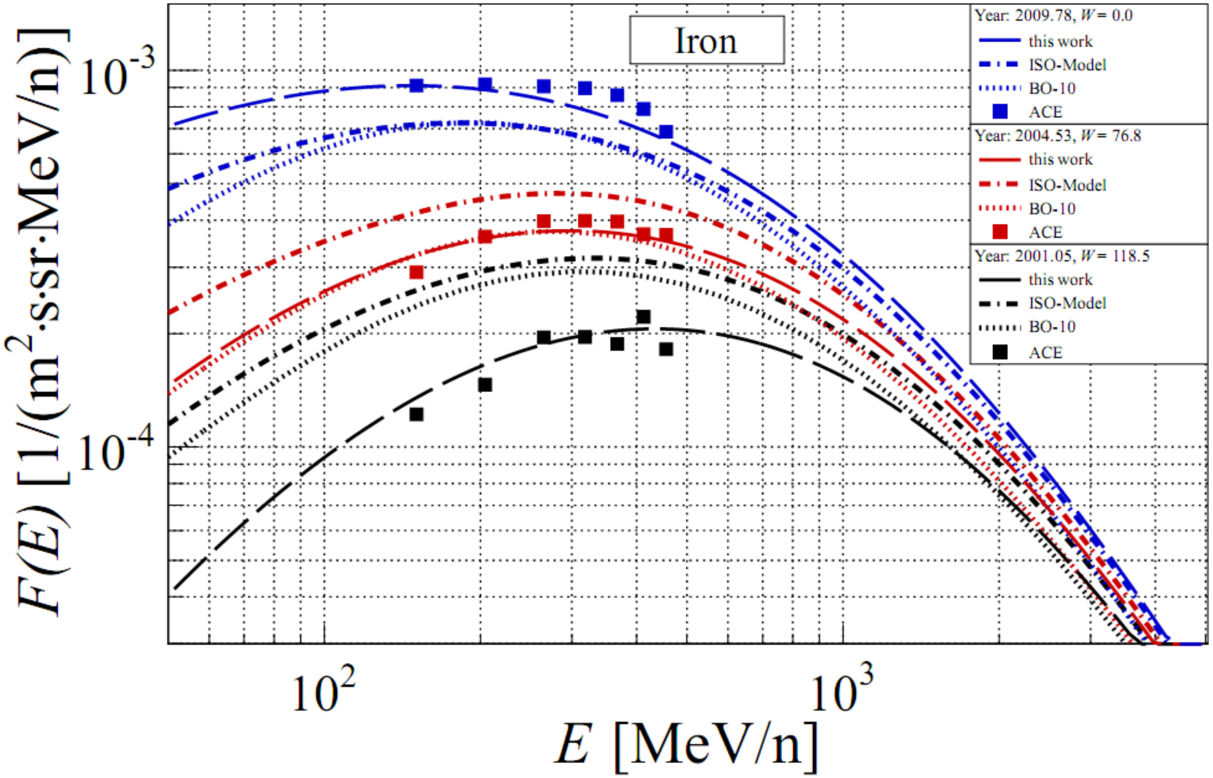


GCR model – comparison to ACE iron data

Solar minimum – Dez. 2009

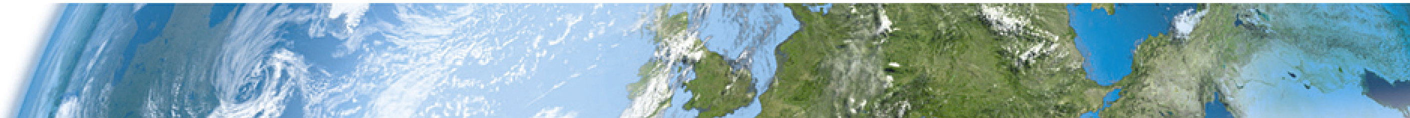
Intermediate modulation – June 2004

Solar maximum – Jan. 2001

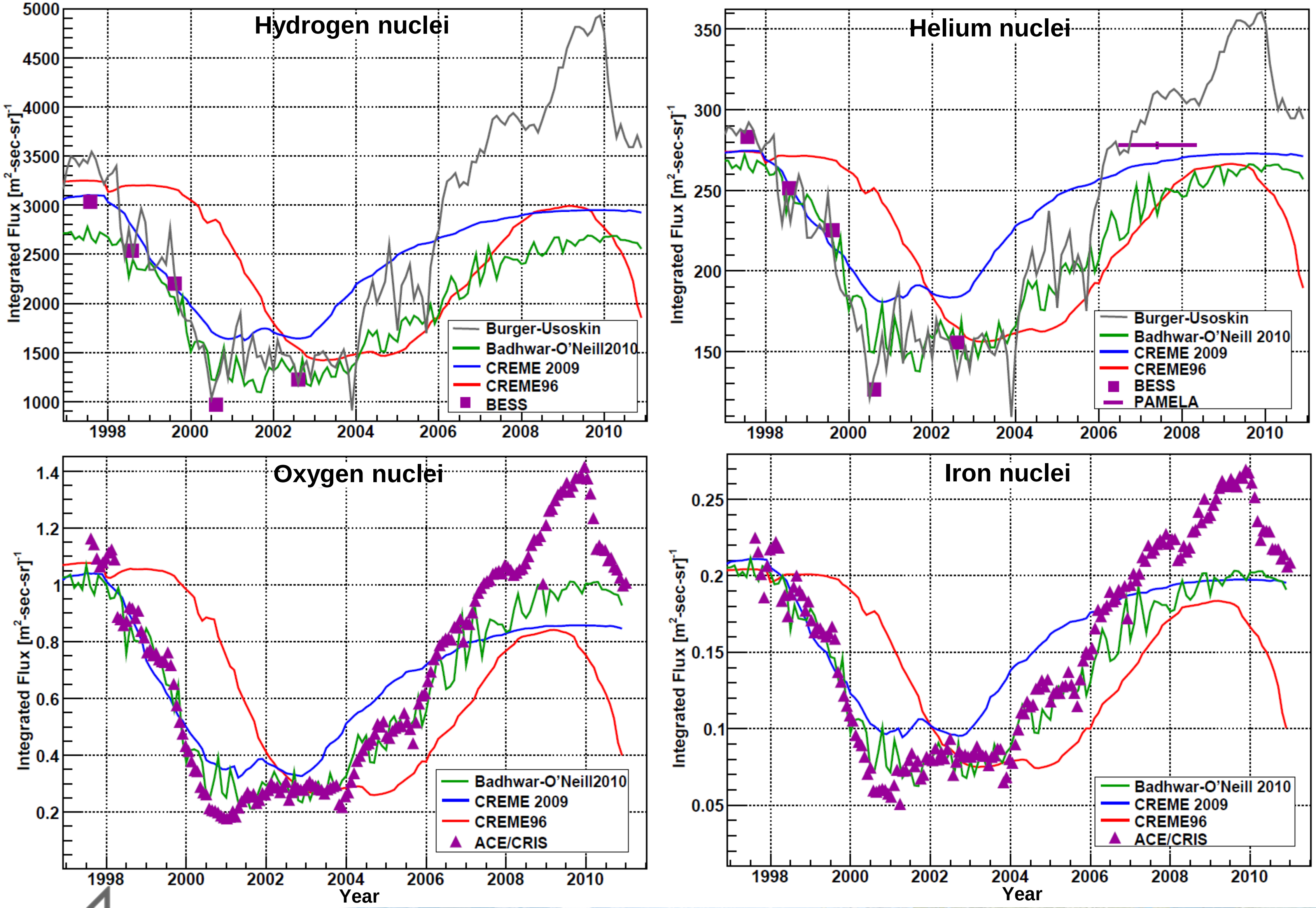


GCR model - comparison to experimental data

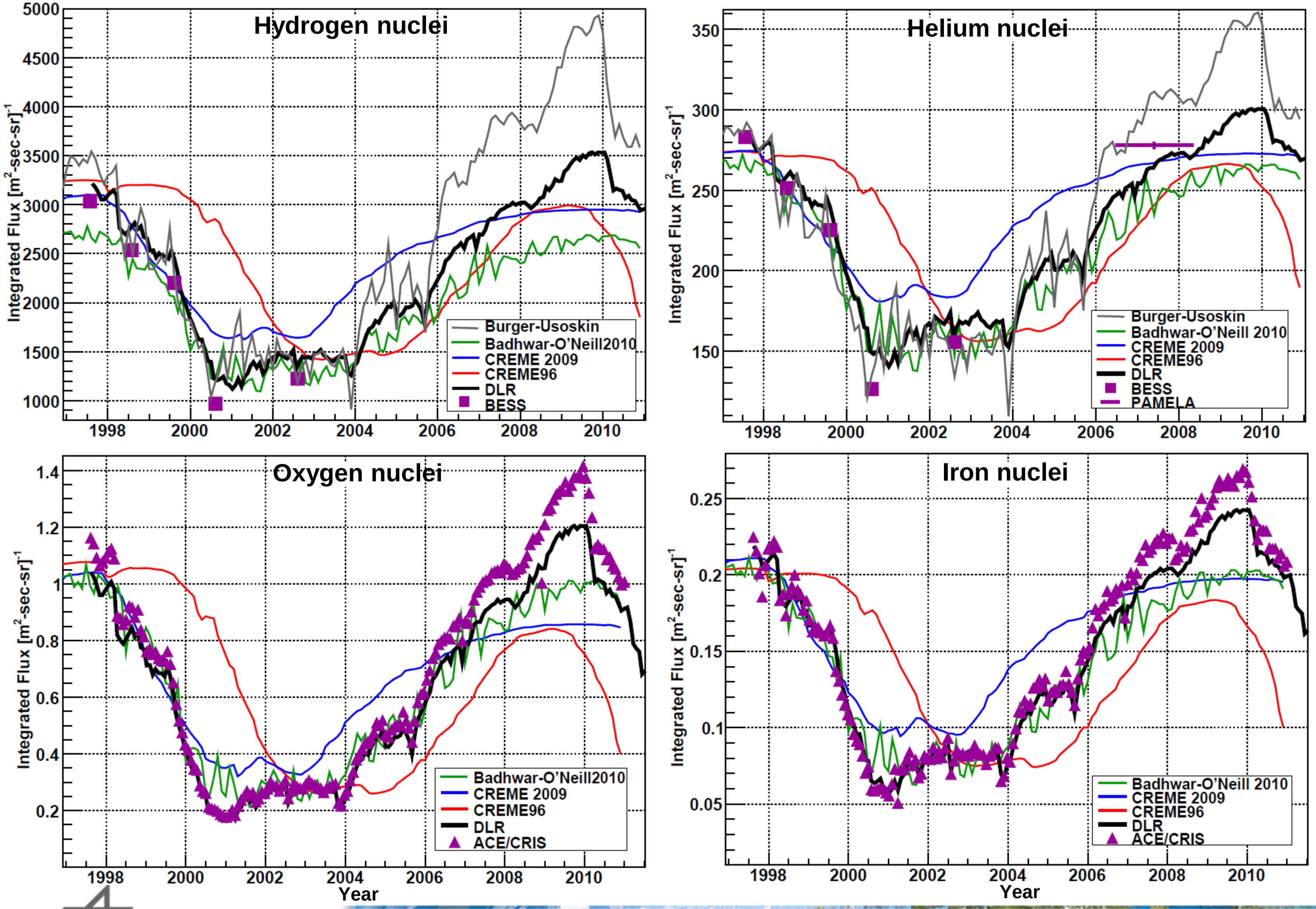
					relative deviation from experimental data		
Experiment	Ion	Energy range [MeV/n]	Year	*W*	this work	ISO	BO-10
ACE/CRIS	Fe	129.1 - 470.9	2001.05	118.5	8 %	73 %	58%
ACE/CRIS	Fe	129.1 - 470.9	2004.53	76.8	5 %	23 %	7%
ACE/CRIS	Fe	129.1 - 470.9	2009.78	0.0	8 %	23 %	24%
BESS1998	H	$215 – 21.5 \cdot 10^3$	29th July 1998	47.1	4%	17%	5%
BESS2000	H	$215 – 21.5 \cdot 10^3$	10th Aug. 2000	116.1	16%	120%	34%
BESS1998	He	$215 – 21.5 \cdot 10^3$	29th July 1998	47.1	9%	9%	5%
BESS2000	He	$215 – 21.5 \cdot 10^3$	10th Aug. 2000	116.1	12%	59%	24%
HEAO-3-C2	C	$620 – 3.5 \cdot 10^3$	Oct. 1979 – June 1980	88.4	6%	7%	7%
HEAO-3-C2	Fe	$800 – 3.5 \cdot 10^3$	Oct. 1979 – June 1980	88.4	11%	19%	9%



Temporal variation in GCR flux



Temporal variation in GCR flux



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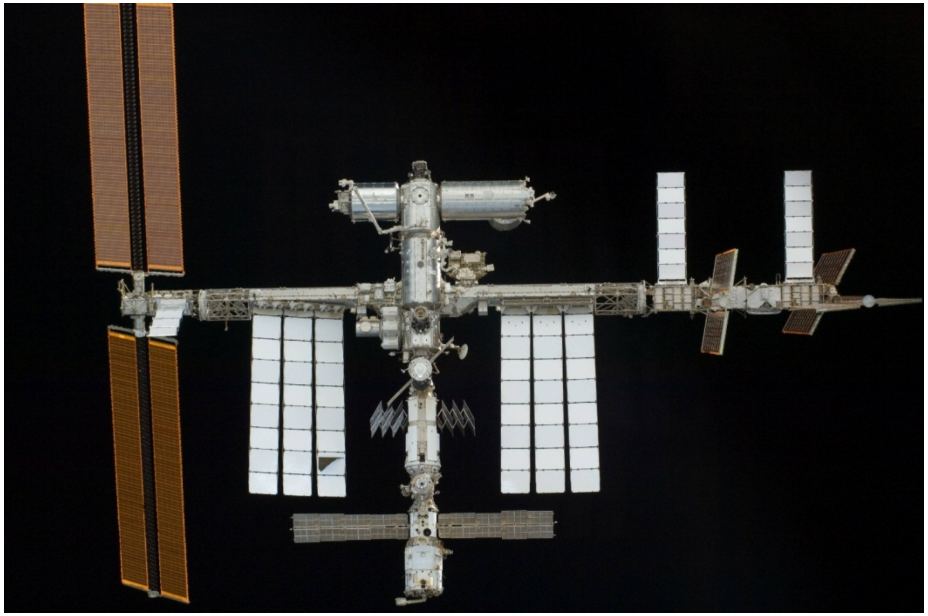
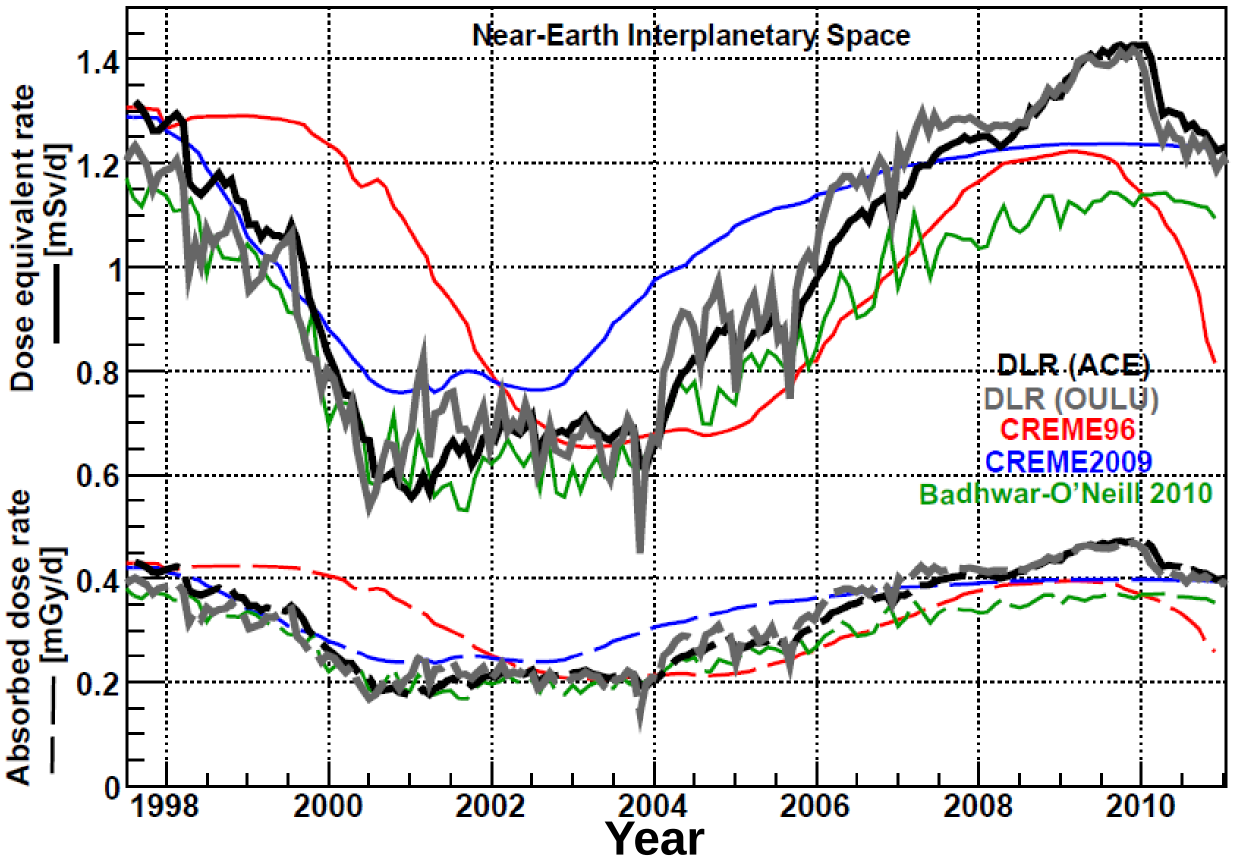
Radiation exposure in interplanetary space and low Earth orbit

GCR model comparison

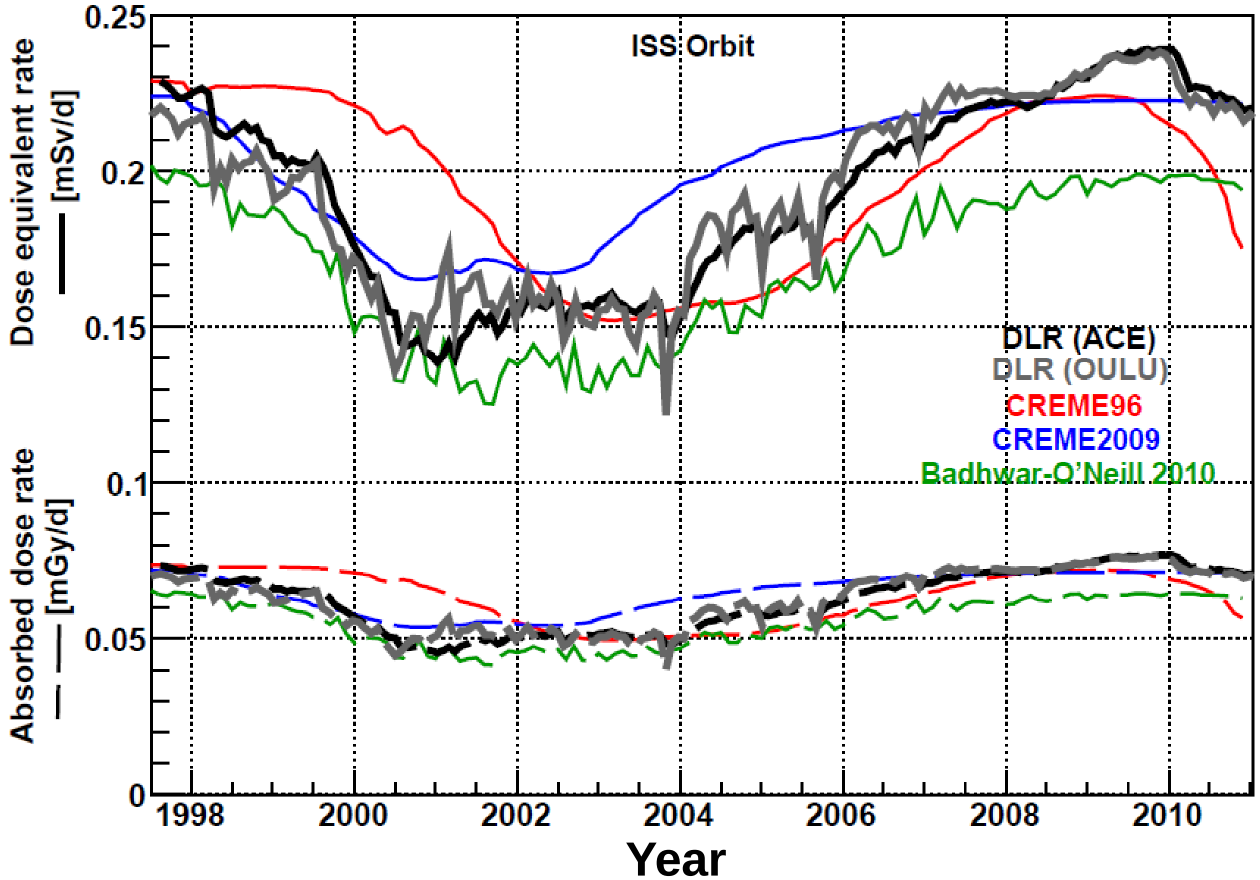


GCR exposure in interplanetary space



dD/dt (µGy/d)	**173 – 472**
dH/dt (µSv/d)	**556 – 1427**

GCR exposure in low Earth orbit



dD/dt (µGy/d)	**45 – 77**
dH/dt (µSv/d)	**139 – 239**

GCR exposure using DLR model

- Dose rates using the DLR model are higher with respect to the Badhwar-O'Neill2010

- Dose rates using DLR relative to Badhwar-O'Neill model in Jan 2010:

Dose Quantities	Near-Earth Interplanetary Space	ISS Orbit
dD/dt	**~ +28 %**	**~ +19 %**
dH/dt	**~ +25 %**	**~ +20 %**

- Increase in dose in Jan 2010 relative to July 1997

Dose Quantities	Near-Earth Interplanetary Space	ISS Orbit
dD/dt & *dH/dt*	**~ +10-12 %**	**~ +5-6 %**

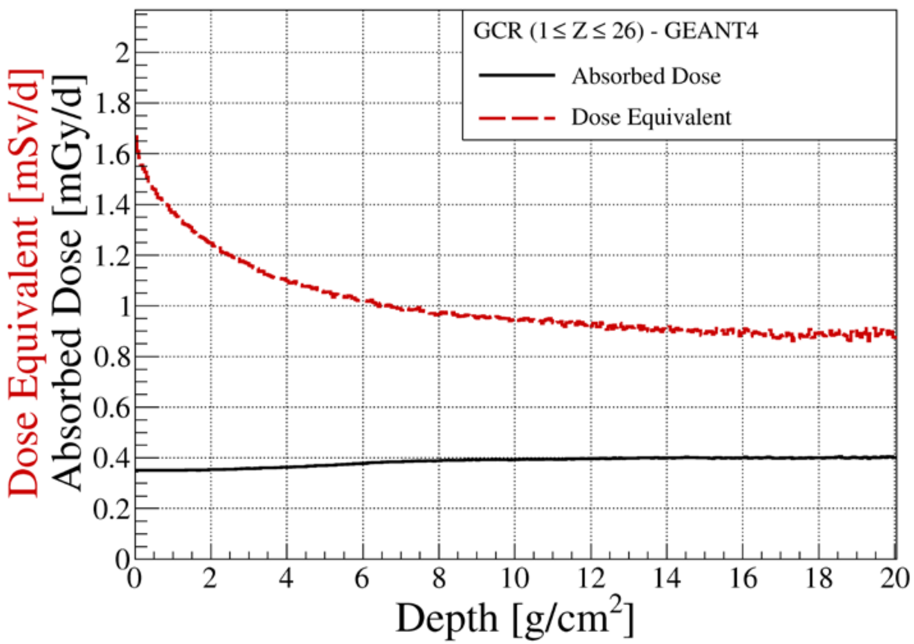
Radiation exposure in interplanetary space

Radiation exposure in interplanetary space

S. McKenna-Lawlor, P. Goncalves, A. Keating, G. Reitz, D. Matthiae, Overview of energetic particle hazards during prospective manned mission to Mars, Planet. Space Science, 2012

- Solar Minimum CREME2009
- GCR: Z=1-26, 10 MeV/n – 100 GeV/n
- 20 cm radius water sphere
- Absorbed dose rate:
  0.35 – 0.4 mGy/d
- Dose equivalent rate:
  1.6 – 0.9 mSv/d
- Mars mission: 400 – 600 days in deep space
  0.36 – 0.96 Sv

  Carreer limits at LEO, depending on age:
  0.4 – 1.7 Sv (female)
  0.7 – 3.0 Sv (male)



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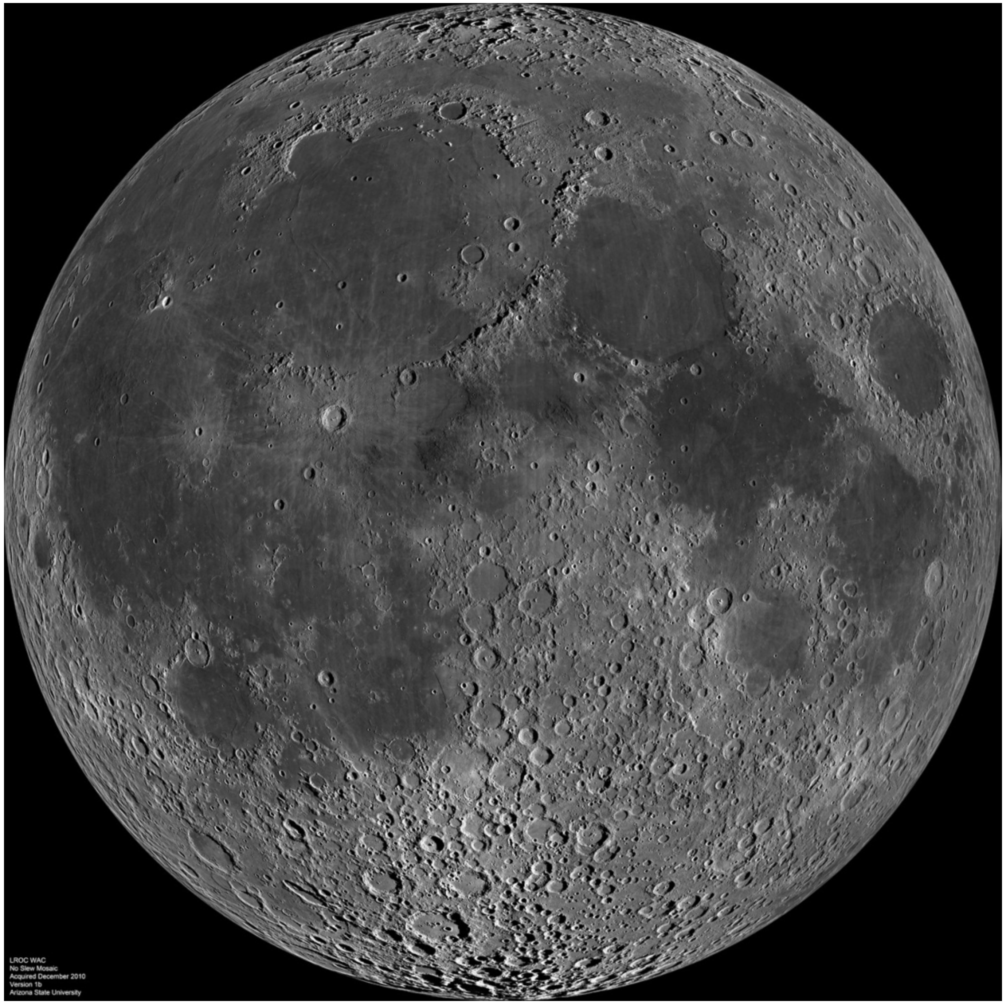
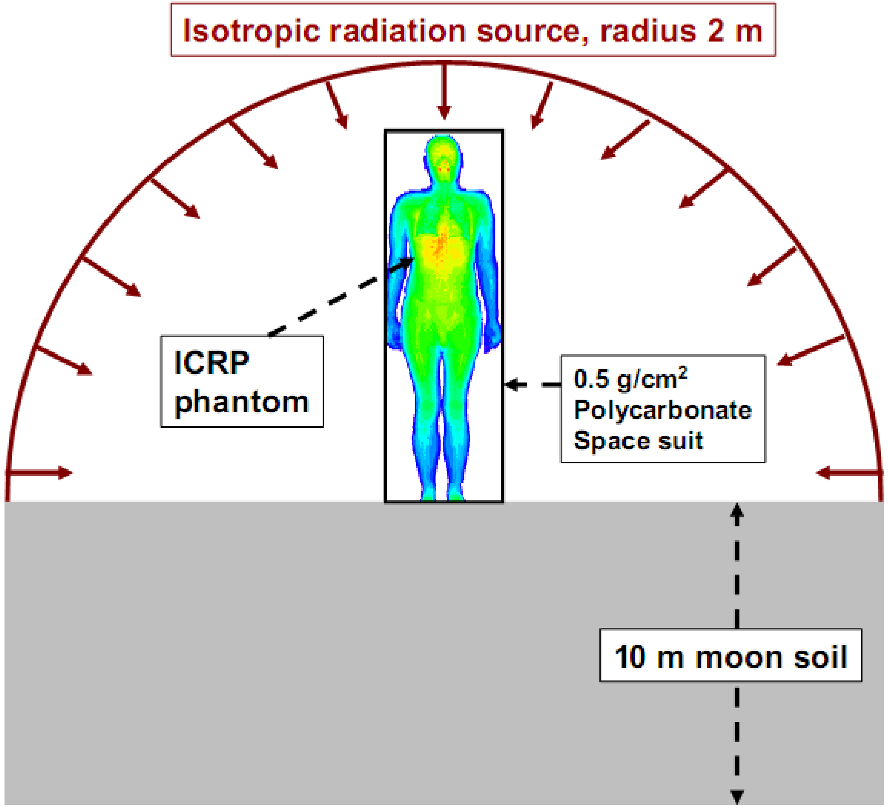
Radiation exposure on the moon surface



Radiation exposure on the lunar surface

G. Reitz, T. Berger, D. Matthiae, Radiation exposure in the moon environment, Planet. Space Science, 2012

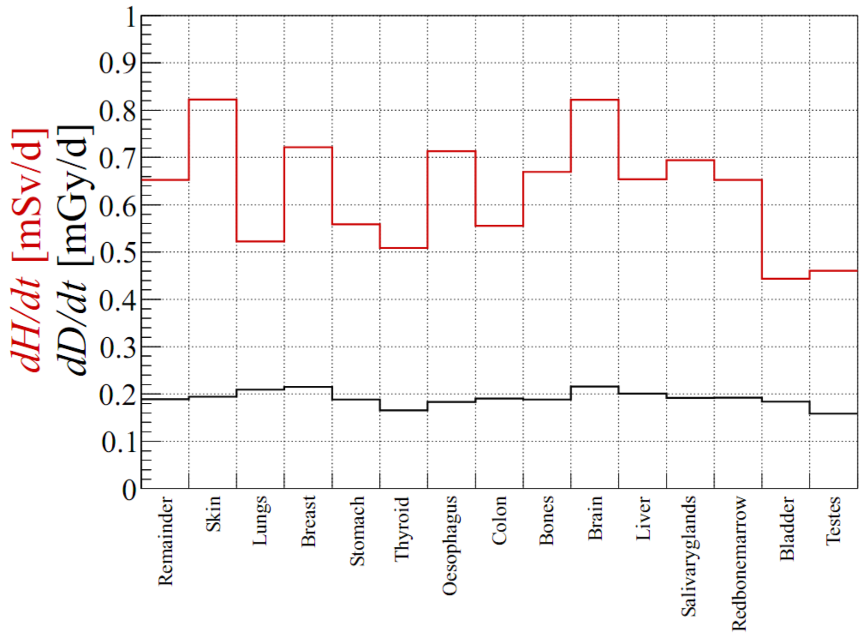
- Solar Minimum (Dec. 2009)
- GCR: Z=1-26, E=10 MeV/n – 100 GeV/n
- Radiation source:
    - Half sphere, radius 2 m
    - Isotropic from above
- Target:
    - ICRP phantom, male
    - 0.5 g/cm^2 polycarbonate space suit, approximated from *NASA-TP-2003-212158, "Analysis of a Radiation Model of the Shuttle Space Suit"*
- Moon soil:
    - 10m
    - Atomic composition: 60.3% O, 0.4% Na, 5.1% Mg, 6.5% Al, 16.9% Si, 4.7% Ca, 1.1% Ti, 4.4% Fe; Mare, after *J. F. Lindsay "Lunar Stratigraphy and Sedimentology", Elsevier, ISBN 0-444-414443-6 (1976)*

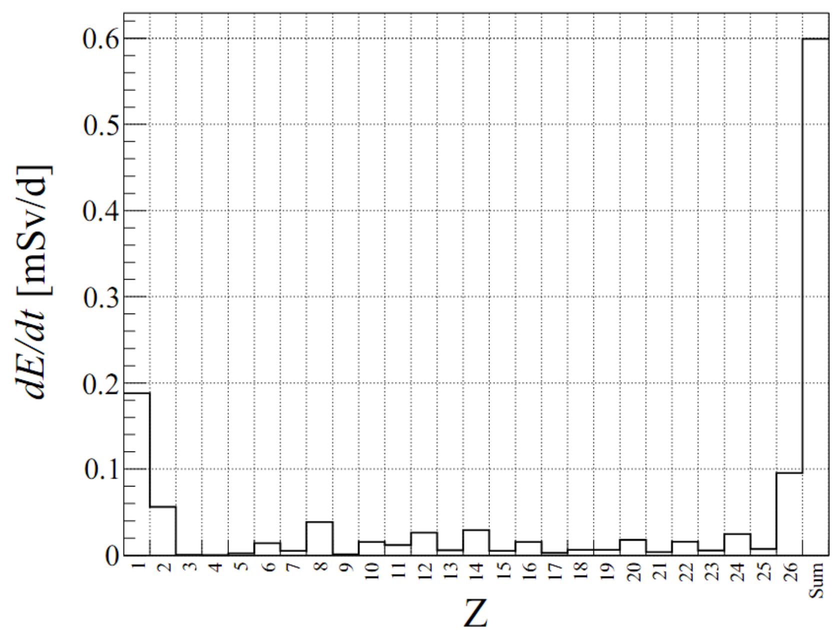


Radiation exposure on the lunar surface

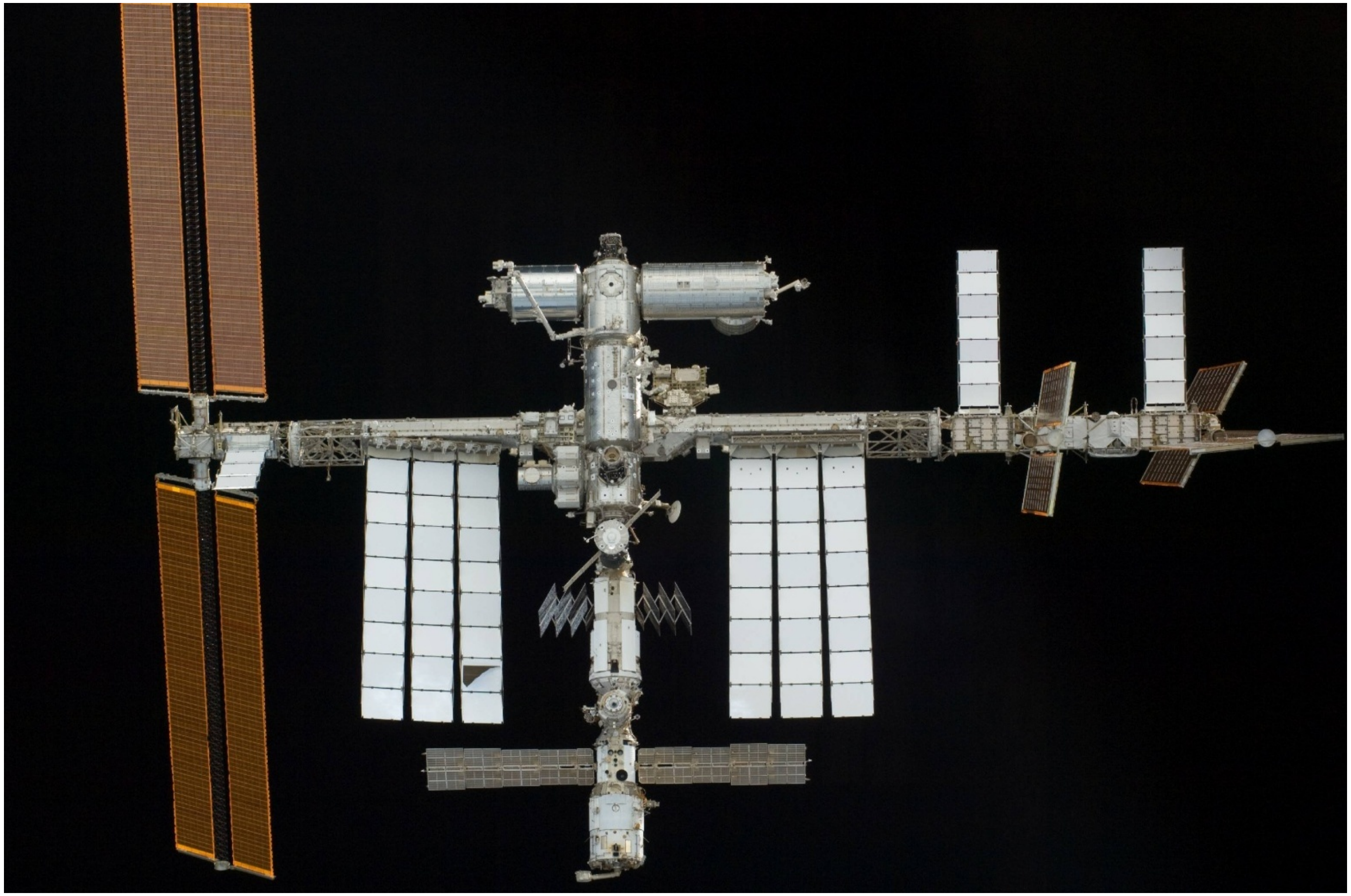
- Solar Minimum (Dec. 2009)
- Z=1-26, E=10 MeV/n – 100 GeV/n
- Organ absorbed dose rates:
  0.16 mGy/d – 0.22 mGy/d
- Organ dose equivalent rates:
  0.44 mSv/d – 0.82 mSv/d
- Effective dose rate: **0.6 mSv/d**

- *Dachev et al., 2001:*
  0.26 mGy/d in silicon in 200km lunar orbit
  Considering shadowing effect and conversion to dose in water:
  0.69·1.23·0.26 mGy/d = **0.22 mGy/d**





Radiation exposure at the ISS orbit



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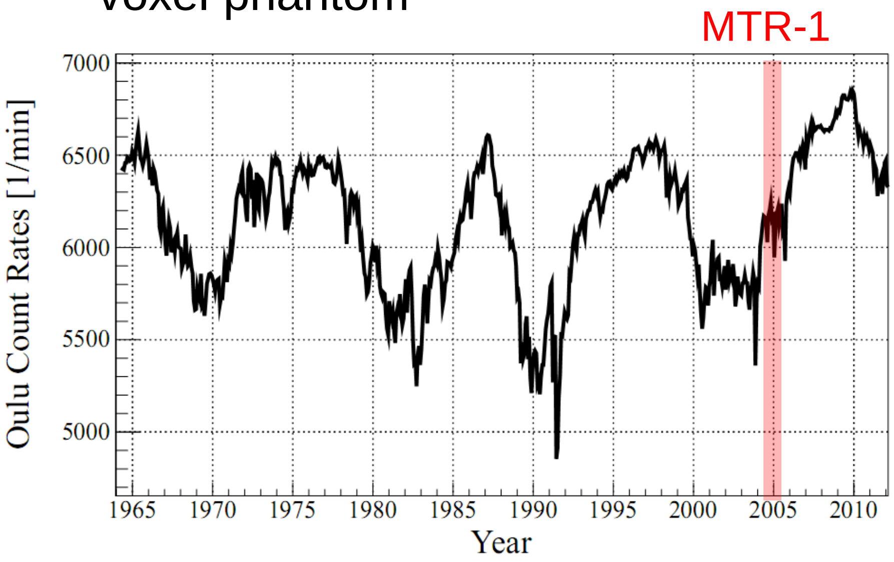
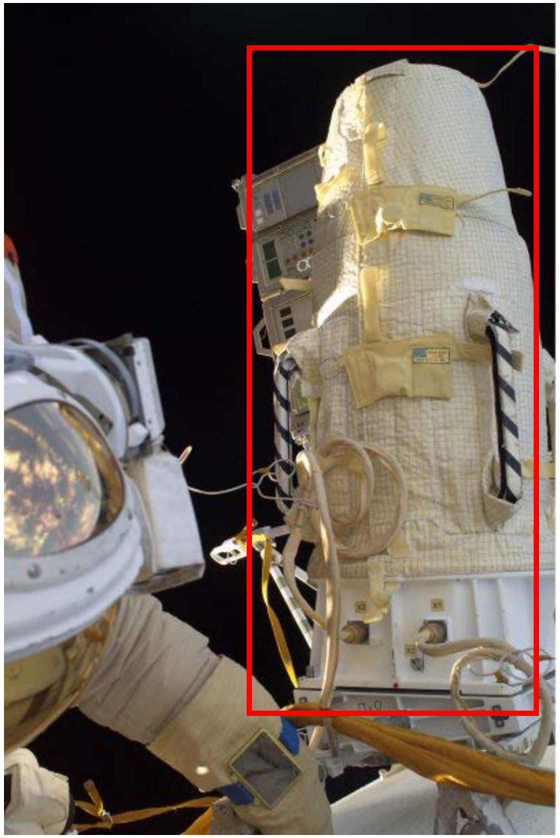
MATROSHKA 1

- Outside the space station
- Solar modulation between solar mininmum and maximum (2004-2005)
- Simulation: 1 g/cm^2 Al spherical shielding
- 20 cm water sphere and NUNDO voxel phantom





MTR-1 (2004−05)
539 days

MATROSHKA 1

- Outside the space station
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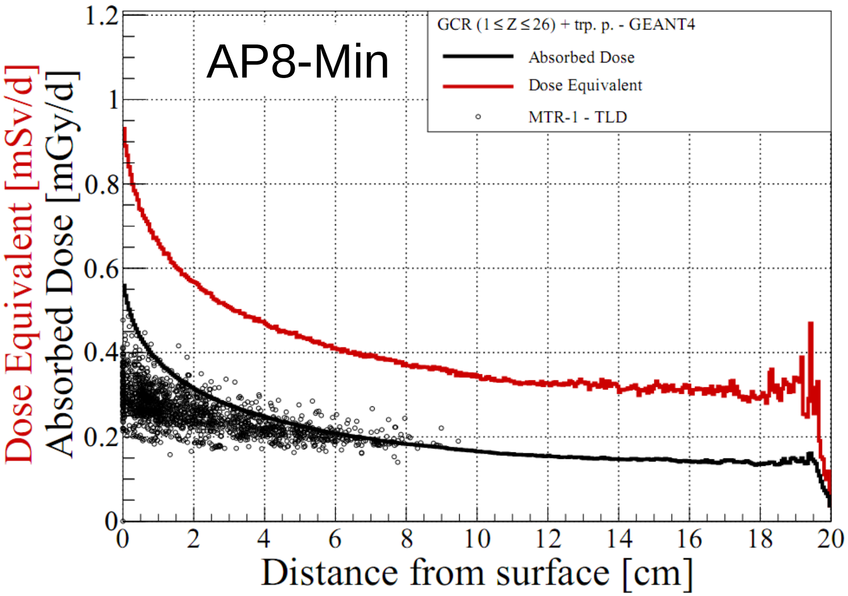
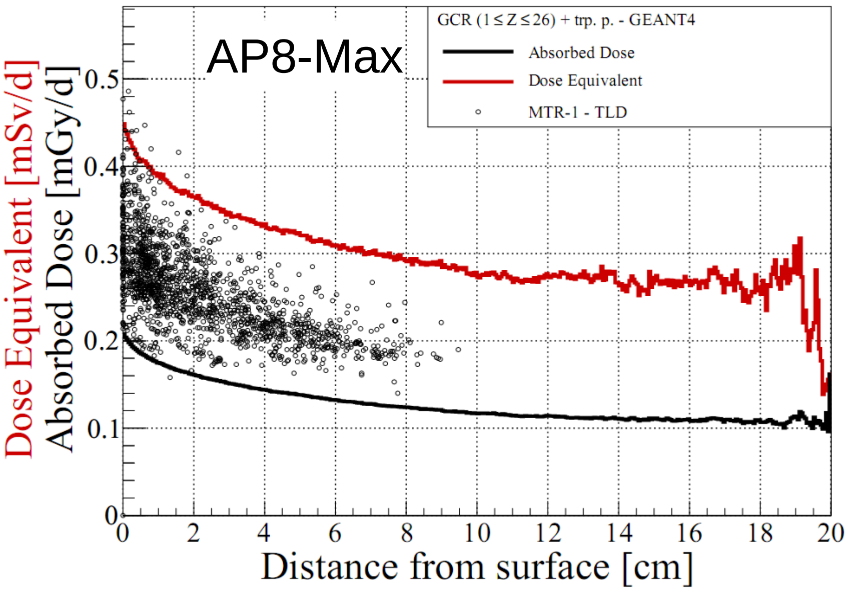
- Simulation: 1 g/cm^2 Al spherical shielding
- 20 cm water sphere and NUNDO voxel phantom





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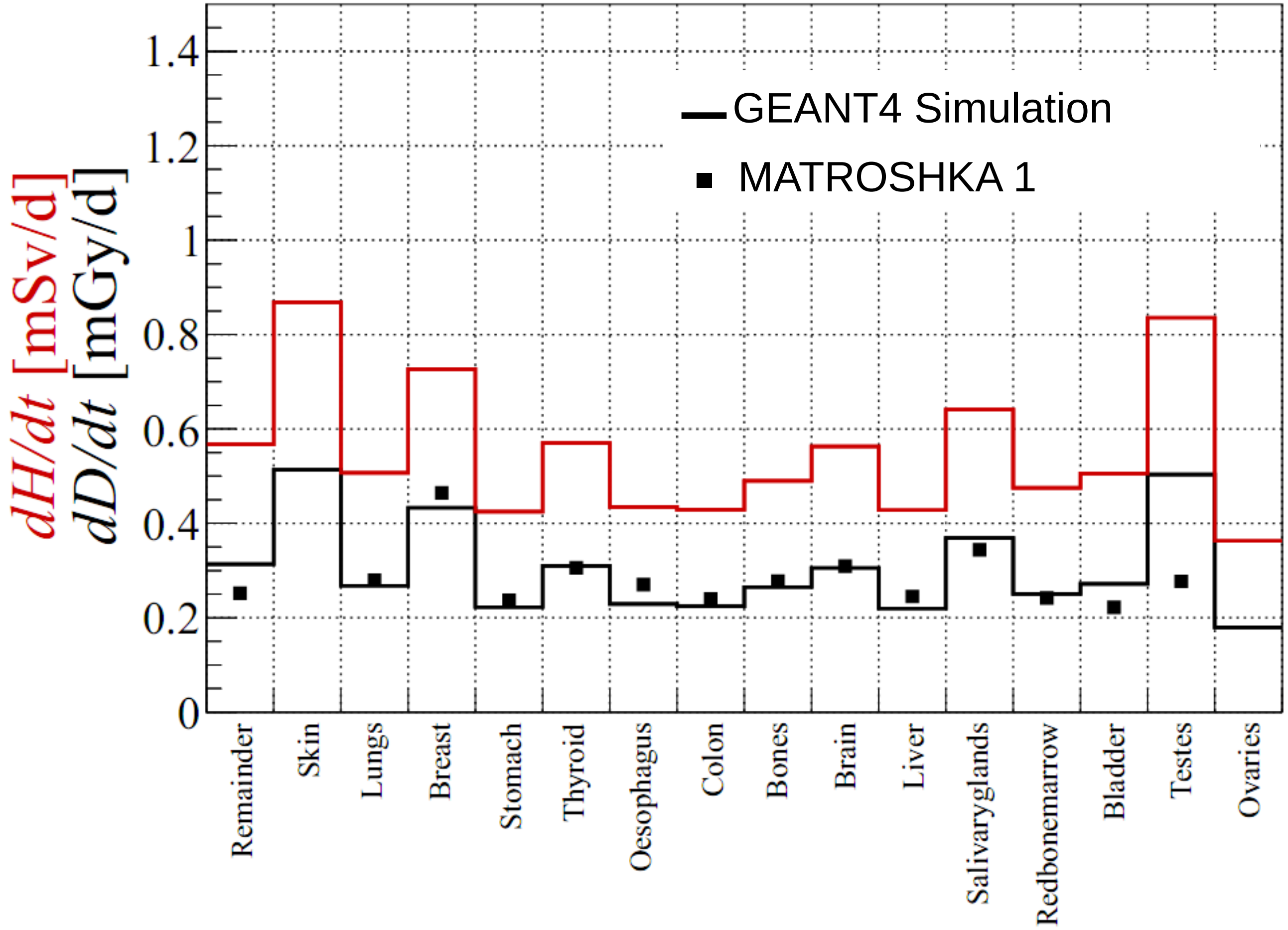
MATROSHKA - 1 simulated using the NUNDO voxel phantom – AP8min



Solar minimum, Dez. 2009

Ap8-min 350 km, 25 g/cm² Aluminum
Absorbed Dose

GEANT4

Trapped protons:

40 μGy/d < *dD/dt* < 85 μGy/d

GCR:

85 μGy/d < *dD/dt* < 105 μGy/d

DOSTEL1/2, DOSIS

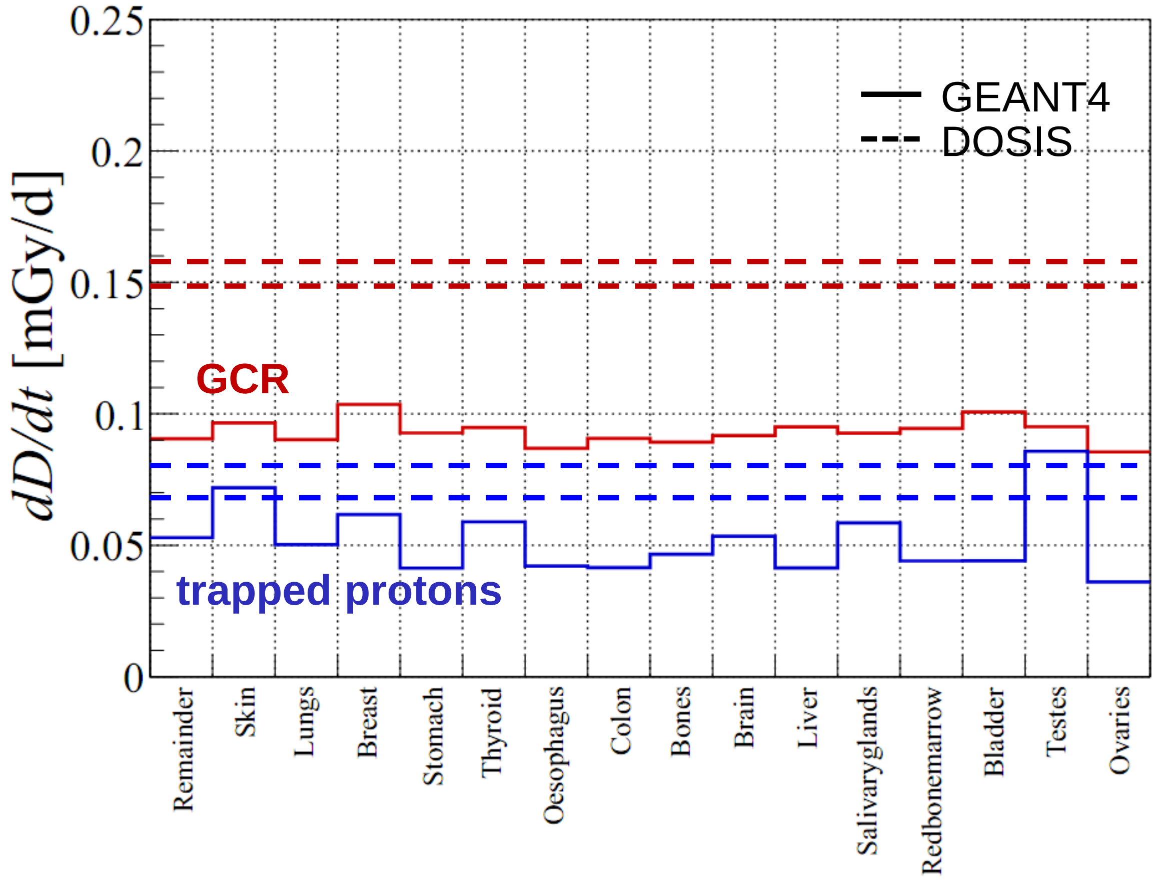
(S. Burmeister):

SAA:

dD/dt = 68 / 80 μGy/d

GCR:

dD/dt = 150 / 157 μGy/d



Solar minimum, Dez. 2009

Ap8-min 350 km, 25 g/cm² Aluminum
Quality Factor

GEANT4

Trapped protons:

$1.1 < Q < 1.8$

GCR:

$2.4 < Q < 3.3$

DOSTEL1/2, DOSIS

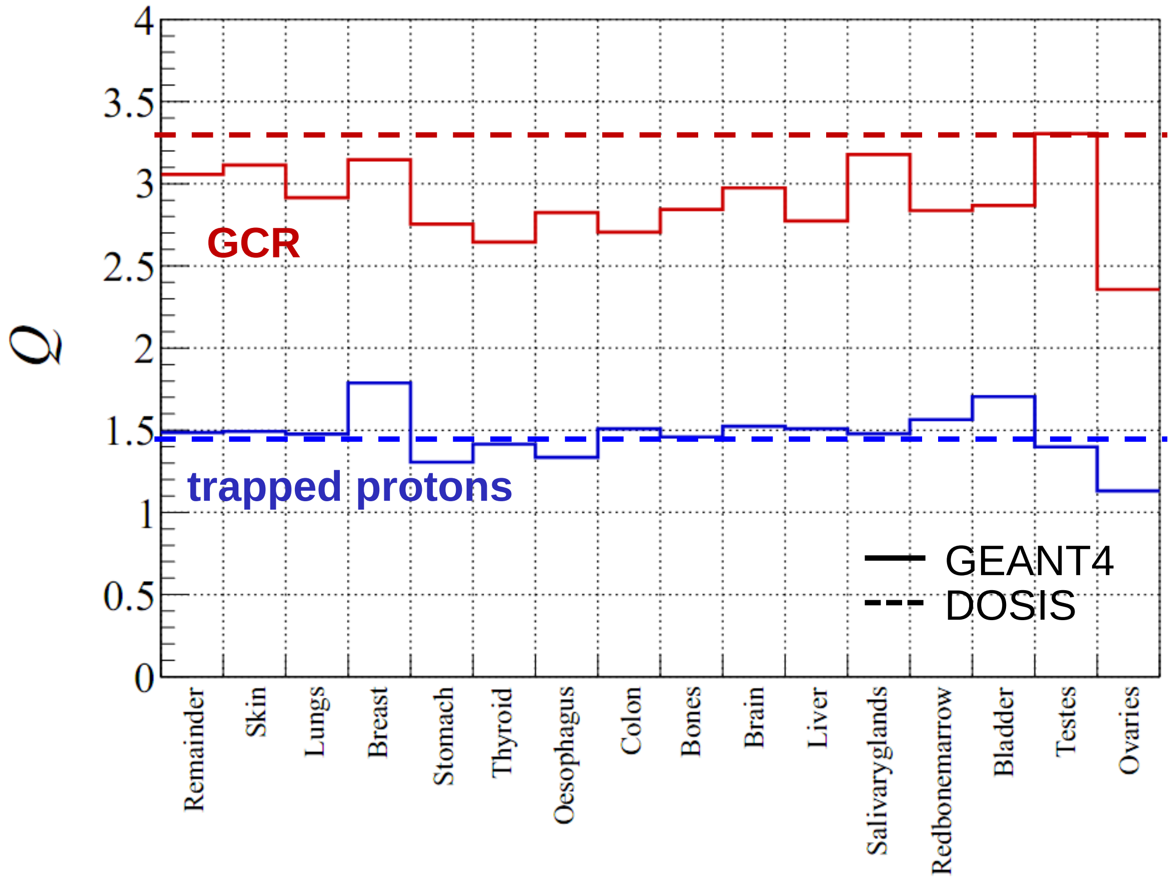
(S. Burmeister):

SAA:

$Q = 1.40 / 1.43$

GCR:

$Q = 3.30$



DLR

Solar minimum, Dez. 2009
Ap8-min 400 km, 25 g/cm² Aluminum
Absorbed Dose

GEANT4

Trapped protons:

100 µGy/d < *dD/dt* < 160 µGy/d

GCR:

85 µGy/d < *dD/dt* < 105 µGy/d

DOSTEL1/2, DOSIS 3D

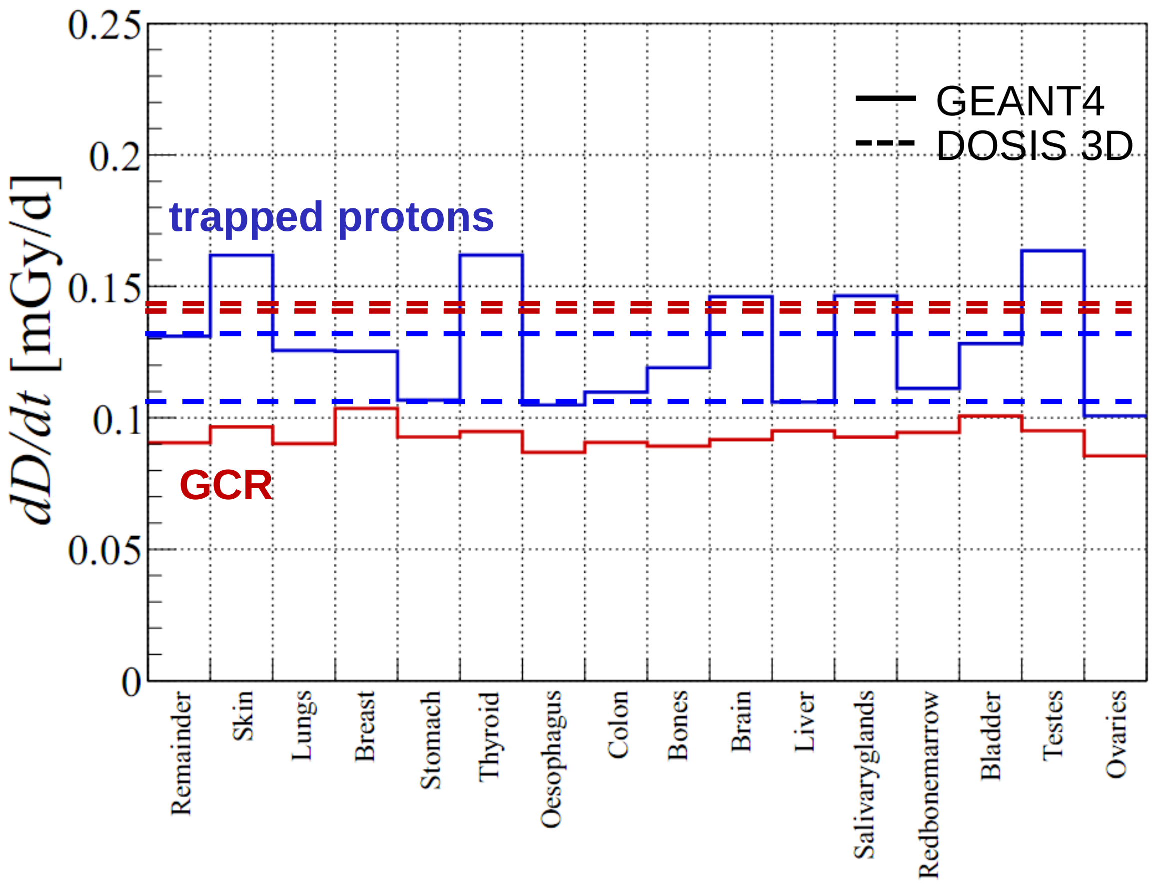
(S. Burmeister):

SAA:

dD/dt = 131 / 106 µGy/d

GCR:

dD/dt = 146 / 143 µGy/d



Summary

- Discrepancies between GCR models and experimental data
- Differences in dose estimations by applying different models
- Dose estimation for an unshielded water sphere by applying the DLR model from solar maximum to minimum:

Dose Quantities	Near-Earth Interplanetary Space	ISS Orbit
dD/dt (µGy/d)	**173 – 472**	**45 – 77**
dH/dt (µSv/d)	**556 – 1427**	**139 – 239**

- Reasonable agreement between numerical estimates and experiments
- Discrepancies between calculated and measured GCR dose rates at LEO

Thank you for your attention!