Calculation of Radiation Exposure Levels in Low Earth Orbit and Beyond

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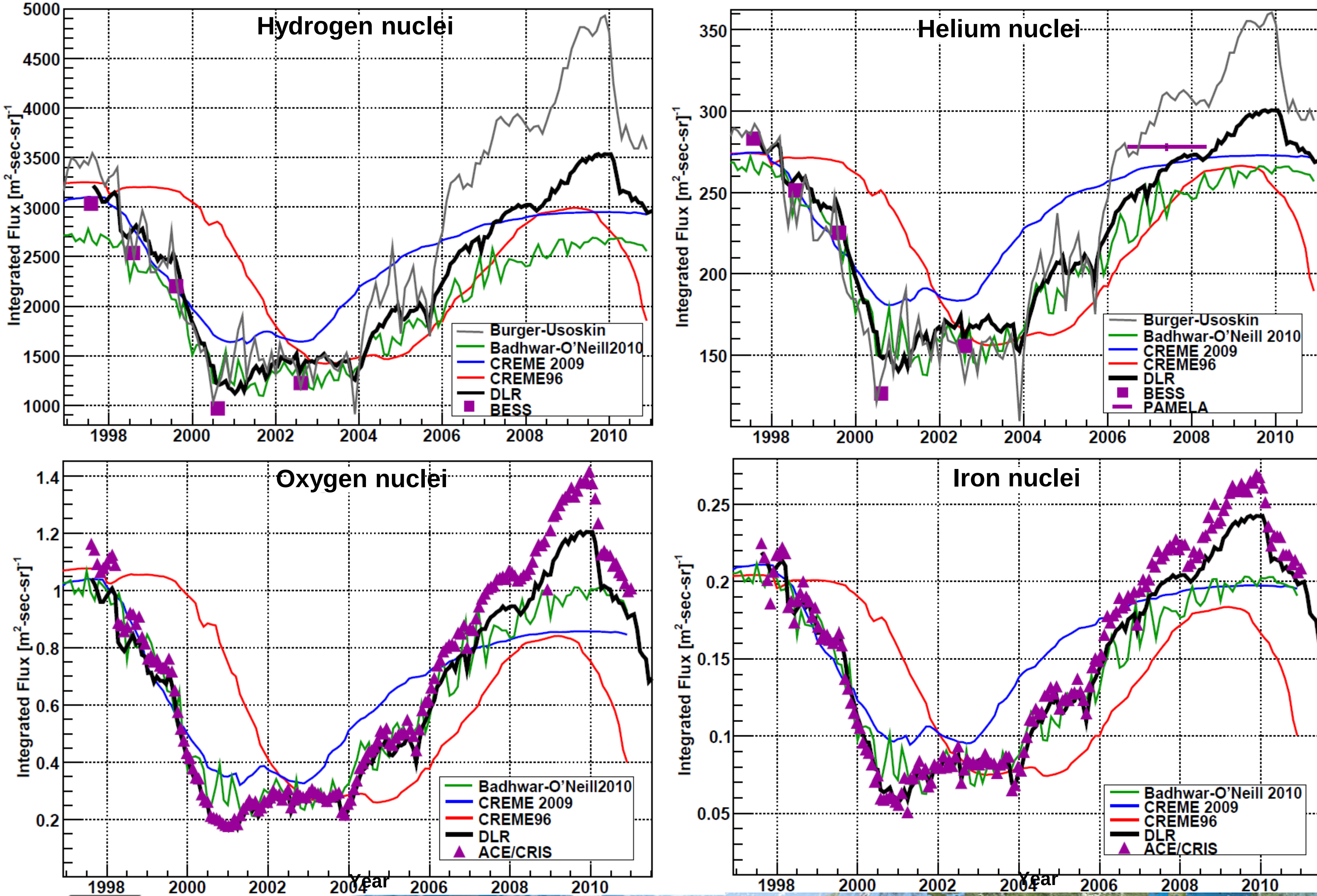
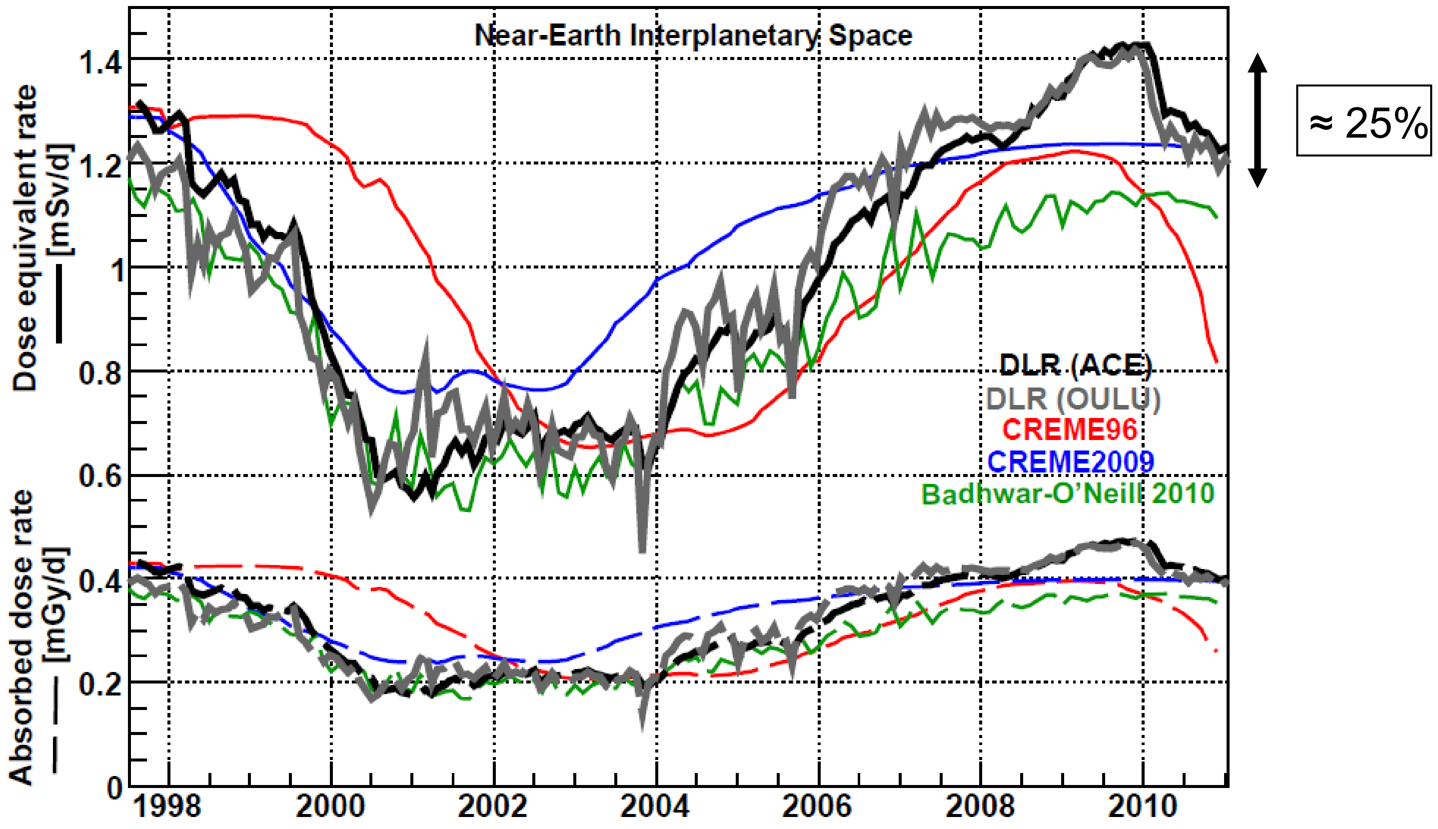
Outline

- GCR model comparison, particle fluxes / dose rate estimates
- Badhwar-O'Neill 2011 model
- Estimates of the radiation exposure
  - Interplanetary space
  - ISS orbit
    - Solar minimum / DOSIS / DOSIS 3D
  - Implementation of COLUMBUS shielding distribution
  - GCR / trapped protons, organ dose rates
- Shielding dependence of organ doses for spherical shielding geometry

Temporal variation in GCR flux (17th WRMISS)



GCR exposure in interplanetary space (17th WRMISS)



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

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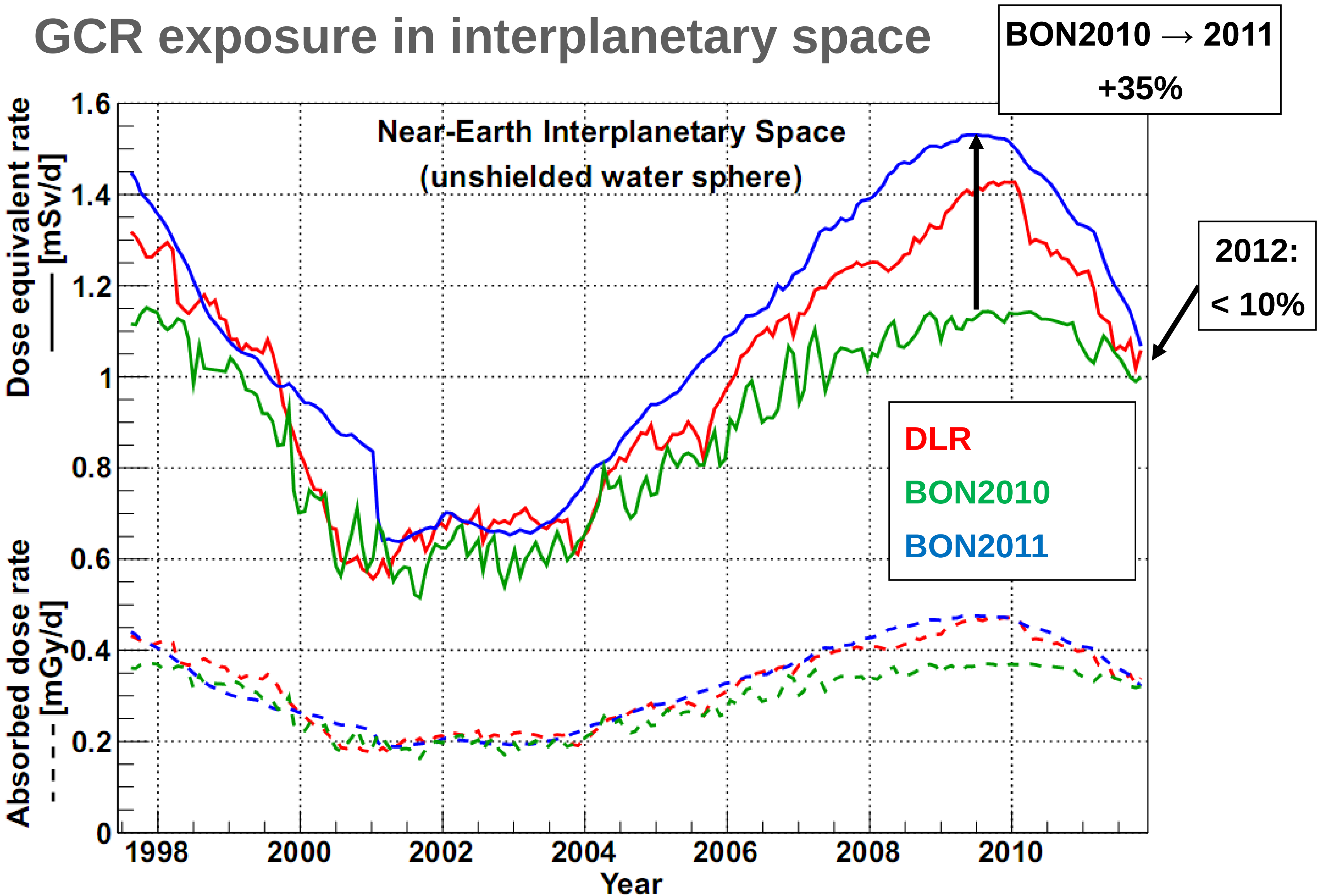
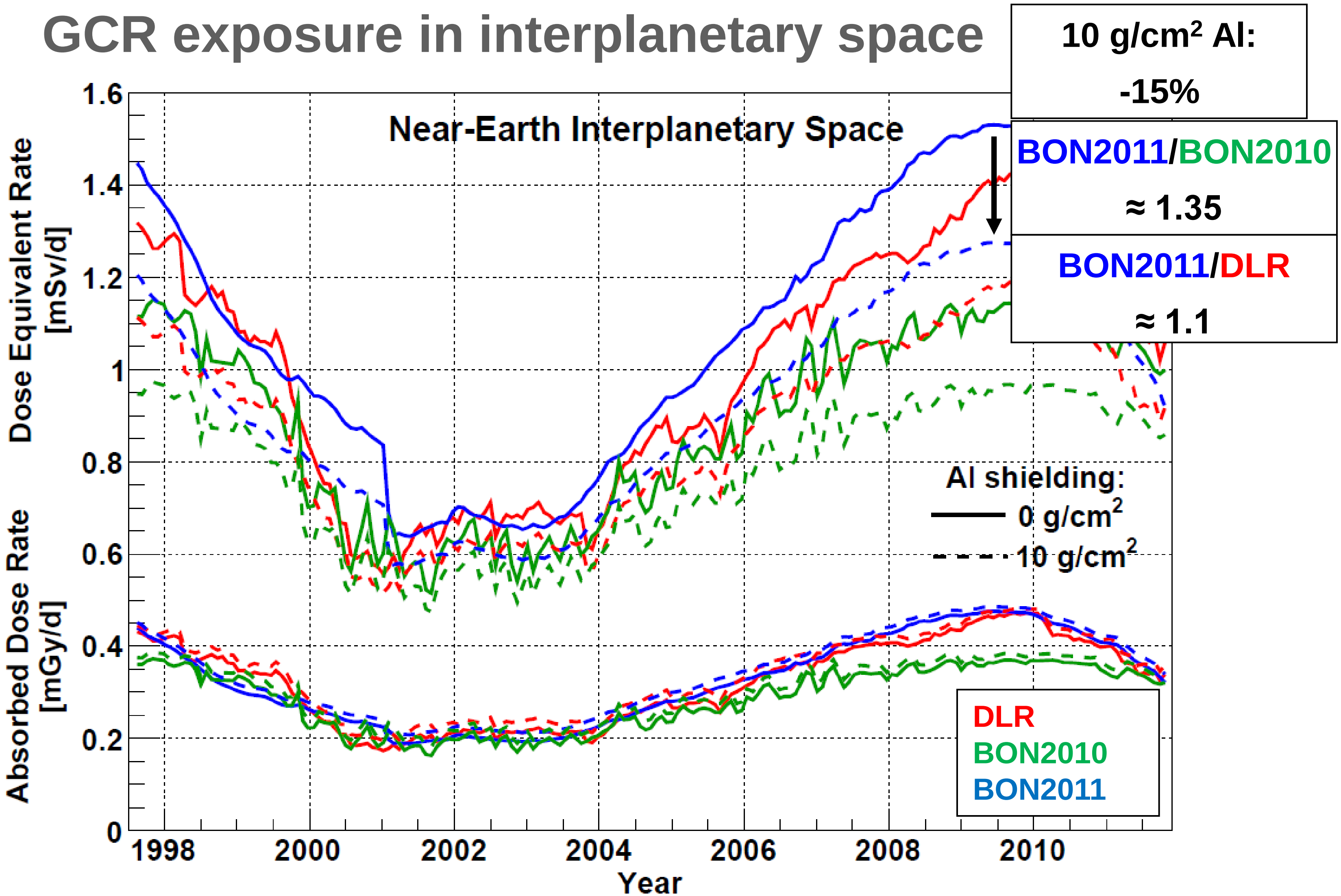
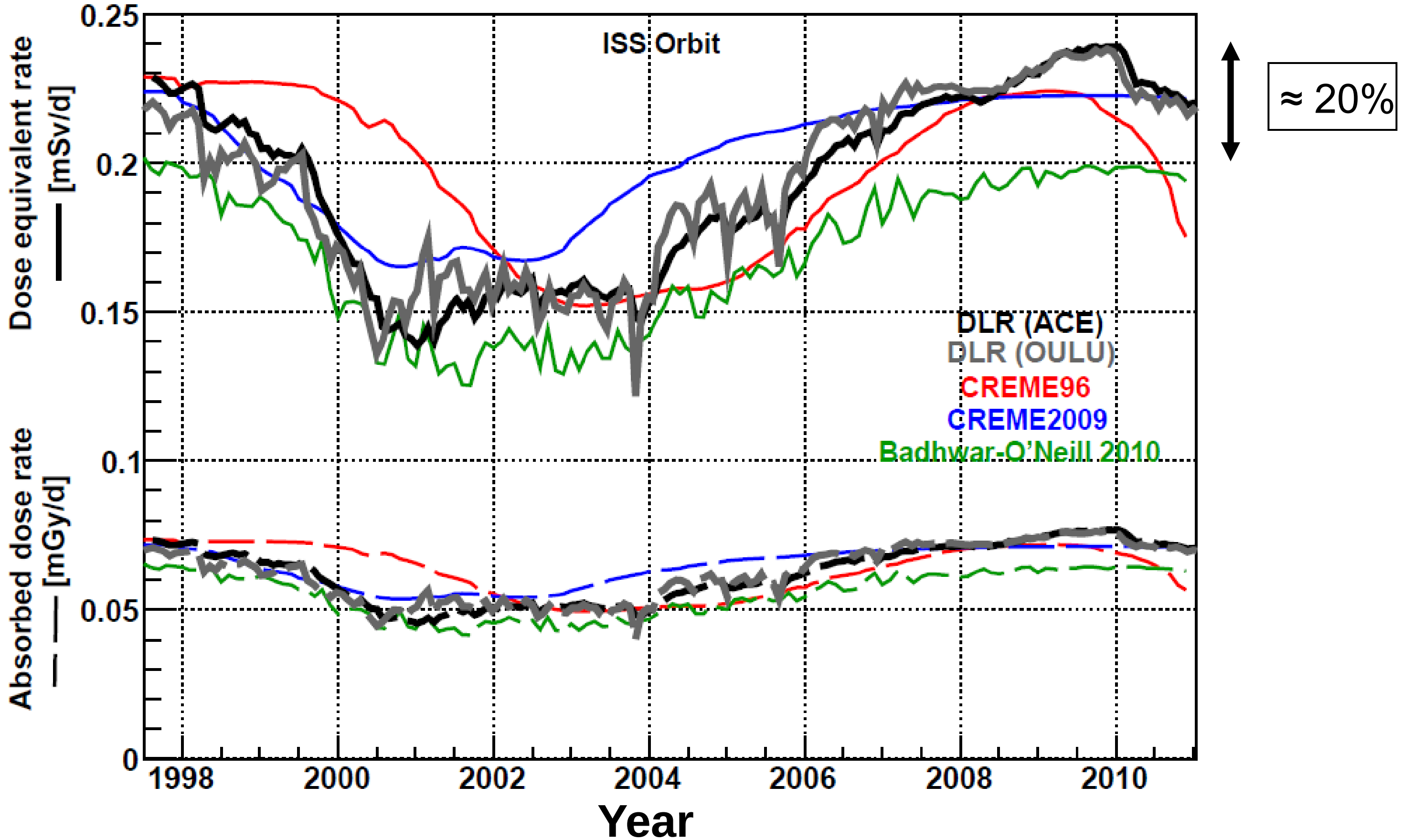
GCR exposure in interplanetary space



GCR exposure in interplanetary space



GCR exposure in low Earth orbit (17th WRMISS)



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

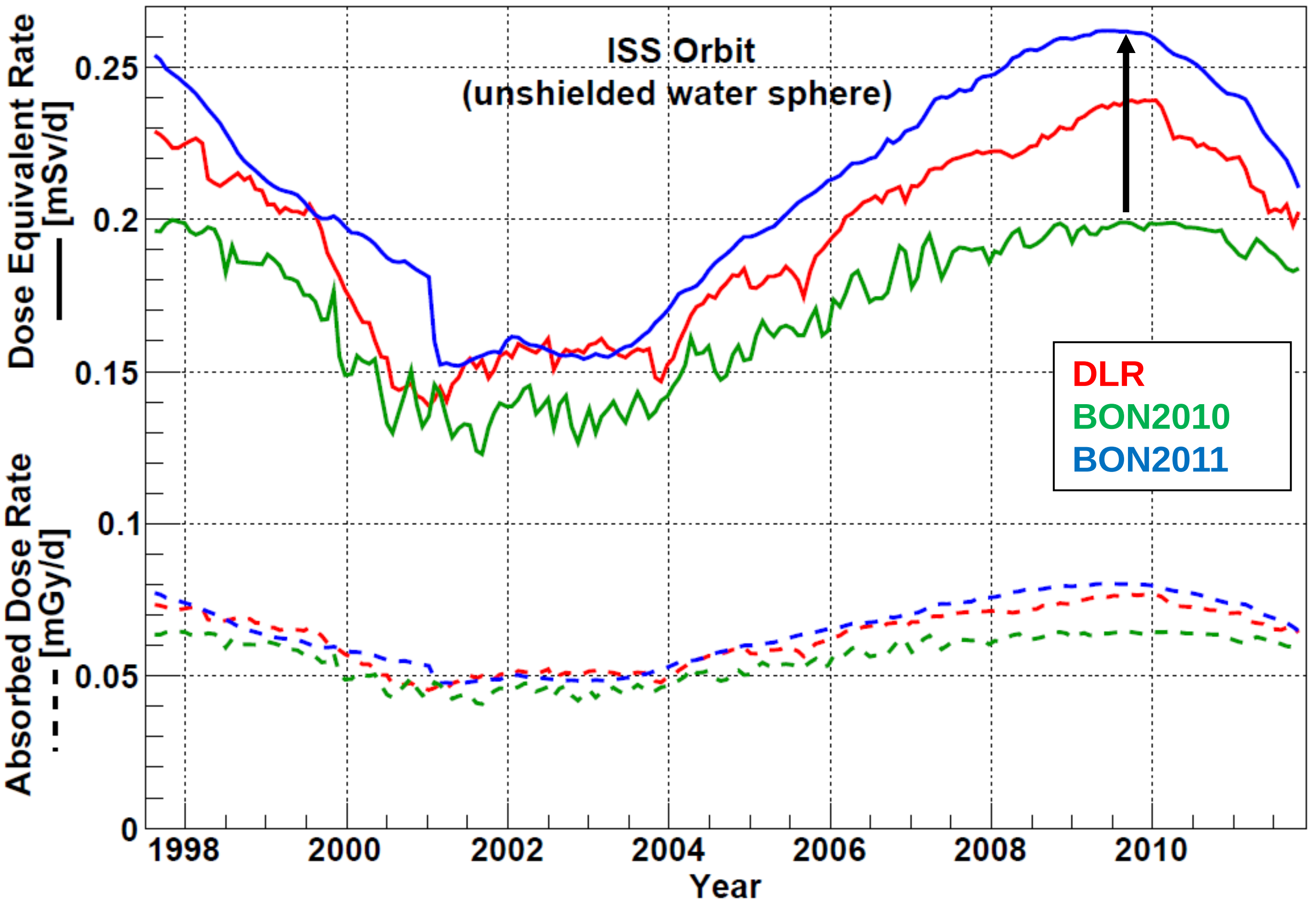
GCR exposure in LEO

BON2010 → 2011

+30%

2012:

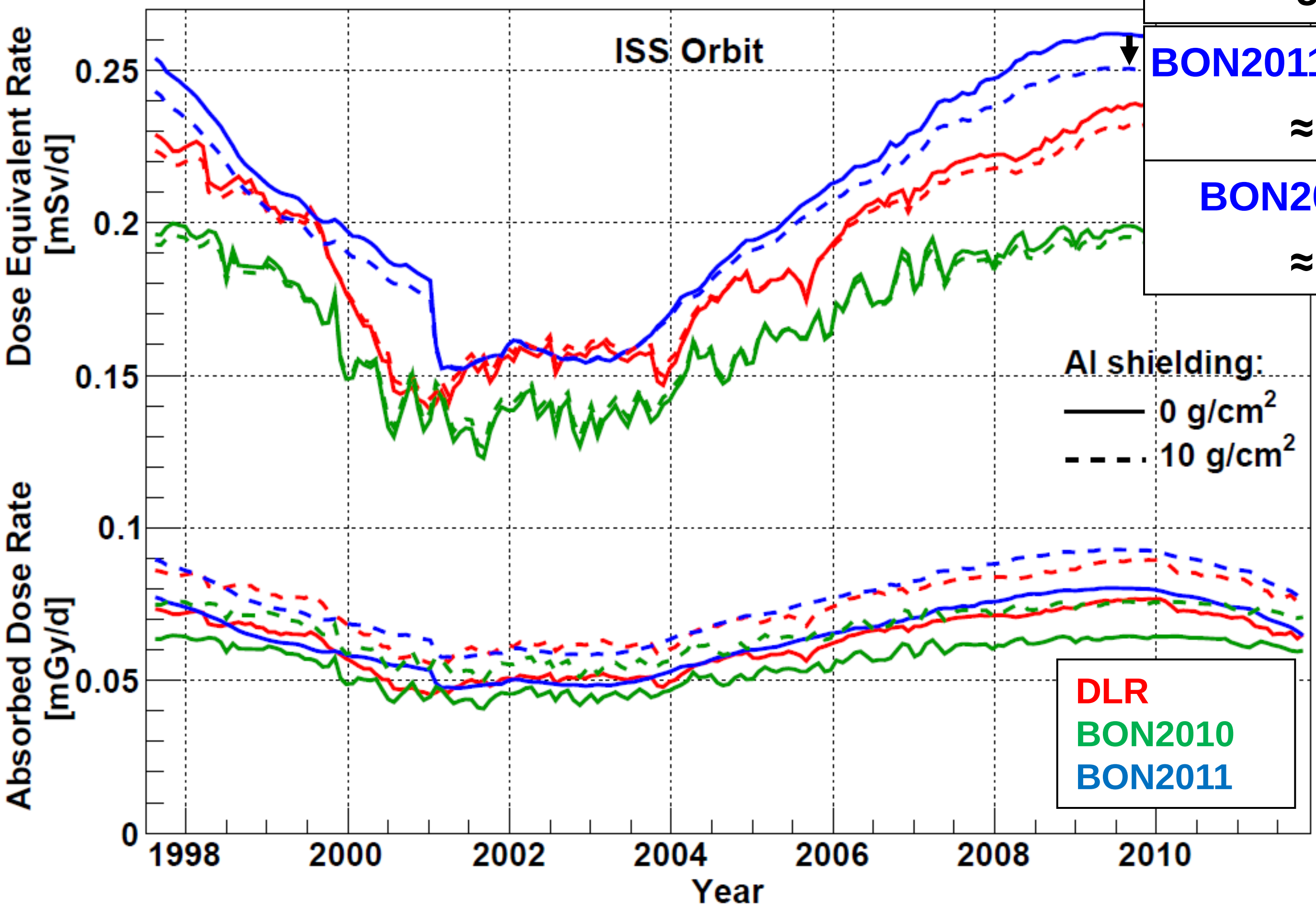
≈15%



GCR exposure in LEO - shielding dependency

10 g/cm² Al:

-5%



BON2011/BON2010

≈ 1.3

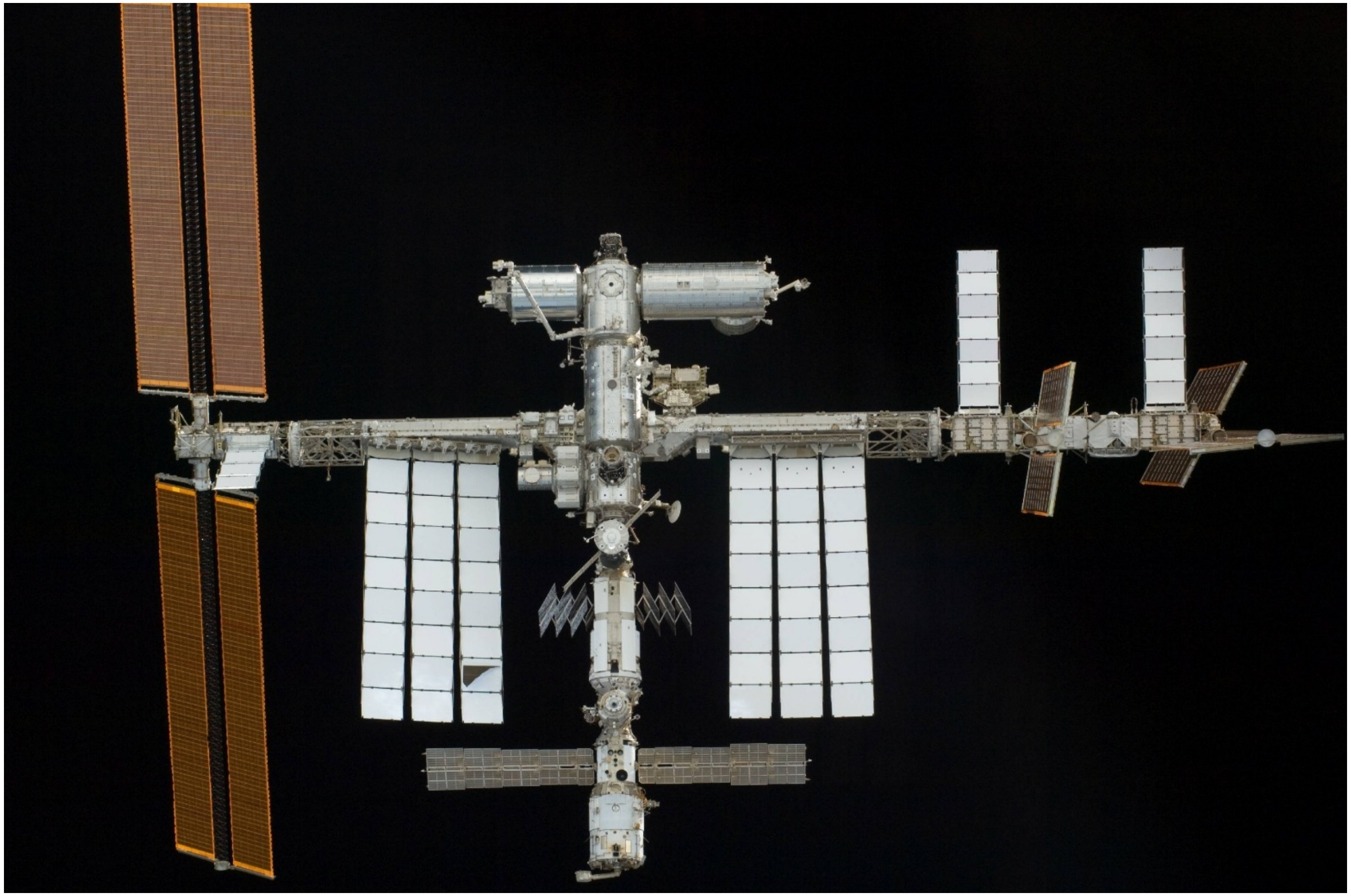
BON2011/DLR

≈ 1.1

Summary of model comparison

- During solar minimum/GCR maximum 2009:
  - Interplanetary space:
    differences ≈ 25% (without BON2011), 1.15 – 1.42 mSv/d
    → BON2011/BON2010 ≈ 1.35
    → BON2011/DLR ≈ 1.1
    10 g/cm^2 Al shielding → -15% in dose equivalent rate
  - Low Earth Orbit
    differences ≈ 20% (without BON2011), 0.2 – 0.24 mSv/d
    → BON2011/BON2010 ≈ 1.3
    → BON2011/DLR ≈ 1.1
    10 g/cm^2 Al shielding → -5% in dose equivalent rate
- 2012: Differences reduced: <10% (interplanetary space); ≈15% (LEO)

Radiation exposure at the ISS orbit



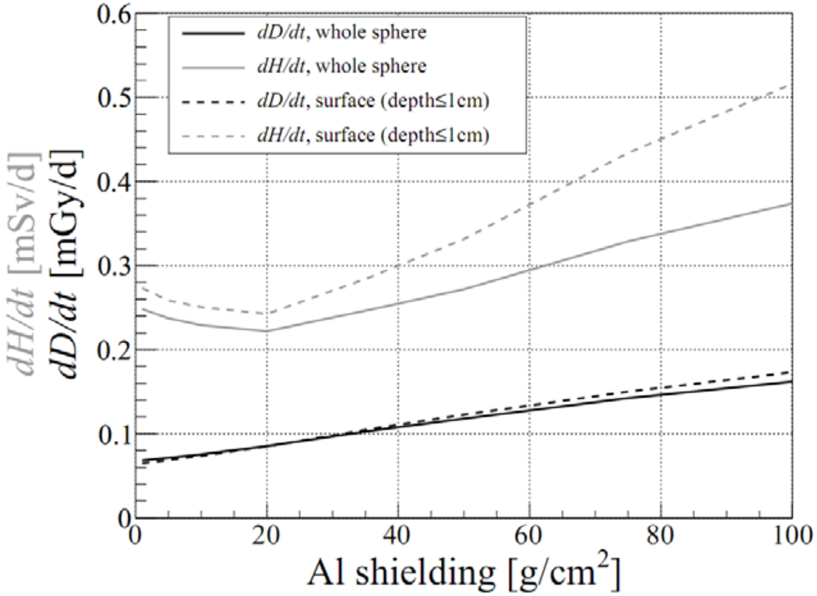
GCR radiation eposure on ISS Dec. 2009 (max. GCR intensity)

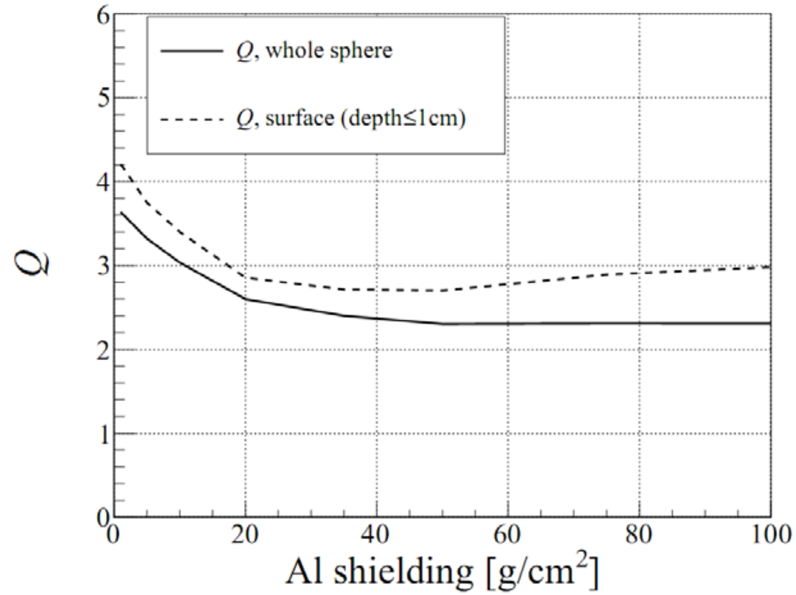
- Dose rates in a water sphere with radius 20 cm
    - whole sphere
    - surface (depth < 1cm)

- Spherical aluminium shielding

- GCR: 1 ≤ Z ≤ 26

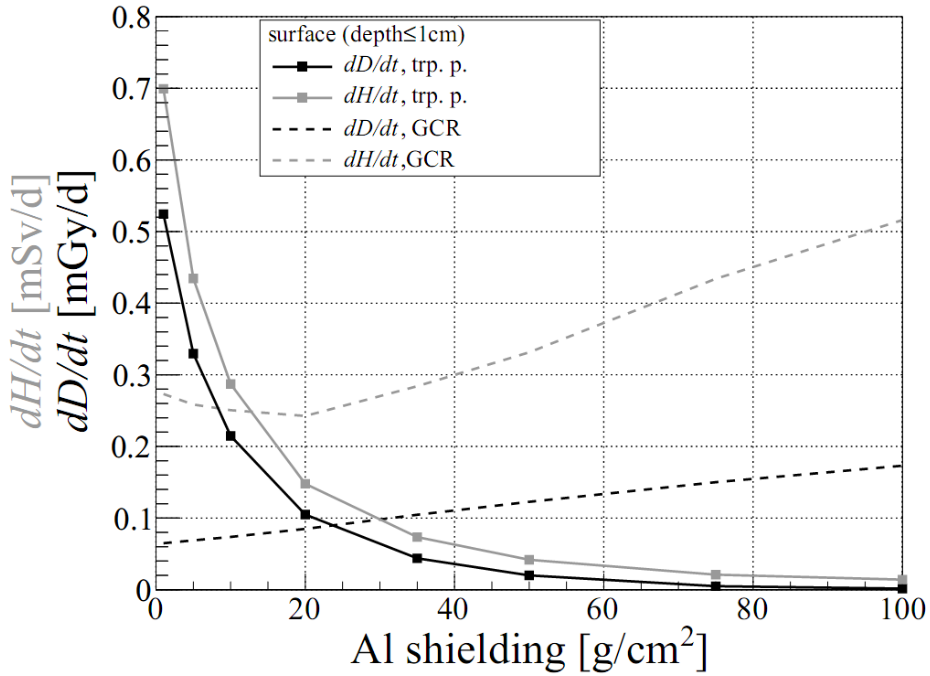
Matthiä et al., ASR 52 (2013)





GCR and trapped protons radiation exposure Dec. 2009 (max. GCR intensity), AP8min, 350 km

- Dose rates in a water sphere with radius 20 cm
    - surface (depth < 1cm)
- Spherical aluminium shielding
- GCR: 1 ≤ Z ≤ 26
- Trapped protons: AP8min, 350km, ISS orbit



Solar minimum, Dez. 2009 (17th WRMISS)
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

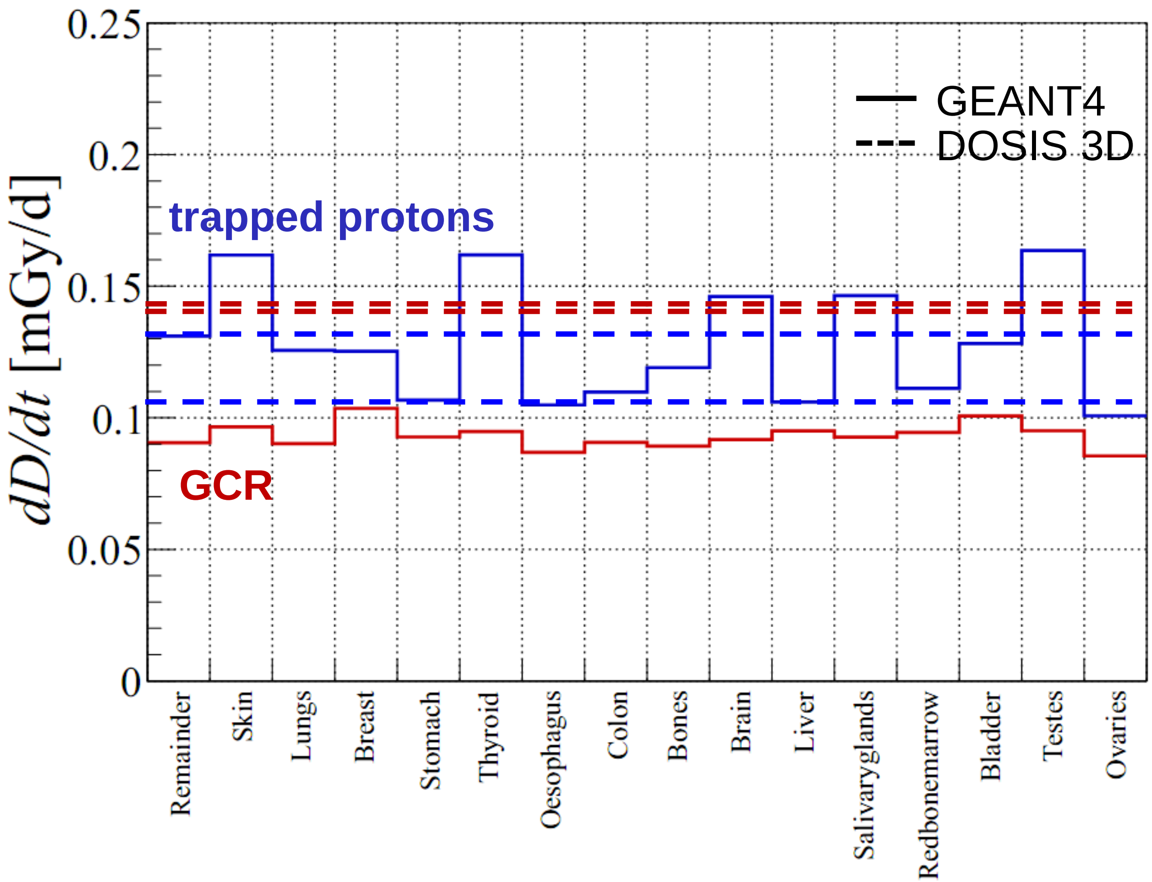
(S. Burmeister):

SAA:

dD/dt = 131 / 106 µGy/d

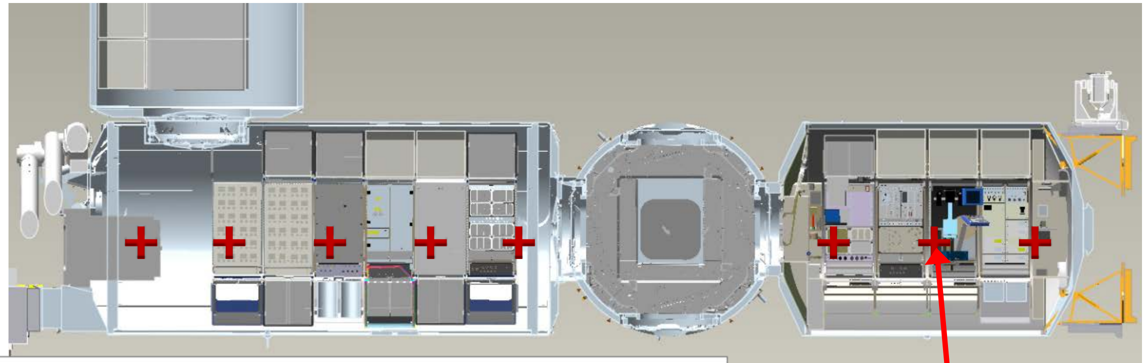
GCR:

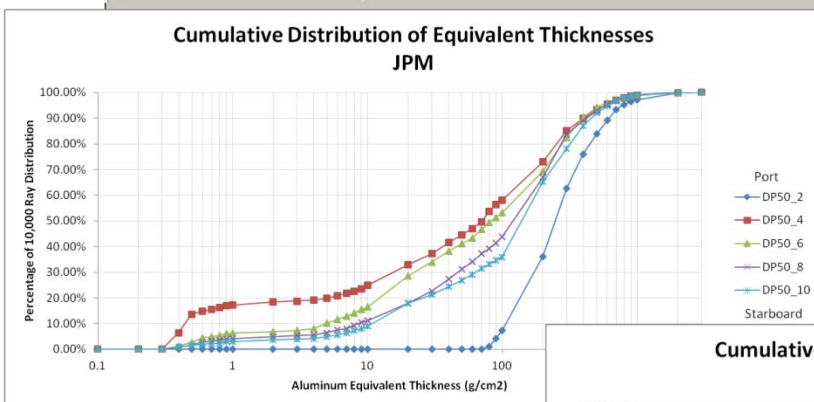
dD/dt = 146 / 143 µGy/d



Columbus shielding distribution

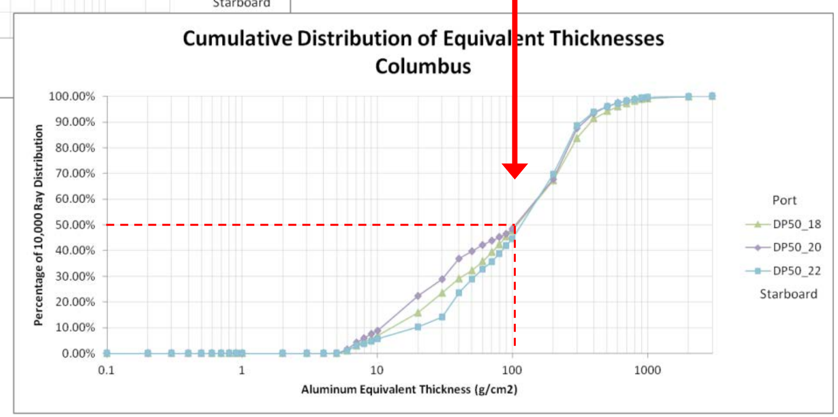
N. Stoffle et al., 17th WRMISS (2012)





COLUMBUS

median shielding ≈100 g/cm2



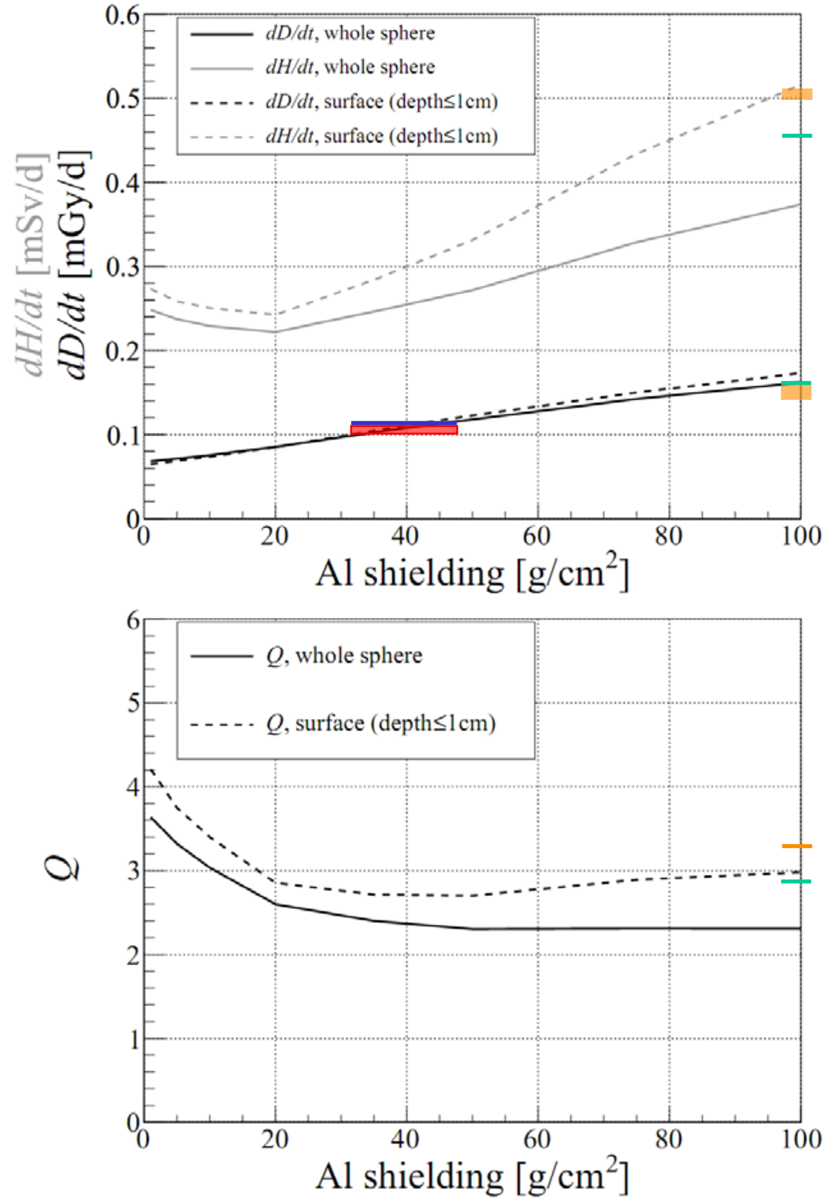
GCR radiation eposure on ISS Dec. 2009 (max. GCR intensity)

- Dose rates in a water sphere with radius 20 cm
  - surface (depth < 1cm)
  - whole sphere

- Spherical aluminium shielding

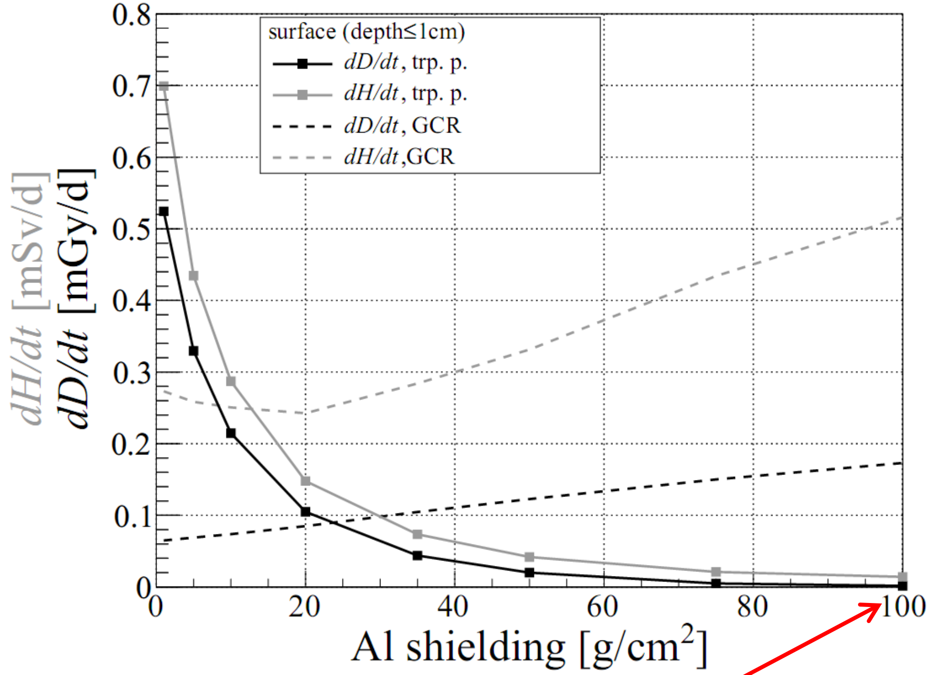
- Columbus Module:
  - ≈ 100 g/cm², Stoffle et al. (2012)
  - 158 µGy/d, 448 µSv/d, *Q* = 2.84, Semones et al. (2009)
  - 150 - 157 µGy/d, 496 – 517 µSv/d, *Q* = 3.30, Burmeister et al. (2012)

- Zvezda Service Module:
  - 32 – 47 g/cm², Jardrnickova et al. (2009)
  - 100 – 110 µGy/d, Lishnevskii et al. (2012)
  - 125 µGy/d, Semones et al. (2009)



GCR and trapped protons radiation exposure Dec. 2009 (max. GCR intensity), AP8min, 350 km

- Dose rates in a water sphere with radius 20 cm
  - surface (depth < 1cm)
- Spherical aluminium shielding
- GCR: 1 ≤ Z ≤ 26
- Trapped protons: AP8min, 350km, ISS orbit

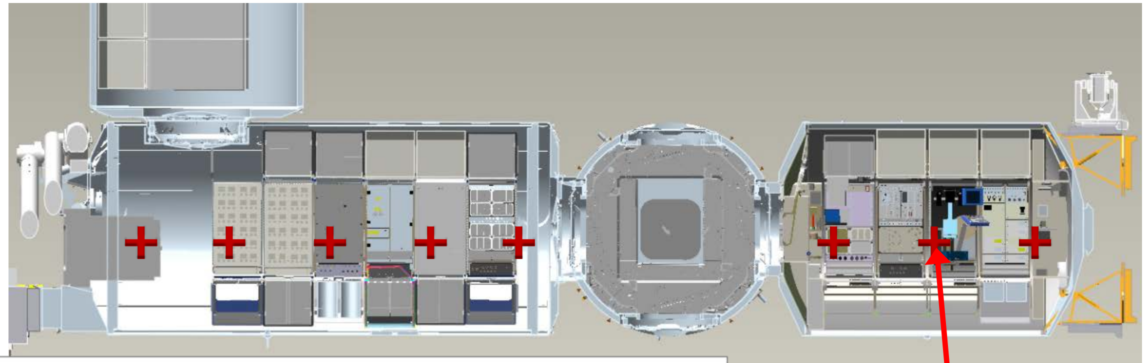


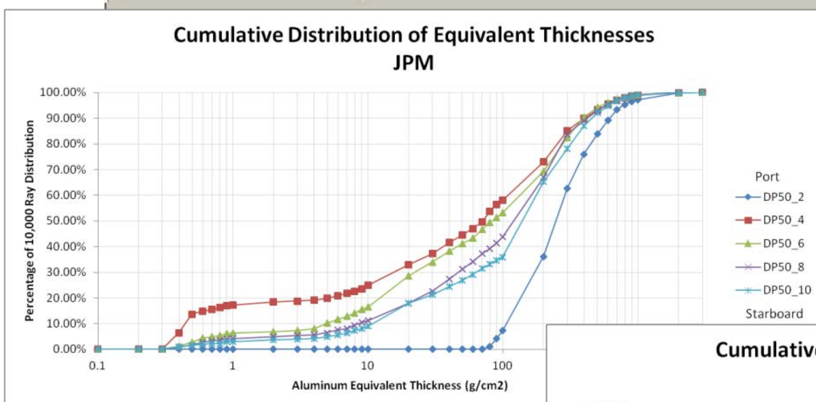
100 g/cm^2 Al: dose rate ≈ 0

but e.g. DOSIS: 70 – 80 µGy/d, 100 – 110 µSv/d !

Columbus shielding distribution

N. Stoffle et al., 17th WRMISS (2012)

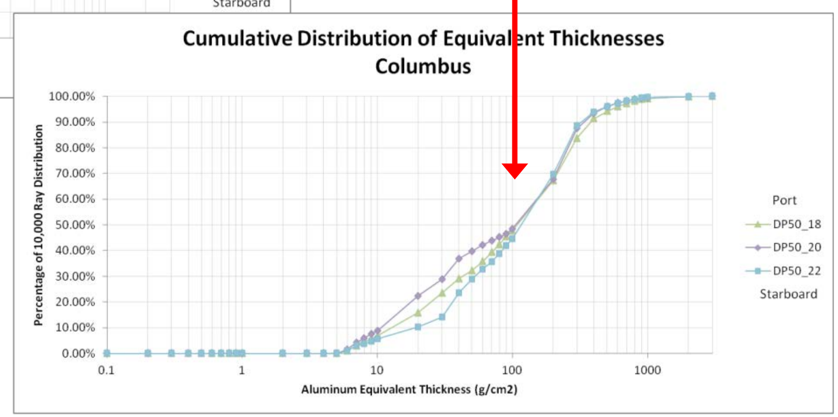




COLUMBUS

~~median shielding ≈100 g/cm2~~

→ cumulative distribution function



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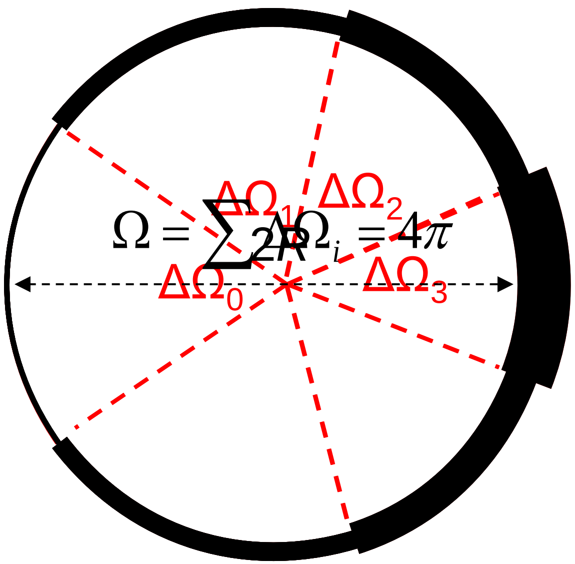
Construction of shielding geometry from cumulative distribution function CDF

S [g/cm²]	CDF [%]	ΔΩ
1	20	0.2*4π
3	60	0.4*4π
5	90	0.3*4π
10	100	0.1*4π

sphere with radius R



Radiation exposure on ISS, trapped protons + GCR Dec. 2009 (max. GCR intensity)

target sphere: 5 cm radius

	trapped protons, AP8 min			GCR		
	$0\ g/cm^2 – 0.5\ g/cm^2$			$0\ g/cm^2 – 0.5\ g/cm^2$		
Target	*dD/dt* [µGy/d]	*dH/dt* [µSv/d]	*Q*	*dD/dt* [µGy/d]	*dH/dt* [µSv/d]	*Q*
5 cm H_2O sphere	75	111	1.48	140	480	3.43
Experiment:						
DOSIS DOSTEL 1*	80	112	1.40	157	517	3.30
DOSIS DOSTEL 2*	68	96	1.43	150	496	3.30
NASA TEPC§	165	293	1.78	158	448	2.84

**Burmeister et al., 17th WRMISS (2012)*

§Semones et al., 14th WRMISS (2009)

Radiation exposure on ISS, trapped protons + GCR Dec. 2009 (max. GCR intensity)

for organ dose calculation, target sphere: 20 cm radius

	trapped protons, AP8 min			GCR		
	0 g/cm² – 0.5 g/cm²			0 g/cm² – 0.5 g/cm²		
Target	*dD/dt* [μGy/d]	*dH/dt* [μSv/d]	Q	*dD/dt* [μGy/d]	*dH/dt* [μSv/d]	*Q*
20 cm H_2O sphere	55	83	1.50	142	435	3.06
Experiment:						
DOSIS DOSTEL 1*	80	112	1.40	157	517	3.30
DOSIS DOSTEL 2*	68	96	1.43	150	496	3.30
NASA TEPC §	165	293	1.78	158	448	2.84

**Burmeister et al., 17th WRMISS (2012)*

§Semones et al., 14th WRMISS (2009)

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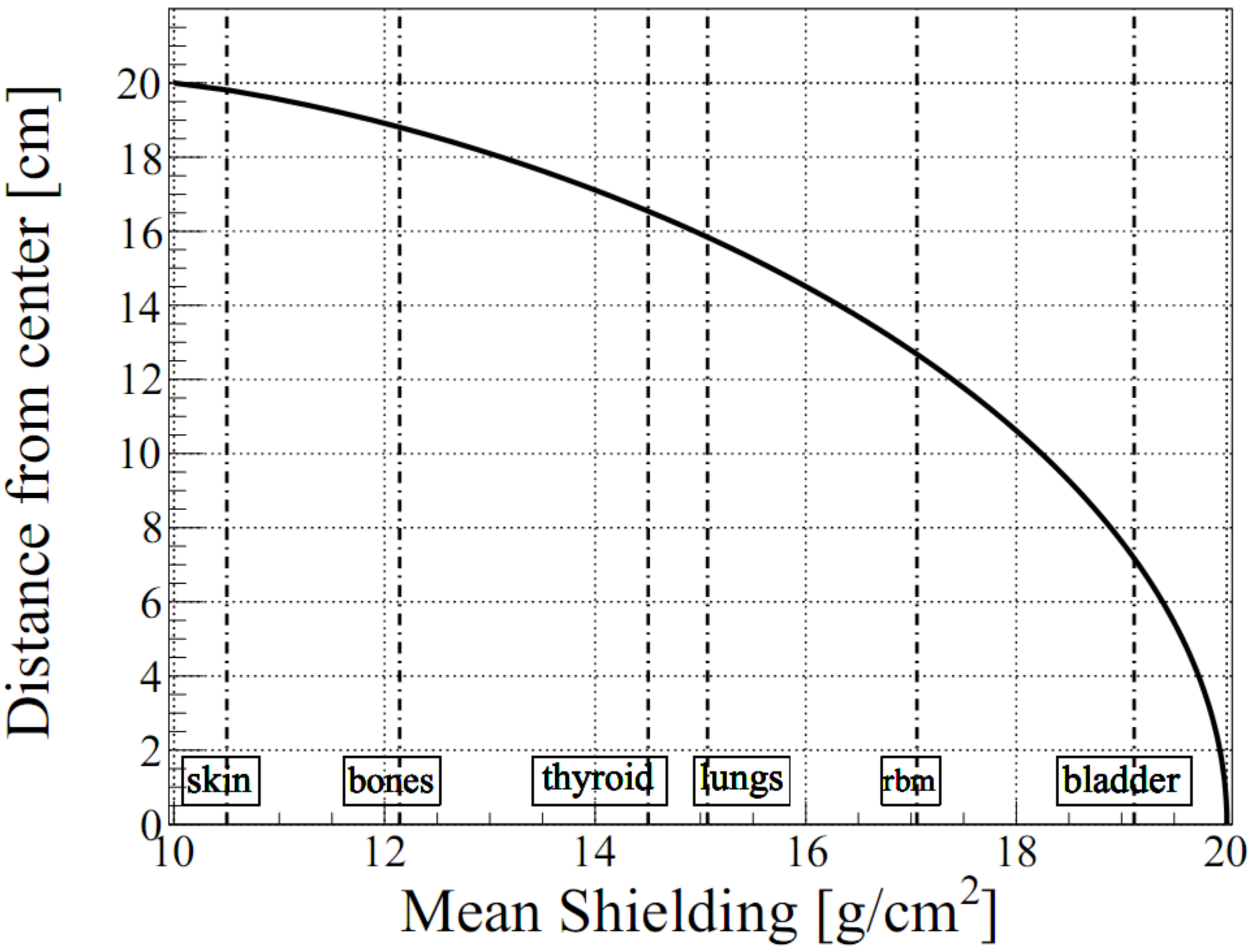
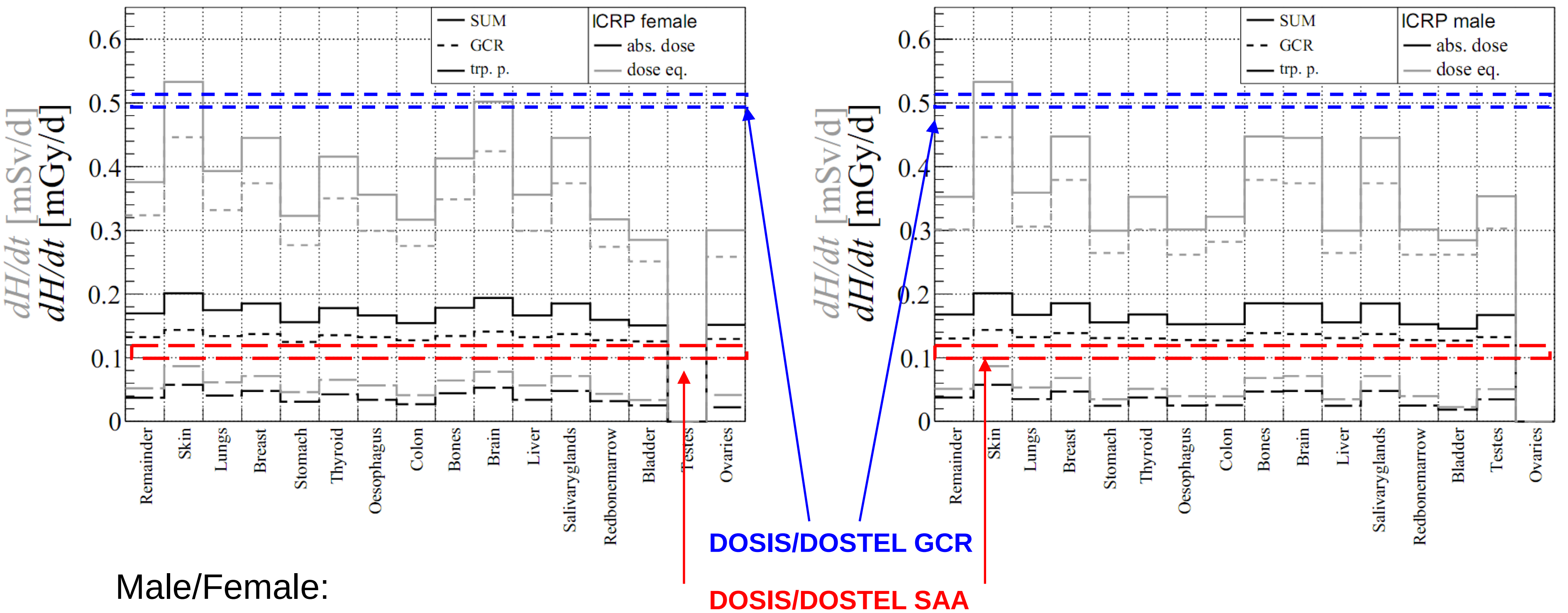
Mean shielding in a water sphere with radius 20 cm

Isotropic irradiation – Positions in the sphere corresponding to average shielding of selected organs of the male ICRP phantom



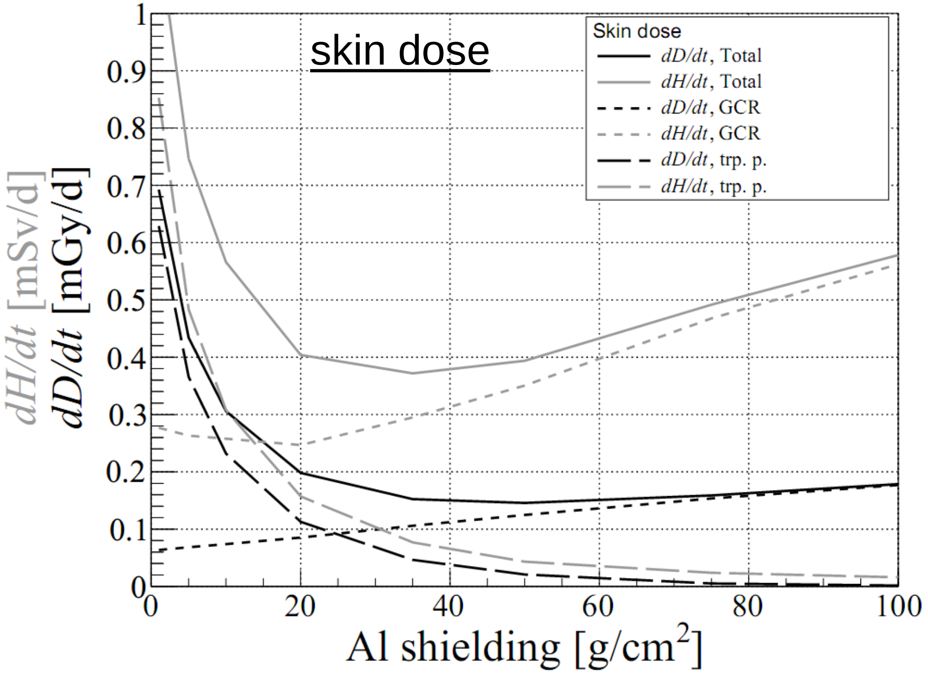
Radiation exposure on ISS, trapped protons + GCR Dec. 2009 (max. GCR intensity)

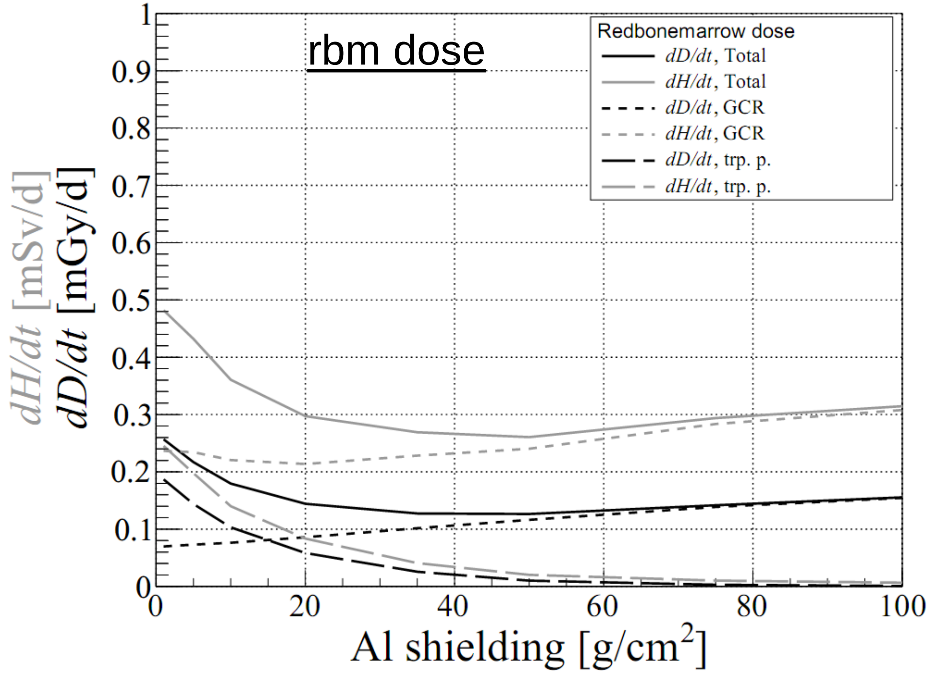


Male/Female:

0.28 mSv/d (bladder) – 0.54 mSv/d (skin)

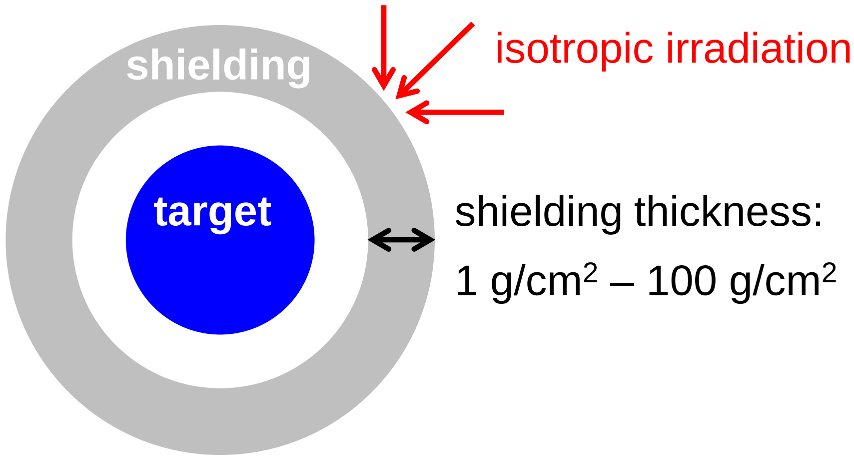
Radiation exposure on ISS, trapped protons + GCR Dec. 2009 (max. GCR intensity) Organ dose vs. shielding



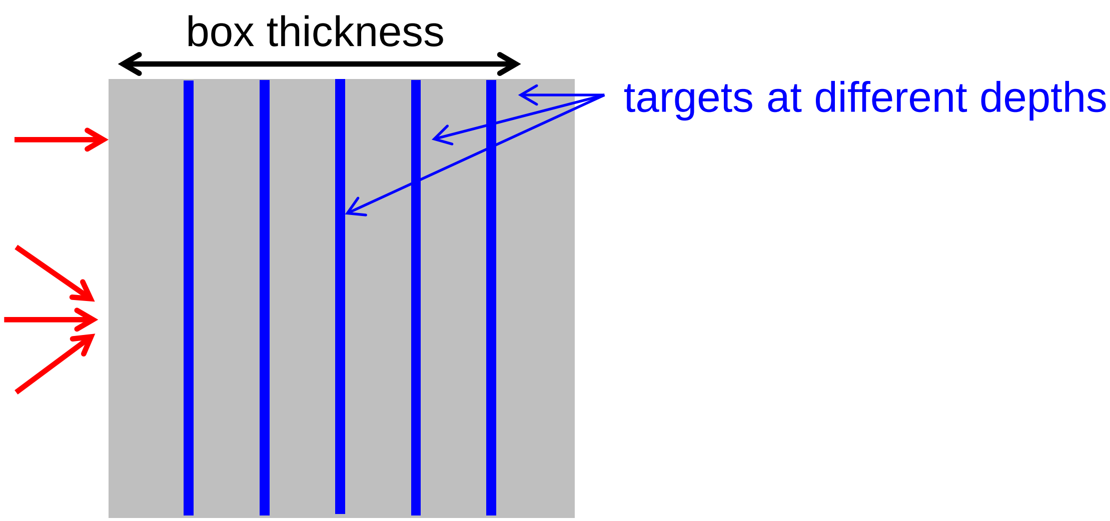


Comparison of different shielding geometries

- Spherical shielding

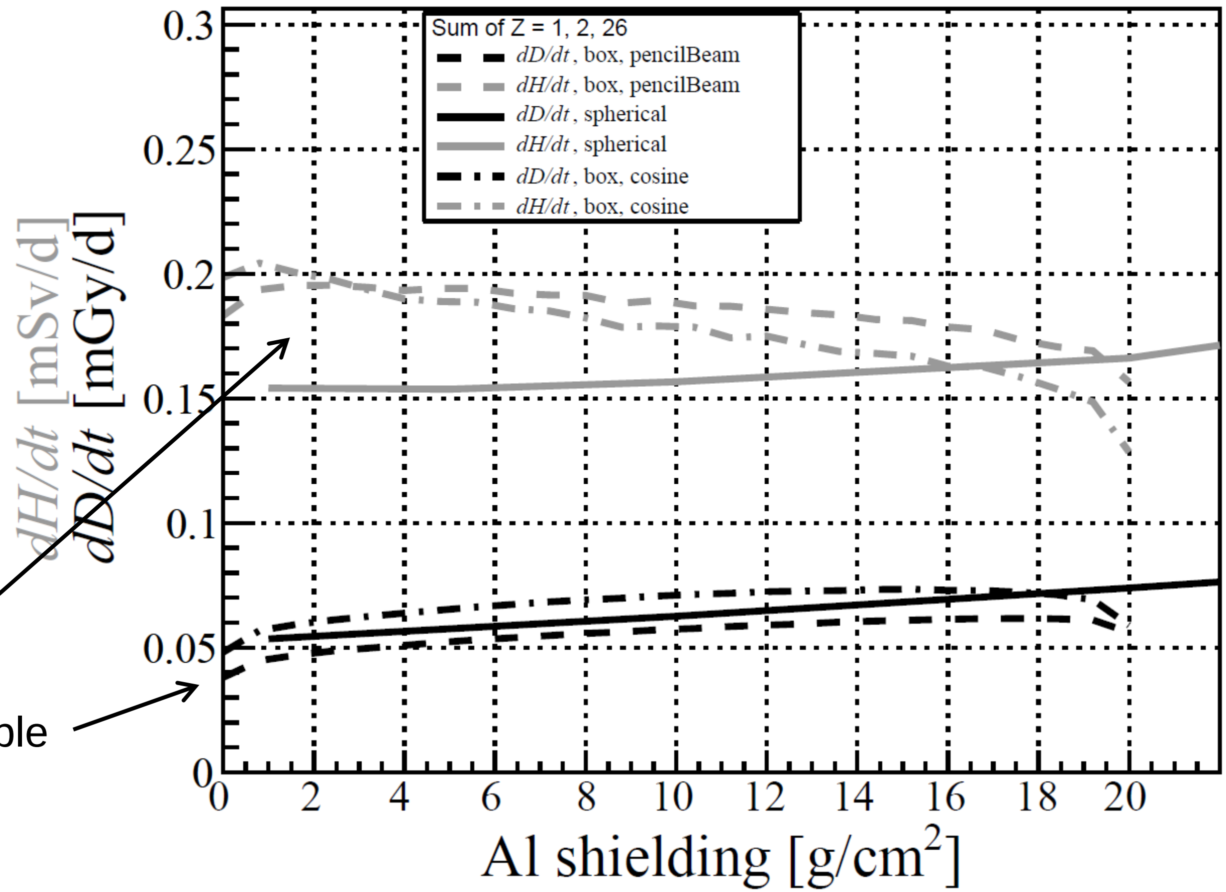


- Planar shielding:
  a) pencil beam
  b) cosine



Comparison of different shielding geometries
Box of 20 g/cm² Aluminium

- Solar minimum
- Z=1, 2, 26
- Box, 20 g/cm² Al, 7,4 cm
- Different spherical shielding



quality factor differs

absorbed dose comparable

Comparison of different shielding geometries
Box of 100 g/cm² Aluminium

-Solar minimum

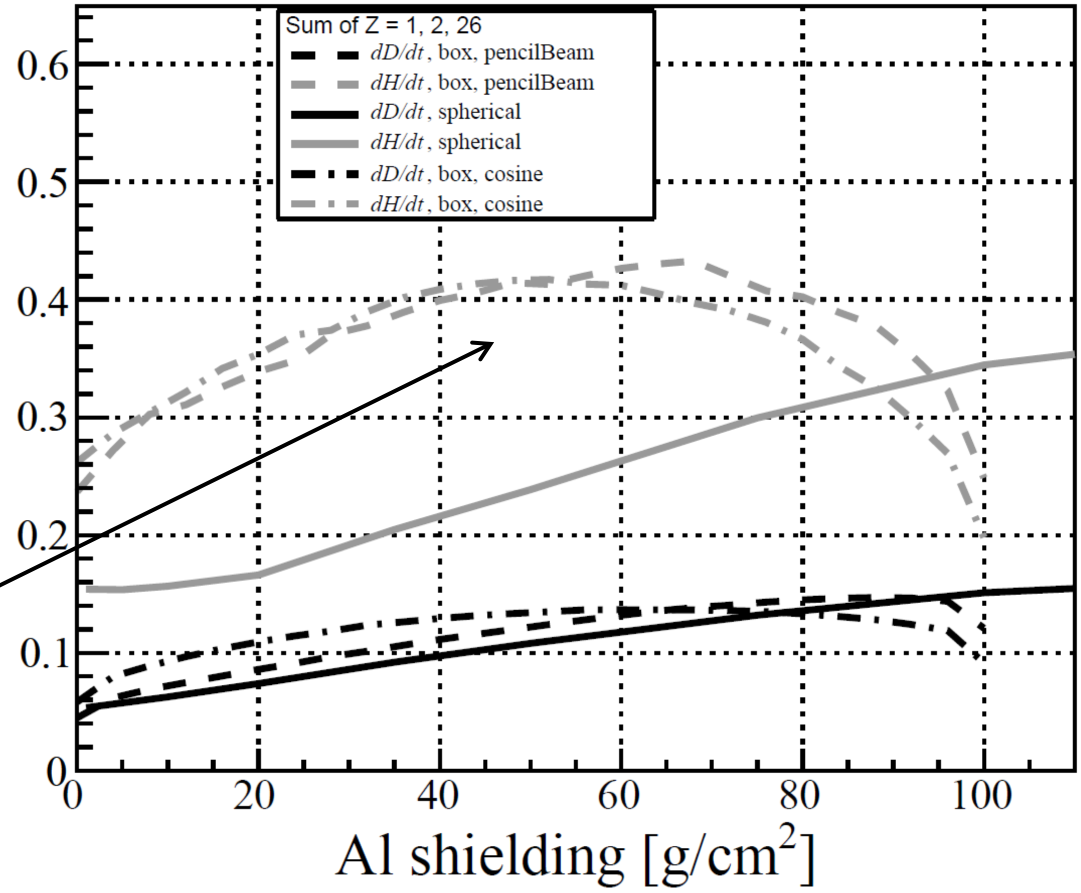
-Z=1, 2, 26

-Box, 100 g/cm² Al, 37,2 cm

-Different spherical shielding

secondary particle build-up

backscattering



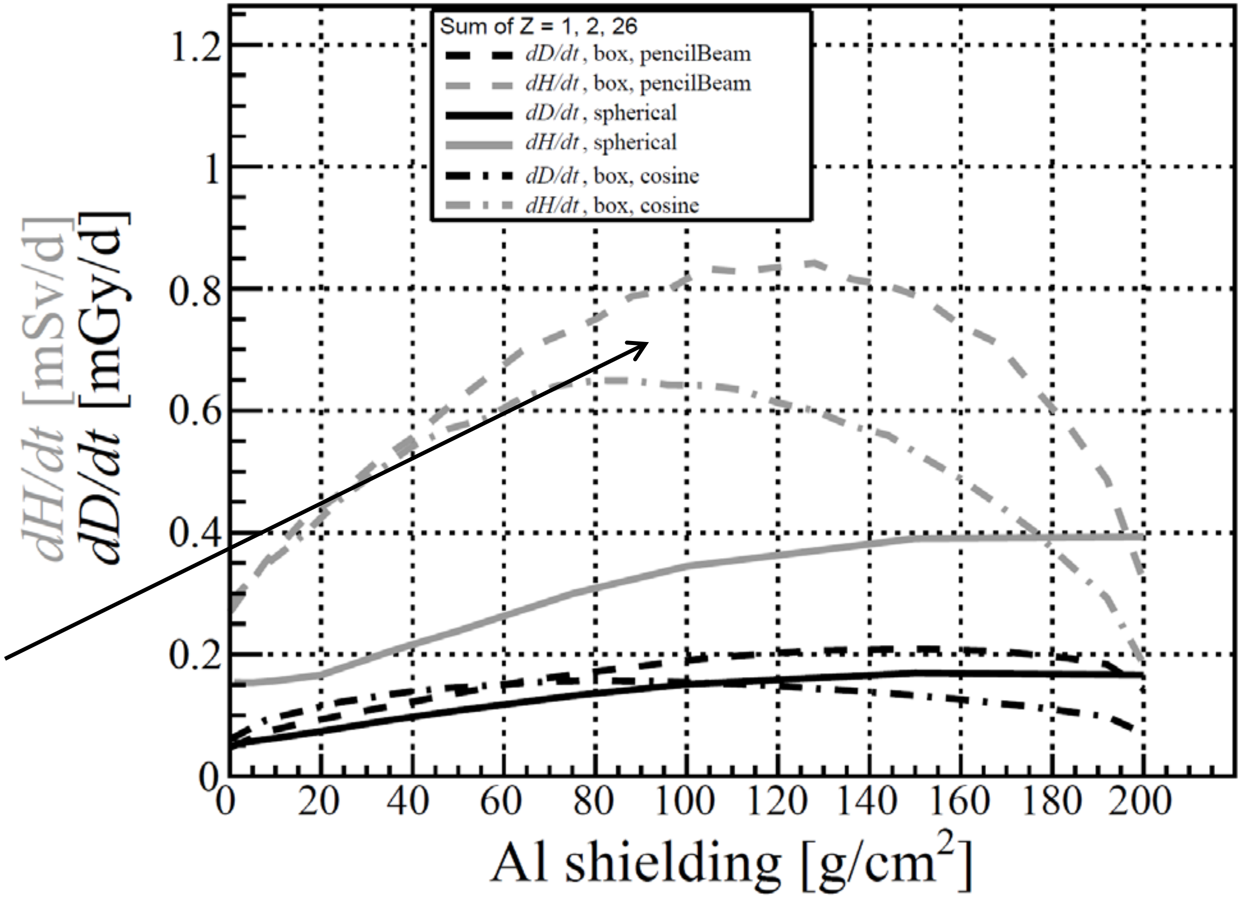
Comparison of different shielding geometries
Box of 200 g/cm² Aluminium

-Solar minimum

-Z=1, 2, 26

-Box, 200 g/cm² Al, 74,3 cm

-Different spherical shielding



secondary particle build-up

backscattering

Summary

- Dose estimates are strongly dependent on GCR model:
  - Solar minimum:
    35% differences (interplanetary space)
    30% differences (LEO)

- With DLR model: good agreement with measurements for 2009

- Organ dose equivalent rates in Columbus (ICRP male/female phantoms):
  0.28 mSv/d (bladder) – 0.54 mSv/d (skin) *(meas. 0.45[§] – 0.52[*] mSv/d)*

- Spherical shielding geometry (LEO, GCR + trp. p.):
  - Calculated organ dose rates decrease up to 30 – 50 g/cm^2, increase above

- Different shielding geometries not comparable

Thank you for your attention!

**Burmeister et al., 17th WRMISS (2012)*
§Semones et al., 14th WRMISS (2009)