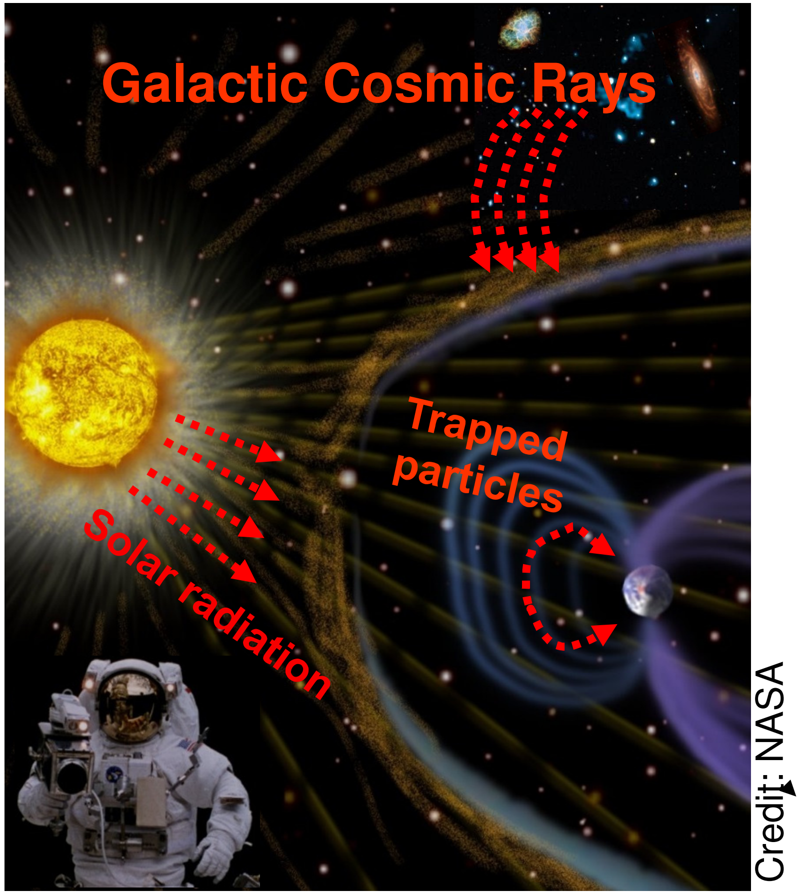
# Numerical estimation of Galactic Comic Ray (GCR) exposure in space - An Investigation of GCR models and shielding effects

Alankrita Isha Mrigakshi[1,2], **Daniel Matthiä**[1], Thomas Berger[1], Günther Reitz[1], Robert F. Wimmer-Schweingruber[2]

[1] German Aerospace Center (DLR), Institute of Aerospace Medicine, Cologne, Germany
[2] Christian-Albrechts-Universität zu Kiel, Kiel, Germany

# Space Radiation – A concern for human spaceflight

- GCR radiation is highly penetrating and densely ionizing and has the potential to cause biological damage
  - ➢ Assessment of radiation related health risk
- Future manned mission beyond LEO to encounter higher GCR intensity
  - ➢ Prediction of radiation exposure
- How reliable are these predictions?
  - ➢ Discrepancies found between measured and calculated dose rates for LEO




**Sources of radiation in space**

# Contents

1. Assessment of GCR models
   Since radiation models are a necessary prerequisite for dose calculations

2. Numerical estimation of GCR exposure

   – How the differences in the GCR model spectra affect the dose rates

   – Effect of shielding

   – Exposure during the deep solar minimum in 2009 in comparison with previous solar minima

3. Summary

# Assessment of GCR Models

# GCR Models

- Must be able to describe the temporal variation of GCR intensity for particle range $1 \leq Z \leq 26$ with energies between 10 -$10^5$ MeV/nuc

- <u>Models:</u>

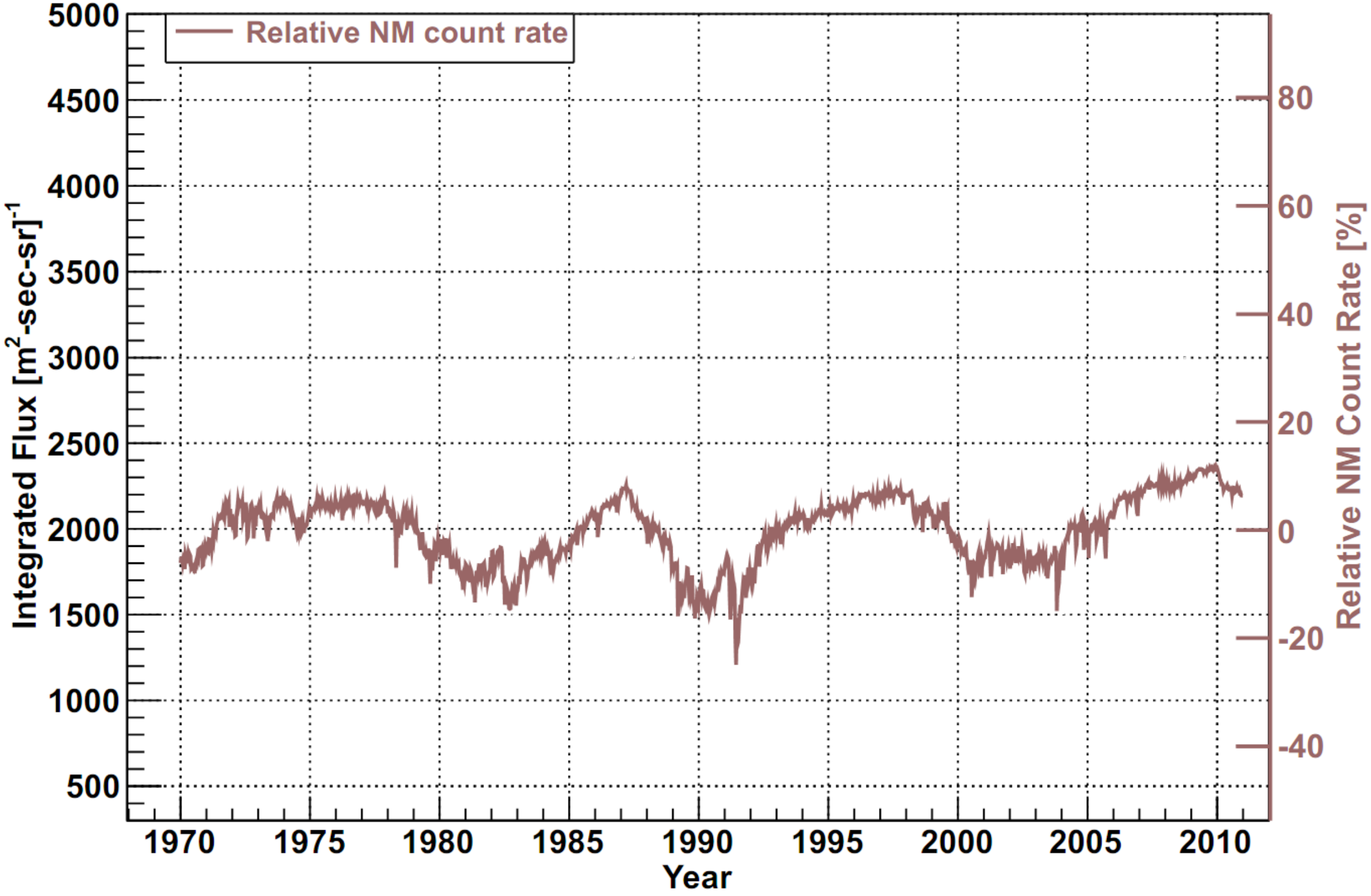
| | |
|---|---|
| **CREME96** | (based on Nymmik et al.,1992) |
| **CREME2009** | (based on ISO15390,2004) |
| **Badhwar-O'Neill2010** | (P.M. O'Neill, 2010) |
| **Burger-Usoskin:** H, He | (Usoskin et al., 2005; Burger et al., 2000) |
| **SPENVIS** | (ISO15390) |

- Model spectra compared with measurements from various high altitude balloon flights and space-borne experiments

*Mrigakshi et al., Assessment of Galactic Cosmic Ray Models, J. Geophys. Res., 117, A08109, 2012*


DLR

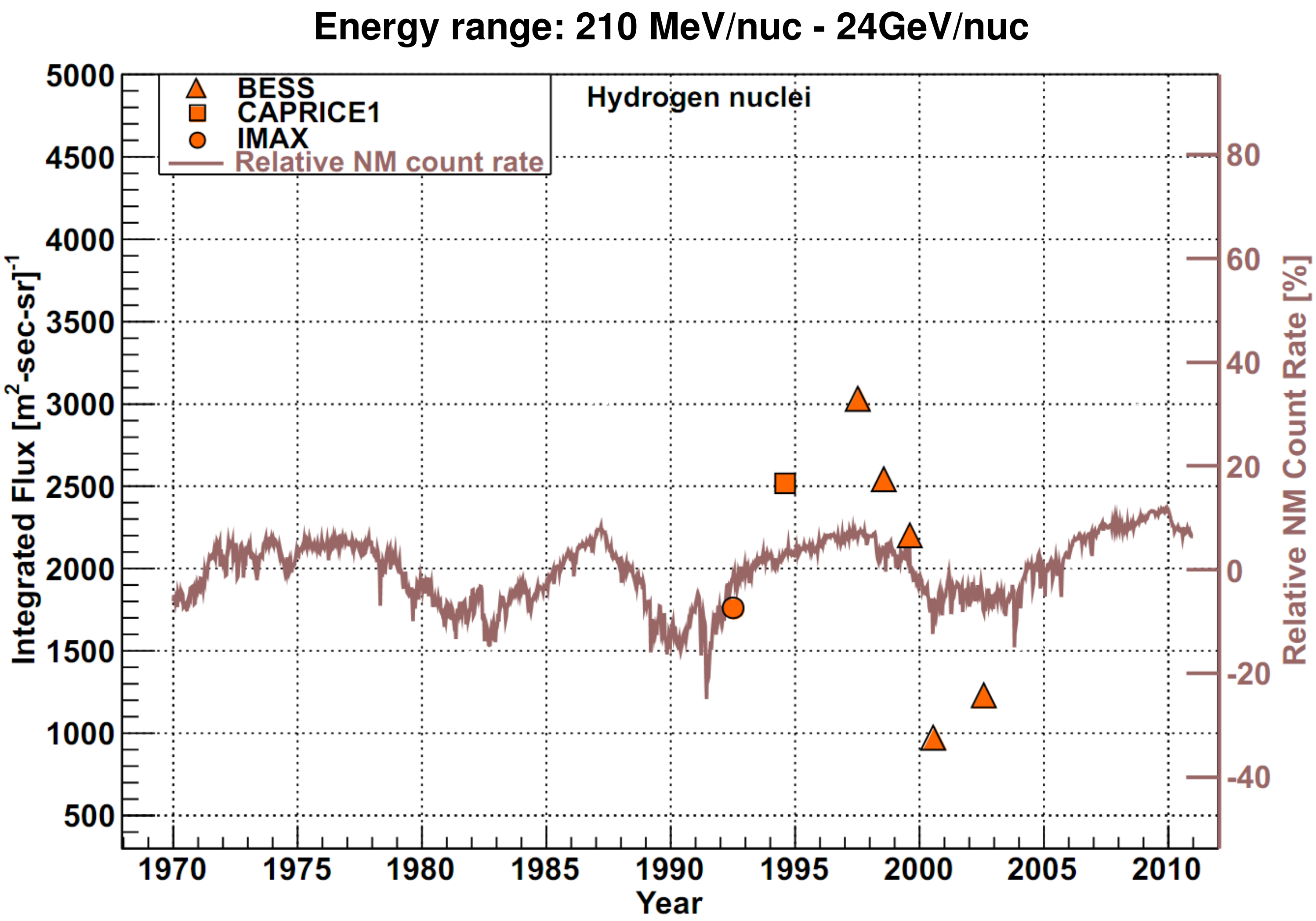
# Temporal variation of GCR flux



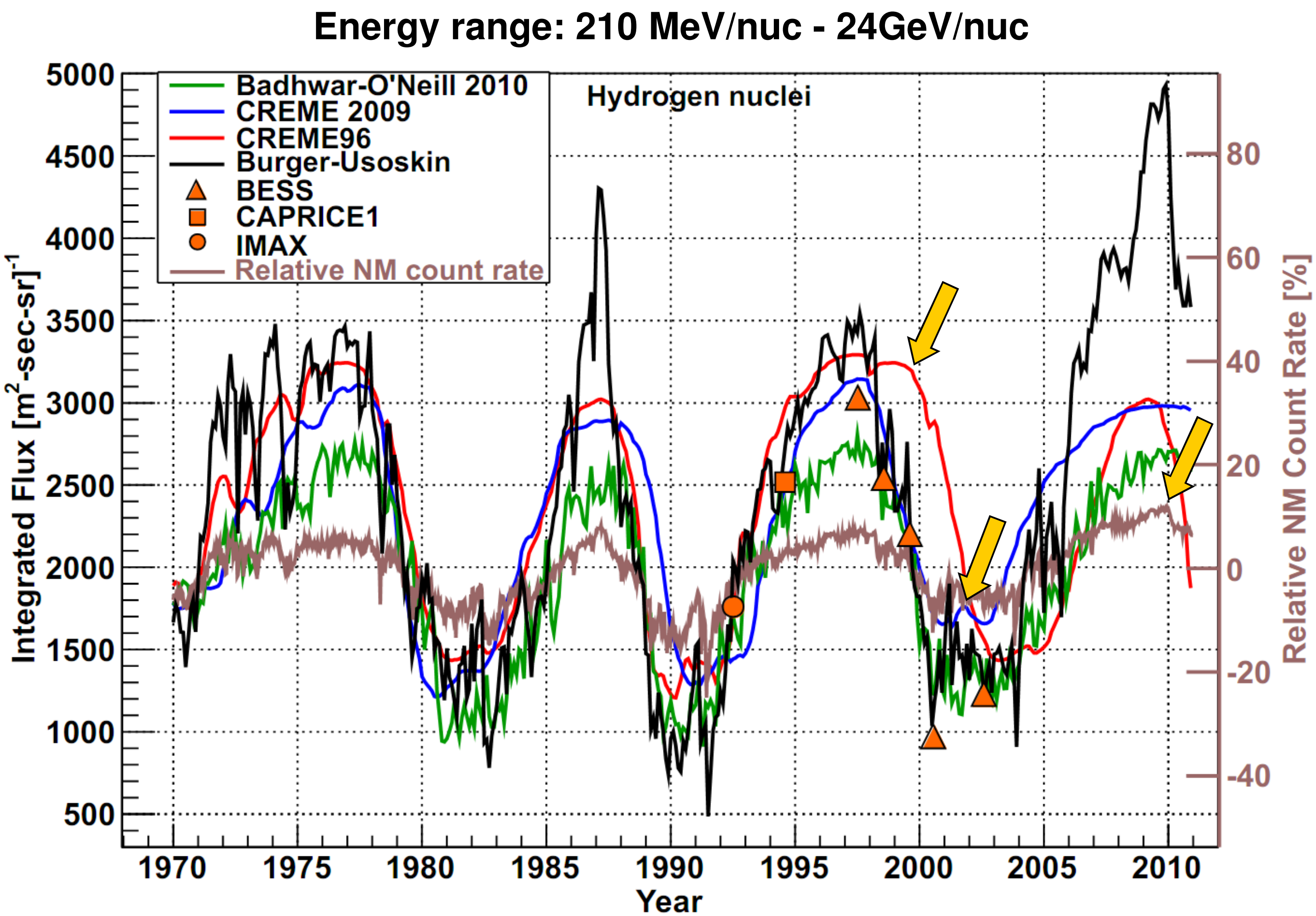



DLR

# Temporal variation of GCR flux – H nuclei



# Temporal variation of GCR flux – H nuclei






DLR

# A new GCR model

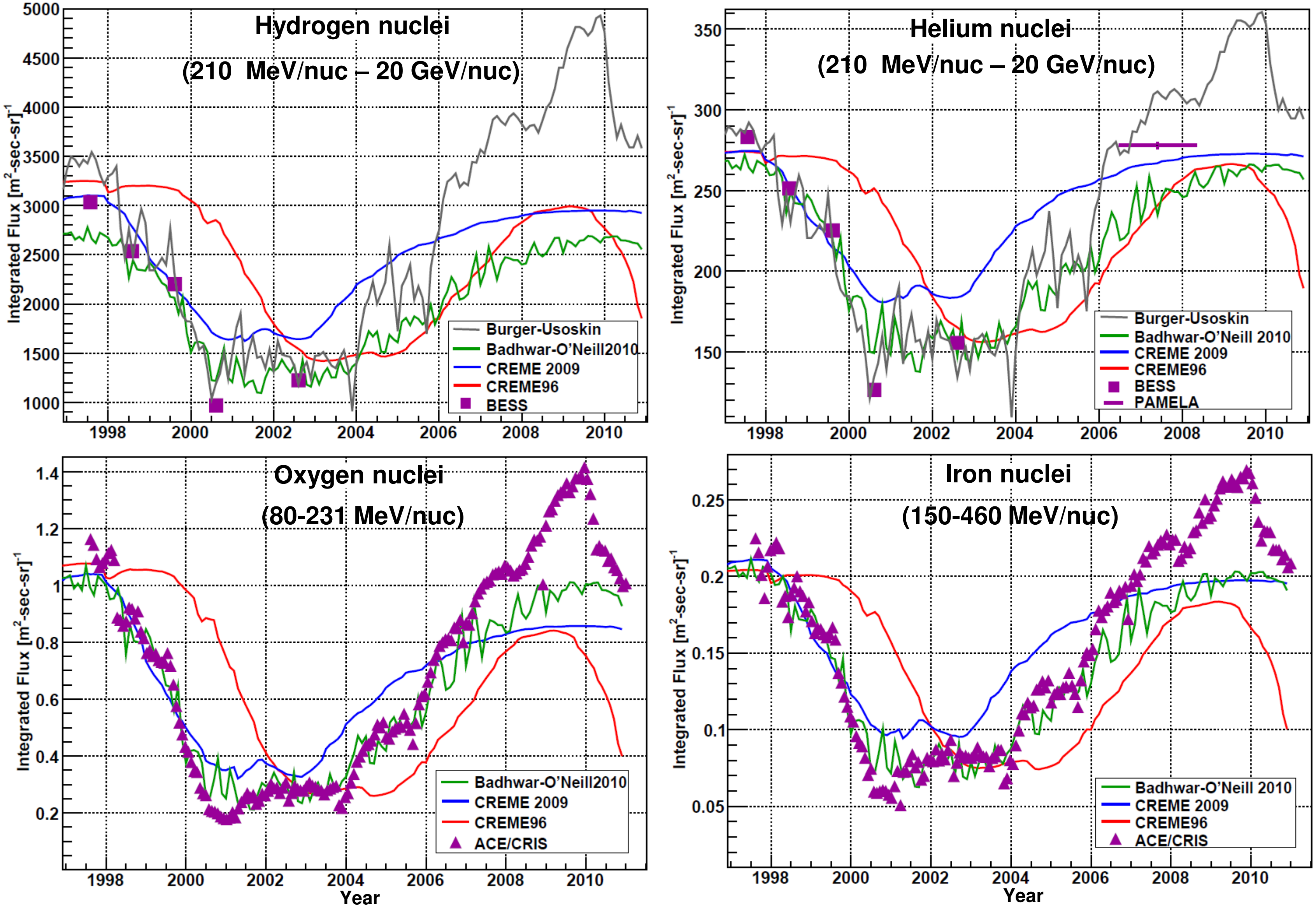
– GCR model developed at DLR based on ISO model for particles ranging from $1 \leq Z \leq 28$ and for periods from 1964 onwards

– based ISO model

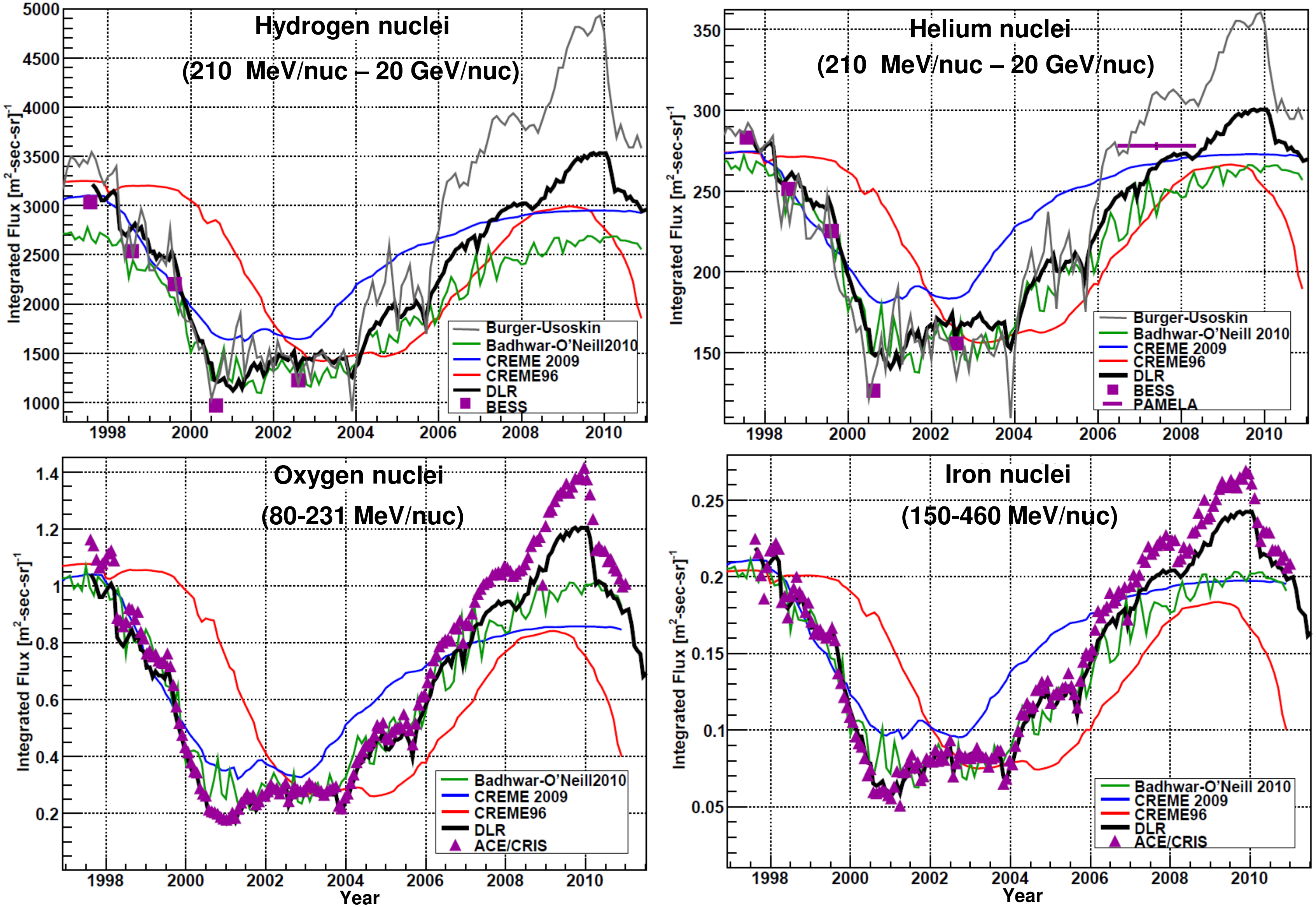
– Solar modulation derived by fitting carbon measurements from ACE (Matthiä/ACE) and Oulu neutron monitor count rates (Matthiä/OULU)

*Matthiä, D., Berger, T., Mrigakshi A. , T., Reitz G., A Ready-to-Use Galactic Cosmic Ray Model, Adv. in Space Res., 2013*

# Temporal Variation in GCR flux



# Temporal Variation in GCR flux

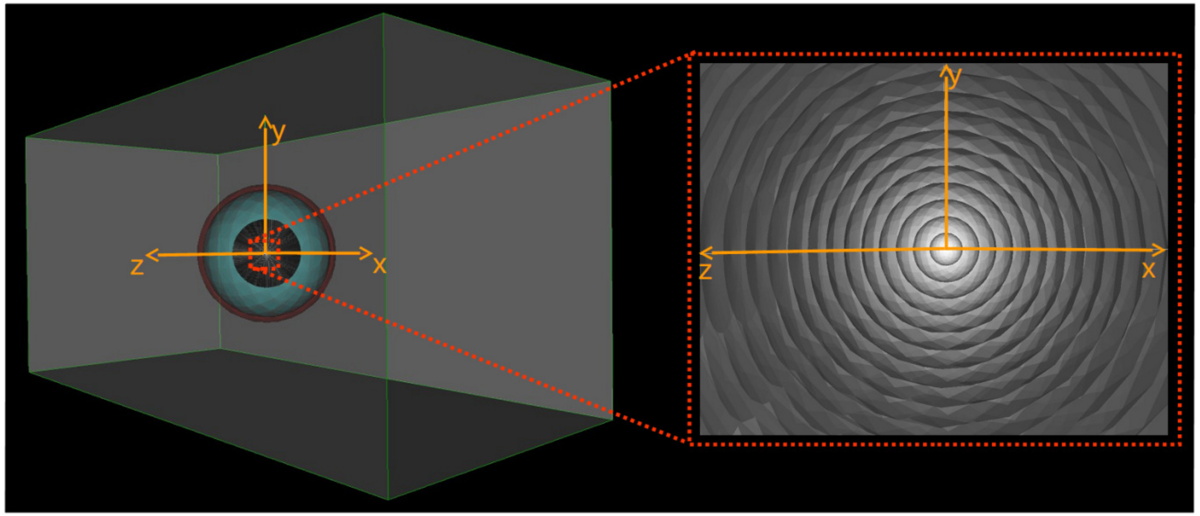


# Numerical estimation of GCR exposure

# Monte-Carlo simulation with GEANT4

Simulation Setup

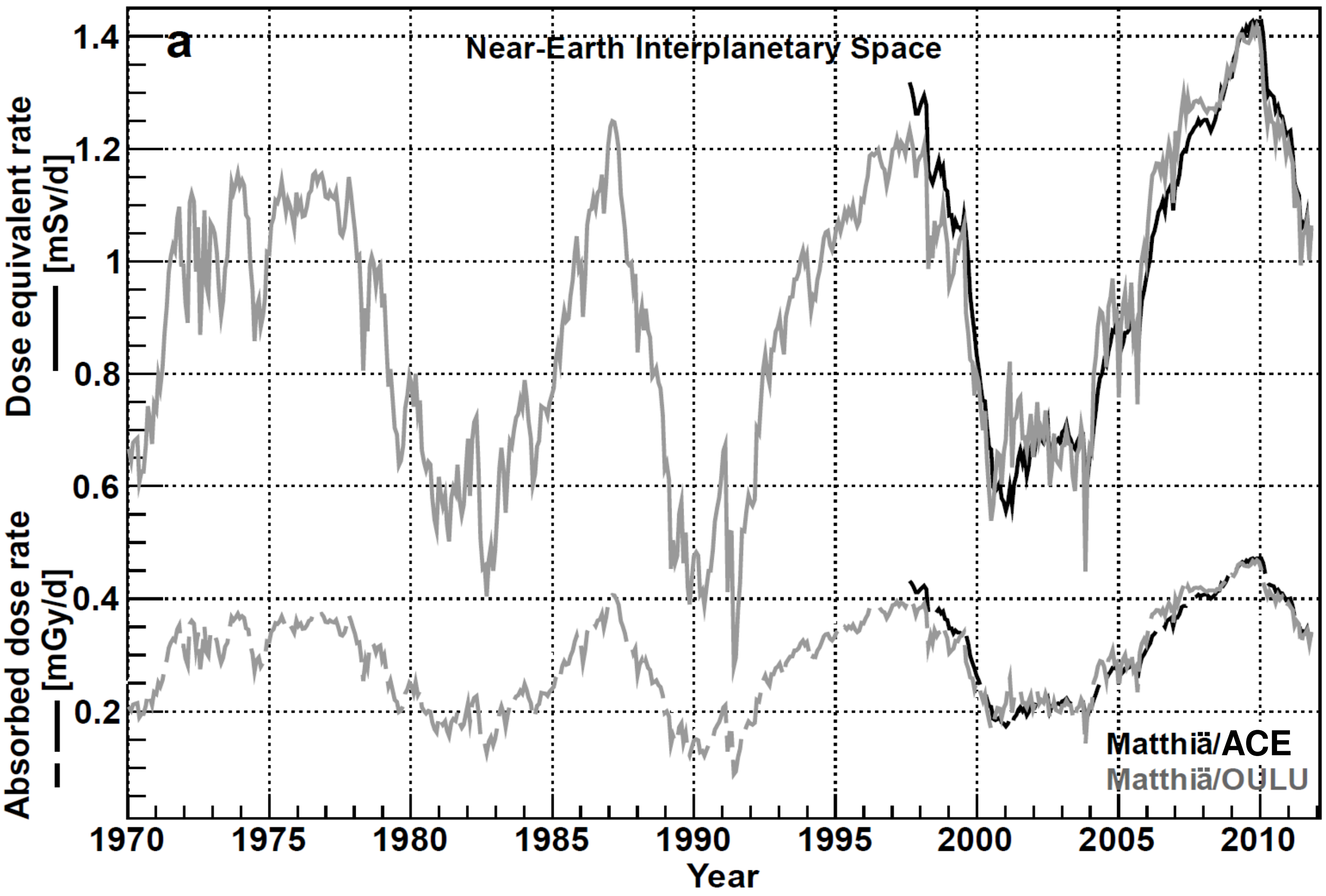
- Isotropic irradiation of a spherical water phantom of 25 cm radius either unshielded or shielded by aluminium of 0.3, 10 and 40 g/cm2
- QGSP_BERT_HP and JAM/JQMD physics models for hadronic interactions and emstandard_opt3 for electromagnetic interactions




*Mrigakshi et al., How Galactic Cosmic Ray models affect the estimation of radiation exposure in space, Adv. Space Res., 51, 825-834, 2013*

*Mrigakshi et al., Estimation of Galactic Comic Ray exposure inside and outside the Earth's magnetosphere during the recent solar minimum between solar cycles 23 and 24, Adv. Space Res., 2013*

# GCR dose estimation (no shielding): Near-Earth interplanetary space

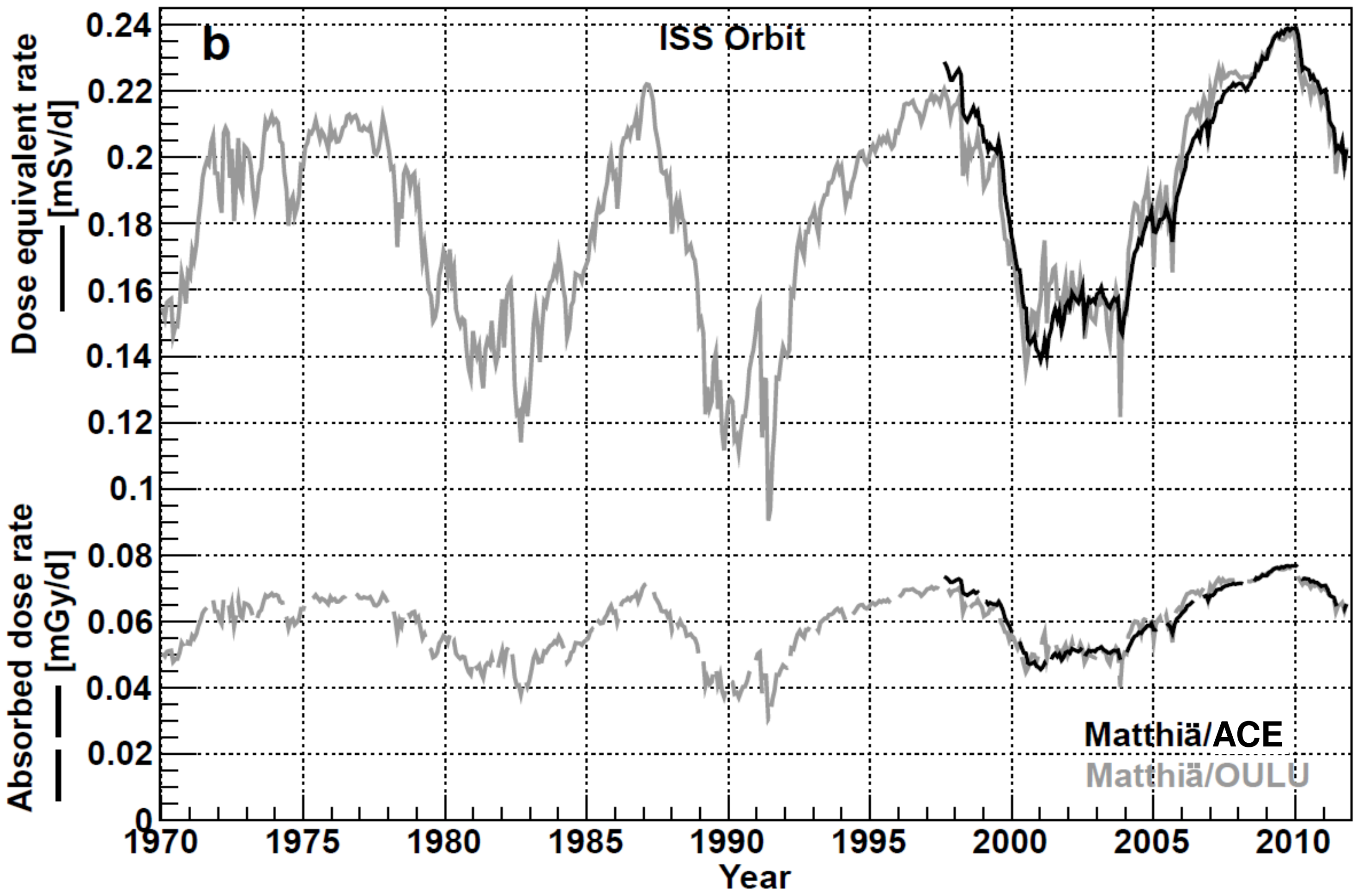



*dH/dt*:
**0.28 – 1.43 mSv/d**

*dD/dt*:
**0.14 – 0.47 mGy/d**


DLR

# GCR dose estimation (no shielding): ISS orbit

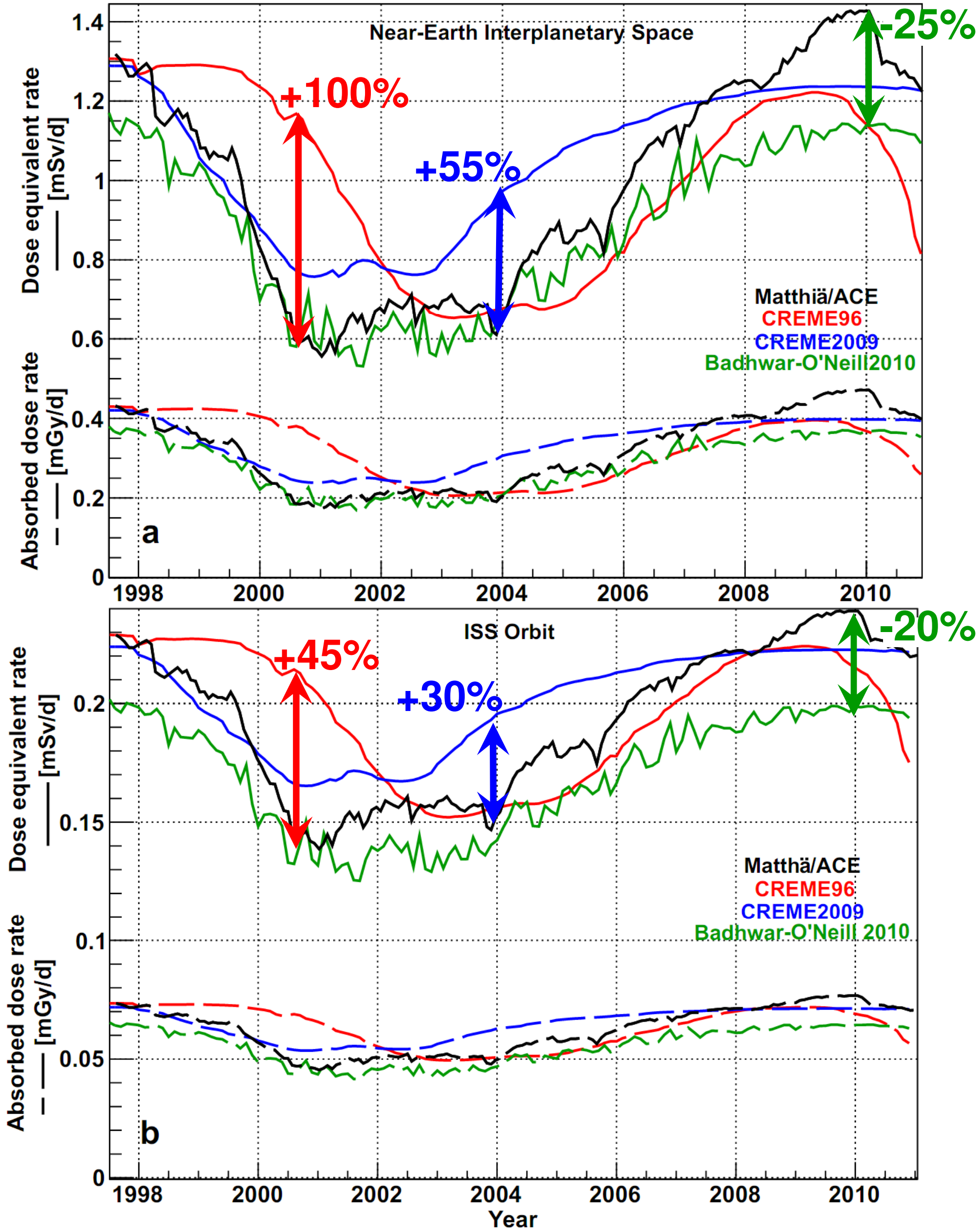



*dH/dt*:
**0.09 – 0.24 mSv/d**

*dD/dt*:
**0.03 – 0.08 mGy/d**


DLR

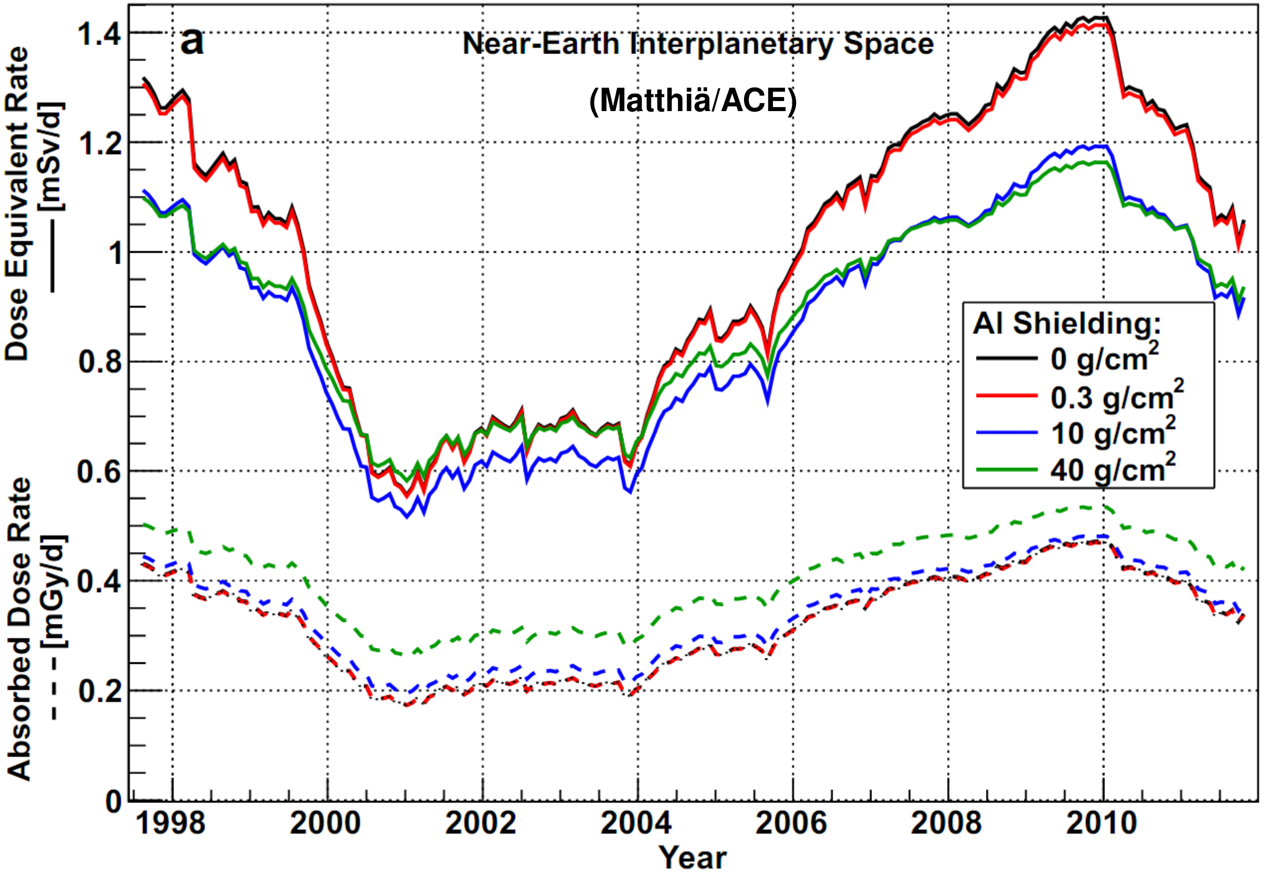
# Dose rates using different GCR models (no shielding)





DLR

# Variation of dose with shielding: Near-Earth interplanetary space




→ *dH/dt*: Variable behaviour with increasing shielding depending on the solar activity

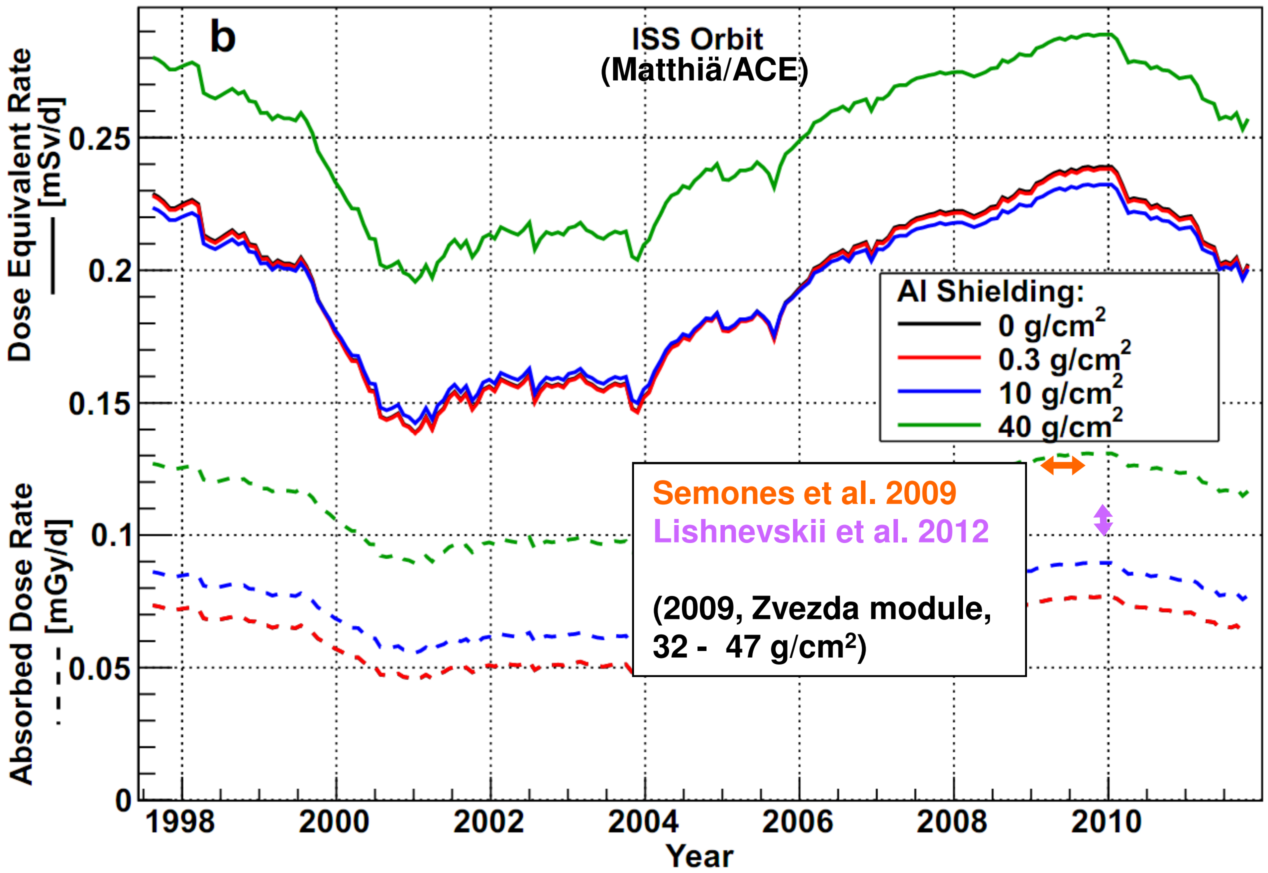
→ *dD/dt*: Increases with increasing shielding

**Peak dose rate in November 2009**

| Shielding ($g/cm^2$) | dD/dt (mGy/d) | dH/dt (mSv/d) |
|---|---|---|
| 0 | **0.47** | **1.43** |
| 0.3 | **0.47** | **1.41** |
| 10 | **0.48** | **1.19** |
| 40 | **0.53** | **1.16** |

→ Highest dose rates in November 2009. Relative to the peak exposure in 1997 solar minimum, the doses are higher by 6%-10%

# Variation of dose with shielding: ISS orbit




→ *dH/dt*:
Increased exposure at higher shielding

Dependence on solar activity at lower shieldings

→ *dD/dt*:
Increases with increasing shielding

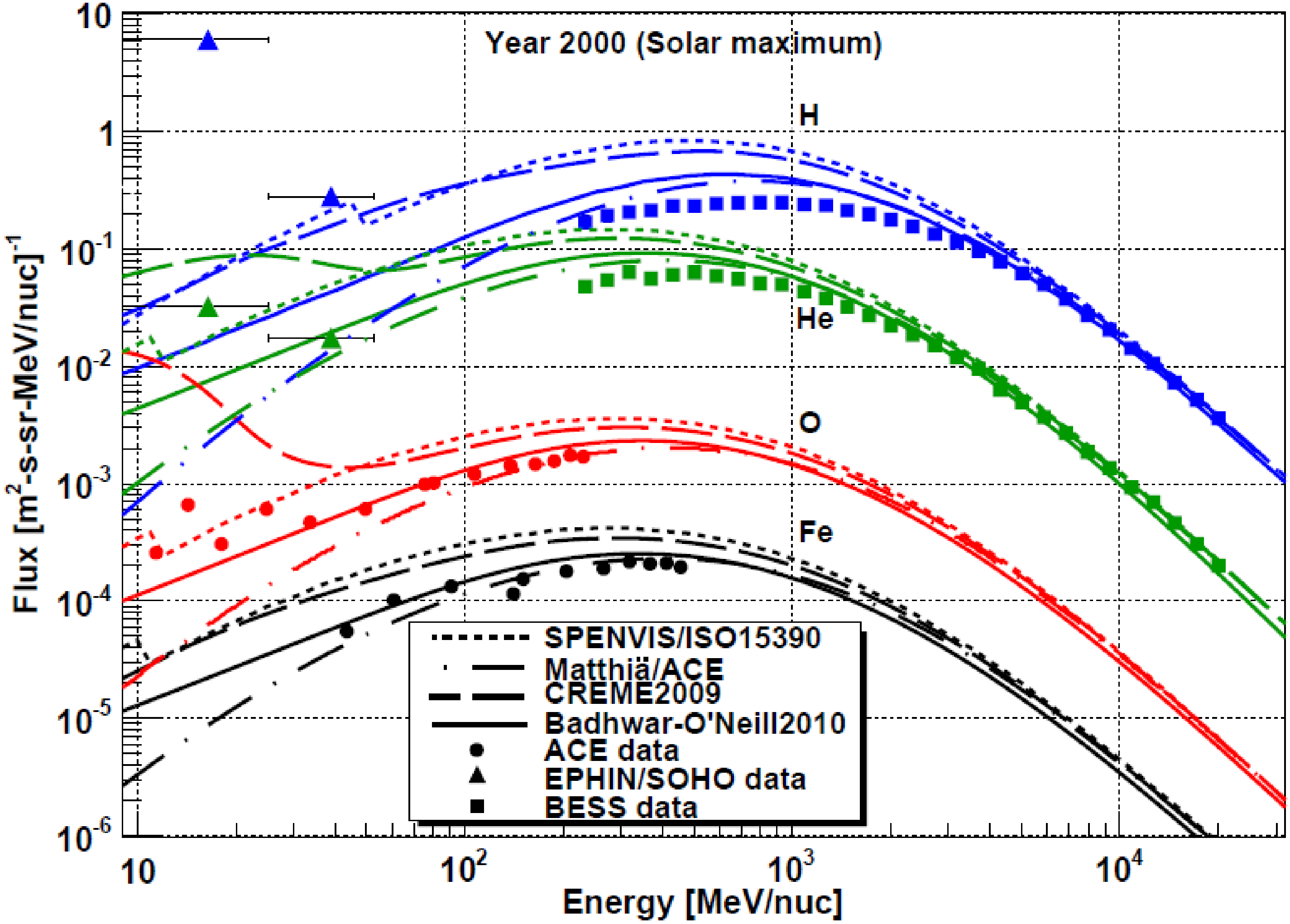
**Peak dose rate in November 2009**

| Shielding ($g/cm^2$) | dD/dt (mGy/d) | dH/dt (mSv/d) |
|---|---|---|
| 0 | **0.08** | **0.24** |
| 0.3 | **0.08** | **0.24** |
| 10 | **0.09** | **0.23** |
| 40 | **0.13** | **0.29** |

→ Dose rates in November 2009 higher by 3%-4% relative to the peak exposure during the 1997 solar minimum

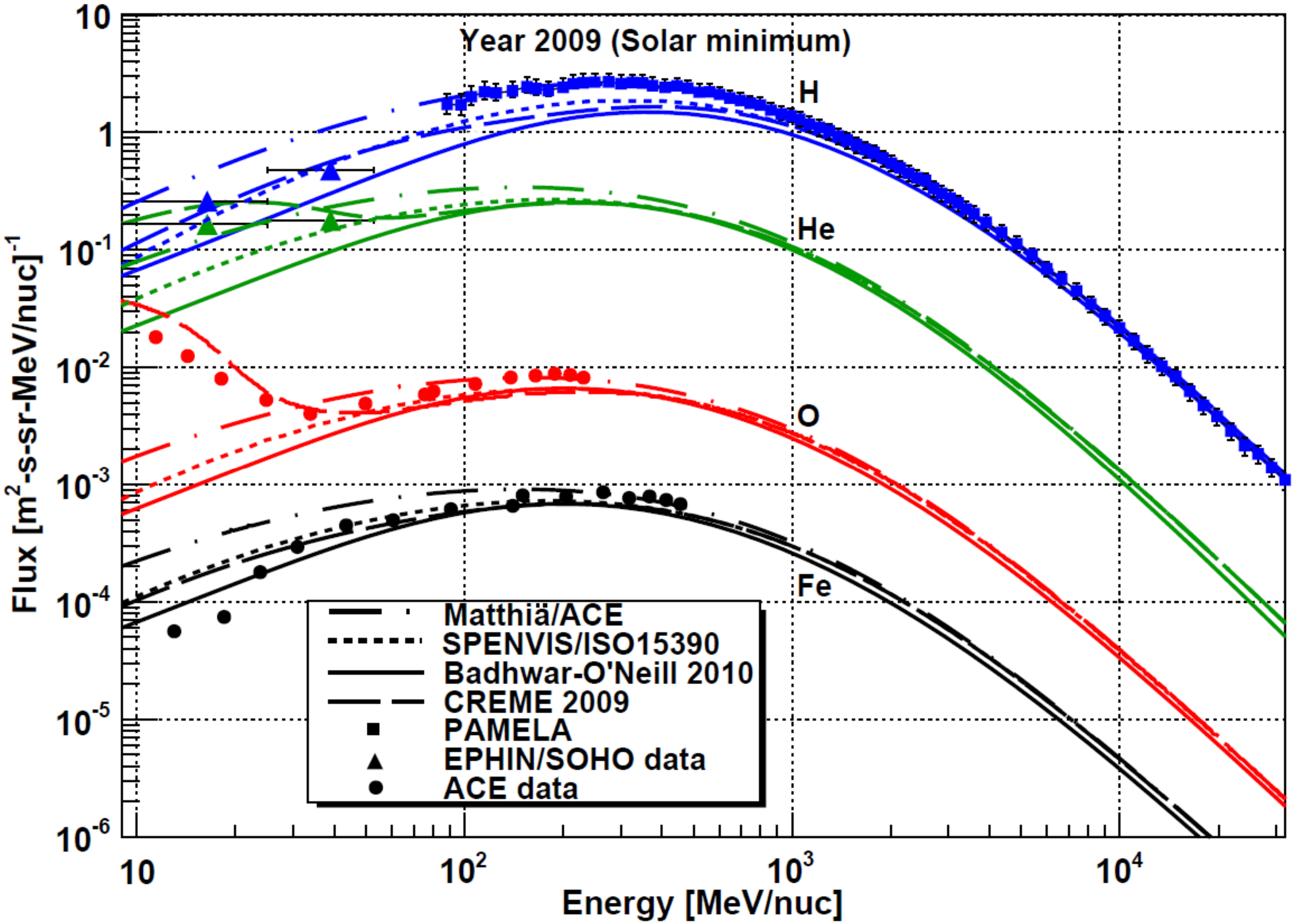

DLR

# What about SPENVIS/ISO15390?




$$\longrightarrow \frac{\text{Dose}_{\text{SPENVIS/ISO15390}}}{\text{Dose}_{\text{Matthiä/ACE}}} = \mathbf{1.45} \quad \text{(No shielding)}$$

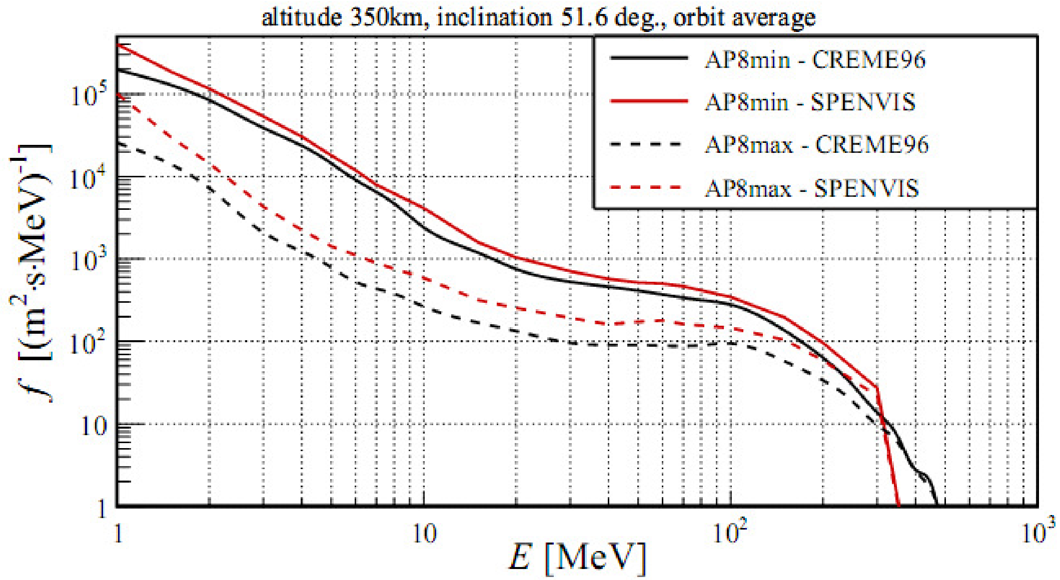
# What about SPENVIS/ISO15390?

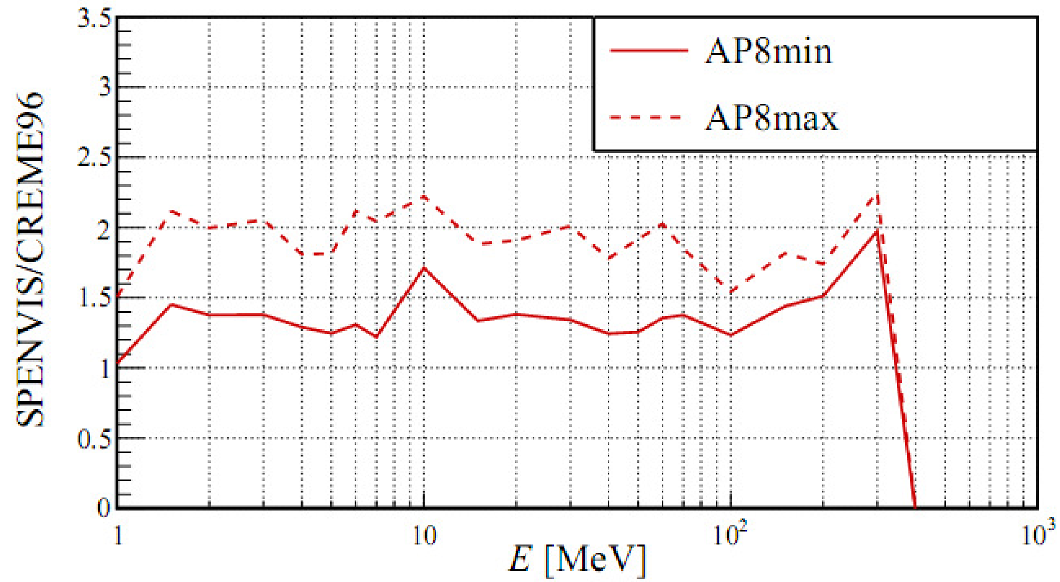



$$\longrightarrow \frac{\text{Dose}_{\text{SPENVIS/ISO15390}}}{\text{Dose}_{\text{Matthiä/ACE}}} = \mathbf{0.87} \quad \text{(No shielding)}$$


DLR

# Trapped Protons: SPENVIS and CREME




- Trapped proton spectra for ISS orbit:

  51.6°, 350km altitude

- Discrepancies between SPENVIS AP8 and CREME AP8


DLR

## Summary

- Intercomparison of GCR models for dosimetry purposes and measurements:
  - Large discrepancies for various epochs during the last decade

- GCR model by Matthiä et. al 2012 shows best agreement with the measurements

- It was quantitatively shown that the choice of GCR model affects the dose estimations

- Absorbed dose and dose equivalent rates for unshielded and shielded (aluminium) water phantom were calculated

- GCR exposure during late 2009 was estimated to be the highest since 1970: possible worst-case GCR scenario

## Summary

– SPENVIS/ISO15390 GCR model investigated for August 2000 (solar maximum) and November 2009 (solar minimum)

  - Produces higher fluxes for the year 2000 in comparison with measurements and vice-versa for the year 2009
  - Relative to Matthiä/ACE , the SPENVIS model yields higher dose rates by ≈45% for the year 2000 and lower by ≈13% for 2009

– Discrepancies observed for different implementations of AP8

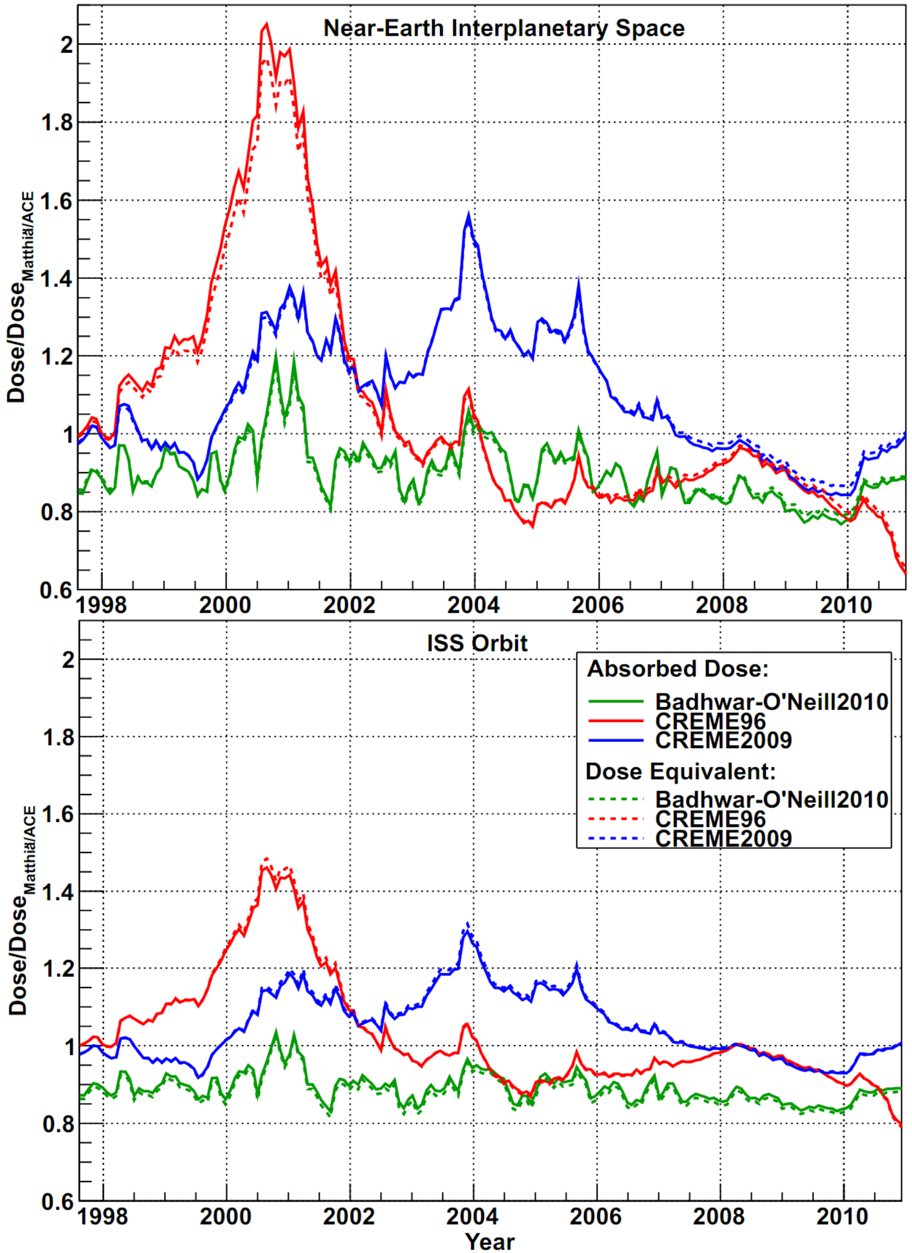
***Acknowledgment:*** *Alankrita Mrigakshi receives the SpaceLife scholarship funded by the Helmholtz association and DLR as a participant of the SpaceLife Program*

*Alankrita.Mrigakshi@dlr.de*

***Thank you for your attention!***

# APPENDIX

# Inter-comparison of dose using different models: $Dose_{Models}/Dose_{Matthiä/ACE}$




No shielding

- Large differences (up to 100%)
- Least difference between Badhwar-O'Neill2010 and Matthiä/ACE
- Dose using DLR model relative to Badhwar-O'Neill2010 in November 2009:

| | Outside Magnetosphere | ISS Orbit |
|---|---|---|
| dD/dt | ~ **+28 %** | ~ **+19 %** |
| dH/dt | ~ **+25 %** | ~ **+20 %** |

## Variation of Dose Rates with Shielding

– Dose measurements Vs calculations:

**32 – 47 g/cm² in Zvezda Module, ISS (Jardrnickova et al. 2009 )**

| | Absorbed dose rate (µGy/d) | |
|---|---|---|
| | Measurement | Calculation (40 g/cm²) |
| May-August 2009 (Semones et al. 2009 ) | 125 | 130 |
| December 2009 (Lishnevskii et al. 2012 ) | 100-110 | 131 |

– Estimated absorbed dose rates from **0 - 40 g/cm²** range from **77 - 131 µGy/d** during the periods of measurements shown above

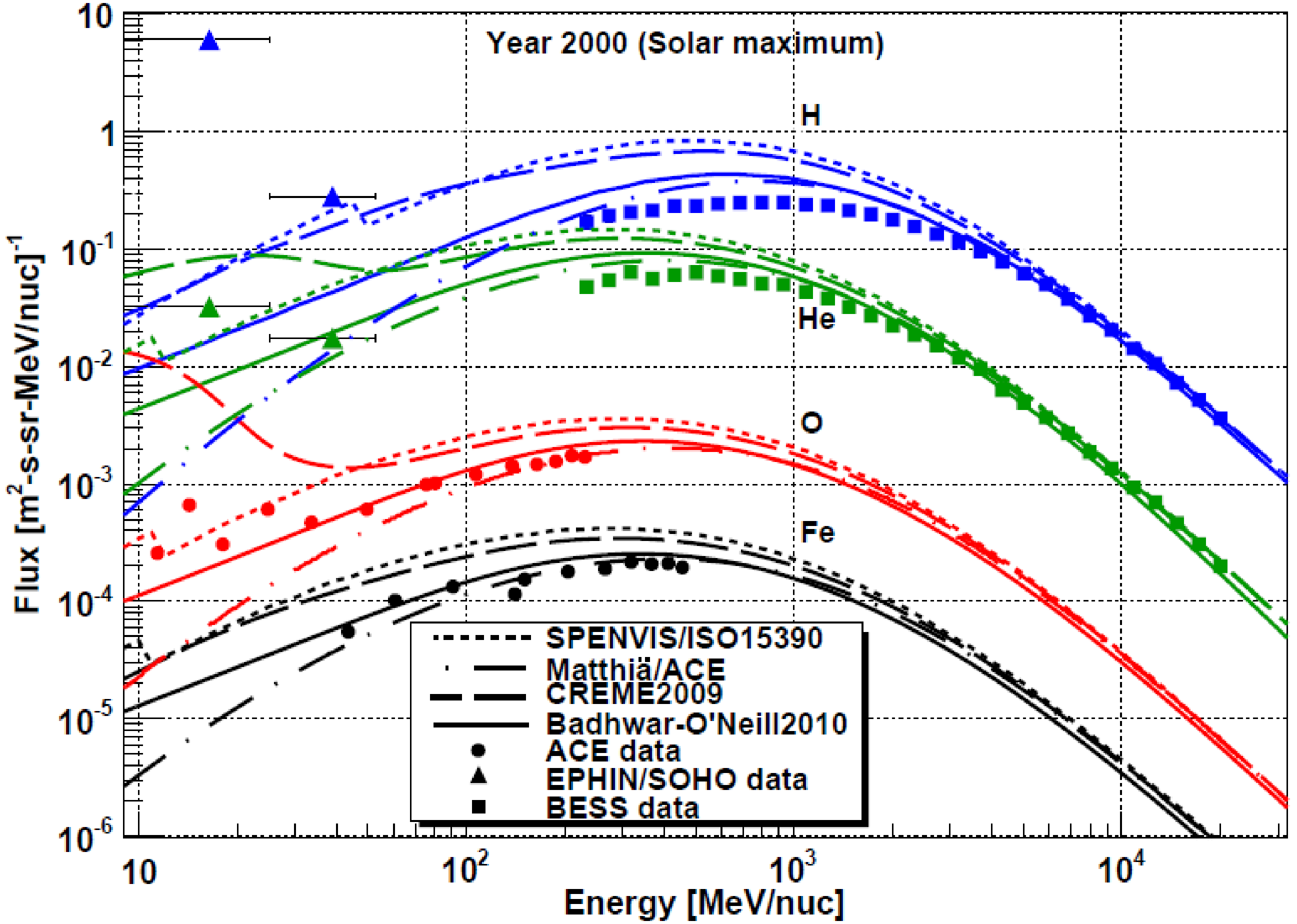
– Absorbed dose rates of about **160 µGy/d was** measured in the **Columbus module** by Semones et al. 2010 during **August-September 2009.** Higher mean shielding of about **100 g/cm²** was calculated by Stoffle et. al, 2012 for the module

**→ Large variations in dose rates with shielding, therefore an accurate information about the amount and the distribution of shielding is essential for reasonable prediction of dose**



DLR

# What about SPENVIS/ISO15390?

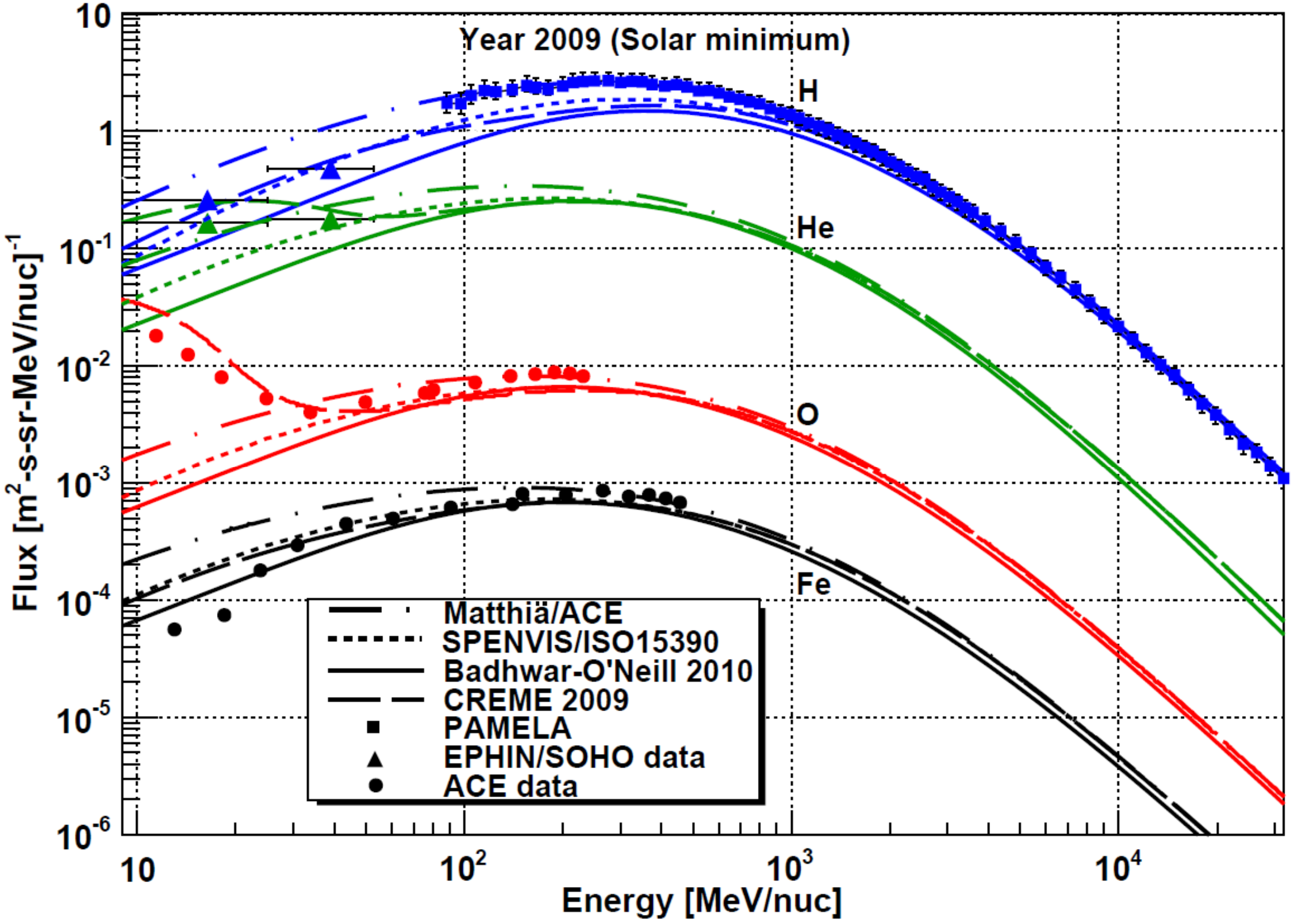



**Difference in dose rates using SPENVIS and the Matthia models (No shielding)**

| | dD/dt (µGy/d) | dH/dt (µSv/d) | $Dose_{SPENVISISO15390}/Dose_{Matthia/ACE}$ |
|---|---|---|---|
| SPENVIS/ISO15390 | 273 | 861 | ~1.45 |
| Matthiä/ACE | 187 | 599 | |


DLR

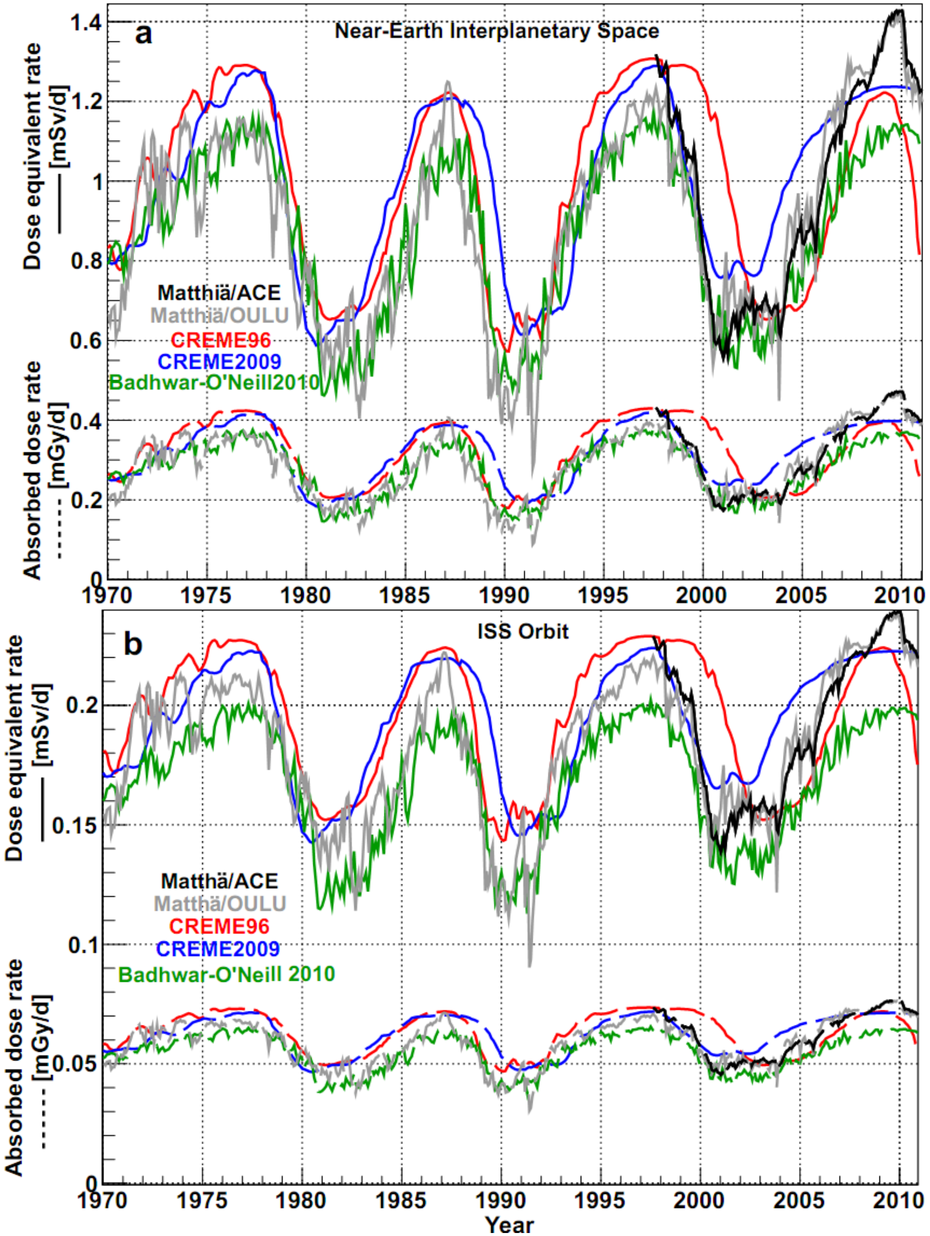
# What about SPENVIS/ISO15390?




**Difference in dose rates using SPENVIS and the Matthia models (No shielding)**

| | dD/dt (µGy/d) | dH/dt (µSv/d) | $Dose_{SPENVISISO15390}/Dose_{Matthia/ACE}$ |
|---|---|---|---|
| SPENVIS/ISO15390 | 405 | 1247 | ~0.87 |
| Matthiä/ACE | 472 | 1427 | |

# Dose rates using different GCR models **(No shielding)**



# A new GCR model

– GCR model developed at DLR based on ISO model for particles ranging from $1 \le Z \le 28$ and for periods from 1964 onwards

– ISO model:

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

– Solar modulation derived by fitting carbon measurements from ACE (Matthiä/ACE) and Oulu neutron monitor count rates (Matthiä/OULU)

*Matthiä, D., Berger, T., Mrigakshi A. , T., Reitz G., A Ready-to-Use Galactic Cosmic Ray Model, Adv. in Space Res., 2013*



DLR