DOSIS & DOSIS 3D onboard the ISS
Status and Science Overview from 2009 - 2018

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DOSIS & DOSIS 3D: Science Team

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[5]ATI	Technical University Vienna	Vienna, Austria
[6]MTA EK	Centre for Energy Research	Budapest, Hungary
[7]NPI	Nuclear Physics Institute	Prague, Czech Republic
[8]SCK•CEN	Belgian Nuclear Research Center	Mol, Belgium
[9]NASA	Space Radiation Analysis Group	Houston, United States
[10]OSU	Oklahoma State University	Stillwater, United States
[11]NIRS	National Institute of Radiological Sciences	Chiba, Japan
[12]IMBP	Russian Academy of Sciences	Moscow, Russia
[13]JAXA	Japan Aerospace Exploration Agency	Tsukuba, Japan
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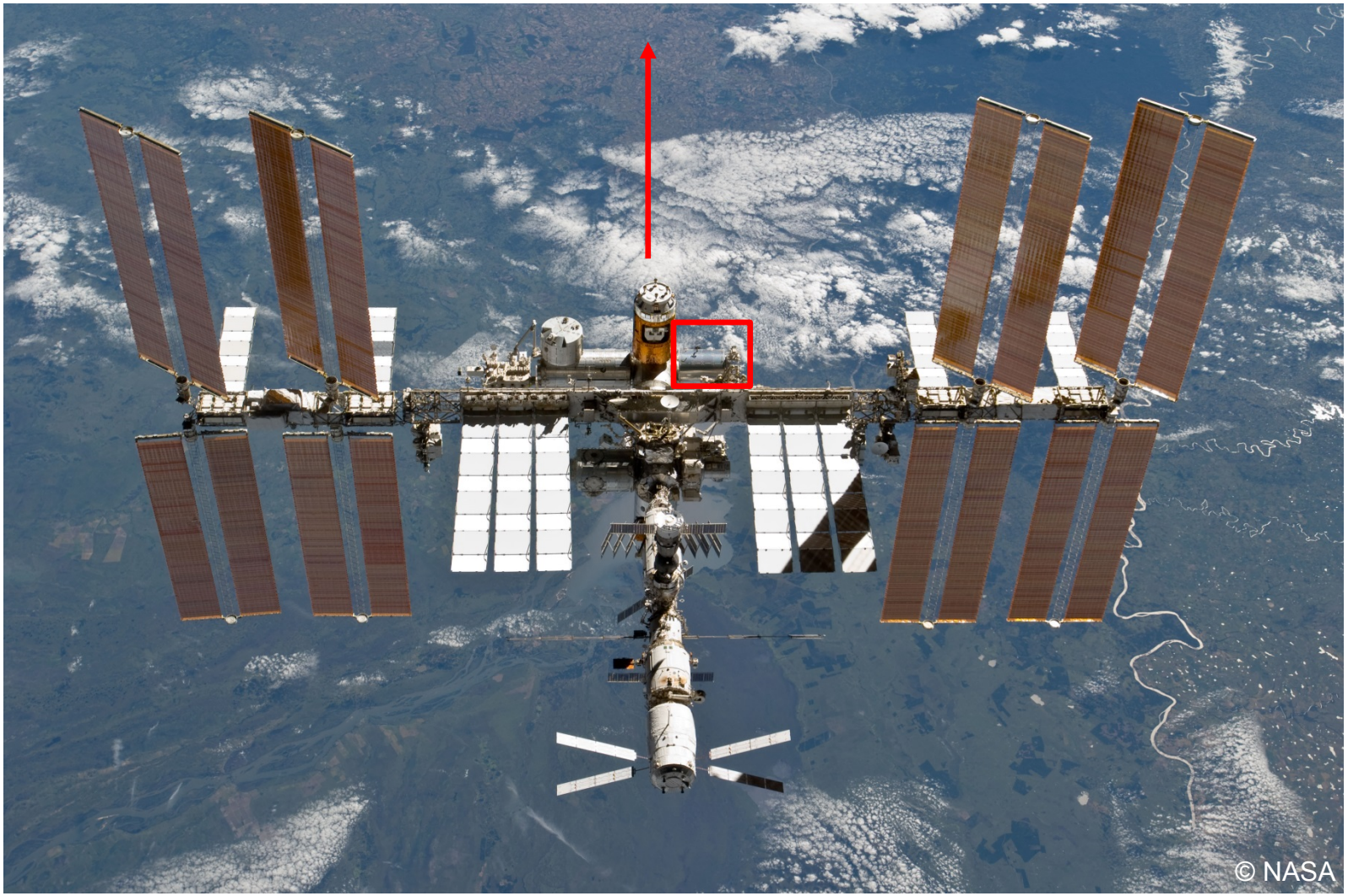
DOSIS & DOSIS 3D: Columbus

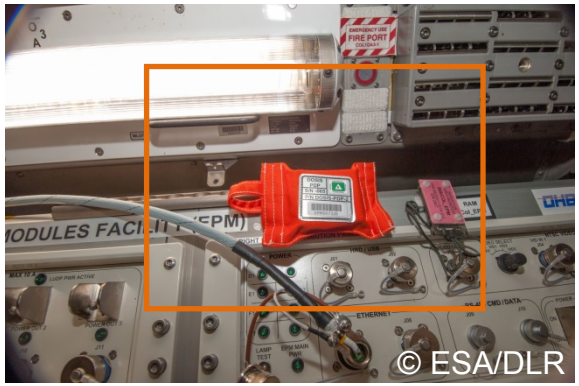


DOSIS & DOSIS 3D: Scientific Goals

The main objective of the **DOSIS & DOSIS 3D** experiment is the determination of the absorbed dose and dose equivalent using a variety of active and passive radiation detector devices distributed throughout the ISS.

- Monitor the radiation environment inside Columbus with **active** and **passive** radiation detectors for the determination of the temporal and spatial dose distribution

- Combine data gathered by NASA, JAXA, IMBP into a 3D radiation map of the International Space Station



DOSIS & DOSIS 3D: Active detectors (2 x DOSimetry TELescope)

Dosis Main Box
DOSIS-MAIN-1-001

C | A | U

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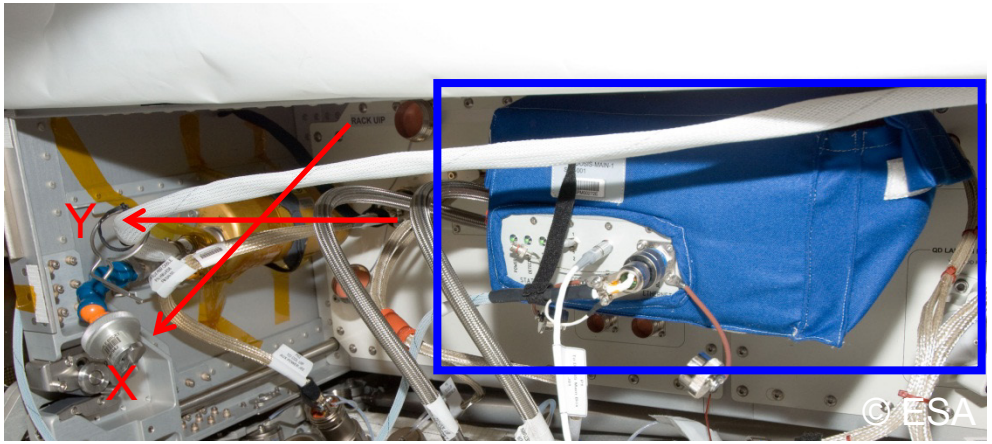

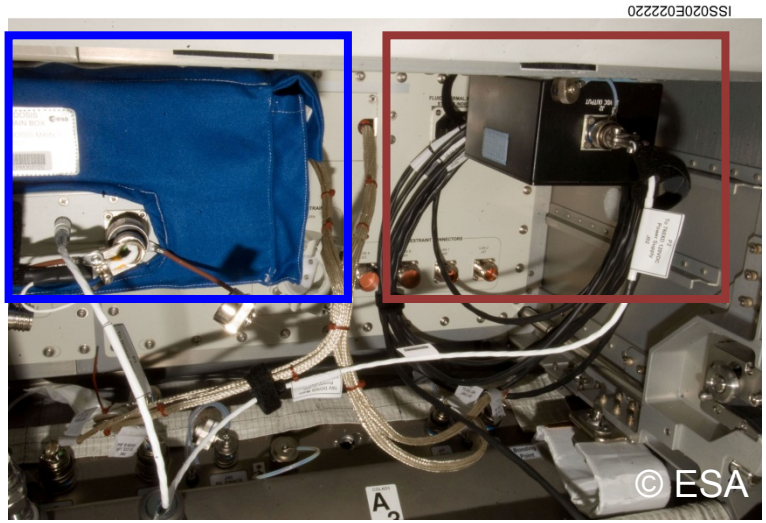

- Ethernet connection to EPM rack "Right Utility Distribution Panel“
- DOSIS-MAIN-BOX connected to EPM LAN like an external EPM instrument
- Data downlink is an EPM operation from ground performed once per month over CADMOS – COLCC – MUSC – Scientists
- Up to July 2018: 71 data downlinks (**DOSIS 3D**)

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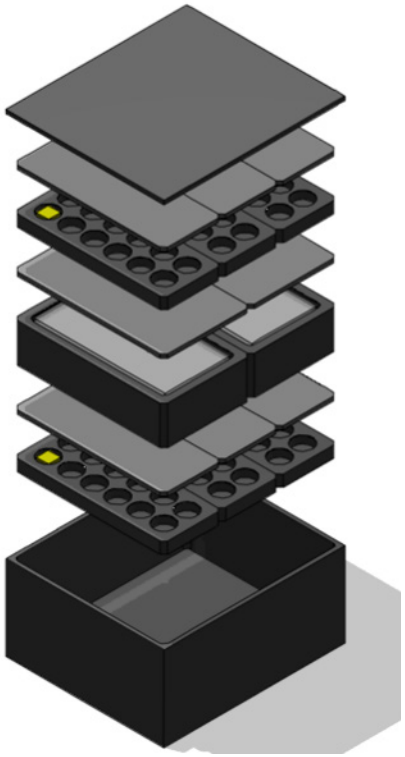
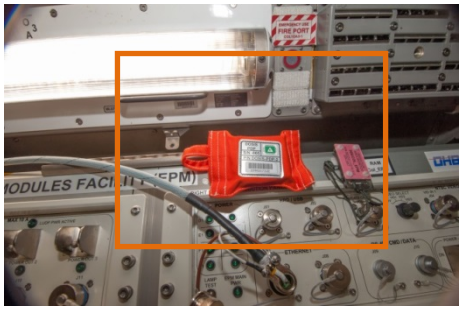
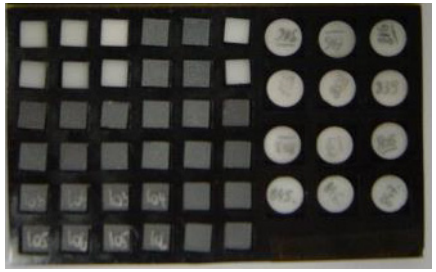
DOSIS & DOSIS 3D: Passive Detector Packages (PDP)





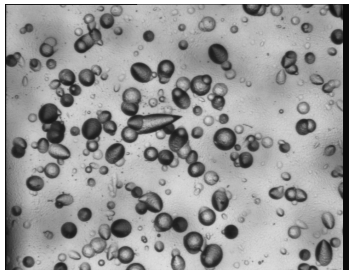


Thermoluminescence detectors (TLD) / OSLD

First usage of LiF (Lithiumfluoride) for the measurement of radiation following an atomic weapon test

Measurement of internal radiation dose received by cancer patients treated with radioactiv isotopes at Oak Ridge Institute for Nuclear Studies

F. Daniels *Science* **117**, 343, **1953**



Nuclear Track Etch Detectors (CR-39)

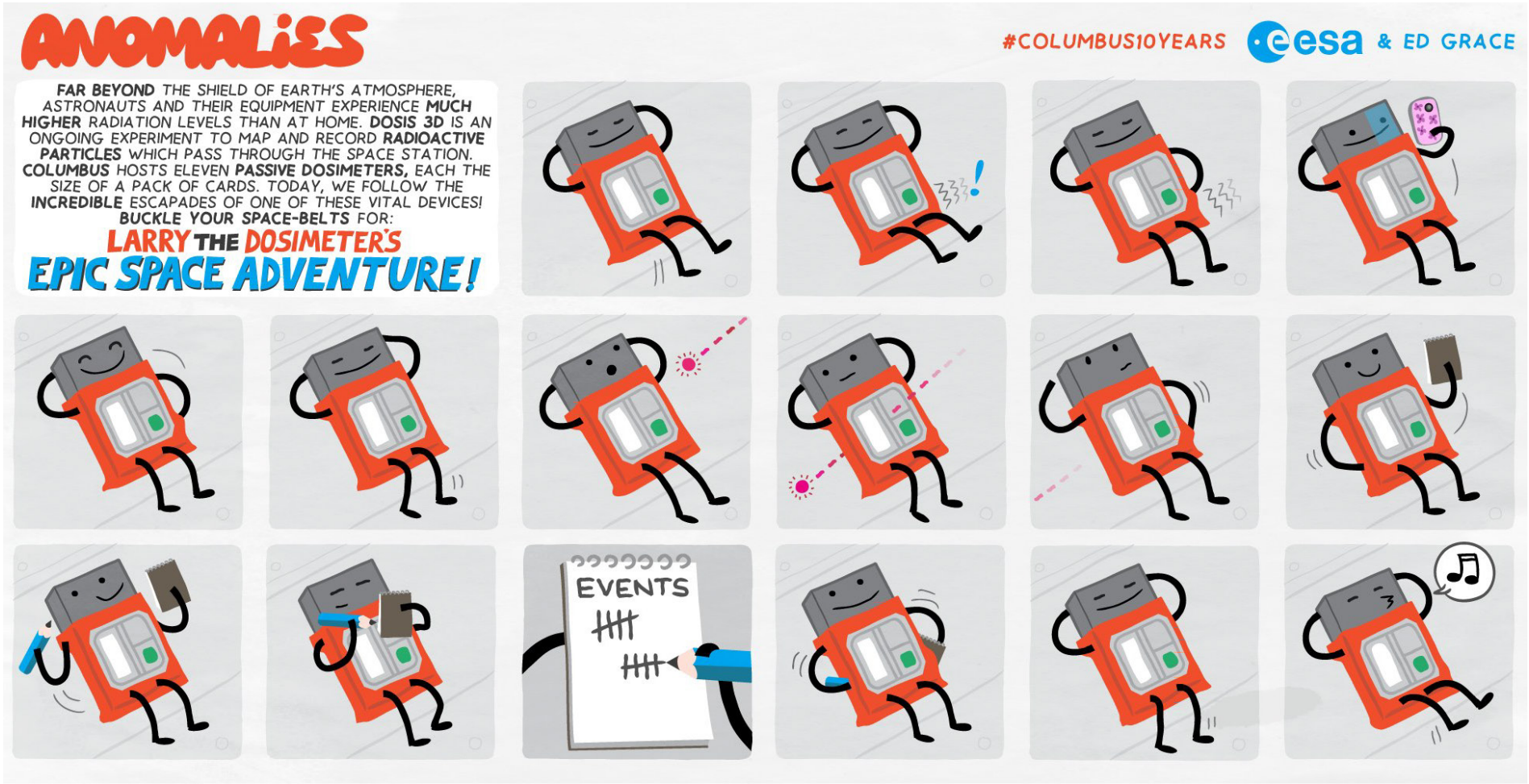
Material : CR-39 = allyl diglycol carbonate

Heavy charged particles break chemical bonds in the material.This trail can be made visible by etching the material.

R. P. Henke and E. V. Benton, Nucl.Instr.Meth. 97 (**1971**) 483-9

TLD/OSLD + CR-39 → Absorbed dose + Dose Equivalent

DOSIS & DOSIS 3D: Passive Detector Packages (PDP)

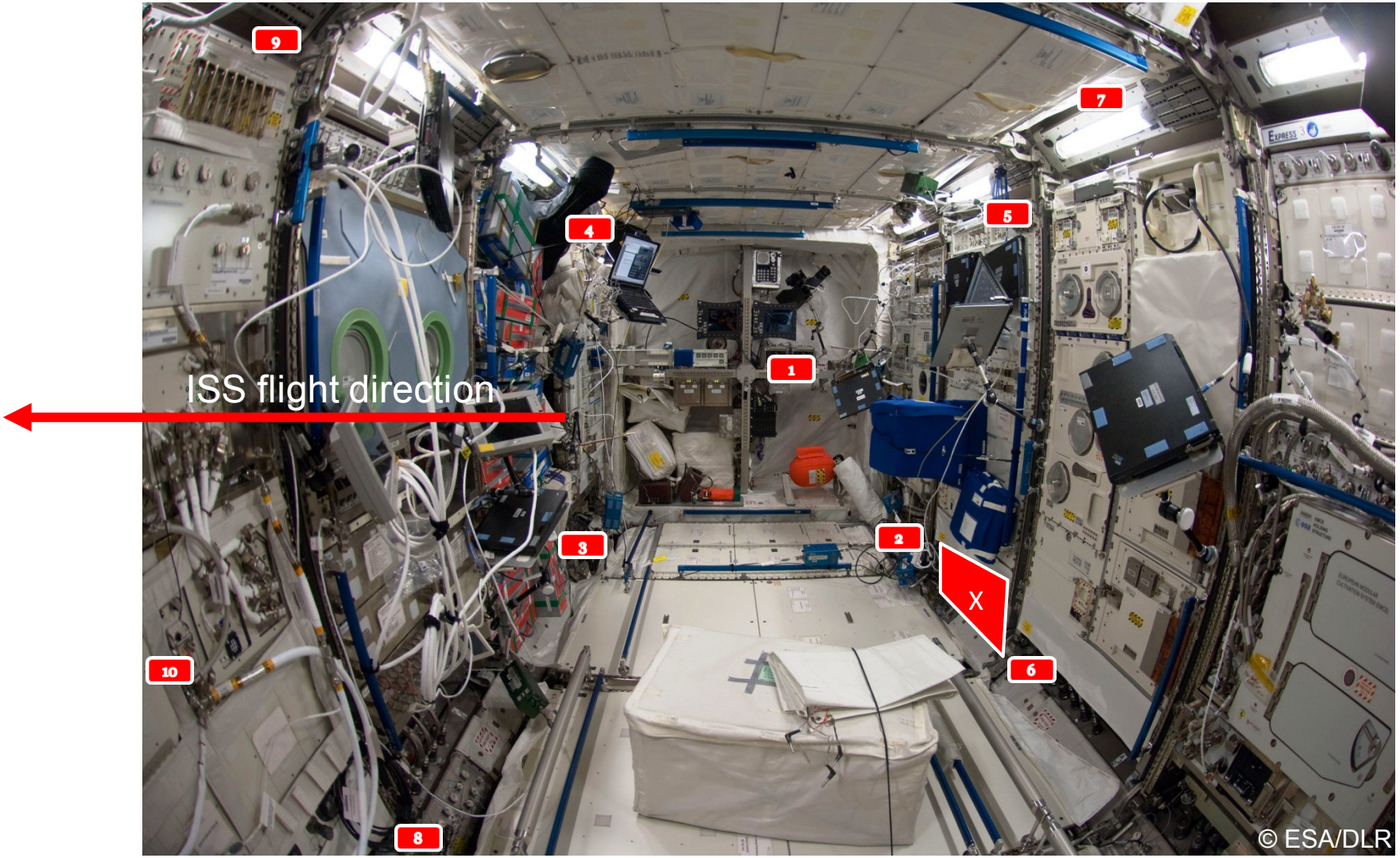


https://twitter.com/esaspaceflight/status/1024685877635817473

DOSIS & DOSIS 3D: PDP Positions

PDP Nr	Columbus Location	Related Rack	Position		Columbus coordinate system [cm]		
					X	Y	Z
1	Star Cone	-	Behind bend in right cone structure	Aft	681	-57	0
2	A4 UIP	HRF 2	Left side on UIP next to Vacuum connector	Aft	665	-123	-93
3	F4 UIP	HRF 1	Left side on UIP next to Vacuum connector	Forward	570	123	-93
4	B1 HRF 1	HRF 1	Front panel of Cooling Stowage Drawer	Forward	600	104	60
5	A3 EPM	EPM	410 mm left from upper right edge	Aft	463	-104	93
6	A2 UIP	BLB	Left side on UIP next to Vacuum connector	Aft	436	-123	-93
7	O2 UIP	-	Left side on UIP next to Vacuum connector	Aft	436	-101	106
8	F1 UIP	EDR	Left side on UIP next to Vacuum connector	Forward	243	123	-93
9	F1 EDR	EDR	77 mm left from upper right edge	Forward	333	104	93
10	End Cone	-	On PBA Cover	Forward	221	95	85
X	DOSIS-MAIN-BOX	EPM	On the left side of the DOSIS-MAIN-BOX	Aft	516	-116	-60

DOSIS & DOSIS 3D: PDP Positions



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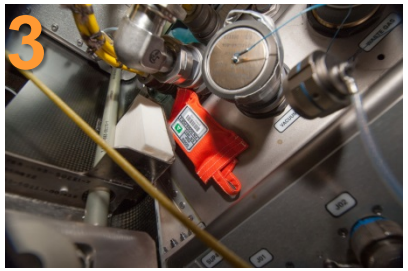
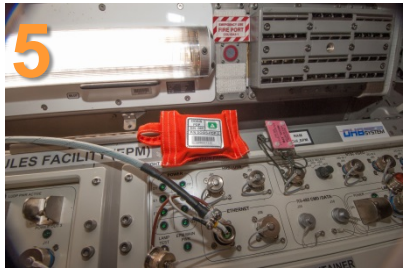
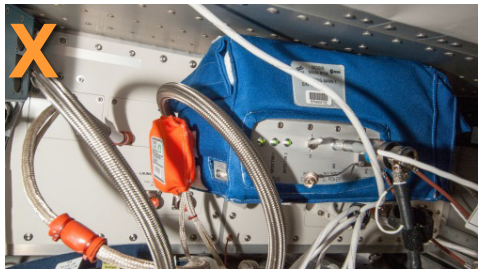
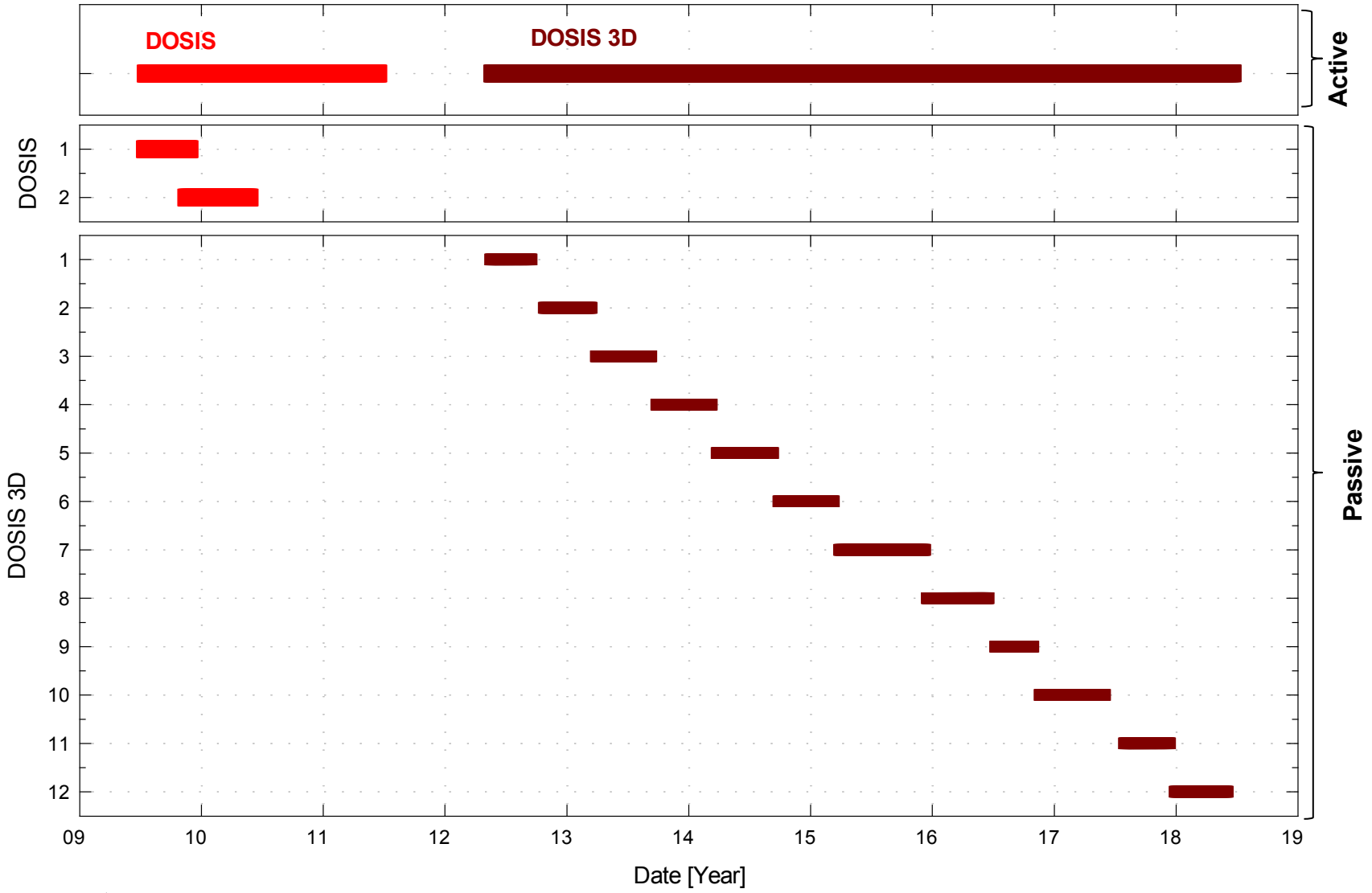
DOSIS & DOSIS 3D: PDP Positions







DOSIS & DOSIS 3D: Timeline



DOSIS & DOSIS 3D: Timeline → Active

Experiment	Detector	Timeline		Measurement period	Data [days]	ISS altitude [km]
DOSIS (Active)	DOSTEL-1	Launch (STS-127)	July 15, 2009	July 18, 2009 - May 28, 2010	290	337-350
		Installation	July 18, 2009			
		Activation	July 18, 2009			
		Retrieval	April 21, 2011			
		Return (Soyuz-25S)	May 24, 2011			
	DOSTEL-2	Launch (STS-127)	July 15, 2009	July 18, 2009 - June 16, 2011	645	337-375
		Installation	July 18, 2009			
		Activation	July 18, 2009			
		Retrieval	June 17,2011			
		Return (STS-135)	July 21, 2011			
DOSIS 3D (*) (Active)	DOSTEL-1	Launch (Soyuz-30S)	May 15, 2012	May 21, 2012 – August 19, 2018	2281	398-418
	DOSTEL-2	Installation	May 21, 2012	May 21, 2012 – August 16, 2018	2278	
		Activation	May 21, 2012			

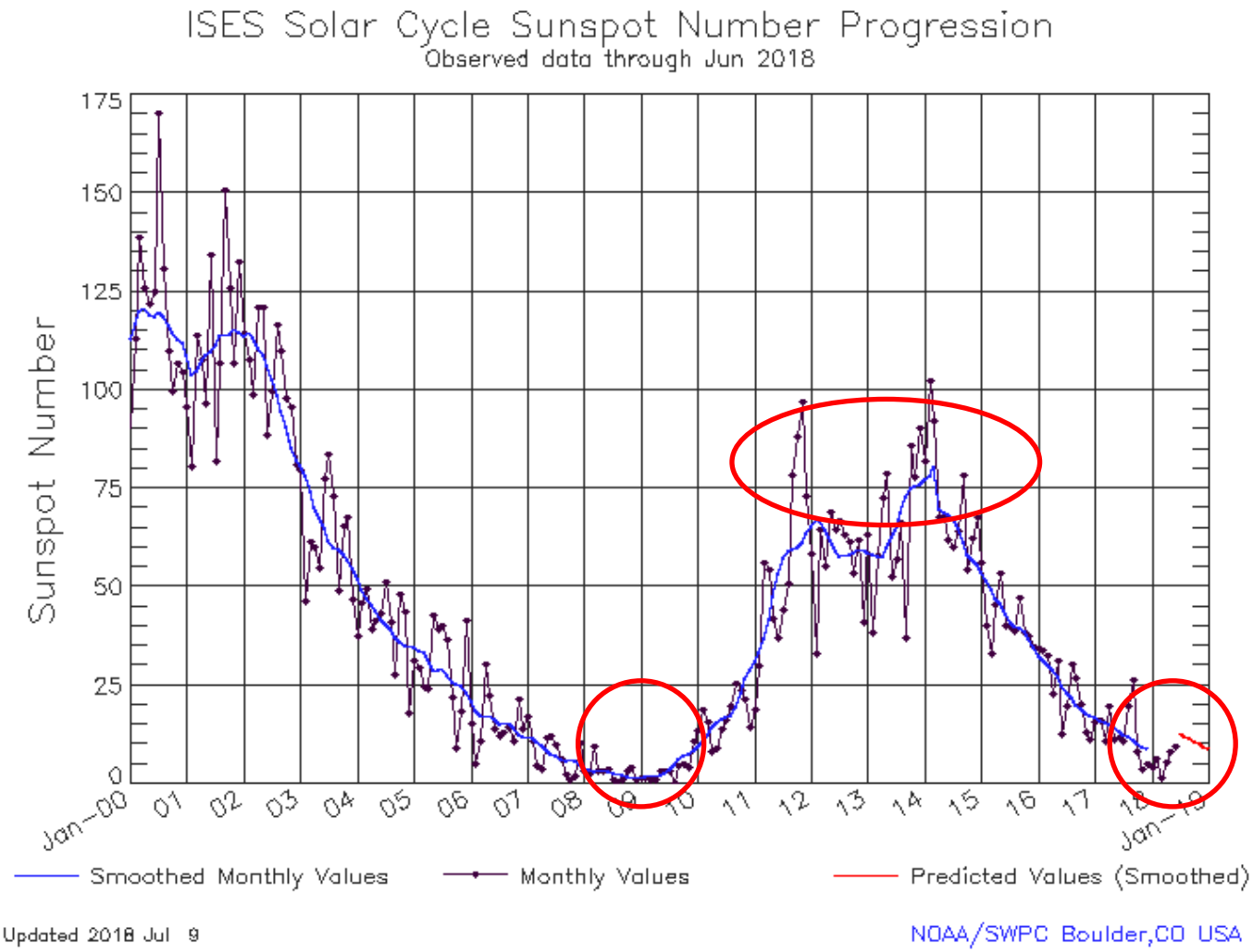
(*) up to 73rd data downlink performed August 23rd 2018

DOSIS & DOSIS 3D: Timeline → Passive

Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS (Passive)	1	Launch (STS-127) Installation Retrieval Return (STS-129)	July 15, 2009 July 18, 2009 November 21, 2009 November 27, 2009	136	**127**	**93**	339-348
	2	Launch (STS-129) Installation Retrieval Return (STS-132)	November 16, 2009 November 21, 2009 May 18, 2010 May 26, 2010	191	**178**	**93**	337-349

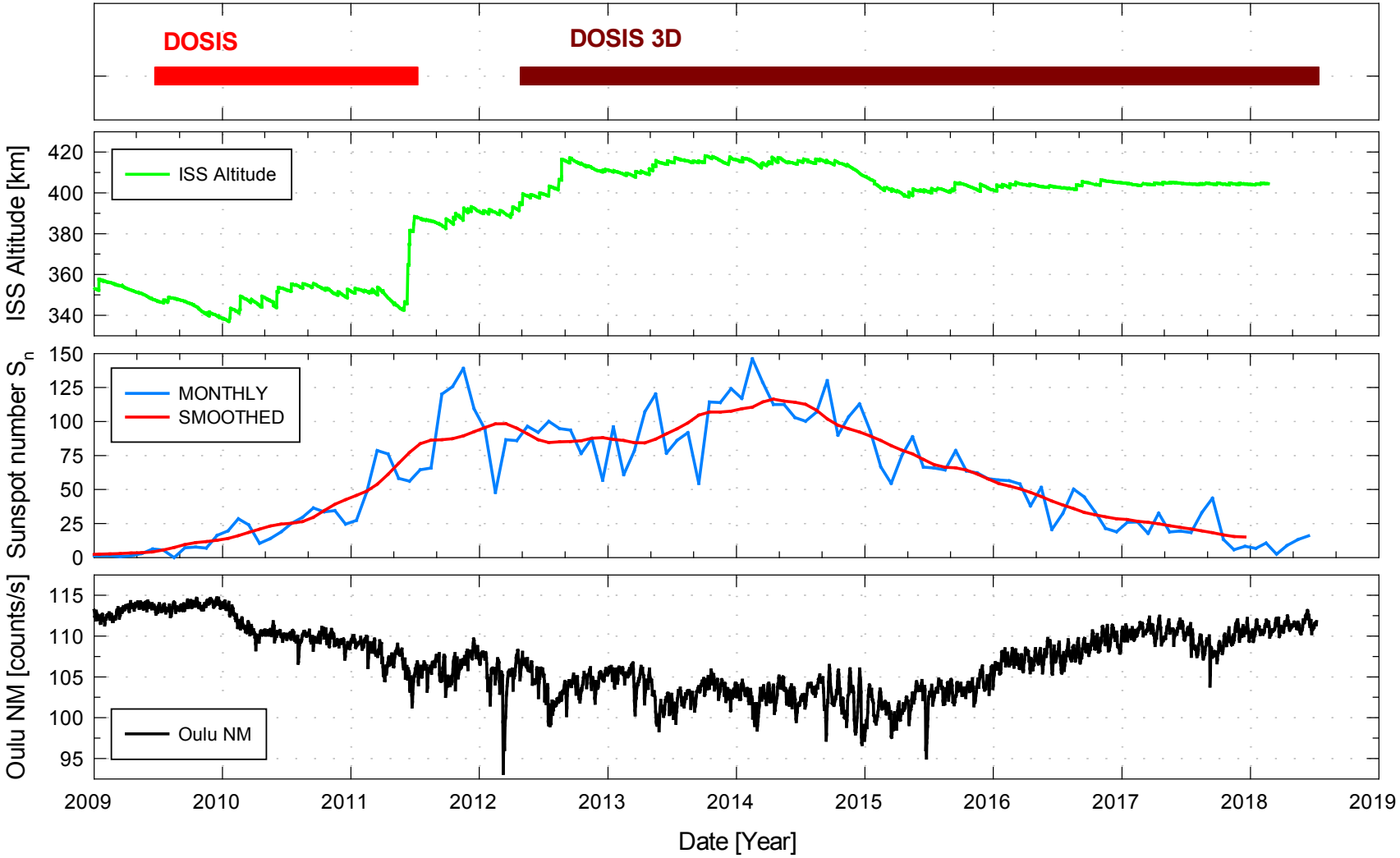
Experiment	Phase	Timeline		Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS 3D (Passive)	1	Launch (Soyuz 30S) Installation Retrieval Return (Soyuz 30S)	May 15, 2012 May 21, 2012 September 11, 2012 September 17, 2012	125	**113**	**90**	397-417
	2	Launch (Soyuz 32S) Installation Retrieval Return (Soyuz 32S)	October 23, 2012 October 27, 2012 March 13, 2013 March 16, 2013	144	**137**	**95**	407-416
	3	Launch (Soyuz 34S) Installation Retrieval Return (Soyuz 34S)	March 28, 2013 April 03, 2013 September 06, 2013 September 11, 2013	167	**156**	**93**	409-417
	4	Launch (Soyuz 36S) Installation Retrieval Return (Soyuz 36S)	September 25, 2013 October 01, 2013 March 06, 2014 March 11, 2014	167	**156**	**93**	413-418
	5	Launch (Soyuz 38S) Installation Retrieval Return (Soyuz 38S)	March 25, 2014 March 28, 2014 September 05, 2014 September 11, 2014	170	**161**	**95**	413-417
	6	Launch (Soyuz 40S) Installation Retrieval Return (Soyuz 40S)	September 26, 2014 September 27, 2014 March 09, 2015 March 12, 2015	167	**161**	**96**	401-416
	7	Launch (Soyuz 42S) Installation Retrieval Return (Soyuz 43S)	March 27, 2015 March 28, 2015 December 10, 2015 December 11, 2015	259	**256**	**99**	398-405
	8	Launch (Soyuz 45S) Installation Retrieval Return (Soyuz 45S)	December 15, 2015 December 18, 2015 June 15, 2016 June 18, 2016	186	**161**	**97**	401-405
	9	Launch (Soyuz 47S) Installation Retrieval Return (Soyuz 47S)	July 07, 2016 July 09, 2016 October 26, 2016 October 30, 2016	115	**109**	**95**	401-406
	10	Launch (Soyuz 49S) Installation Retrieval Return (Soyuz 49S)	November 17, 2016 November 21, 2016 June 01, 2017 June 02, 2017	197	**192**	**97**	403-406
	11	Launch (Soyuz 51S) Installation Retrieval Return (Soyuz 51S)	July 28, 2017 July 30, 2017 December 12, 2017 December 14, 2017	139	**135**	**97**	404-405
	12	Launch (Soyuz 53S) Installation Retrieval Return (Soyuz 53S)	December, 17, 2017 December 20, 2017 May 30, 2018 June 03, 2018	168	**161**	**96**	403-405

DOSIS & DOSIS 3D: Solar Cycle

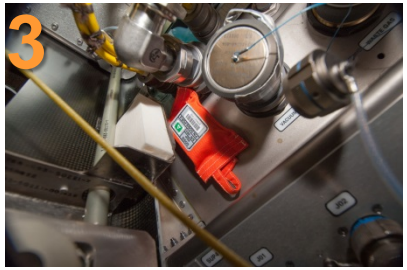


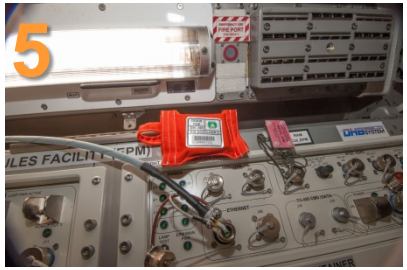
http://www.swpc.noaa.gov/products/solar-cycle-progression

DOSIS & DOSIS 3D: Timeline / ISS Altitude / S_n / Oulu NM



DOSIS & DOSIS 3D: PDP – Results





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DOSIS & DOSIS 3D: PDP – Results

Experiment	Phase	Timeline	Duration [days]	Installed [days]	Installed [%]	ISS altitude [km]
DOSIS (Passive)	1	July 15, 2009 – November 27, 2009	136	**127**	93	339-348
	2	November 16, 2009 – May 26, 2010	191	**178**	93	337-349
DOSIS 3D (Passive)	1	May 15, 2012 – September 17, 2012	125	**113**	90	397-417
	2	October 23, 2012 – March 16, 2013	144	**137**	95	407-416
	3	March 28, 2013 – September 11, 2013	167	**156**	93	409-417
	4	September 25, 2013 – March 11, 2014	167	**156**	93	413-418
	5	March 25, 2014 – September 11, 2014	170	**161**	95	413-417
	6	September 26, 2014 – March 12, 2015	167	**161**	96	401-416
	7	March 27, 2015 – December 11, 2015	259	**256**	99	398-405
	8	December 15, 2015 – June 18, 2016	186	**161**	97	401-405
	9	July 07, 2016 – October 30, 2016	115	**109**	95	401-406
	10	November 17, 2016 – June 02, 2017	197	**192**	97	403-406
	11	July 28, 2017 – December 14, 2017	139	**135**	97	404-405
	12	December 17, 2017 – June 02, 2018	168	**167**	96	403-405

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DOSIS & DOSIS 3D: PDP – Results → Publication

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SWSC

RESEARCH ARTICLE — OPEN ACCESS

DOSIS & DOSIS 3D: long-term dose monitoring onboard the Columbus Laboratory of the International Space Station (ISS)

Thomas Berger[*,1], Bartos Przybyla[1], Daniel Matthiä[1], Günther Reitz[1], Sönke Burmeister[2], Johannes Labrenz[2], Pawel Bilski[3], Tomasz Horwacik[3], Anna Twardak[3], Michael Hajek[4,5], Manfred Fugger[5], Christina Hofstätter[5], Lembit Sihver[5,6], Jozsef K. Palfalvi[7], Julianna Szabo[7], Andrea Stradi[7], Iva Ambrozova[8], Jan Kubancak[8], Katerina Pachnerova Brabcova[8], Filip Vanhavere[9], Vanessa Cauwels[9], Olivier Van Hoey[9], Werner Schoonjans[9], Alessio Parisi[9], Ramona Gaza[10,11], Edward Semones[10], Eduardo G. Yukihara[12], Eric R. Benton[12], Brandon A. Doull[12], Yukio Uchihori[13], Satoshi Kodaira[13], Hisashi Kitamura[13], and Matthias Boehme[14]

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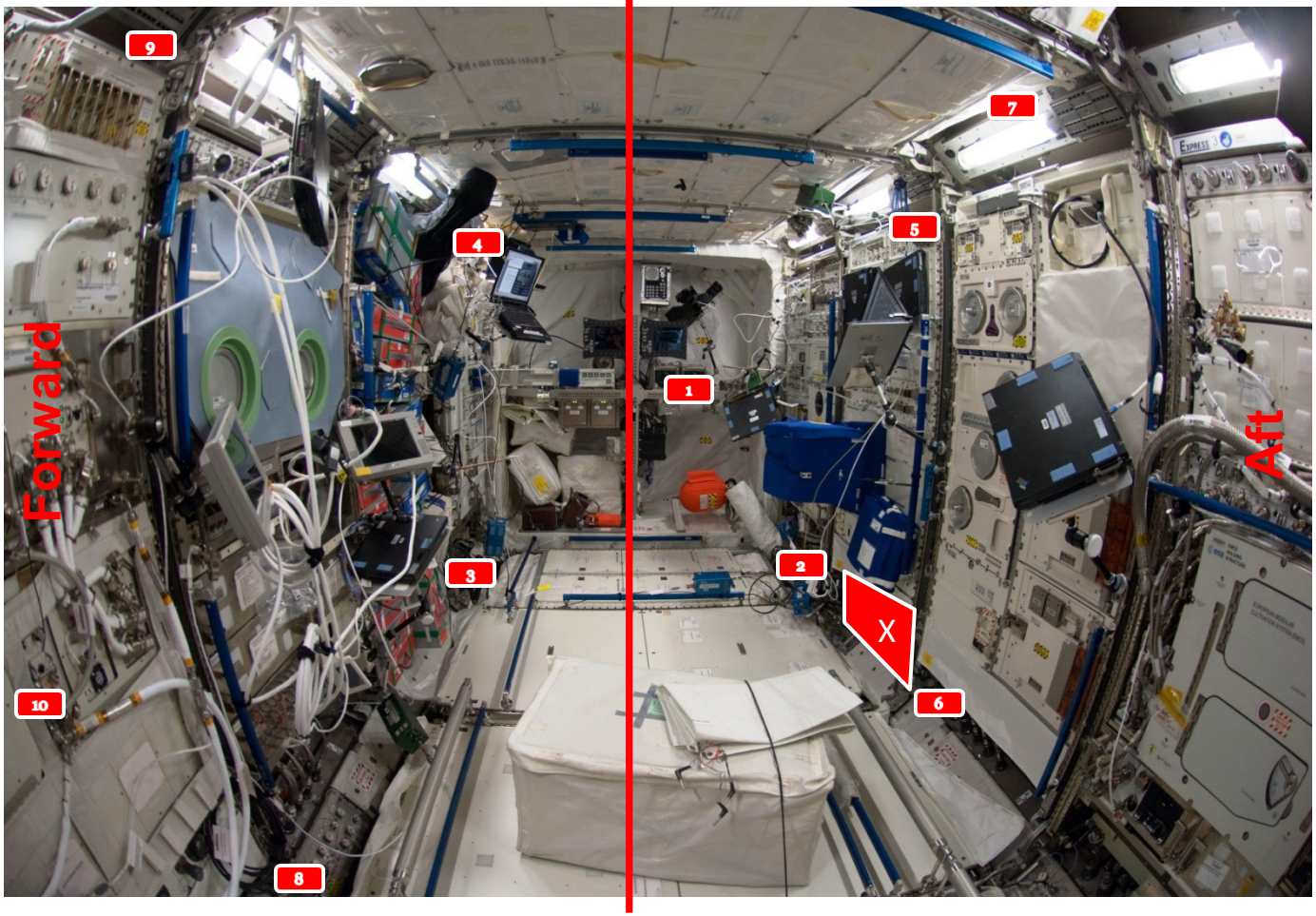
https://www.swsc-journal.org/articles/swsc/full_html/2016/01/swsc160033/swsc160033.html

DOSIS & DOSIS 3D: PDP – Results (Selected)



DLR ATOMINSTITUT SCK•CEN mtaEK NIRS OKLAHOMA STATE UNIVERSITY NASA Nuclear Physics Institute of the CAS public research institution

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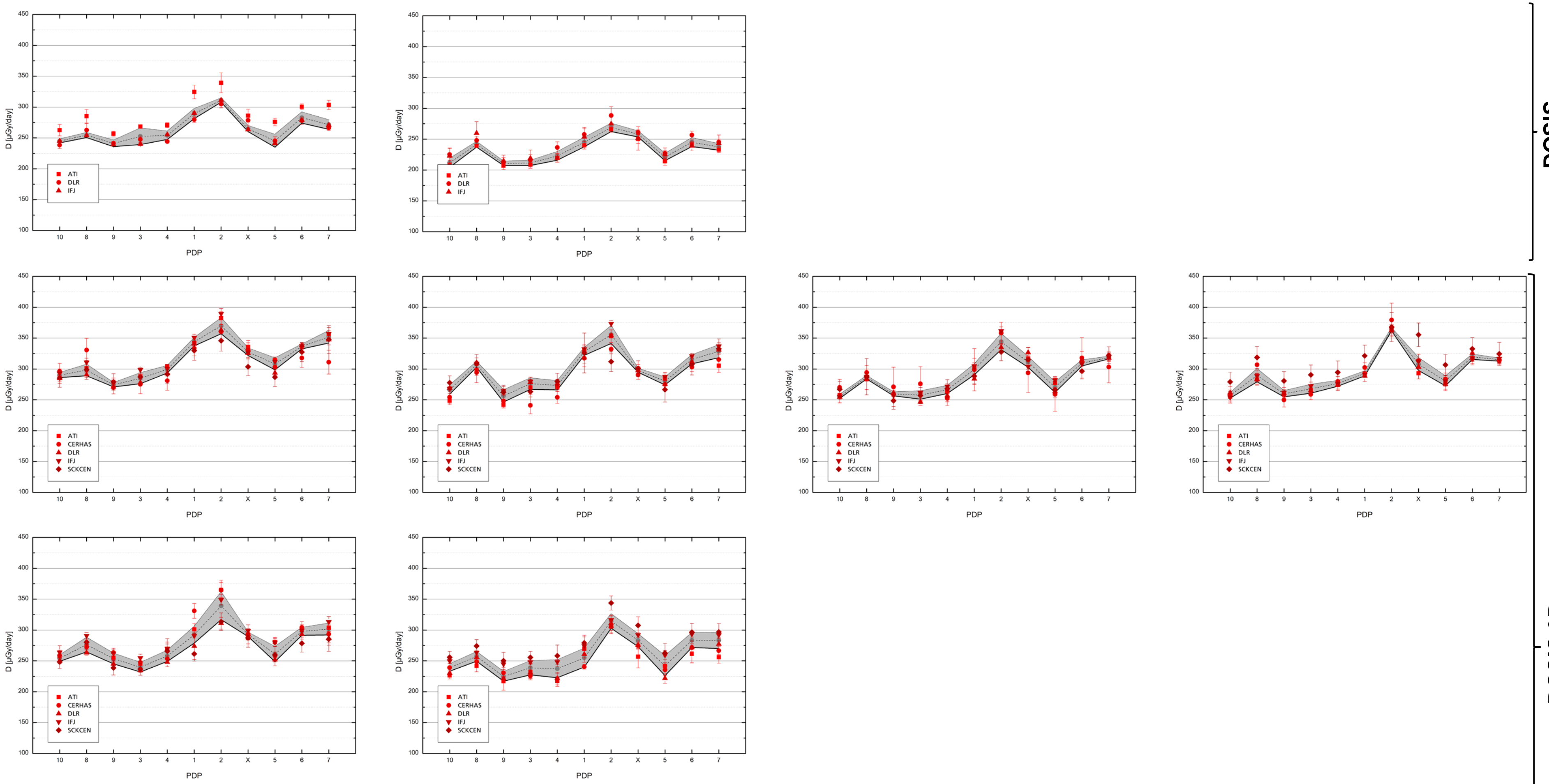
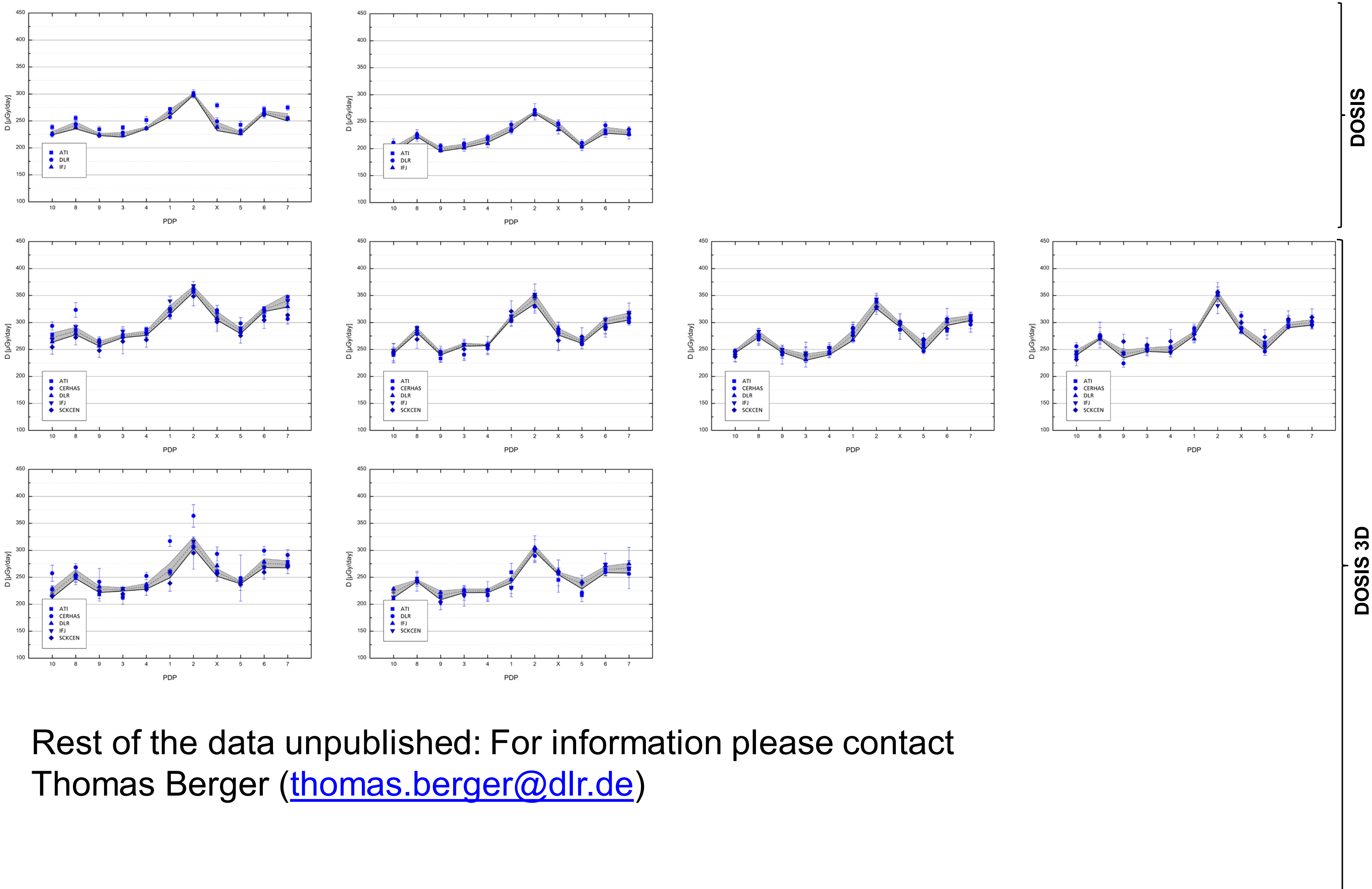


Rest of the data unpublished: For information please contact Thomas Berger (thomas.berger@dlr.de)



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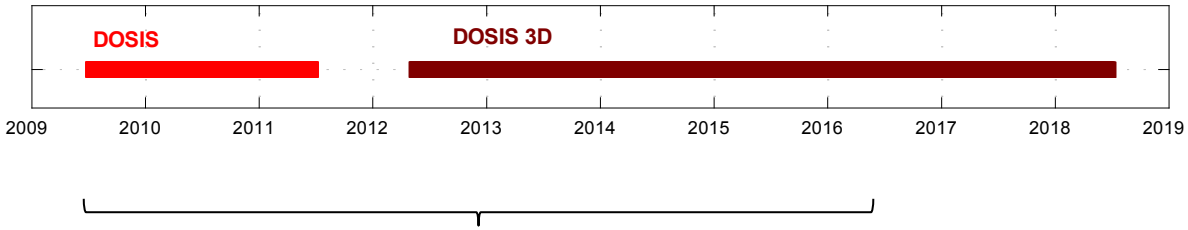
DOSIS & DOSIS 3D: DOSTEL – Results



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DOSIS & DOSIS 3D: DOSTEL – Results → Publication

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SWSC

RESEARCH ARTICLE — OPEN ACCESS

DOSIS & DOSIS 3D: radiation measurements with the DOSTEL instruments onboard the Columbus Laboratory of the ISS in the years 2009–2016

Thomas Berger[1,*], Sönke Burmeister[2], Daniel Matthiä[1], Bartos Przybyla[1], Günther Reitz[1], Pawel Bilski[3], Michael Hajek[4,5], Lembit Sihver[5,6], Julianna Szabo[7], Iva Ambrozova[8], Filip Vanhavere[9], Ramona Gaza[10,11], Edward Semones[10], Eduardo G. Yukihara[12], Eric R. Benton[12], Yukio Uchihori[13], Satoshi Kodaira[13], Hisashi Kitamura[13], and Matthias Boehme[14]

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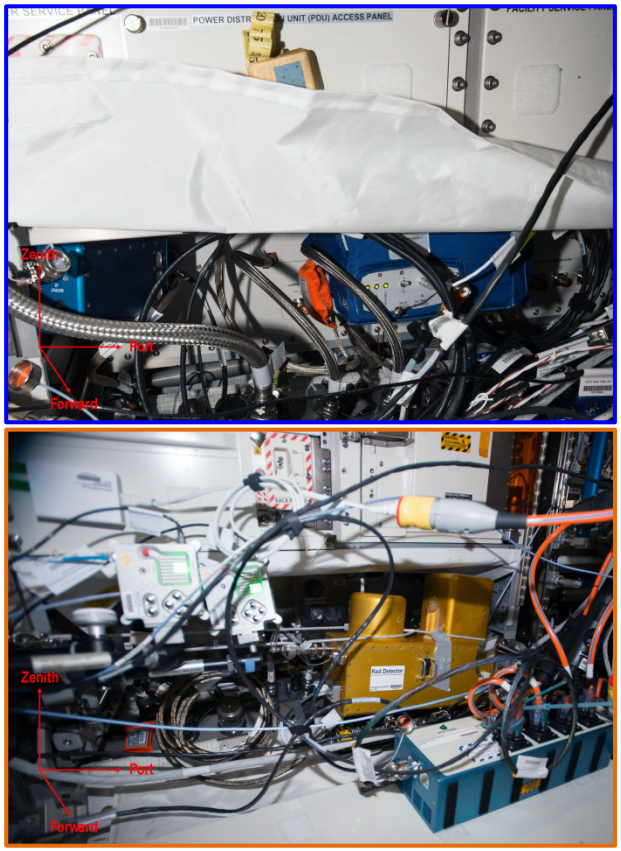
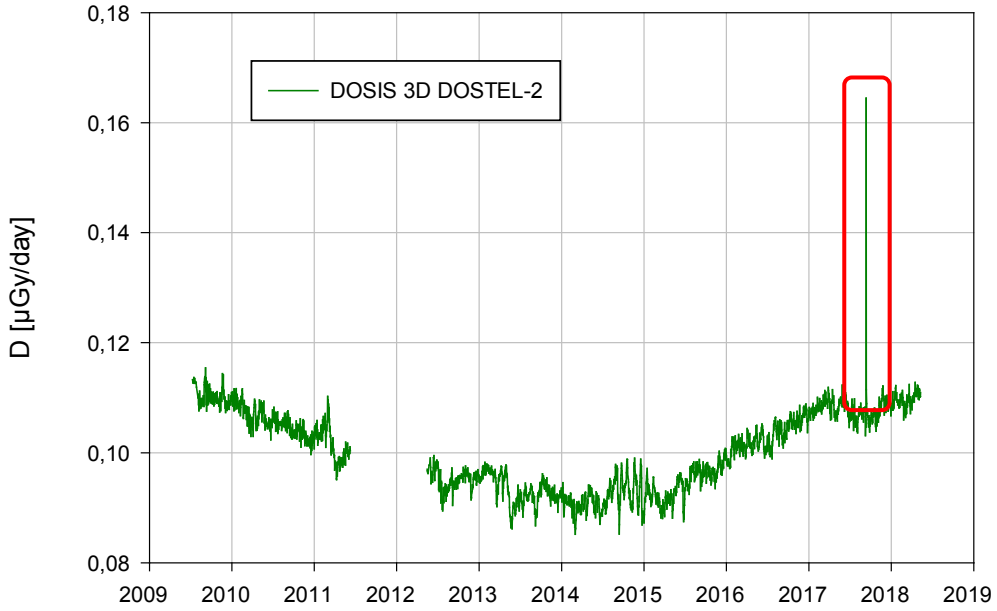
DOSIS & DOSIS 3D:
Active Detector Comparison

DOSIS & DOSIS 3D: Comparison → ISS-RAD / D3D-DOSTEL





See: Burmeister et al. WRMISS 2018
Matthiä et al. WRMISS 2018

Berger, T., Matthiä, D., Burmeister, S., Rios, R., Lee, K., Semones, E.; Hassler, D.M., Stoffle, N., Zeitlin, C. (2018). The Solar Particle Event on 10 September 2017 as observed on-board the International Space Station (ISS). *Space Weather, 16,* https://doi.org/10.1029/2018SW001920

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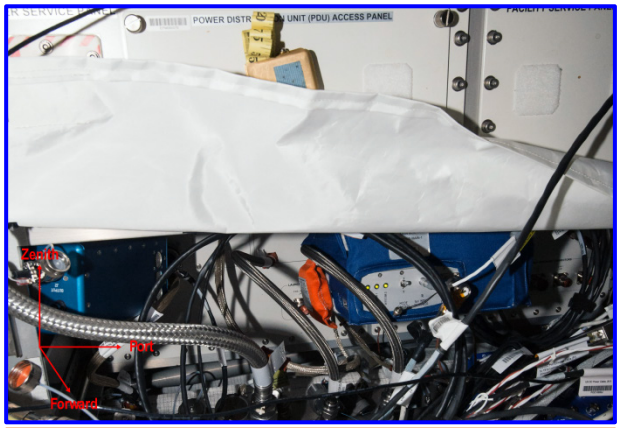
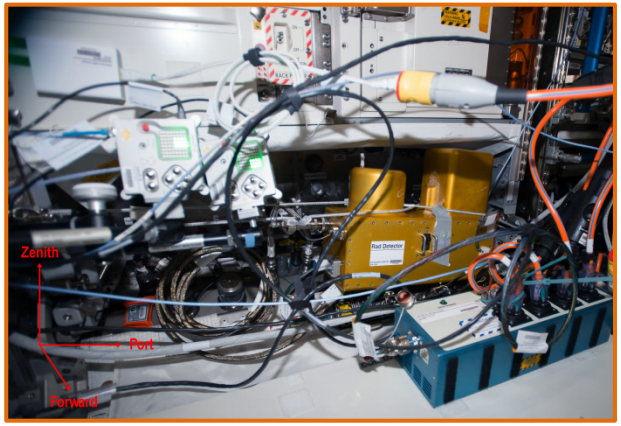
DOSIS & DOSIS 3D: Comparison → ISS-RAD / D3D-DOSTEL





AGU100 ADVANCING EARTH AND SPACE SCIENCE

Space Weather

RESEARCH ARTICLE
10.1029/2018SW001920

Special Section:
Space Weather Events of 4-10 September 2017

The Solar Particle Event on 10 September 2017 as observed onboard the International Space Station (ISS)

T. Berger[1], D. Matthiä[1], S. Burmeister[2], R. Rios[3], K. Lee[4], E. Semones[4], D. M. Hassler[5], N. Stoffle[3], and C. Zeitlin[3]

[1]German Aerospace Center (DLR), Institute of Aerospace Medicine, Cologne, Germany, [2]Christian Albrechts University (CAU), Kiel, Germany, [3]Leidos Innovations Corporation, Houston, TX, USA, [4]NASA Johnson Space Center, Houston, TX, USA, [5]Southwest Research Institute, Boulder, CO, USA

Key Points:
- A solar particle event—also seen as GLE 72 on Earth—was measured in September 2017 inside the International Space Station
- Data were provided by two detector systems, DOSIS 3D-DOSTEL and ISS-RAD, both in close proximity to each other in the Columbus Laboratory
- The additional absorbed dose due to the 10 September 2017 solar particle event was in the range of 67.8 to 146.2 μGy in Si

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Citation:
Berger, T., Matthiä, D., Burmeister, S., Rios, R., Lee, K., Semones, E., et al. (2018). The solar particle event on 10 September 2017 as observed onboard the International Space Station (ISS). *Space Weather, 16*. https://doi.org/10.1029/2018SW001920

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Abstract The nominal radiation environment in low Earth orbit, especially for the International Space Station (ISS), is dominated by two sources. The first is galactic cosmic radiation, which is modulated by the interplanetary and the Earth's magnetic fields, and the second is trapped radiation in the form of the Van Allen belts. The trapped radiation inside the ISS is mostly due to protons of the inner radiation belt. In addition to these sources sporadic solar particle events (SPEs) can produce high doses inside and outside the ISS, depending on the intensity and energy spectrum of the event. Before 2017, the last SPE observed inside the ISS with relevant radiation detectors occurred in May 2012. Even though we are currently approaching the next solar minimum, an SPE was observed in September 2017, which was (a) a ground-level enhancement, (b) measured with various radiation detector systems onboard the ISS, and (c) observed on the surface of Mars. This paper gives an overview of the 10 September 2017 SPE measured with the DOSIS 3D-DOSTEL and the ISS-RAD (Radiation Assessment Detector) instruments, both located at this time in close proximity to each other in the Columbus Laboratory of the ISS. The additional dose received during the SPE was 146.2 μGy in Si as measured by ISS-RAD and 67.8 μGy in Si as measured by the DOSIS 3D-DOSTEL instruments. In comparison, the dose measured on the surface of Mars with the Mars Science Laboratory-RAD instrument accounted to 418 μGy in Si.

Plain Language Summary Severe solar particle events can be the source for deterministic radiation effects on humans, commonly summarized under the term "radiation sickness." We examine the evolution of the solar particle event from 10 September 2017, which was the first event since May 2012 seen inside the International Space Station. Radiation dose values are provided by two instruments (DOSIS 3D-DOSTEL and ISS-RAD) positioned in close proximity to each other in the Columbus Laboratory.

Berger, T., Matthiä, D., Burmeister, S., Rios, R., Lee, K., Semones, E.; Hassler, D.M., Stoffle, N., Zeitlin, C. (2018). The Solar Particle Event on 10 September 2017 as observed on-board the International Space Station (ISS). *Space Weather, 16,* https://doi.org/10.1029/2018SW001920

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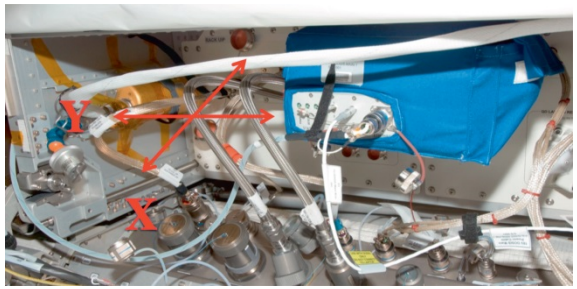
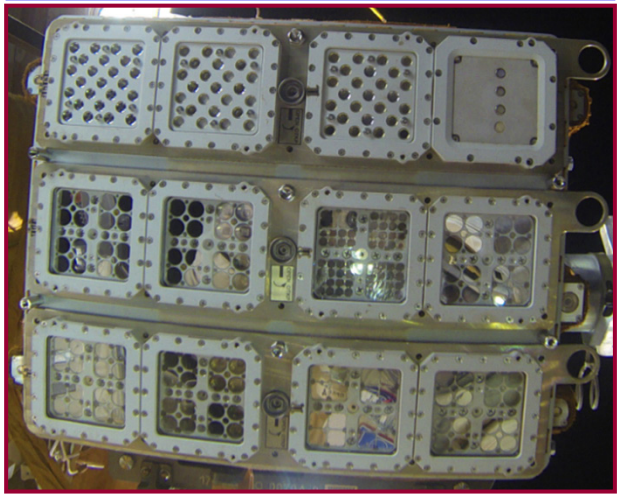
DOSIS & DOSIS 3D: Comparison → DB-8 / D3D-DOSTEL



Berger, T., et al. A comparison of radiation measurements performed with the DOSTEL and the DB-8 silicon detector systems onboard the International Space Station

In preparation for re-submission to Life Sciences in Space Research

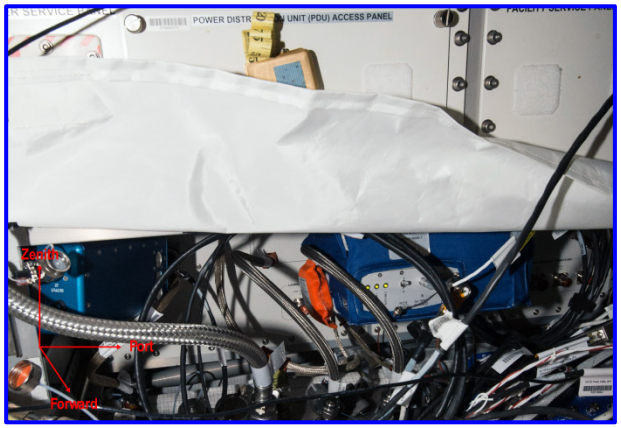
DOSIS 3D: Comparison → R3DR2 / D3D-DOSTEL



Berger, T., Dachev, T.P., Burmeister, S., Matthiä, D., Przybyla, B., *On the comparison of radiation measurements outside and inside the International Space Station (ISS)*

In preparation for Life Sciences in Space Research

DOSIS 3D: Comparison → TRITEL / D3D-DOSTEL



WORK IN PROGRESS

DOSIS & DOSIS 3D: DLR GEANT4 - SPE Simulations

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Space Weather

RESEARCH ARTICLE
10.1029/2018SW001921

Special Section:
Space Weather Events of 4-10 September 2017

The Solar Particle Event on 10–13 September 2017: Spectral Reconstruction and Calculation of the Radiation Exposure in Aviation and Space

Daniel Matthiä[1], Matthias M. Meier[1], and Thomas Berger[1]

[1]German Aerospace Center (DLR), Institute of Aerospace Medicine, Cologne, Germany

Key Points:
- In September 2017 a solar particle event was recorded as GLE by neutron monitors and also measured by several space-borne detectors
- Proton spectra during the event are derived from GOES data and validated through comparison to neutron monitor measurements
- Dose rates are derived for different exposure scenarios in space and aviation. The results are compared to measurements, where available

Supporting Information:
- Supporting Information S1
- Figure S1

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Abstract The solar energetic particle event on 10 September 2017 and on the following days was the strongest event in recent years. It was recorded as ground level enhancement 72 by neutron monitor stations on Earth and measured by a number of instruments in space. One aspect of such a space weather event is the potentially increased radiation exposure in aviation and space. Numerical simulations can help estimate the elevated dose rates during such an event; a critical aspect in these simulations is the description of the primary particle spectrum. In this work, we present 1-hr averaged proton spectra during the event derived from Geostationary Operational Environmental Satellite measurements and described by two different analytic functions. The derived proton spectra are used to calculate the radiation exposure in aviation and different space scenarios: low-Earth orbit, interplanetary space, and Mars surface, and the results are discussed in the context of available experimental data. While the results indicate that in most of these scenarios in aviation and space the event was of little significance compared to the total exposure from galactic cosmic radiation, the skin dose in a lightly shielded environment in interplanetary space may have reached about 30% to 60% of the NASA 30-day dose limit.

See:
Matthiä et al.
23 WRMISS 2018

Matthiä, D., Meier, M. M., & Berger, T. (2018). The solar particle event on 10–13 September 2017: Spectral reconstruction and calculation of the radiation exposure in aviation and space. Space Weather, 16. https://doi.org/10.1029/2018SW001921

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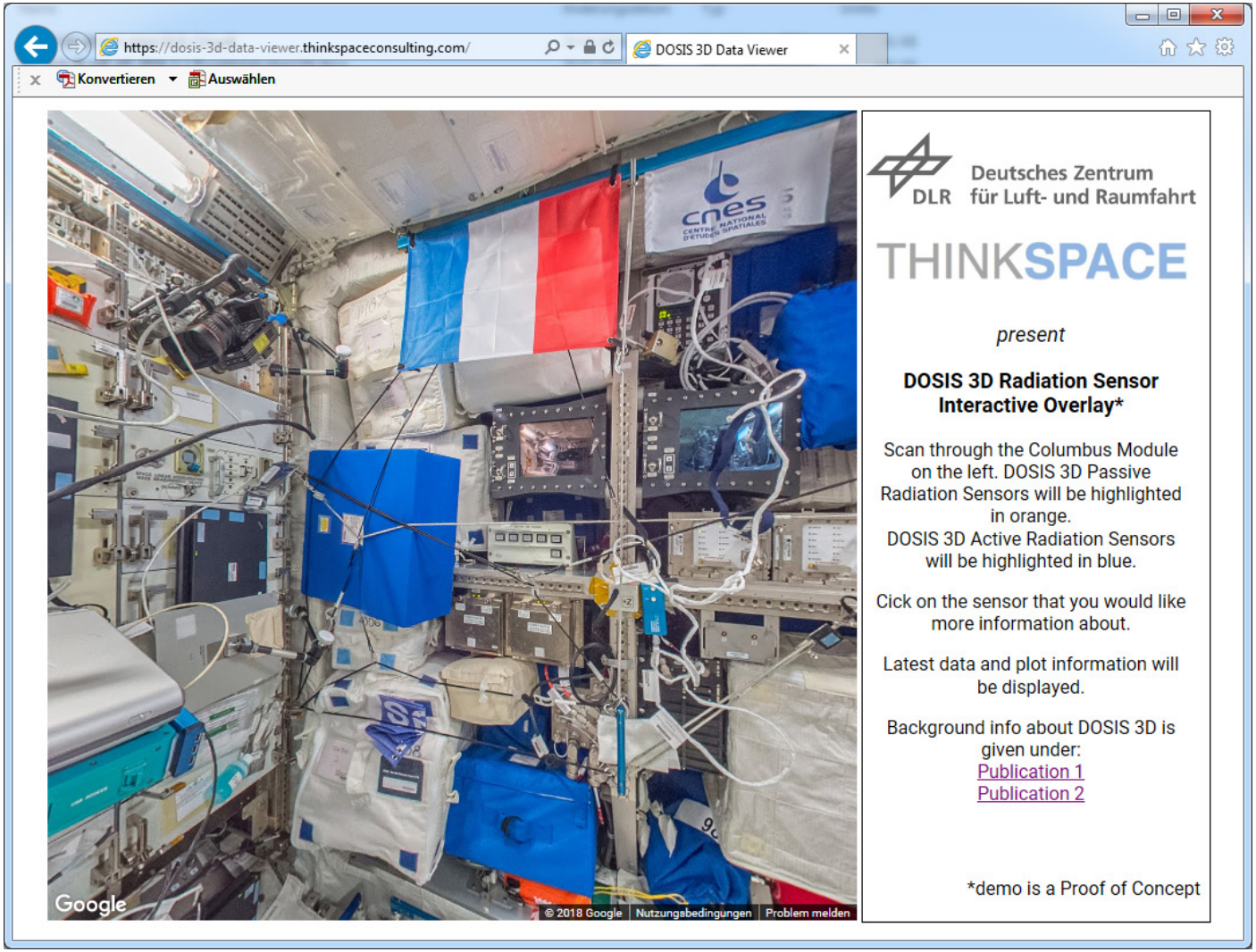
DOSIS & DOSIS 3D:
DATA VIEWER

DOSIS & DOSIS 3D: Data Viewer



https://dosis-3d-data-viewer.thinkspaceconsulting.com/

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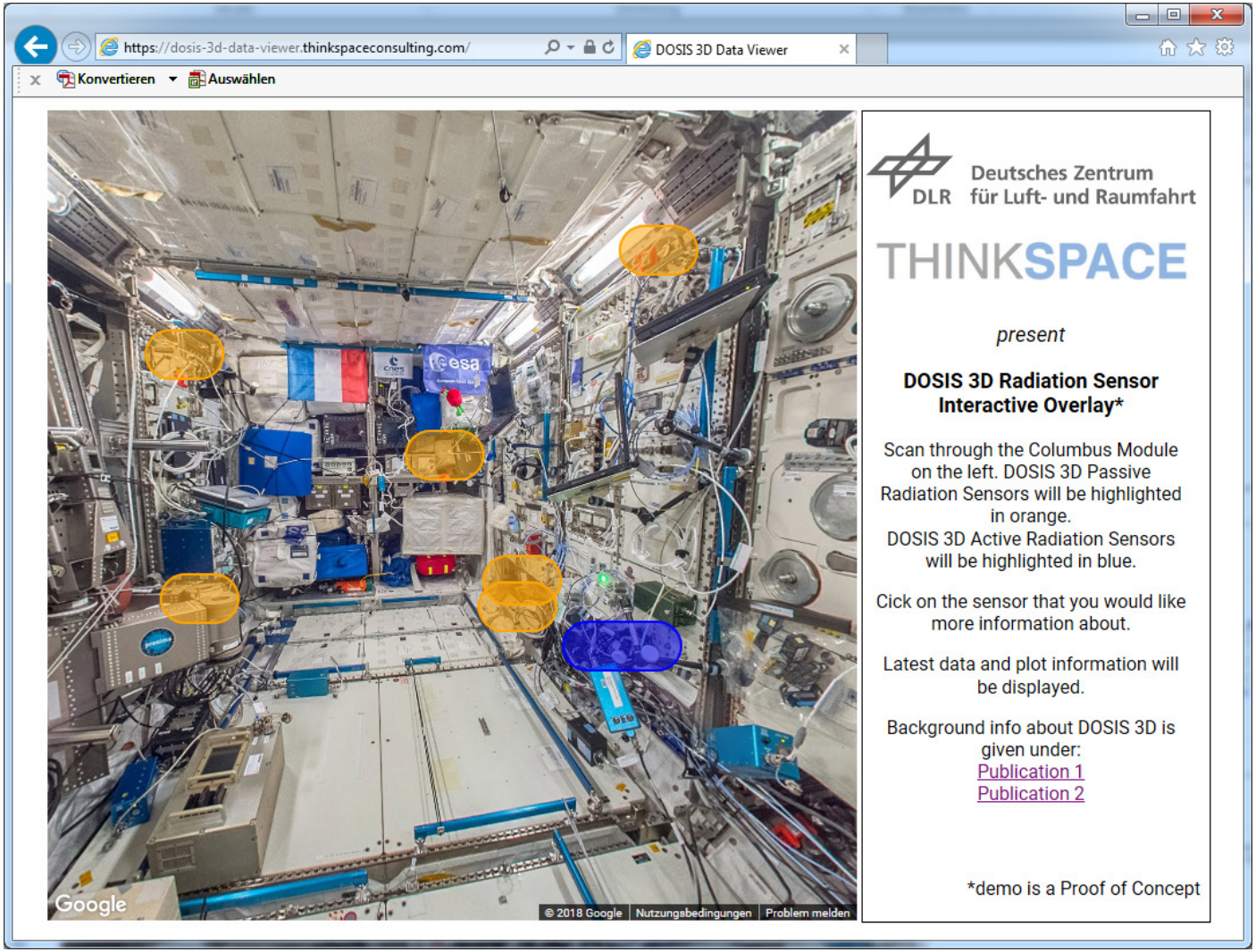
DOSIS & DOSIS 3D: Data Viewer



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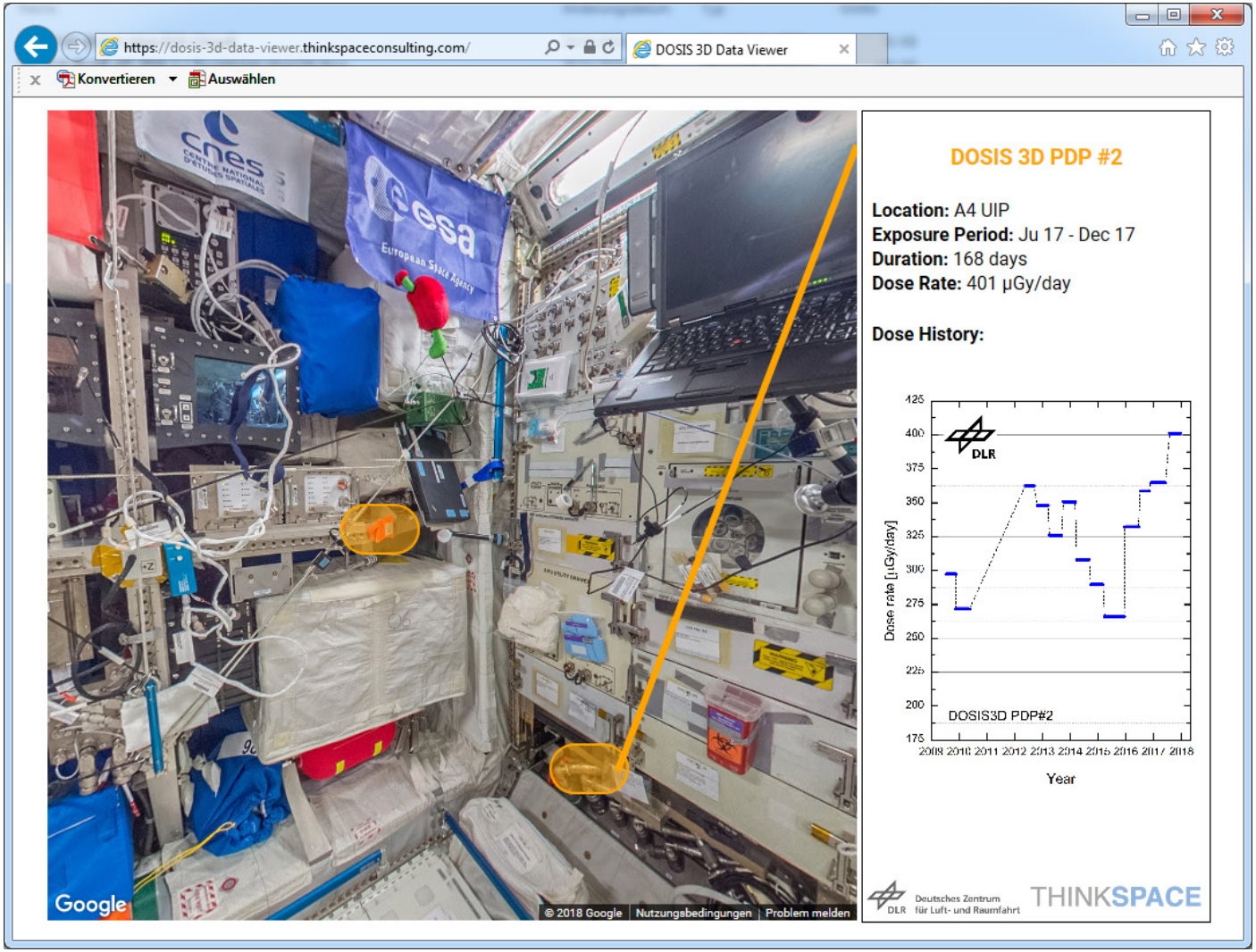
DOSIS & DOSIS 3D: Data Viewer



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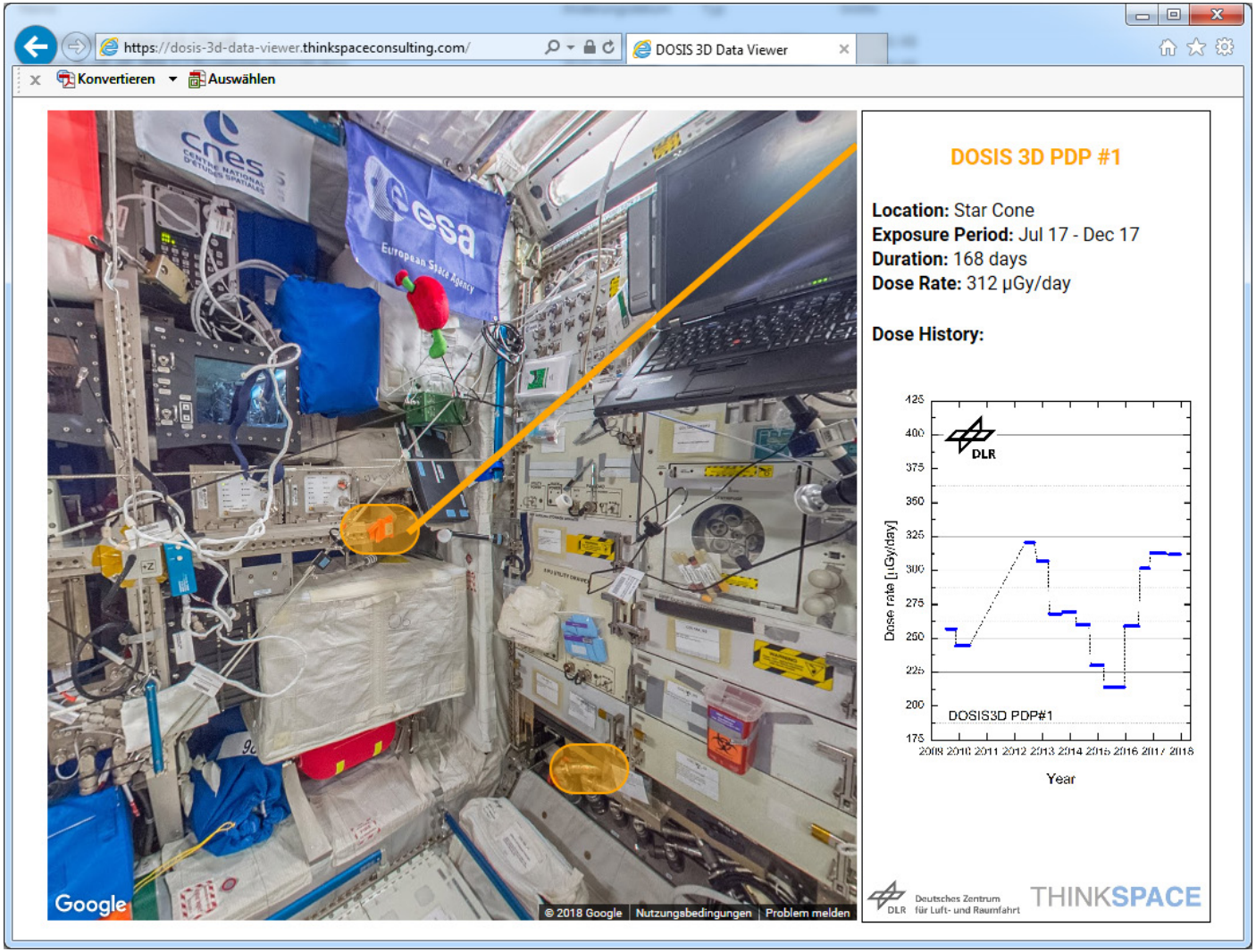
DOSIS & DOSIS 3D: Data Viewer



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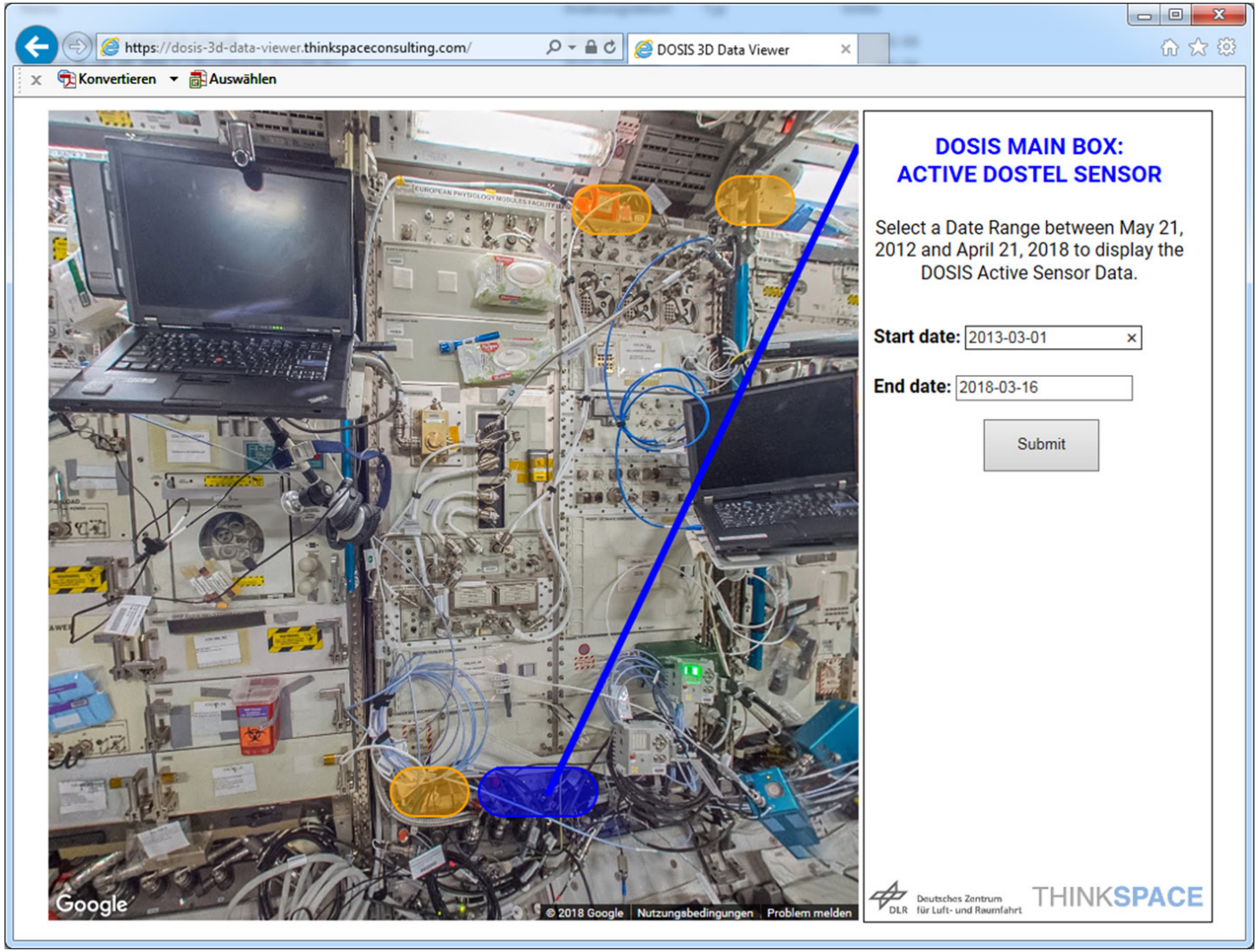
DOSIS & DOSIS 3D: Data Viewer



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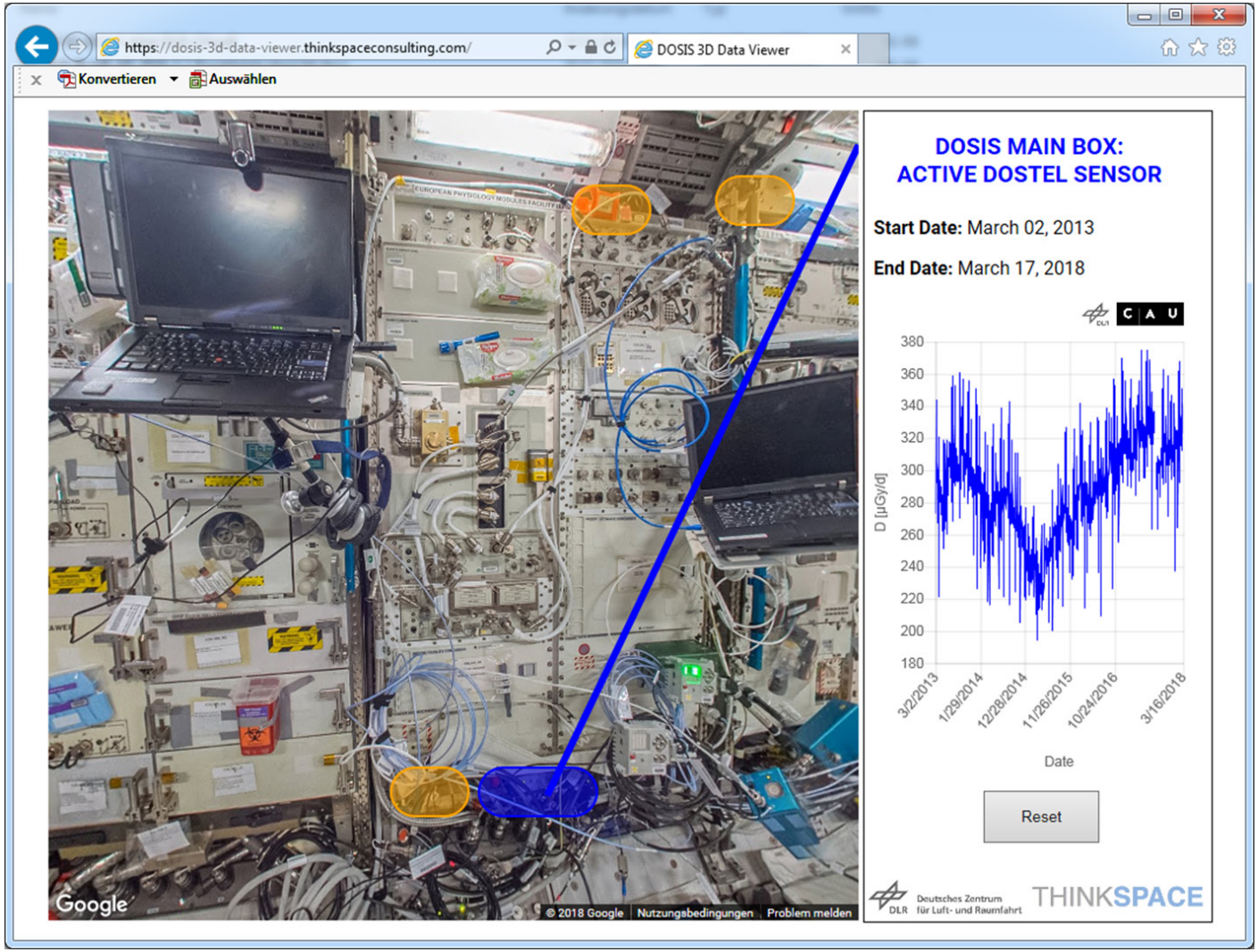
DOSIS & DOSIS 3D: Data Viewer



https://dosis-3d-data-viewer.thinkspaceconsulting.com/

DOSIS & DOSIS 3D: Summary and Outlook

- DOSIS & DOSIS 3D:
  - DOSTEL-1 2512 days of data
  - DOSTEL-2 2864 days of data
- DOSIS & DOSIS 3D:
  - DOSIS 2 long term PDP exposures
  - DOSIS 3D 12 long term PDP exposures
    PDP XIII currently onboard ISS
    (installed 11 June 2018)
- DOSIS 3D:
  - Into depth comparison of data (as given before) is in progress / publications are in work
  - Data Viewer as Proof of Concept implemented
    https://dosis-3d-data-viewer.thinkspaceconsulting.com

DOSIS & DOSIS 3D: Acknowledgements

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All of this experiments would not be possible without the help of all the astronauts working on the DOSIS and DOSIS 3D experiment: **Frank de Winne, Tracy Caldwell-Dyson, Shannon Walker, Ron Garan, Mike Fossum, Andre Kuipers, Joe Acaba, Sunita Williams, Chris Hadfield, Chris Cassidy, Luca Parmitano, Michael Hopkins, Rick Mastracchio, Koichi Wakata, Alexander Gerst, Samantha Cristoforetti, Scott Kelly, Timothy Peake, Jeffrey Williams, Takuya Onishi, Thomas Pesquet, Jack Fischer, Mark Vande Hei, Norishige Kanai, Andrew Feustel**

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MTA EK greatly acknowledges the possibility to participate in the project to the DLR and to the ESA PECS for the financial grant No. PECS4000108464.

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