# Overview of TLD and OSL measurements at SCK•CEN in the framework of the DOSIS and DOSIS 3D and the most recent biological experiments

Olivier Van Hoey, Filip Vanhavere, Werner Schoonjans

The Belgian Nuclear Research Center SCK•CEN, Mol, Belgium

ovhoey@sckcen.be

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

# Outline

- Introduction
- Methodology
- Experiments
  - DOSIS and DOSIS 3D
  - Biological experiments
- Conclusions and outlook

# Introduction

# Introduction

# Introduction

- Radiation doses in space are much higher than on earth

# Introduction

- Radiation doses in space are much higher than on earth

⇒ Important to assess the effects of space radiation on humans, non-human biota and on-board instrumentation

# Introduction

- Radiation doses in space are much higher than on earth

⇒ Important to assess the effects of space radiation on humans, non-human biota and on-board instrumentation

- Radiation fields in space are more complex than on earth

# Introduction

- Radiation doses in space are much higher than on earth

⇒ Important to assess the effects of space radiation on humans, non-human biota and on-board instrumentation

- Radiation fields in space are more complex than on earth

⇒ A combination of different detectors is required to cover the whole LET spectrum

## Introduction

- Radiation doses in space are much higher than on earth

⇒ Important to assess the effects of space radiation on humans, non-human biota and on-board instrumentation

- Radiation fields in space are more complex than on earth

⇒ A combination of different detectors is required to cover the whole LET spectrum

- Passive and compact dosimetry can be provided by the combination of TLDs, OSLDs and track-etch detectors

# Methodology

# Thermoluminescence detectors

# Thermoluminescence detectors

- Detector types
  - TLD Poland
  - LiF:Mg,Ti: MTS-N, MTS-6 and MTS-7
  - LiF:Mg,Cu,P: MCP-N, MCP-6 and MCP-7

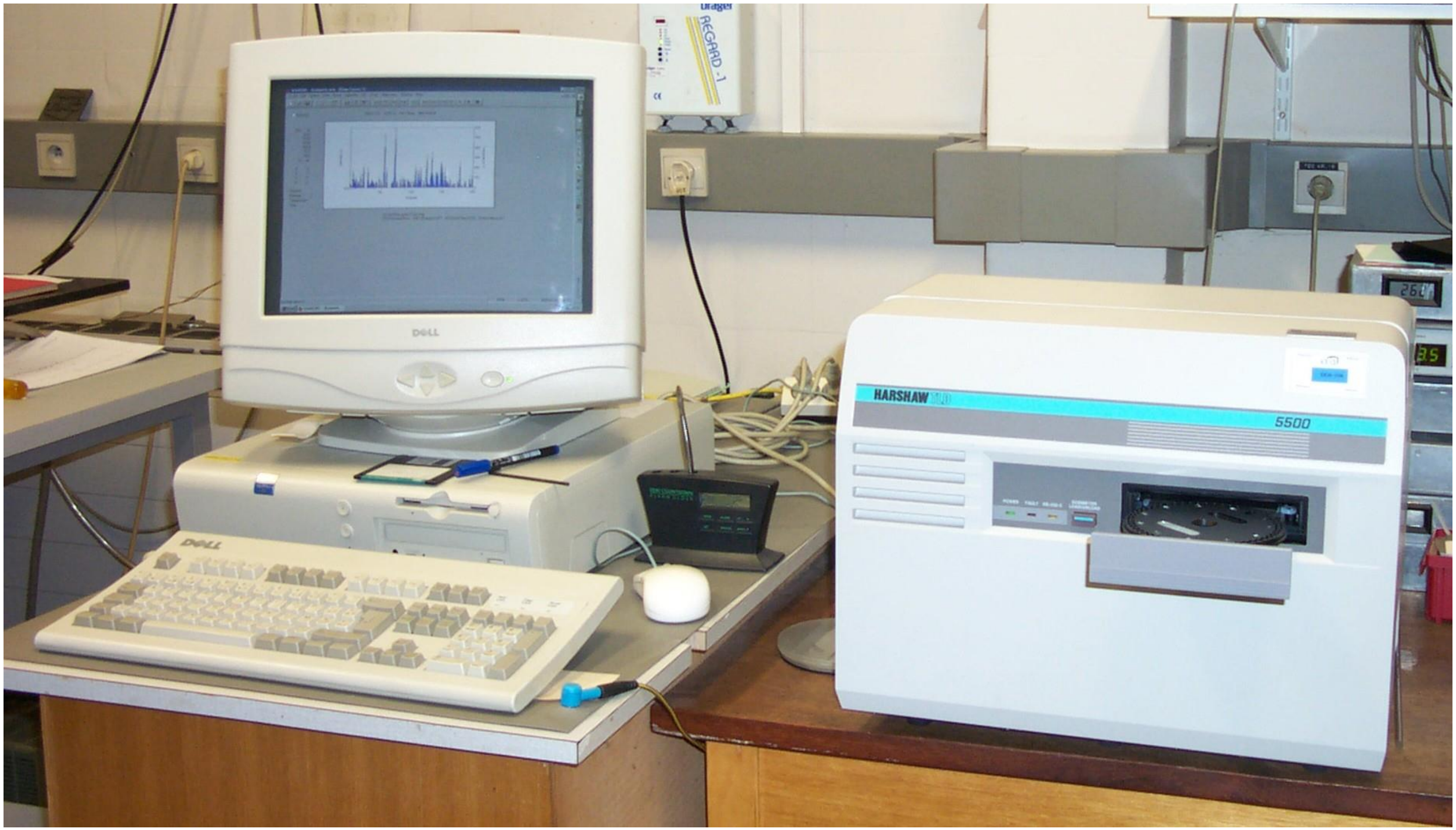
# Thermoluminescence detectors

- Detector types
  - TLD Poland
  - LiF:Mg,Ti: MTS-N, MTS-6 and MTS-7
  - LiF:Mg,Cu,P: MCP-N, MCP-6 and MCP-7
- Annealing
  - LiF:Mg,Ti: 1h at 400°C, 2h at 100°C, slow cooling
  - LiF:Mg,Cu,P: 10min 240°C, fast cooling

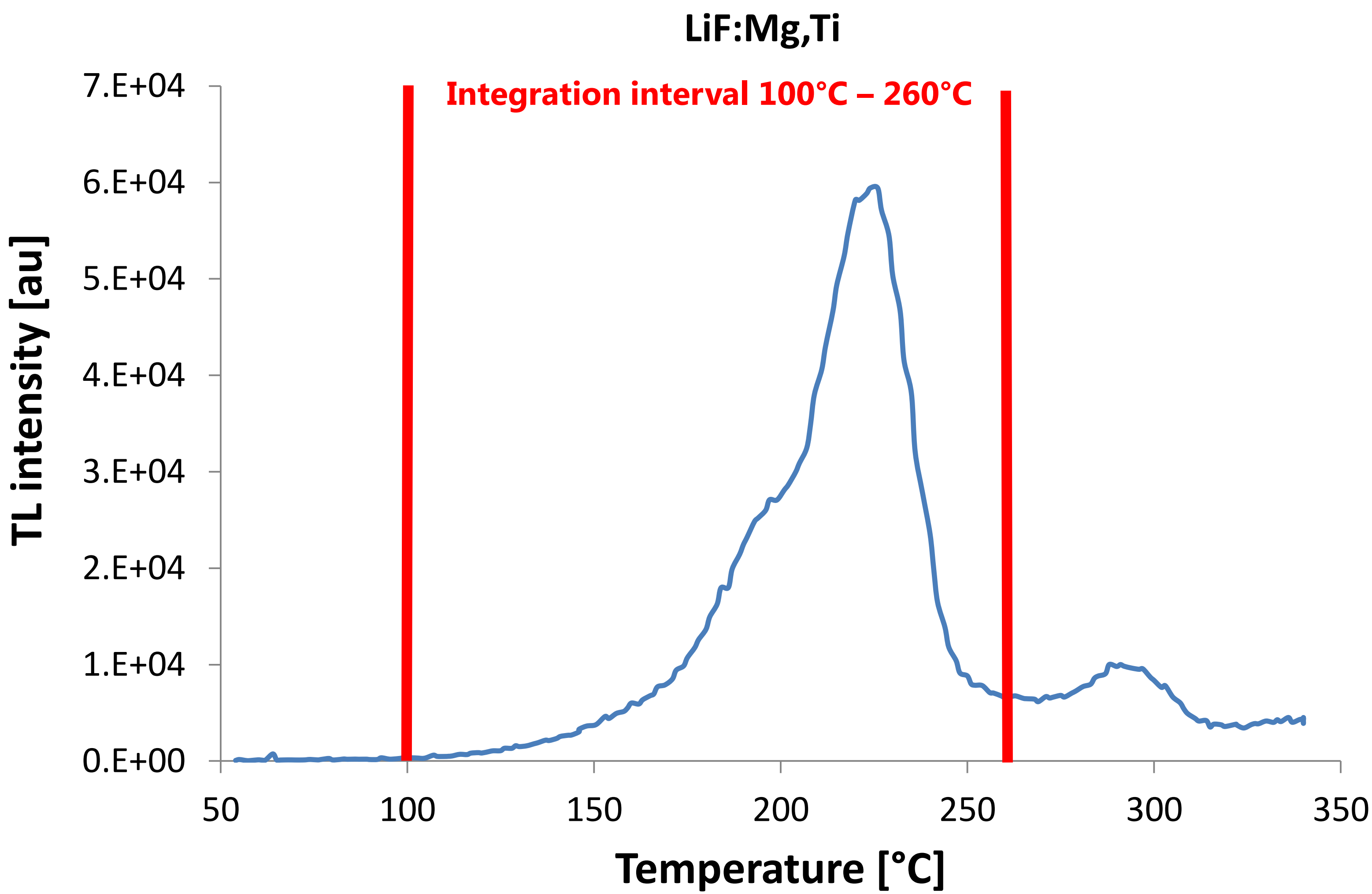
# Thermoluminescence detectors

- Detector types
  - TLD Poland
  - LiF:Mg,Ti: MTS-N, MTS-6 and MTS-7
  - LiF:Mg,Cu,P: MCP-N, MCP-6 and MCP-7
- Annealing
  - LiF:Mg,Ti: 1h at 400°C, 2h at 100°C, slow cooling
  - LiF:Mg,Cu,P: 10min 240°C, fast cooling
- Reading
  - Harshaw 5500
  - 1°C/s heating rate
  - No preheat

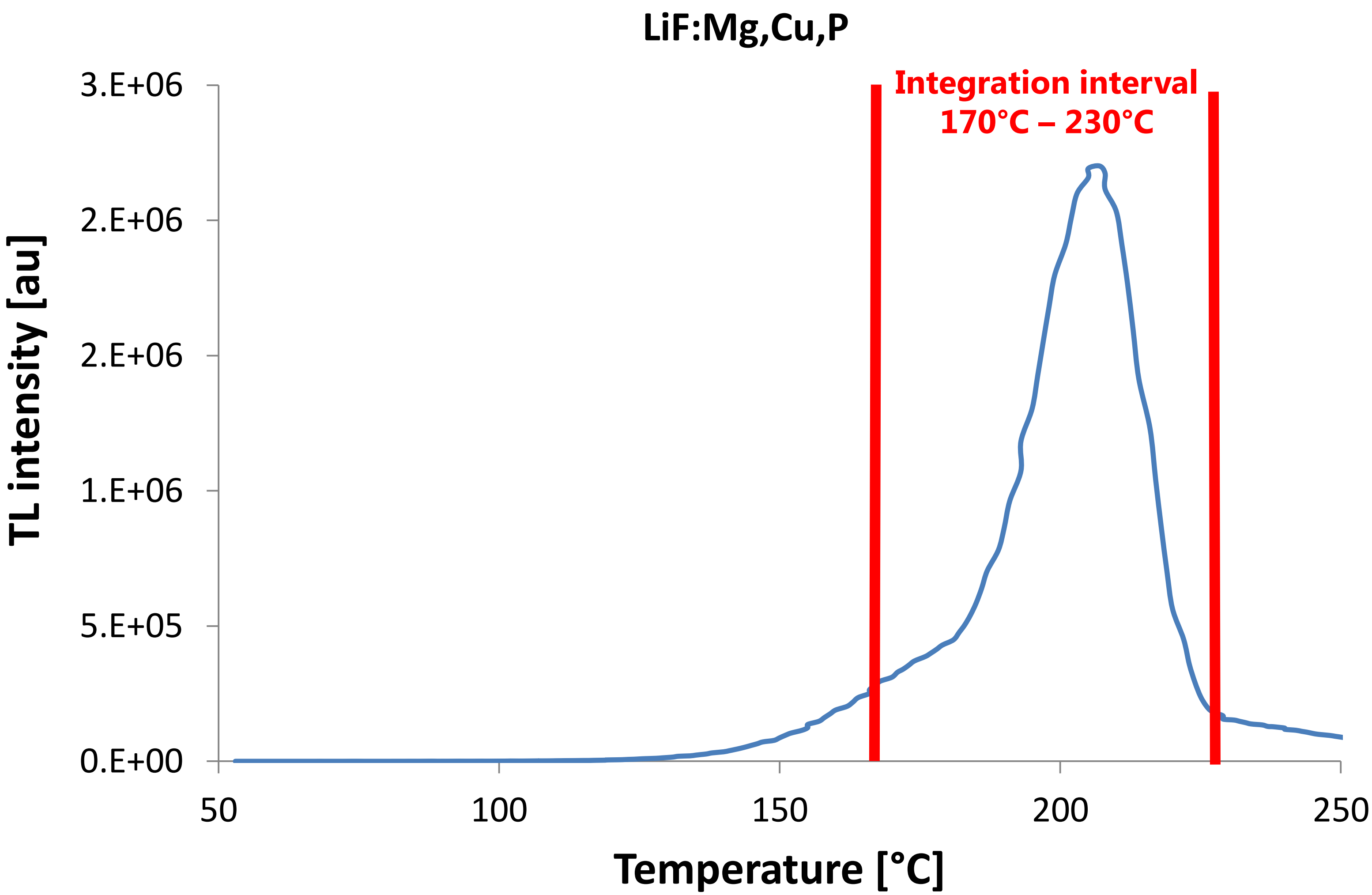
# Thermoluminescence detectors



# Thermoluminescence detectors



# Thermoluminescence detectors



# Optically stimulated luminescence detectors

# Optically stimulated luminescence detectors

- Detector type
  - Landauer
  - $Al_2O_3$:C: Luxel

# Optically stimulated luminescence detectors

- Detector type
  - Landauer
  - $Al_2O_3$:C: Luxel

- Bleaching
  - One day exposure to ambient light

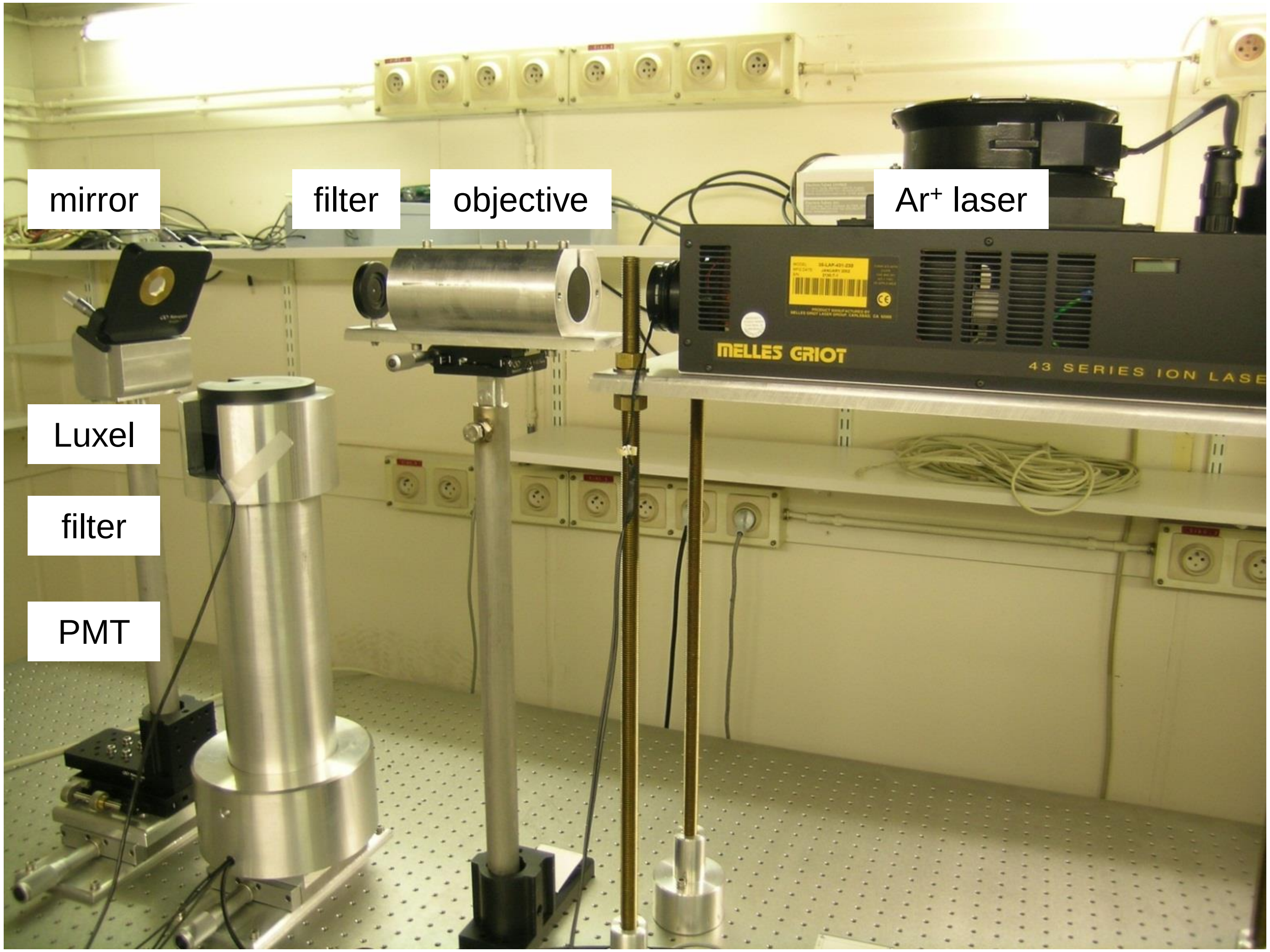
# Optically stimulated luminescence detectors

- Detector type
  - Landauer
  - $Al_2O_3$:C: Luxel

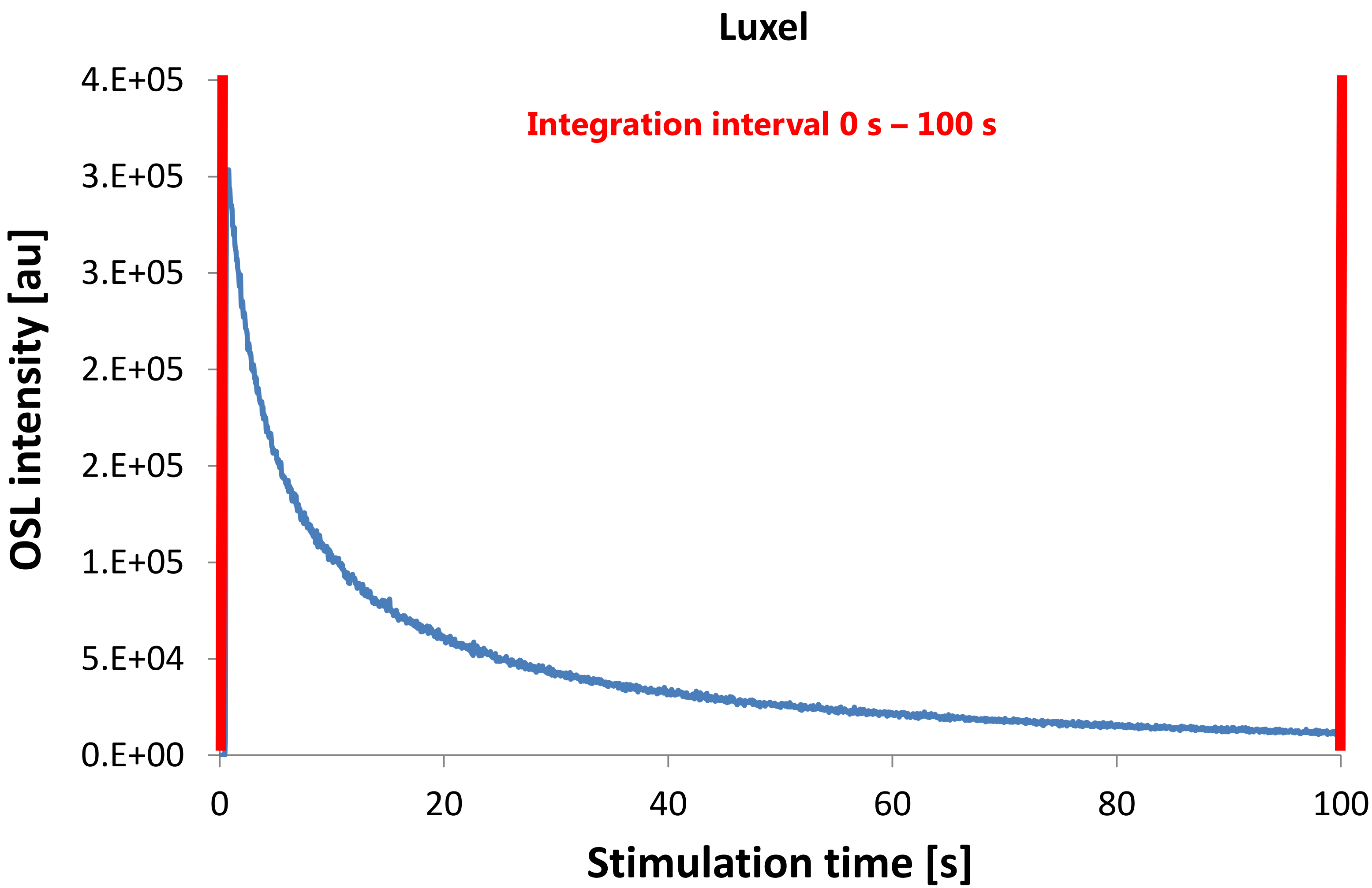
- Bleaching
  - One day exposure to ambient light

- Reading
  - 488 nm $Ar^+$ laser
  - 120 $mW/cm^2$
  - 100 s CW-OSL

# Optically stimulated luminescence detectors



# Optically stimulated luminescence detectors



# Calibration and background

# Calibration and background

- Calibration
  - Separate detector group from same batch
  - 40 mGy $^{60}Co$ in the middle of the flight
  - Individual sensitivity factor determined in advance for the TLDs
  - Doses expressed in terms of absorbed dose in water

# Calibration and background

- Calibration
  - Separate detector group from same batch
  - 40 mGy $^{60}Co$ in the middle of the flight
  - Individual sensitivity factor determined in advance for the TLDs
  - Doses expressed in terms of absorbed dose in water

- Background
  - Two separate detector groups from same batch
  - First group travels to launch site and back as background for boxes
  - Second group stays at SCK•CEN as background for the calibration

# Experiments

# I. DOSIS and DOSIS 3D

# DOSIS and DOSIS 3D

# DOSIS and DOSIS 3D

- Multilateral project  lead by DLR

# DOSIS and DOSIS 3D

- Multilateral project  lead by DLR
- Monitoring the radiation environment in the Columbus module of the International Space Station

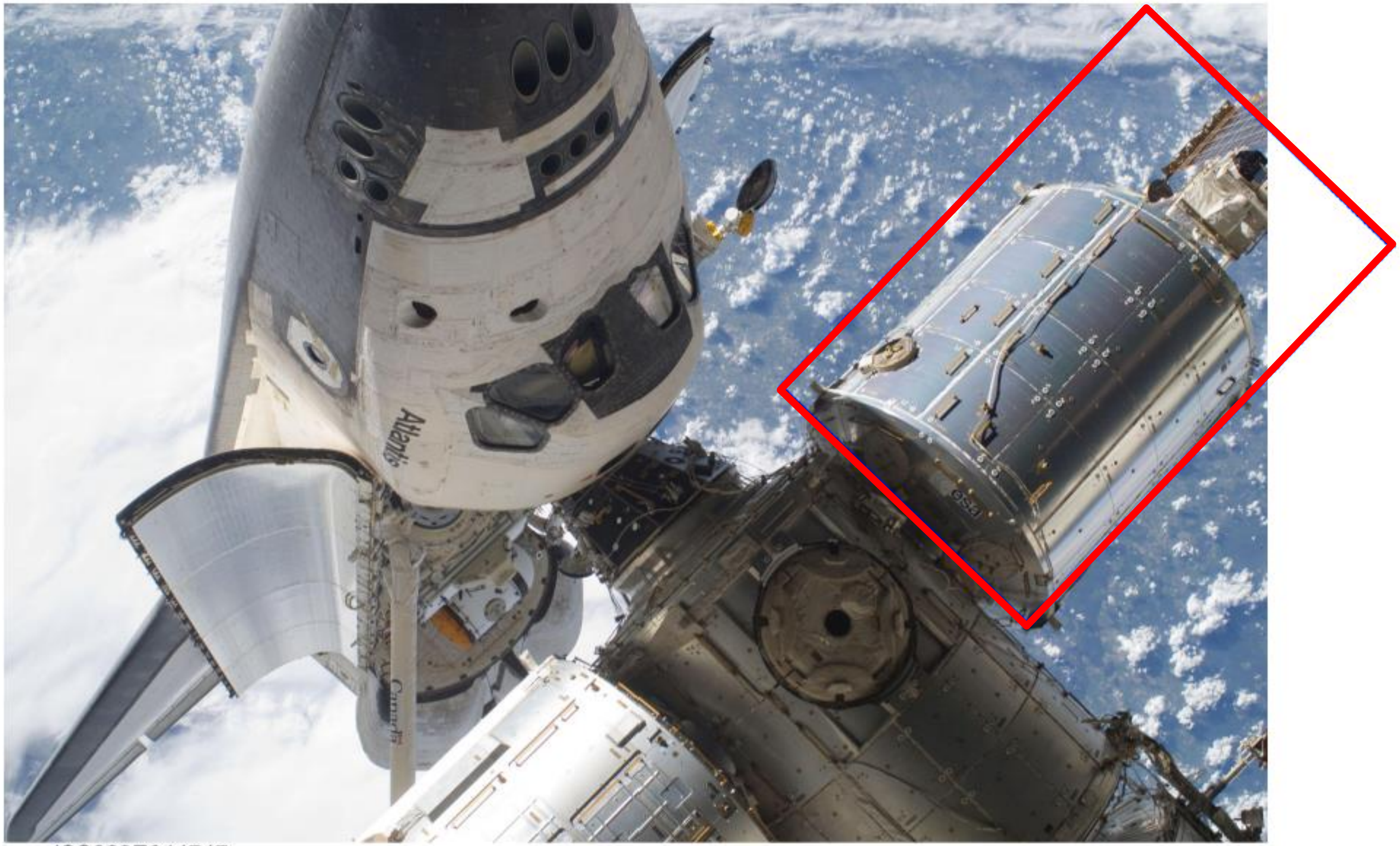
# DOSIS and DOSIS 3D

- Multilateral project  lead by DLR
- Monitoring the radiation environment in the Columbus module of the International Space Station
- Study of the spatial and temporal variations in the radiation field

# DOSIS and DOSIS 3D

- Multilateral project  lead by DLR
- Monitoring the radiation environment in the Columbus module of the International Space Station
- Study of the spatial and temporal variations in the radiation field
- Variety of passive and active detectors

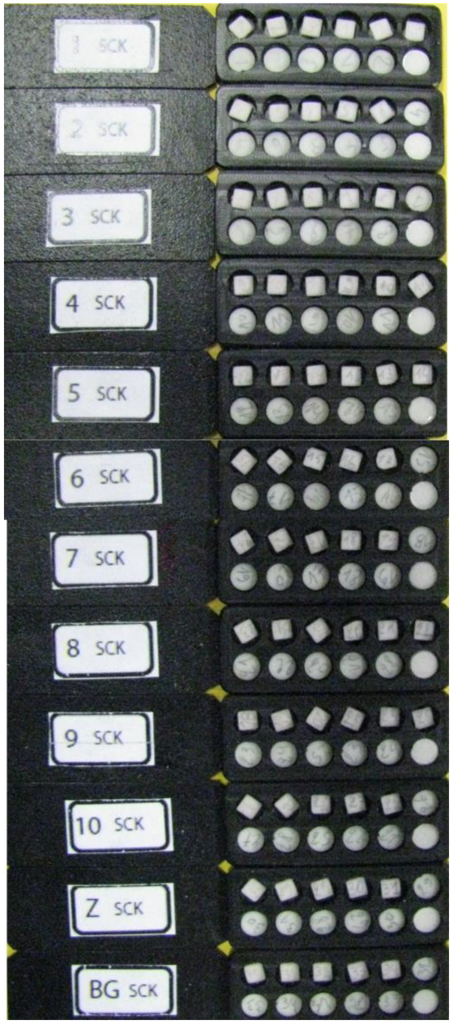
# Columbus module

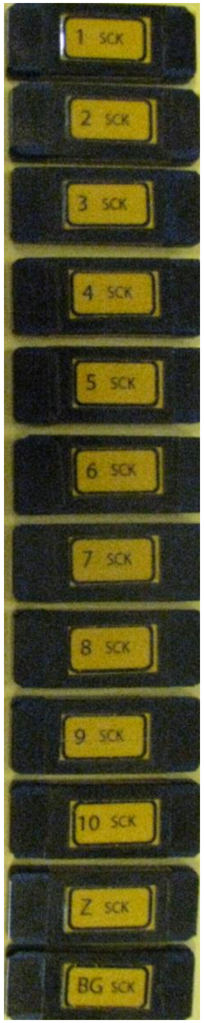


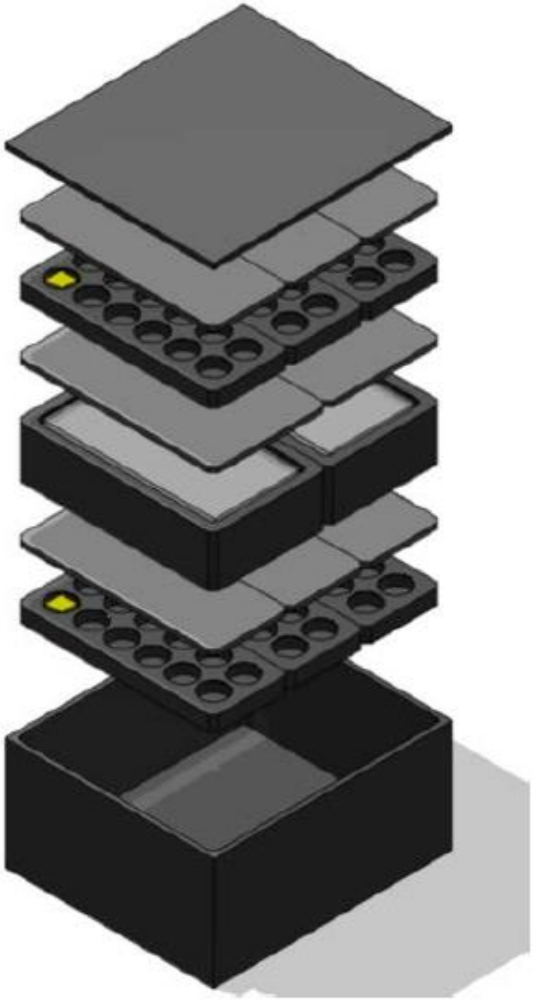

ISS023E044747

*[1] Thomas Berger, presentation at WRMISS 2014*

# Passive detector packages

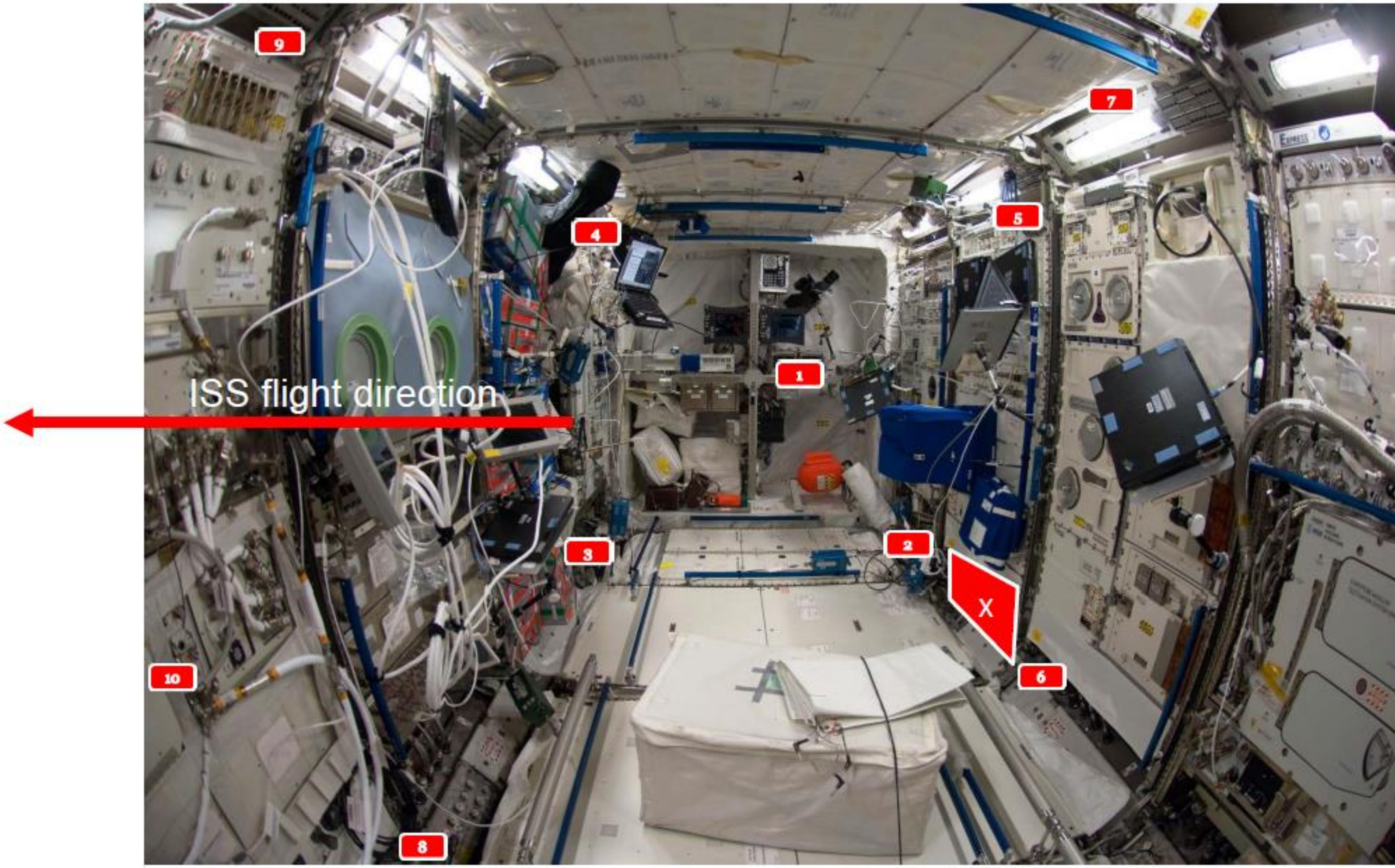


[1] *Thomas Berger, presentation at WRMISS 2014*

# Passive detector packages




*[1] Thomas Berger, presentation at WRMISS 2014*

# Absolute absorbed dose values

# Absolute absorbed dose values

- Absorbed dose in water measured with TLDs and OSLDs

# Absolute absorbed dose values

- Absorbed dose in water measured with TLDs and OSLDs

- Average: 250 µGy/day

# Absolute absorbed dose values

- Absorbed dose in water measured with TLDs and OSLDs
- Average: 250 µGy/day
- Standard deviation: 17%

# Absolute absorbed dose values

- Absorbed dose in water measured with TLDs and OSLDs
- Average: 250 µGy/day
- Standard deviation: 17%
- Minimum: 153 µGy/day

# Absolute absorbed dose values

- Absorbed dose in water measured with TLDs and OSLDs
- Average: 250 µGy/day
- Standard deviation: 17%
- Minimum: 153 µGy/day
- Maximum: 389 µGy/day

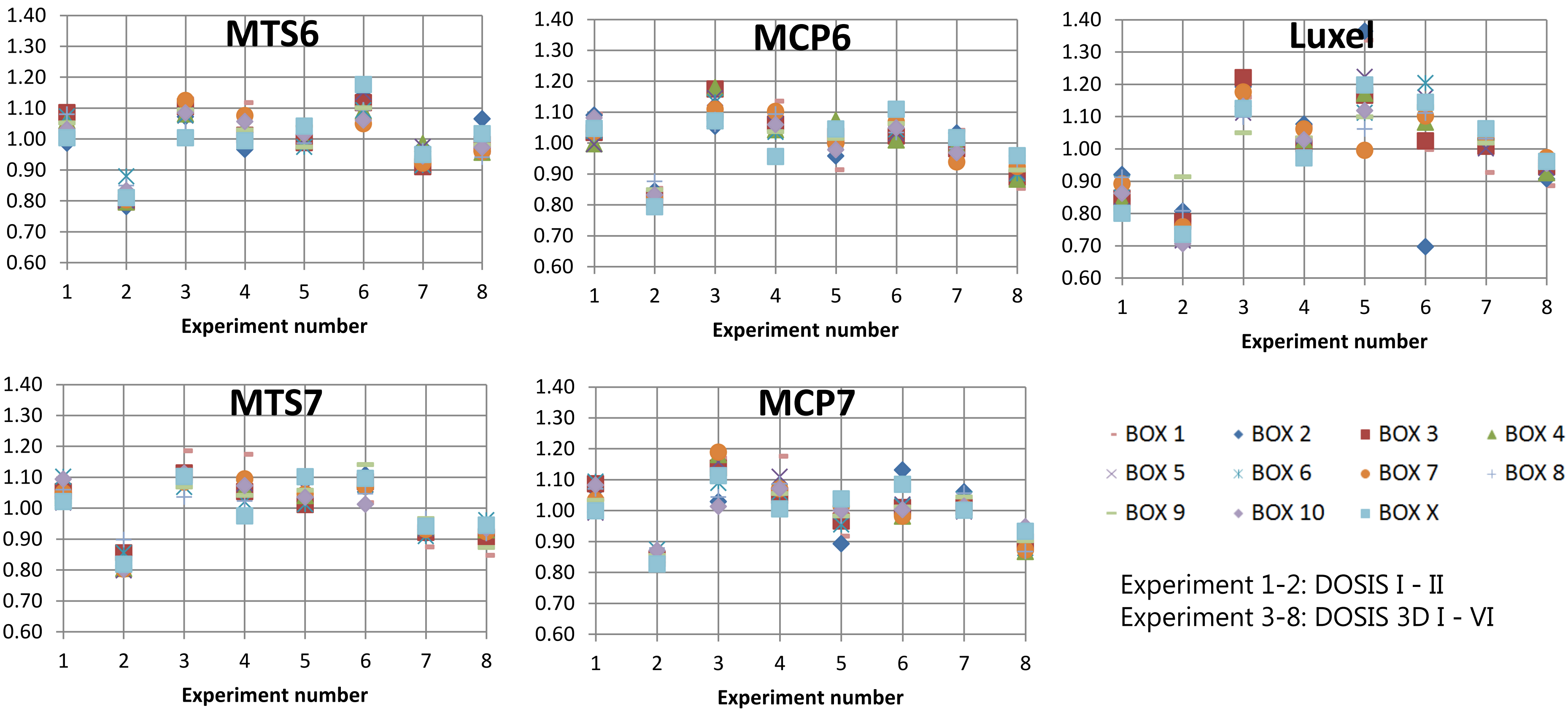
# Dose dependence on solar activity and altitude

# Dose dependence on solar activity and altitude

Daily dose values for each box and detector type normalized to their average over all experiments

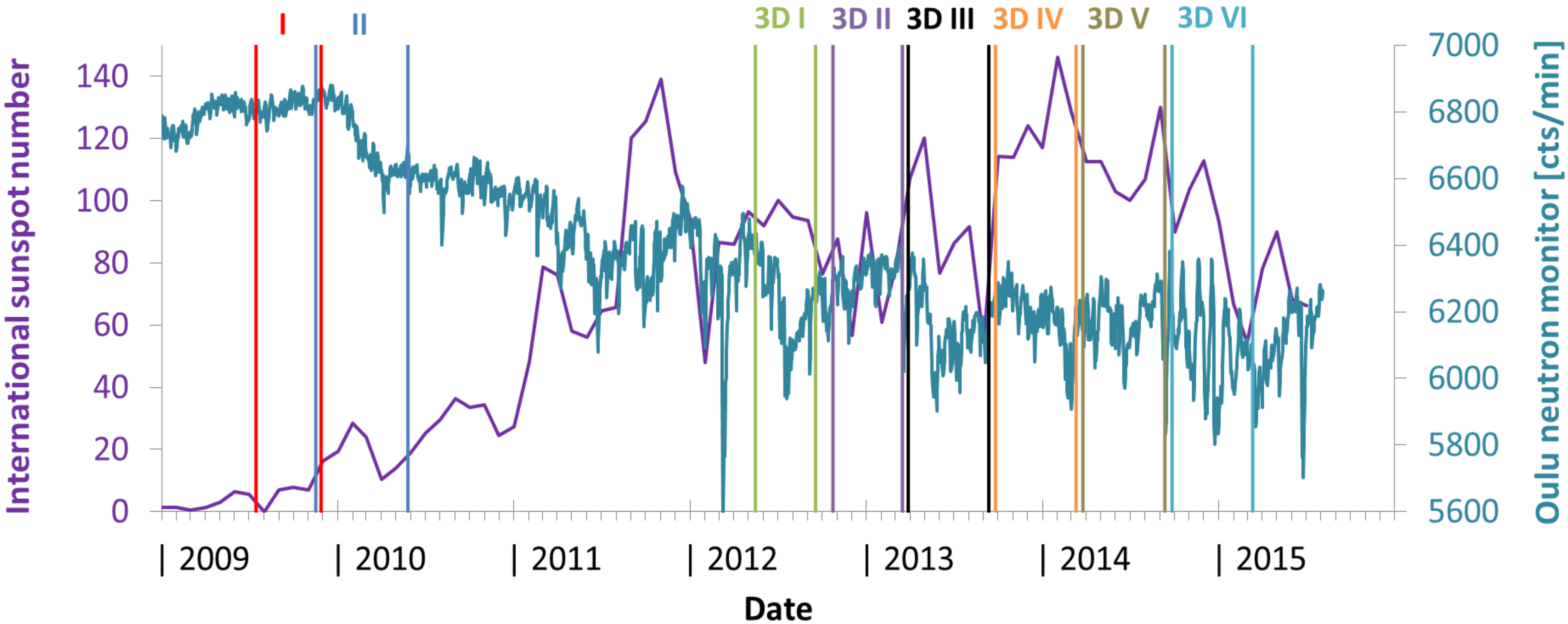
# Dose dependence on solar activity and altitude

Daily dose values for each box and detector type normalized to their average over all experiments



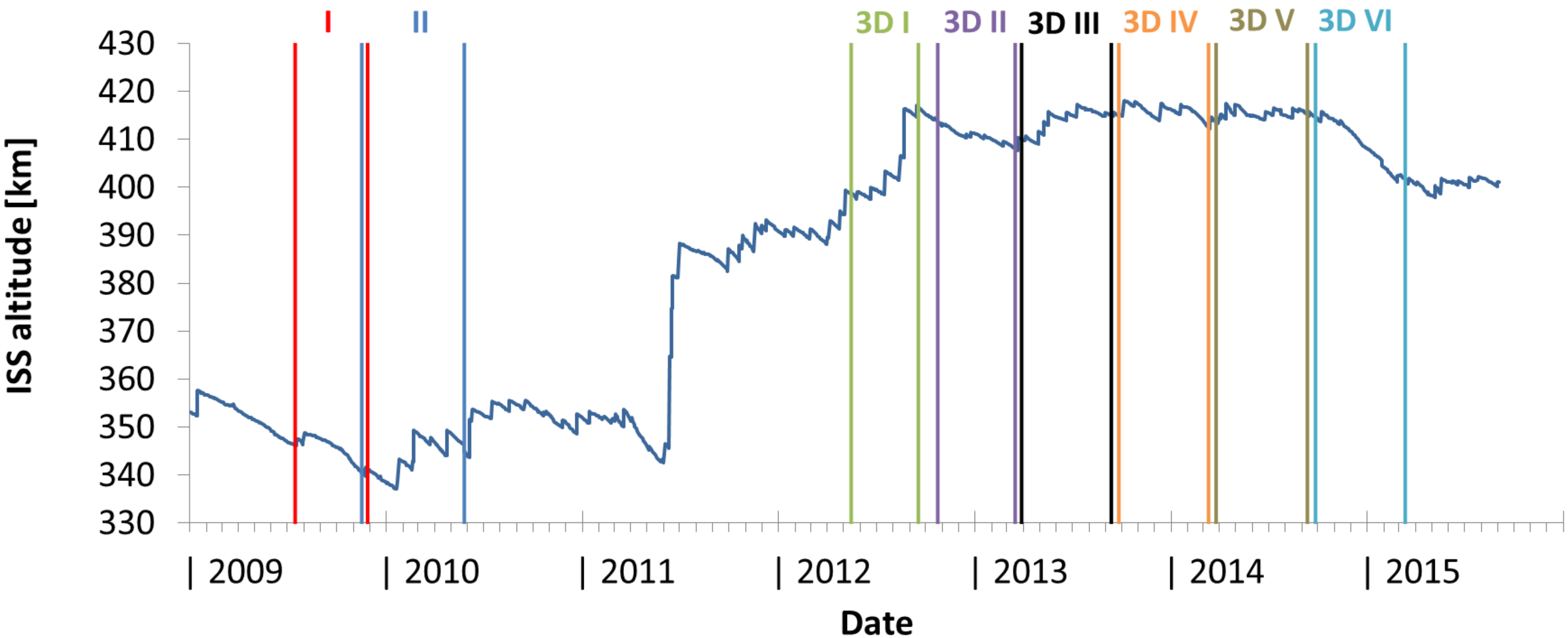

Experiment 1-2: DOSIS I - II
Experiment 3-8: DOSIS 3D I - VI

# Dose dependence on solar activity and altitude




[1] *http://www.nmdb.eu/*
[2] *http://cosmicrays.oulu.fi/*
[3] *http://sidc.oma.be/silso/*

# Dose dependence on solar activity and altitude




*[1] DOSIS 3D Science Team Coordinator Thomas Berger*

# Dose dependence on solar activity and altitude

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments

- Increasing solar activity => decreasing GCRs

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments
- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments

- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values

- Increasing ISS altitude => increasing SAA dose

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments
- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values
- Increasing ISS altitude => increasing SAA dose
  => higher absorbed dose values

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments

- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values

- Increasing ISS altitude => increasing SAA dose
  => higher absorbed dose values

- Similar trends for different detector types and different boxes

# Dose dependence on solar activity and altitude

- ± 30% variation over all experiments
- Increasing solar activity => decreasing GCRs
  => lower absorbed dose values
- Increasing ISS altitude => increasing SAA dose
  => higher absorbed dose values
- Similar trends for different detector types and different boxes
- Larger scatter for Luxels

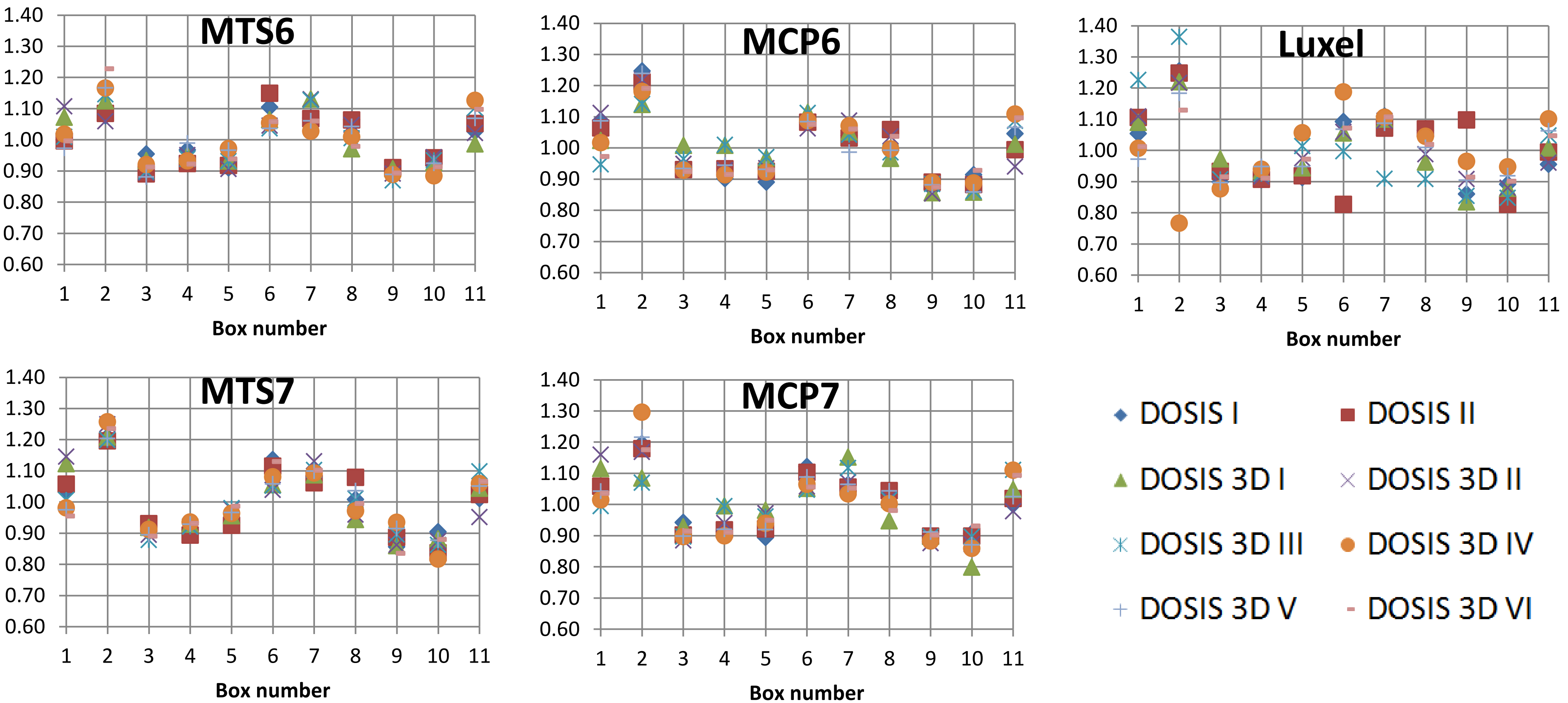
# Dose dependence on shielding

# Dose dependence on shielding

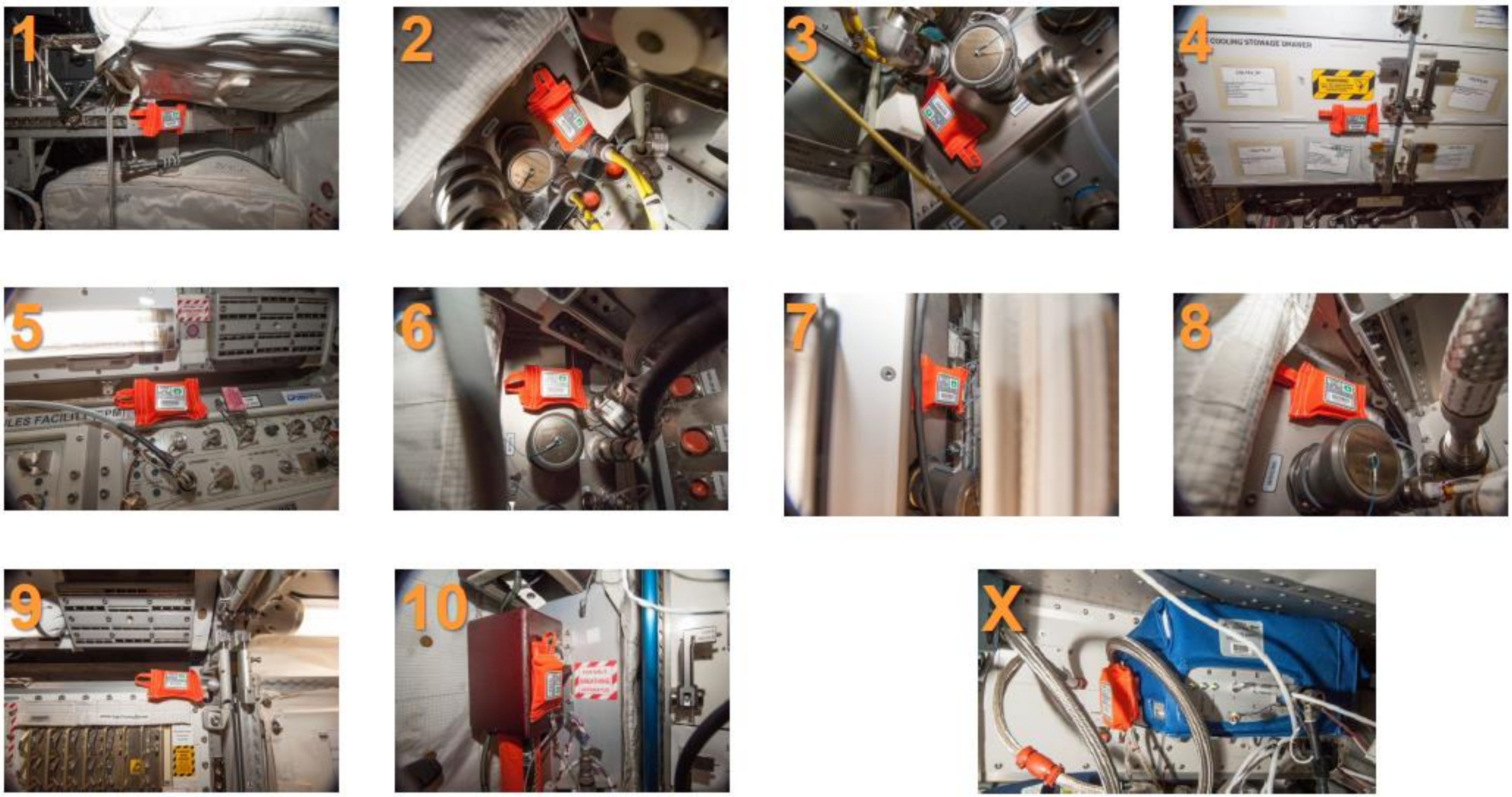
Daily dose values for each experiment and detector type normalized to their average over all boxes

# Dose dependence on shielding

Daily dose values for each experiment and detector type normalized to their average over all boxes



# Dose dependence on shielding




[1] Thomas Berger, presentation at WRMISS 2014

# Dose dependence on shielding

# Dose dependence on shielding

- ± 30% variation over all locations

# Dose dependence on shielding

- ± 30% variation over all locations
- Similar trends for different detector types and different experiments

# Dose dependence on shielding

- ± 30% variation over all locations
- Similar trends for different detector types and different experiments
- Larger scatter for Luxels

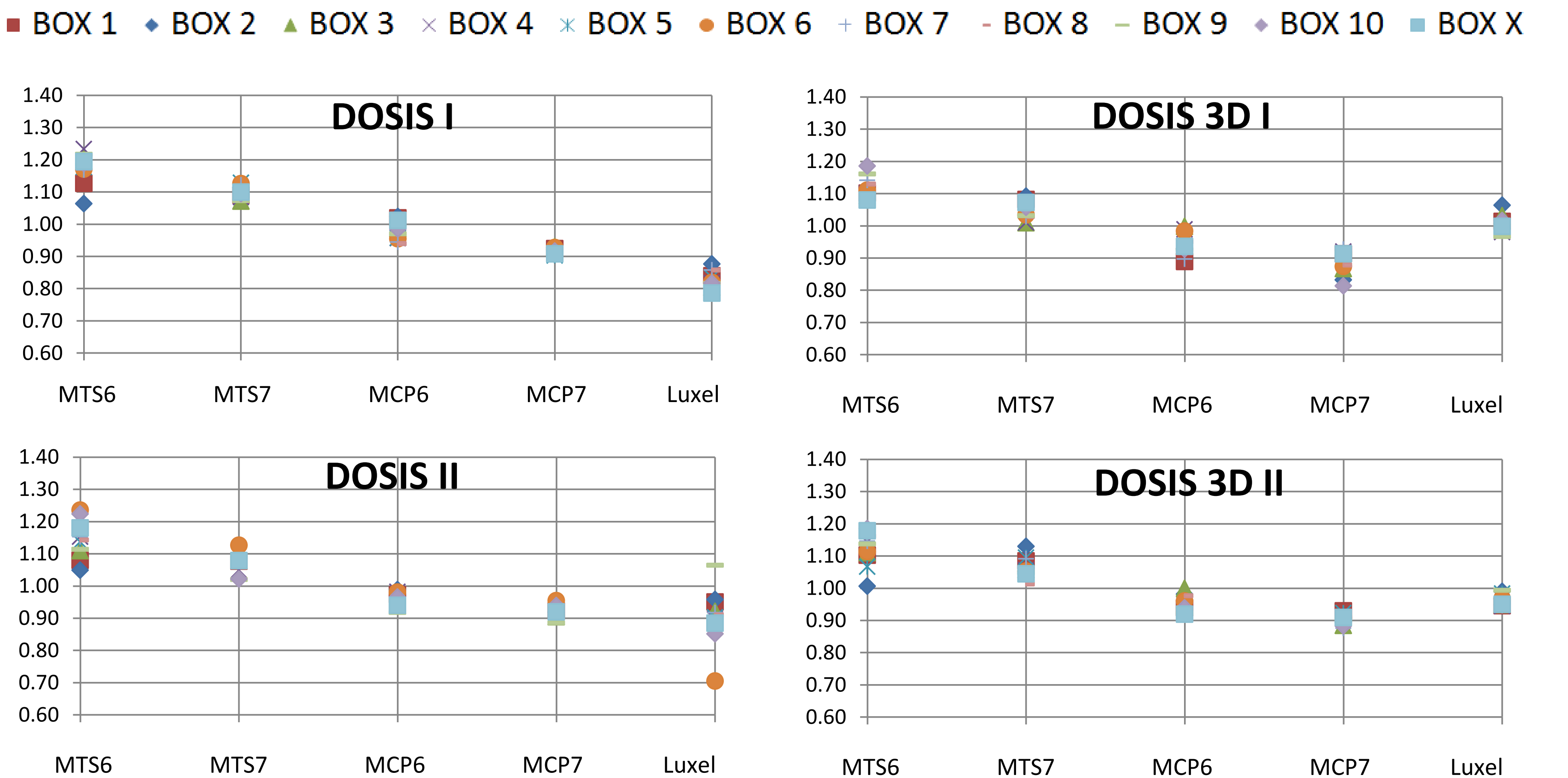
# Dose dependence on detector type

# Dose dependence on detector type

Daily dose values for each experiment and box normalized to their average over all detector types

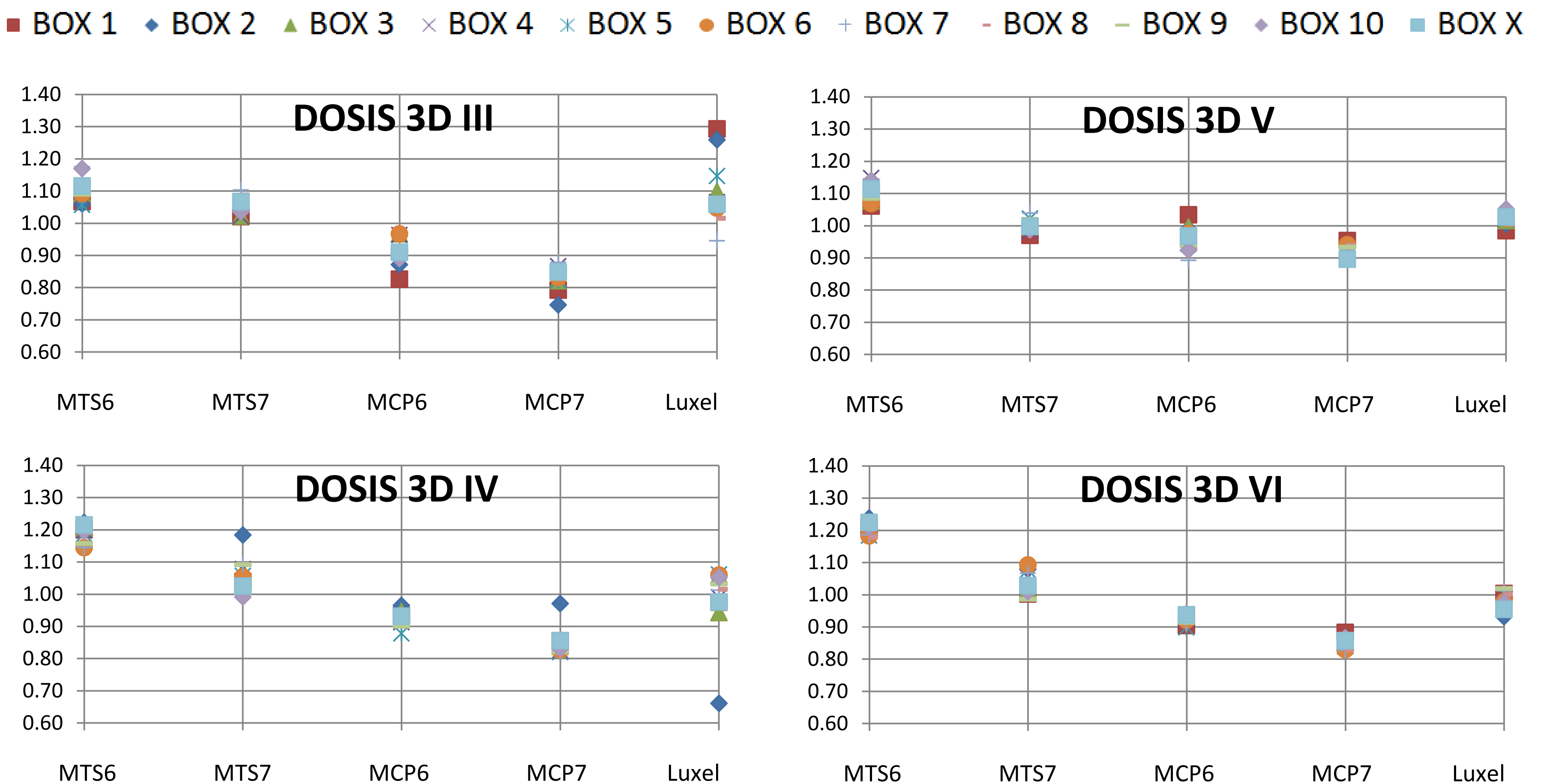
# Dose dependence on detector type

Daily dose values for each experiment and box normalized to their average over all detector types

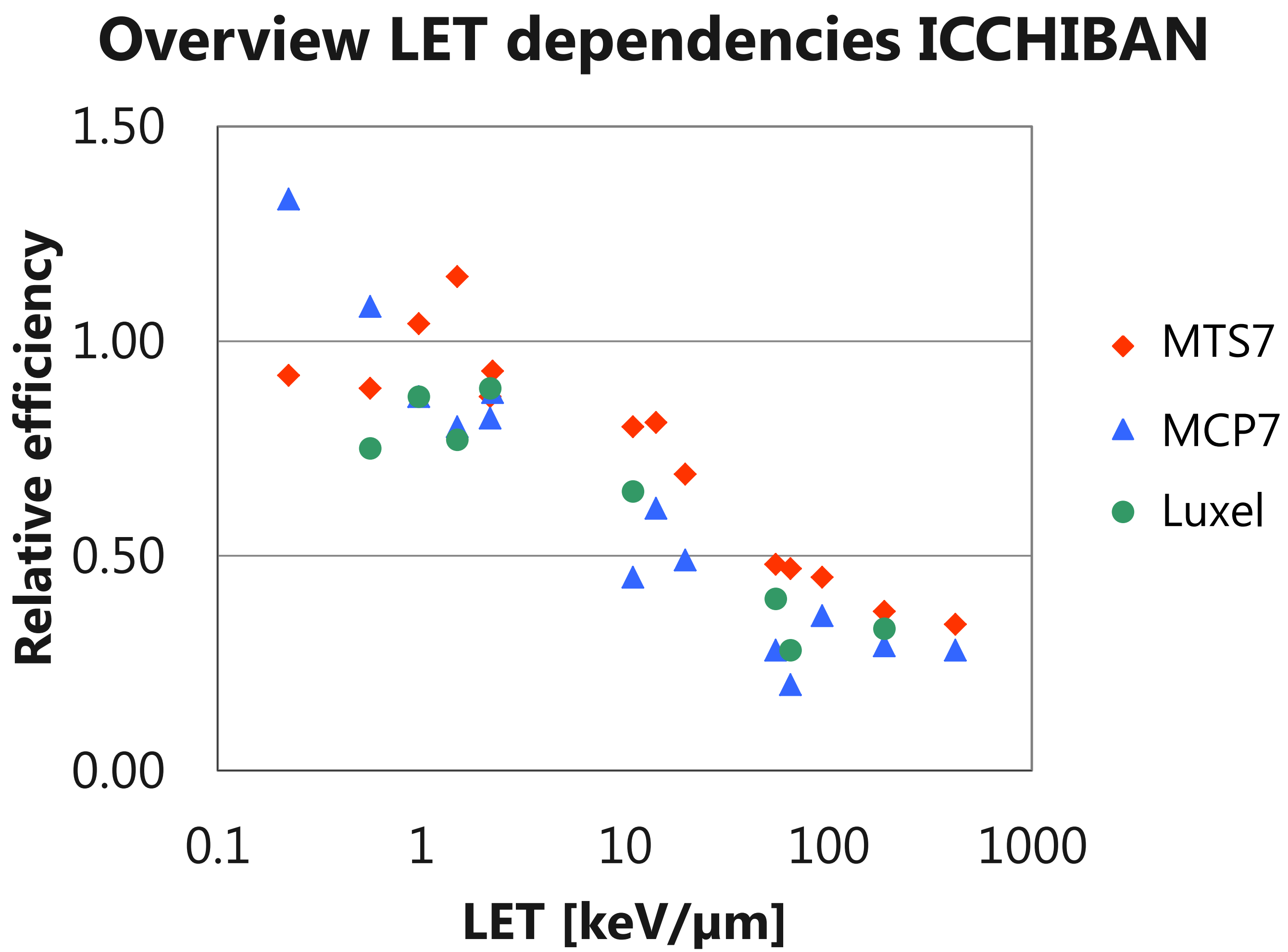


# Dose dependence on detector type

Daily dose values for each experiment and box normalized to their average over all detector types



# Dose dependence on detector type



# Dose dependence on detector type

# Dose dependence on detector type

- ± 35% variation over all detector types

# Dose dependence on detector type

- ± 35% variation over all detector types

- Similar trends for different boxes and different experiments
  - MTS6 > MTS7 > Luxel > MCP6 > MCP7
  - Type 6 > type 7 due to neutron sensitivity
  - MTS > Luxel > MCP due to LET dependence

# Dose dependence on detector type

- ± 35% variation over all detector types
- Similar trends for different boxes and different experiments
  - MTS6 > MTS7 > Luxel > MCP6 > MCP7
  - Type 6 > type 7 due to neutron sensitivity
  - MTS > Luxel > MCP due to LET dependence
- Larger scatter for Luxels

# II. Biological experiments

# Motivation

# Motivation

- Micro-organisms and plants are important for future long flights
  - Recycling of waste and production of food and oxygen
  - Negative effect on the crew health by causing infections
  - Bacteria with biodegradative and biocorrosive properties may jeopardize the integrity of the spatial hardware

# Motivation

- Micro-organisms and plants are important for future long flights
  - Recycling of waste and production of food and oxygen
  - Negative effect on the crew health by causing infections
  - Bacteria with biodegradative and biocorrosive properties may jeopardize the integrity of the spatial hardware

- Response of micro-organisms and plants to space conditions
  - Microgravity
  - Vibrations during launch
  - Changed electromagnetic field
  - Ionizing radiation

# FOTON-M4

# FOTON-M4

- July 18 – September 1 2014

# FOTON-M4

- July 18 – September 1 2014

- FOTON-M4 satellite
  - 250 – 550 km altitude (415 km for ISS)
  - 64.9° inclination (51.6° for ISS)

# FOTON-M4

- July 18 – September 1 2014

- FOTON-M4 satellite
  - 250 – 550 km altitude (415 km for ISS)
  - 64.9° inclination (51.6° for ISS)

- Detectors
  - MTS-6, MTS-7, MCP-6, MCP-7

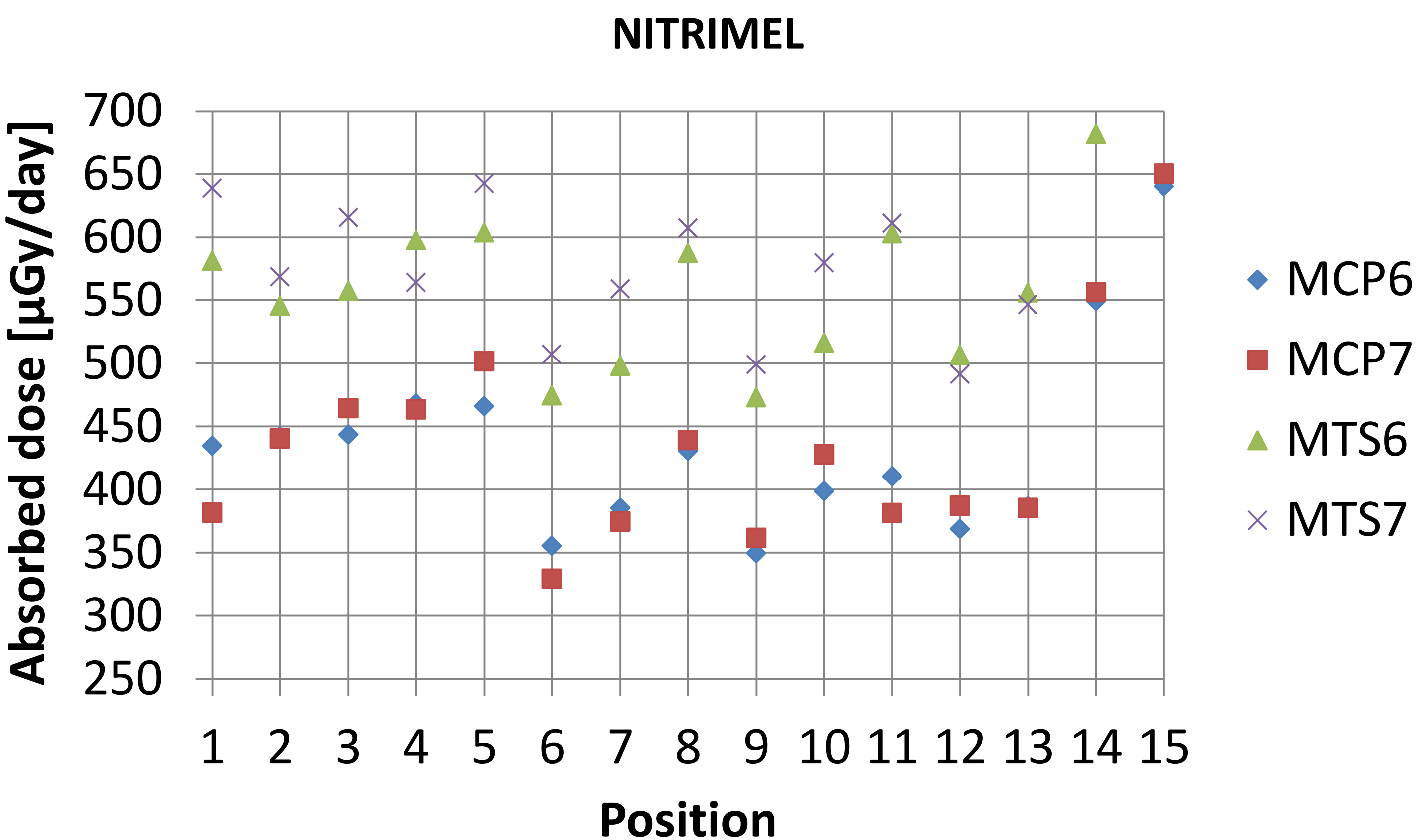
# FOTON-M4

- July 18 – September 1 2014
- FOTON-M4 satellite
  - 250 – 550 km altitude (415 km for ISS)
  - 64.9° inclination (51.6° for ISS)
- Detectors
  - MTS-6, MTS-7, MCP-6, MCP-7
- Experimental goals
  - NITRIMEL: Microgravity effect on nitrifying MELiSSA bacteria
  - pre-BIOROCK: Microgravity effect on Cupriavidus metallidurans CH34

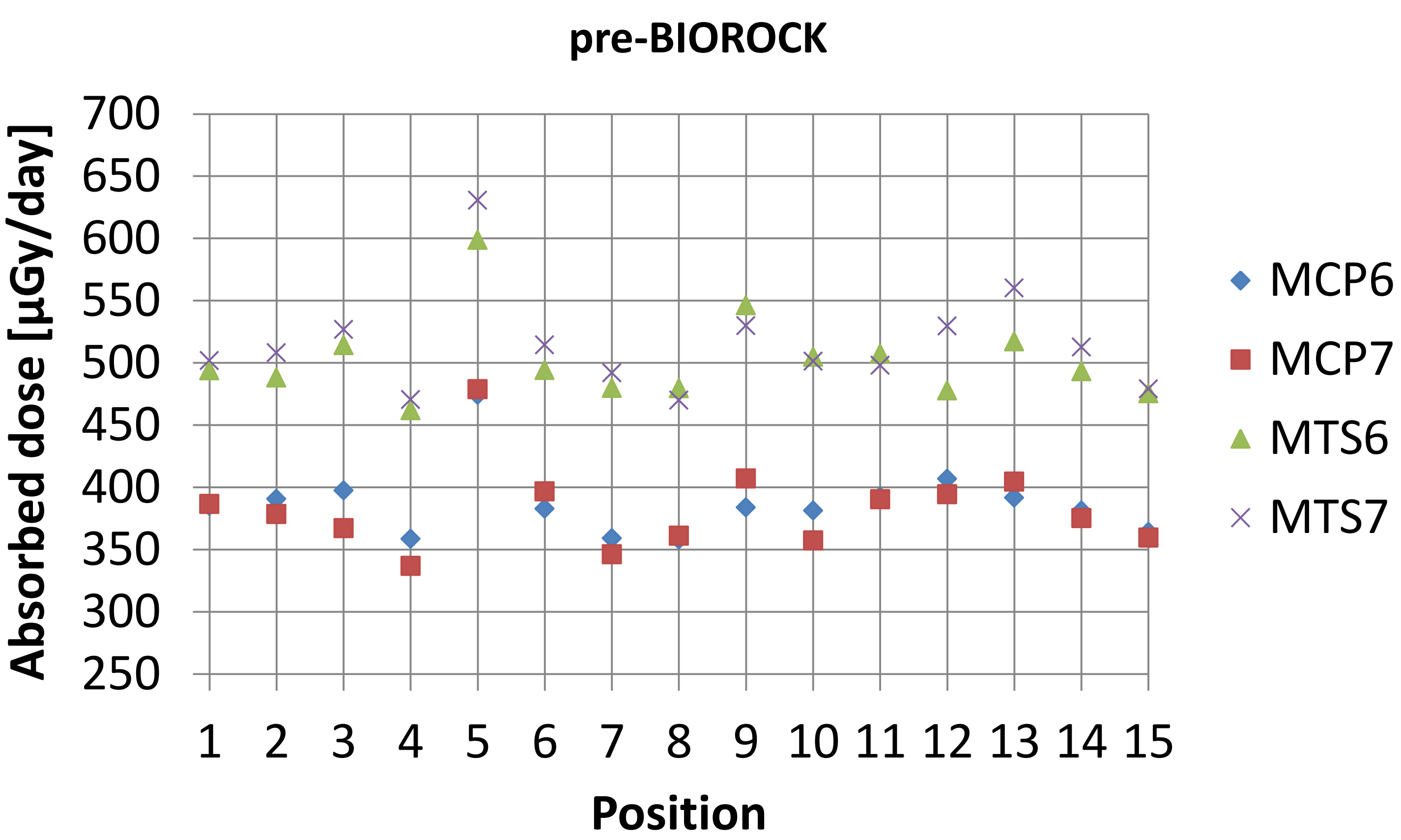
# FOTON-M4

[1] http://www.spaceflight101.com/

# FOTON-M4


NITRIMEL
Absorbed dose [µGy/day]
700
650
600
550
500
450
400
350
300
250
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Position
MCP6
MCP7
MTS6
MTS7

# FOTON-M4


pre-BIOROCK
Absorbed dose [µGy/day]
700
650
600
550
500
450
400
350
300
250
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Position
MCP6
MCP7
MTS6
MTS7

# FOTON-M4

| | FOTON-M4 | DOSIS 3D V |
|---|---|---|
| **Average** | 566 µGy/day | 245 µGy/day |
| **Standard deviation** | 27% | 11% |
| **Minimum** | 329 µGy/day | 196 µGy/day |
| **Maximum** | 1047 µGy/day | 313 µGy/day |
| **MTS7/MTS6** | 1.06 | 0.92 |
| **MCP7/MCP6** | 0.99 | 0.94 |
| **MTS7/MCP7** | 1.38 | 1.20 |

# FOTON-M4

# FOTON-M4

- Significantly higher absorbed doses compared to ISS
  - Lower shielding
  - Higher altitude
  - Higher inclination

# FOTON-M4

- Significantly higher absorbed doses compared to ISS
  - Lower shielding
  - Higher altitude
  - Higher inclination

- MTS7 > MTS6
  - Low statistics
  - Systematic shielding of detectors by each other

# FOTON-M4

- Significantly higher absorbed doses compared to ISS
  - Lower shielding
  - Higher altitude
  - Higher inclination

- MTS7 > MTS6
  - Low statistics
  - Systematic shielding of detectors by each other

- MTS/MCP is higher than for DOSIS 3D
  - Lower shielding

# BISTRO

- September 2 – September 12 2015

# BISTRO

- September 2 – September 12 2015

- Soyuz 44 => ISS => Soyuz 42

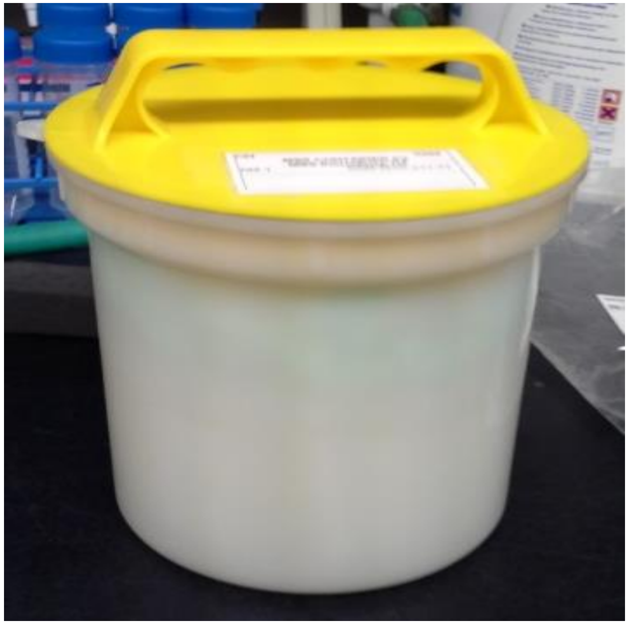
# BISTRO

- September 2 – September 12 2015
- Soyuz 44 => ISS => Soyuz 42
- Detectors
  - SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7
  - NPI: CR-39

# BISTRO

- September 2 – September 12 2015
- Soyuz 44 => ISS => Soyuz 42
- Detectors
  - SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7
  - NPI: CR-39
- Experimental goals
  - Exposure of key MELiSSA micro-organisms
  - Can they withstand space travel in a metabolically inactive state?
  - Are they fully functional upon reactivation after the flight?

# BISTRO



# ARTEMISS-B/C

- End 2016

# ARTEMISS-B/C

- End 2016
- SpaceX capsule => ISS => Soyuz

# ARTEMISS-B/C

- End 2016
- SpaceX capsule => ISS => Soyuz
- Detectors
  - SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7, Luxel
  - NPI: $CaSO_4$:Dy, $Al_2O_3$:C, CR-39

# ARTEMISS-B/C

- End 2016
- SpaceX capsule => ISS => Soyuz
- Detectors
  - SCK•CEN: MTS-6, MTS-7, MCP-6, MCP-7, Luxel
  - NPI: $CaSO_4$:Dy, $Al_2O_3$:C, CR-39
- Experimental goals
  - Effect of spaceflight conditions on MELiSSA bacteria for $CO_2$ and nitrate removal and oxygen and biomass production

# Conclusions and outlook

# Conclusions and outlook

# Conclusions and outlook

- SCK•CEN has been involved in many space experiments using TLDs and OSLDs
  - DOSIS and DOSIS 3D
  - Biological experiments

# Conclusions and outlook

- SCK•CEN has been involved in many space experiments using TLDs and OSLDs
  - DOSIS and DOSIS 3D
  - Biological experiments

- The dose values and their trends with orbital parameters, solar activity, shielding and detector type are consistent

# Conclusions and outlook

- SCK•CEN has been involved in many space experiments using TLDs and OSLDs
  - DOSIS and DOSIS 3D
  - Biological experiments

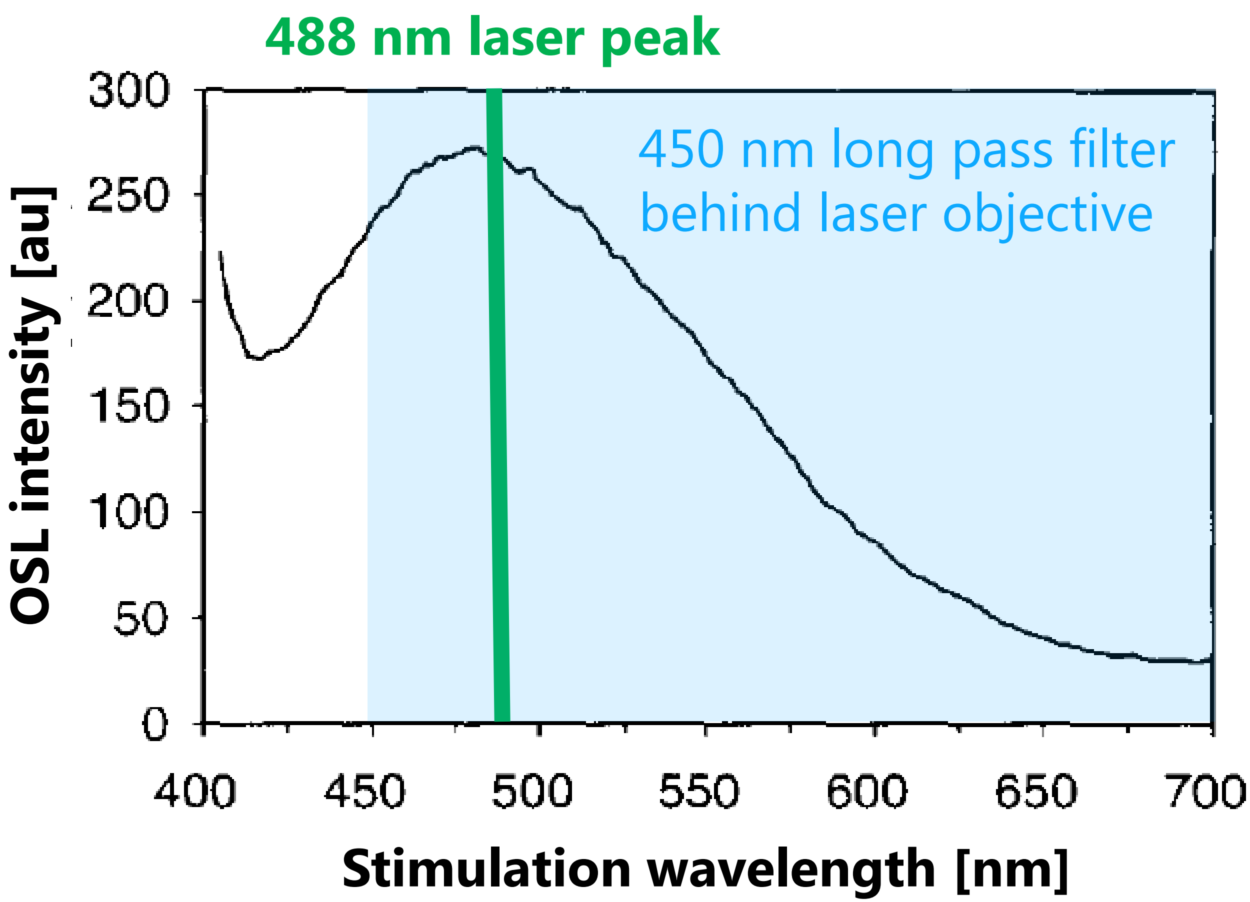
- The dose values and their trends with orbital parameters, solar activity, shielding and detector type are consistent

- We will continue to collaborate with the DOSIS 3D and biological experiments

# Conclusions and outlook

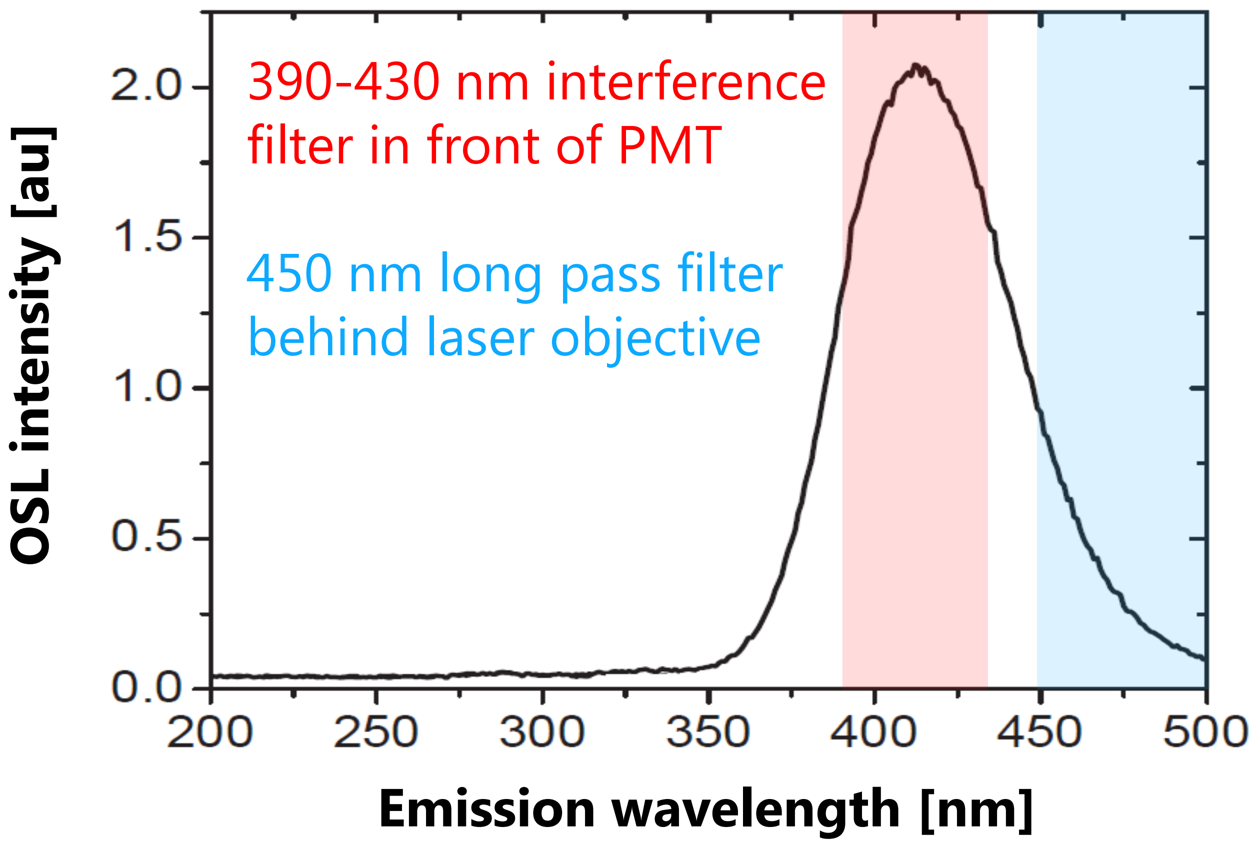
- SCK•CEN has been involved in many space experiments using TLDs and OSLDs
  - DOSIS and DOSIS 3D
  - Biological experiments
- The dose values and their trends with orbital parameters, solar activity, shielding and detector type are consistent
- We will continue to collaborate with the DOSIS 3D and biological experiments
- A PhD student is starting in October 2015 to investigate the LET dependence of glow curves and OSL decay curves

# Optically stimulated luminescence detectors




*[1] Optically Stimulated Luminescence Dosimetry, Botter-Jensen L., McKeever S. W. S. and Wintle A. G., 2003, Elsevier*

# Optically stimulated luminescence detectors




[1] *Optically Stimulated Luminescence, Fundamentals and Applications, Yukihara E. G. et al., 2011, John Wiley & Sons Ltd*

# III. Weather balloon experiment

# Weather balloon experiment

# Weather balloon experiment

- June 29 2015

# Weather balloon experiment

- June 29 2015
- Helium balloon with instrumentation box attached
  - ± 90 min ascending up to ± 30 km height
  - ± 30 min descending with parachute

# Weather balloon experiment

- June 29 2015
- Helium balloon with instrumentation box attached
  - ± 90 min ascending up to ± 30 km height
  - ± 30 min descending with parachute
- Detectors
  - MCP-N
  - EPD-N2
    - Si PIN diode with H rich polymer shield => fast neutrons
    - Si PIN diode with $^{6}Li$ shield => slow neutrons
    - bare Si PIN diode => gamma's (+ electrons, protons, muons ?)

# Weather balloon experiment

- June 29 2015
- Helium balloon with instrumentation box attached
  - ± 90 min ascending up to ± 30 km height
  - ± 30 min descending with parachute
- Detectors
  - MCP-N
  - EPD-N2


    - Si PIN diode with  H rich polymer shield => fast neutrons
    - Si PIN diode with $^{6}$Li shield  => slow neutrons
    - bare Si PIN diode => gamma's (+ electrons, protons, muons ?)

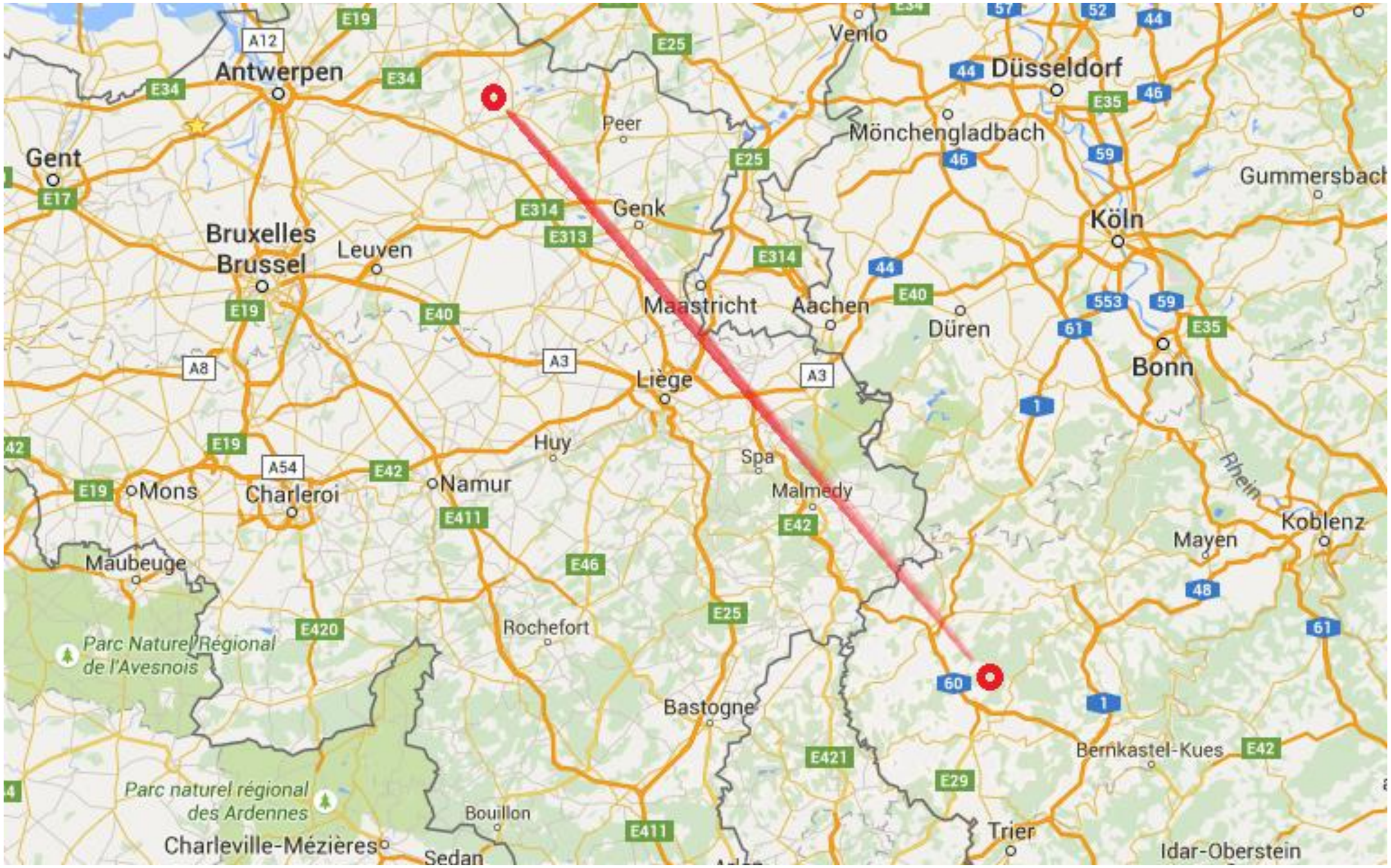
# Weather balloon experiment

- June 29 2015
- Helium balloon with instrumentation box attached
  - ± 90 min ascending up to ± 30 km height
  - ± 30 min descending with parachute
- Detectors
  - MCP-N
  - EPD-N2

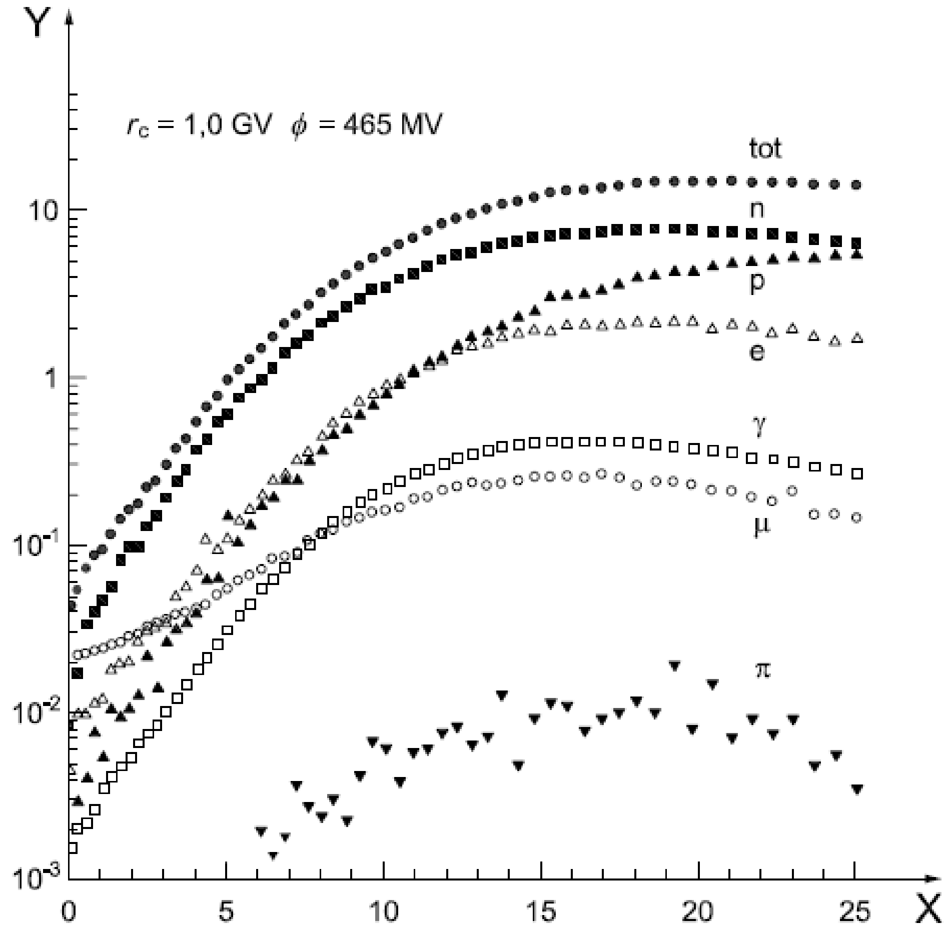

    - Si PIN diode with H rich polymer shield => fast neutrons
    - Si PIN diode with $^{6}$Li shield => slow neutrons
    - bare Si PIN diode => gamma's (+ electrons, protons, muons ?)
- Experimental goal
  - Comparison of radiation field on the ground and in the stratosphere

# Weather balloon experiment

# Flight path


Antwerpen
Gent
Bruxelles
Brussel
Leuven
Peer
Genk
Venlo
Düsseldorf
Mönchengladbach
Köln
Gummersbach
Maastricht
Aachen
Düren
Bonn
Liège
Huy
Spa
Malmedy
Namur
Charleroi
Mons
Maubeuge
Rochefort
Bastogne
Mayen
Koblenz
Rhein
Bernkastel-Kues
Trier
Idar-Oberstein
Bouillon
Sedan
Charleville-Mézières
Parc Naturel Régional de l'Avesnois
Parc naturel régional des Ardennes

# Contribution of the different particles to radiation field



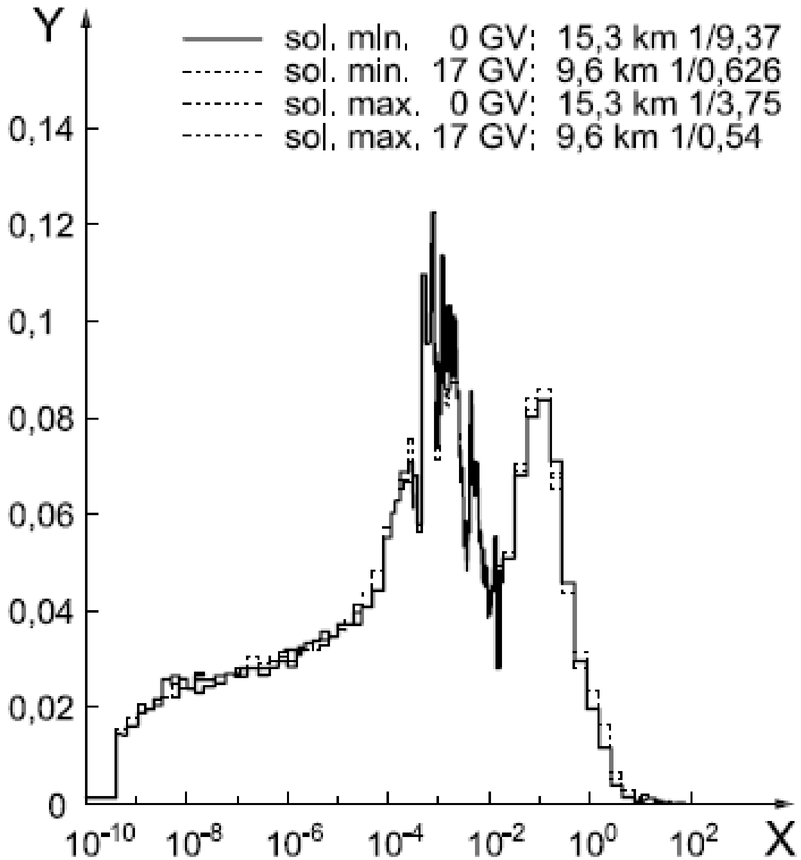

**Key**

X altitude (km)

Y ambient dose equivalent rate (µSv/h)

*[1] ISO 20785-1, Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 2: Characterization of instrument response*

# Neutron energy spectrum




**Key**

X energy (GeV)

Y normalized fluence rate of neutrons

*[1] ISO 20785-1, Dosimetry for exposures to cosmic radiation in civilian aircraft — Part 2: Characterization of instrument response*

# Predicted effective dose based on CARI-6M

[1] *https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/*

# Predicted effective dose based on CARI-6M

- Program developed by the Federal Aviation Administration's Civil Aerospace Medical Institute

*[1] https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/*

# Predicted effective dose based on CARI-6M

- Program developed by the Federal Aviation Administration's Civil Aerospace Medical Institute

- Calculates the effective dose due to galactic cosmic radiation for a given trajectory

*[1] https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/*

# Predicted effective dose based on CARI-6M

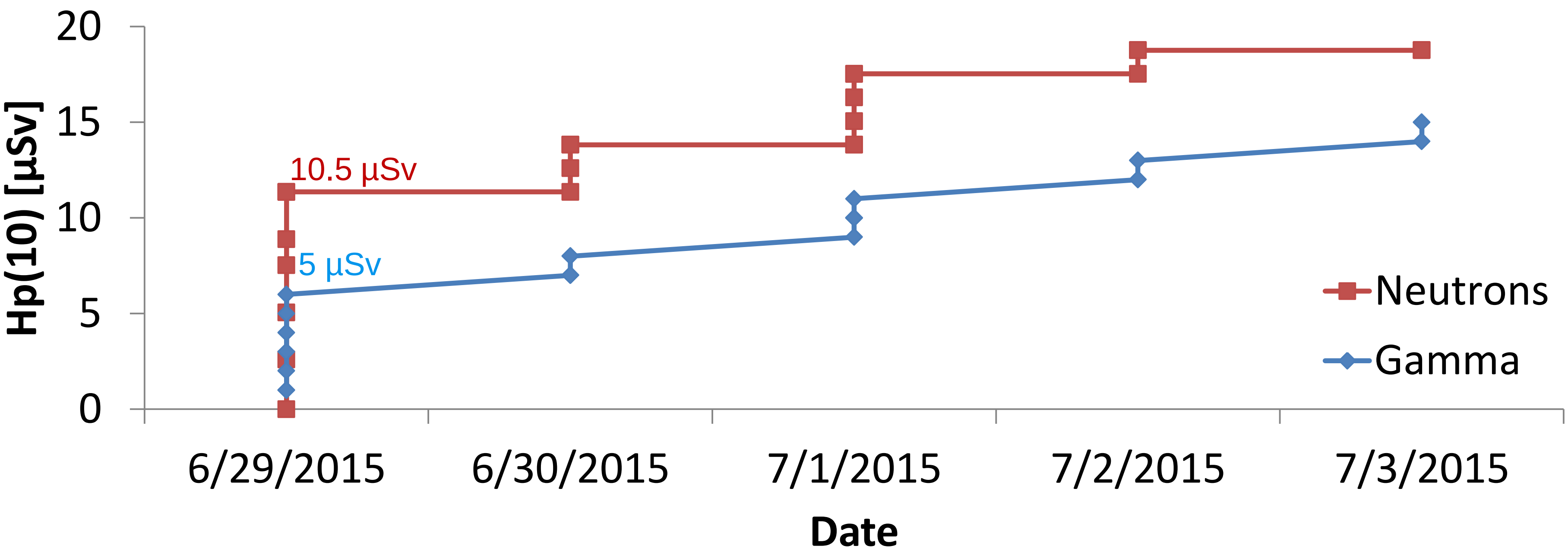
- Program developed by the Federal Aviation Administration's Civil Aerospace Medical Institute

- Calculates the effective dose due to galactic cosmic radiation for a given trajectory

- Total effective dose of 12.8 μSv in two hours

*[1] https://www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/*

# EPD-N2 results




- 1.5 h with significantly elevated dose rate
- Shown values take into account the EPD-N2's overresponse for the high energy neutron field with factor of ±8 [1]

*[1] Radiation Protection Dosimetry (2015), Vol. 163, No. 4, pp. 415–423*

# Results overview

# Results overview

- EPD-N2
  - 10.5 µSv neutron dose
  - 5 µSv gamma dose (+ electrons, protons, muons ?)
  - 15.5 µSv total dose

# Results overview

- EPD-N2
  - 10.5 µSv neutron dose
  - 5 µSv gamma dose (+ electrons, protons, muons ?)
  - 15.5 µSv total dose

- MCP-N
  - 9.0 ± 0.6 µGy absorbed dose

# Results overview

- EPD-N2
  - 10.5 µSv neutron dose
  - 5 µSv gamma dose (+ electrons, protons, muons ?)
  - 15.5 µSv total dose
- MCP-N
  - 9.0 ± 0.6 µGy absorbed dose
- CARI-6M prediction
  - 12.8 µSv total effective dose