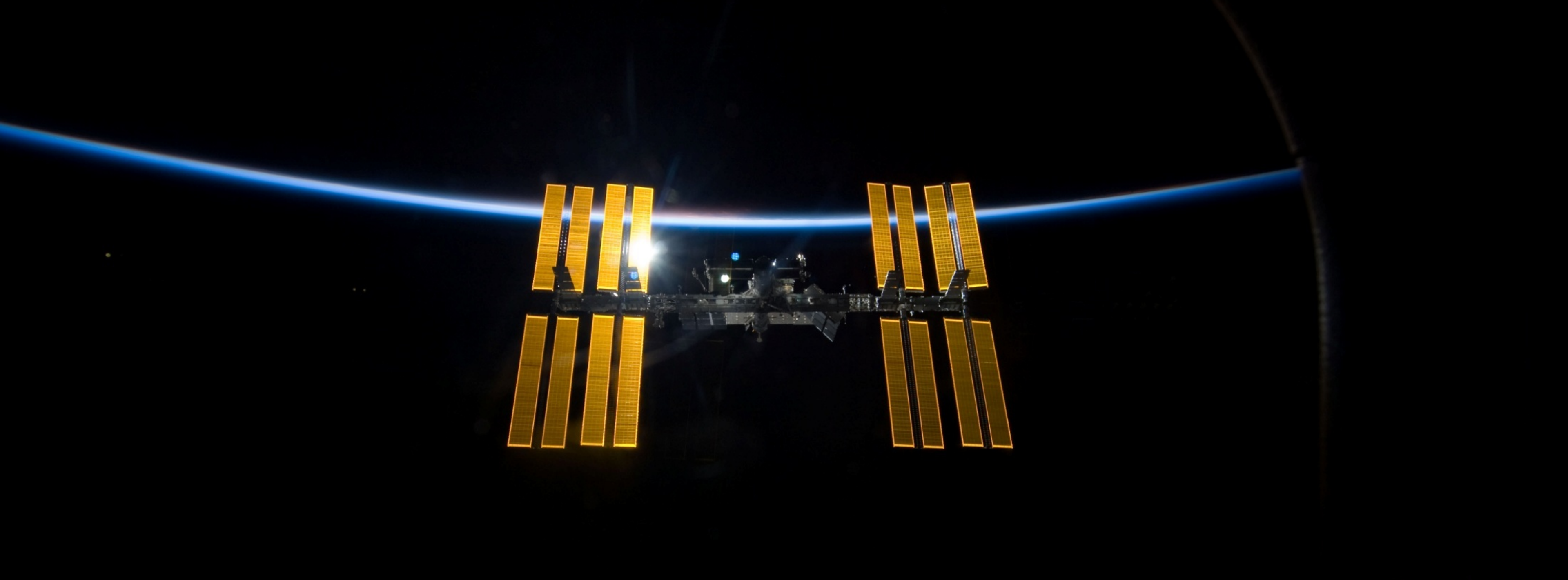
Neutron Measurements using Bubble Detectors: ISS-39/40 and ISS-41/42



Martin Smith, Bubble Technology Industries

20th WRMISS, Cologne, Germany

September 8th – 10th 2015

Collaboration

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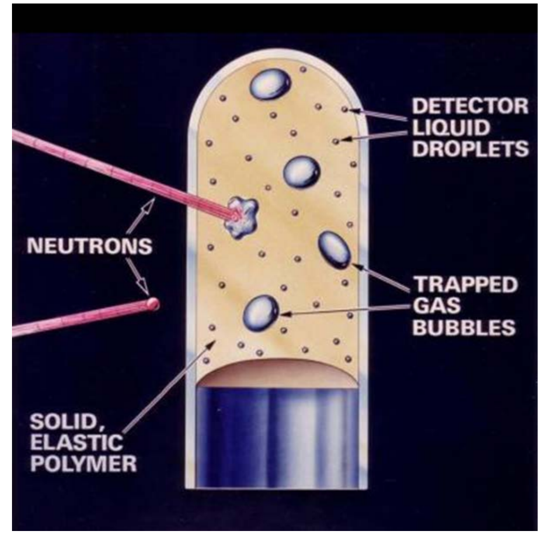
Introduction: Space Radiation

- Radiation prediction, monitoring, and protection technologies are a key part of every space mission involving humans
- NASA's Bioastronautics Roadmap identifies provision of radiation protection as one of the high-priority health and medical issues for exploration-class missions
  - Radiation protection is listed as one of three key areas for lunar missions, and one of eight for Mars missions
  - The risk to space crews due to radiation in deep space may be a serious obstacle to Mars missions
- Neutrons are of particular interest to radiation health and protection
  - Measurements indicate that neutrons may represent 30% of the biologically-effective radiation exposure in low-Earth orbit
  - A significant neutron contribution is also expected in deep space
- Bubble detectors have been used to monitor neutrons in space since 1989 on recoverable Russian Biocosmos (Bion) satellites, the Mir space station, the space shuttle, and the ISS

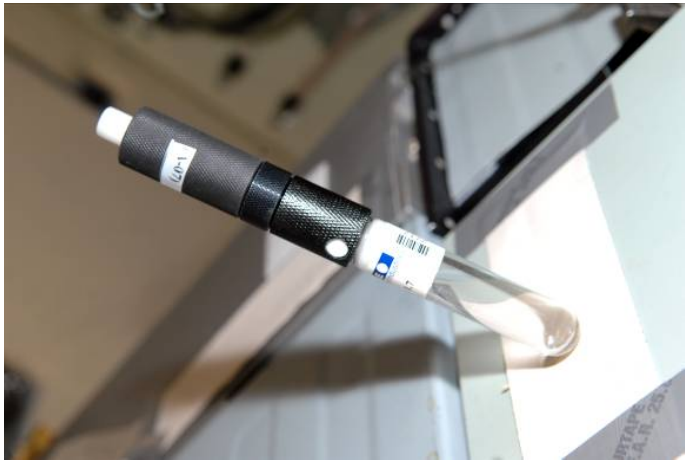
Bubble Detectors

- Bubble detectors are passive, real-time dosimeters manufactured by Bubble Technology Industries
- They contain superheated liquid droplets dispersed in an elastic polymer
- High-LET particles interact with the droplets to form bubbles
- The elastic polymer retains the bubbles to allow visible detection of radiation
- After each measurement, the bubbles can be recompressed and the detector can be reused



Space Bubble Detectors

- Two types of bubble detector are used to monitor neutrons for the Matroshka-R and Radi-N2 experiments on the ISS
  - Space personal neutron dosimeter (SPND)
  - Space bubble detector spectrometer (SBDS)
    - Set of six detectors, each with a different energy threshold, that provides a coarse neutron energy spectrum
- Space bubble detectors use a stronger polymer than terrestrial detectors
  - Allows bubbles to grow slowly during a week-long measurement
- Detectors are temperature compensated
- Bubbles are counted with the space mini reader located in the Russian segment



ISS Measurement Locations

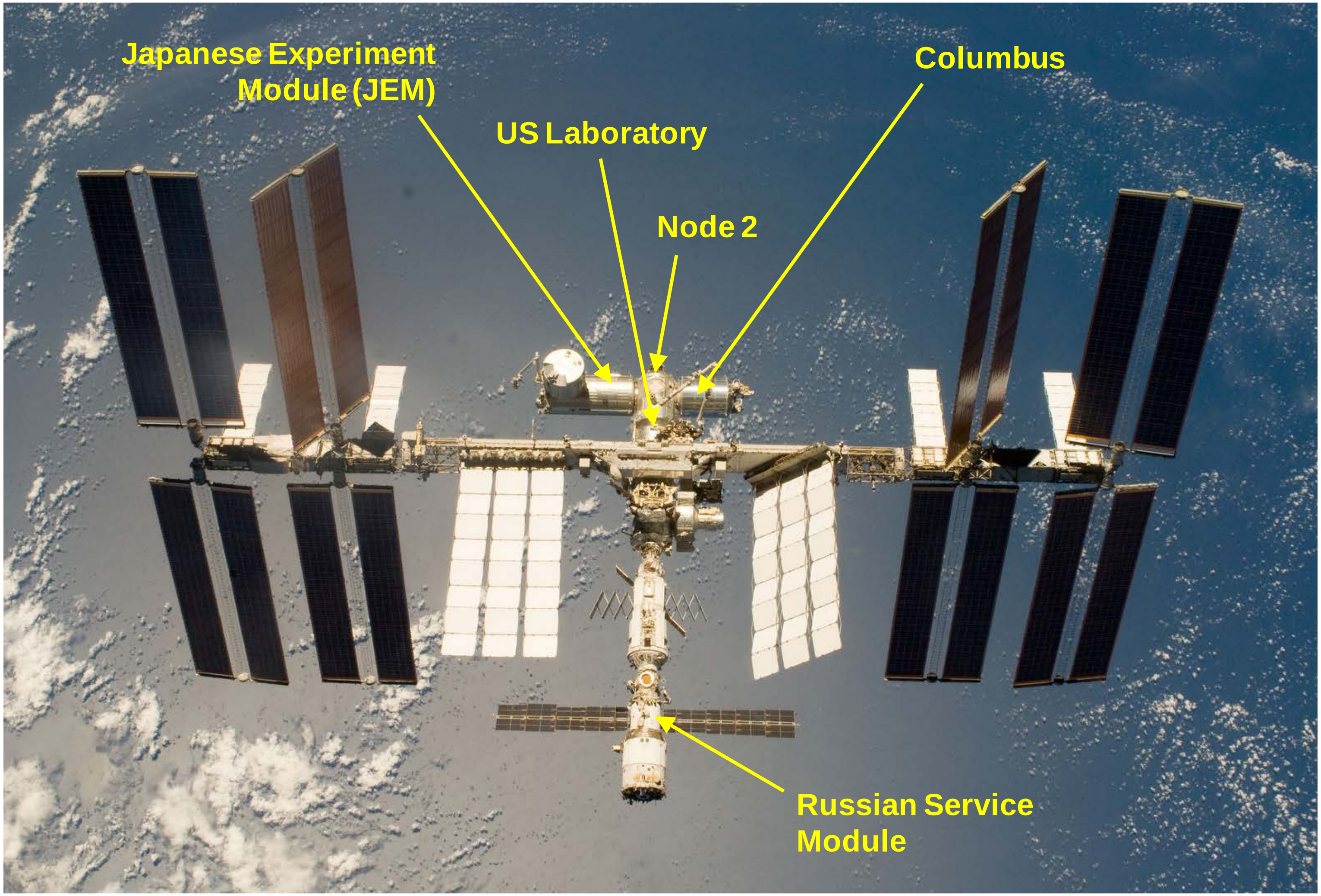


Image from NASA

ISS Bubble-Detector Experiments

Photograph used with permission of Dr. Robert Thirsk

Photograph used with permission of Chris Hadfield

Matroshka-R (2006 – present)

- Neutron dose inside a tissue-equivalent phantom was less than that at its surface
- Neutron dose in the Service Module was ~30% of the total recorded by other devices
- Solar activity and altitude did not have a strong influence on the neutron dose or energy spectrum

Radi-N (2009)

- First spectroscopic measurements
- Showed that neutron dose and energy spectrum were not strongly dependent on location
- Neutron dose received in sleeping quarters was less than that received during daily activities
- Water shield reduced the neutron dose by ~30%

Radi-N2 (2012 – present)

- Continued measurements in the same locations used for Radi-N
- Good agreement with Radi-N data
- Confirmed that solar activity and ISS altitude have little effect on neutron radiation inside the ISS
- Ongoing goal is to collect at least ten weeks of data in each module and to measure a full solar cycle

List of Sessions: ISS-39 to ISS-42

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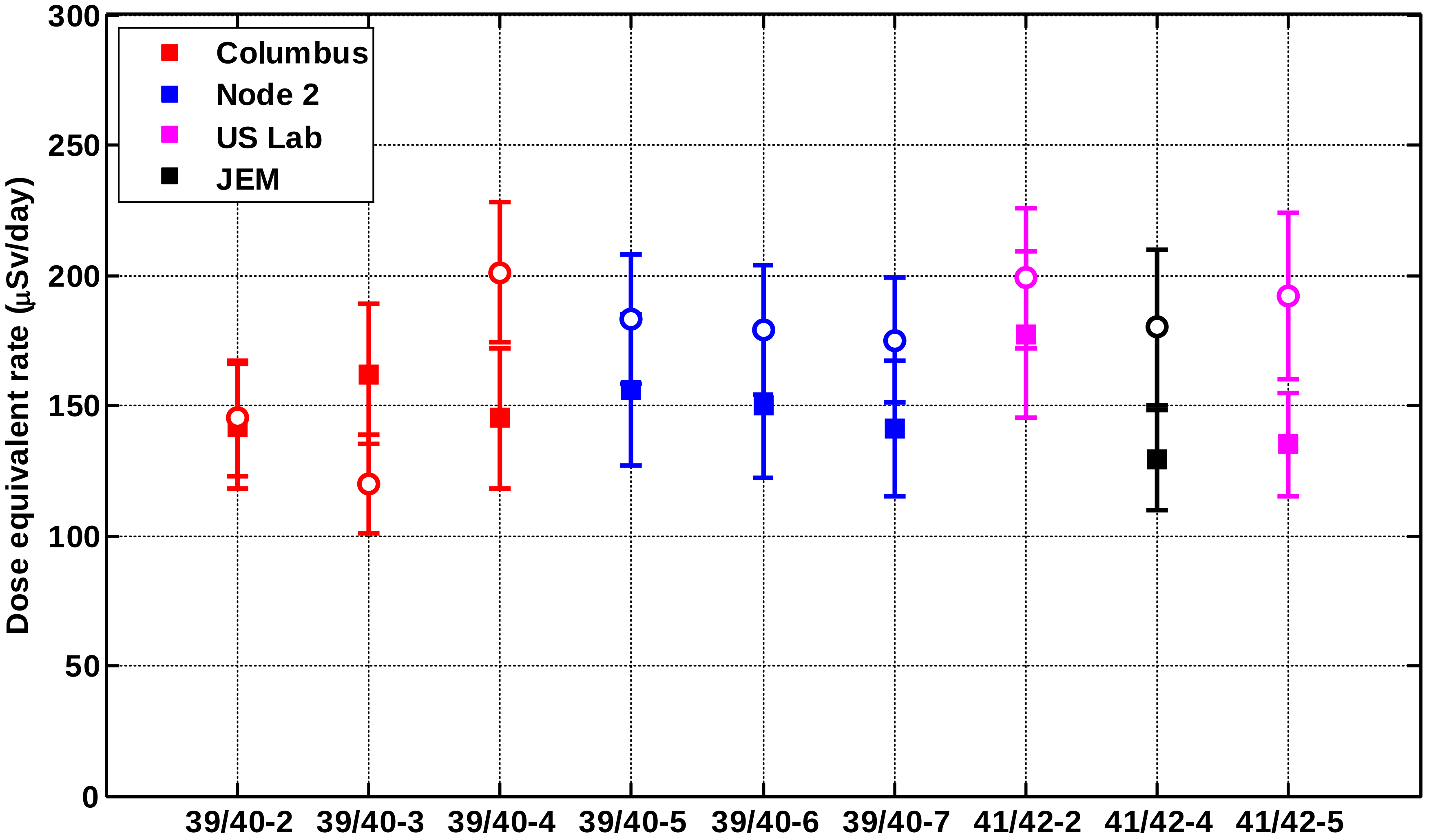
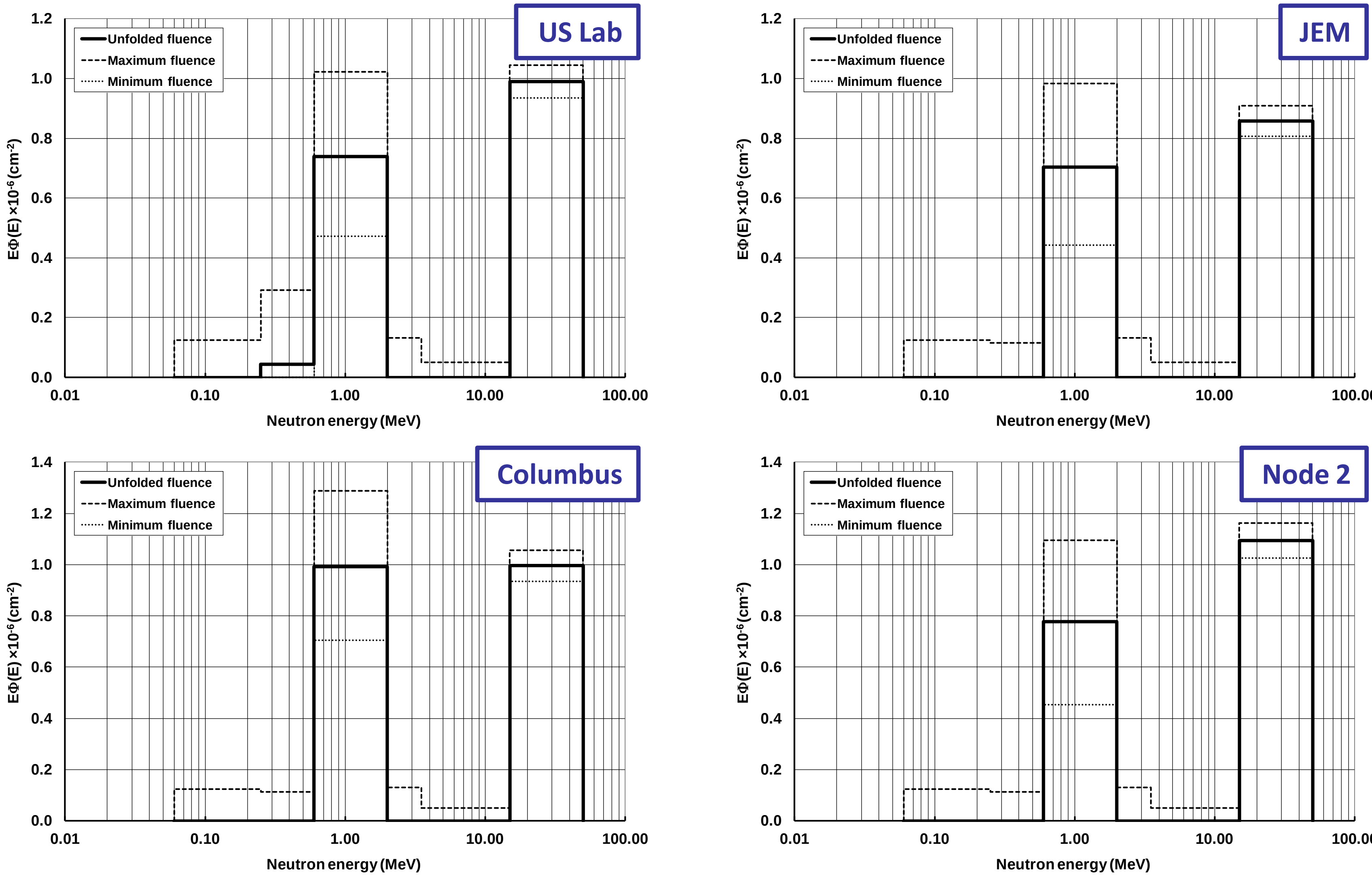
Session	Initialization Date	Retrieval Date	Prime Location	Back-Up Location
39/40-1	21 March 2014	26 March 2014	Service Module	Service Module
39/40-2	14 April 2014	21 April 2014	Columbus	MRM2
39/40-3	12 May 2014	19 May 2014	Columbus	MRM2
39/40-4	10 June 2014	17 June 2014	Columbus	MRM2
39/40-5	7 July 2014	14 July 2014	Node 2	MRM2
39/40-6	4 August 2014	11 August 2014	Node 2	MRM2
39/40-7	2 September 2014	9 September 2014	Node 2	MRM2
41/42-1	10 October 2014	17 October 2014	MRM1	MRM1
41/42-2	6 November 2014	13 November 2014	US Lab	MRM1
41/42-3	4 December 2014	11 December 2014	MRM1	MRM1
41/42-4	6 January 2015	13 January 2015	JEM	MRM1
41/42-5	3 February 2015	10 February 2015	US Lab	MRM1
41/42-6	26 February 2015	5 March 2015	MRM1	MRM1

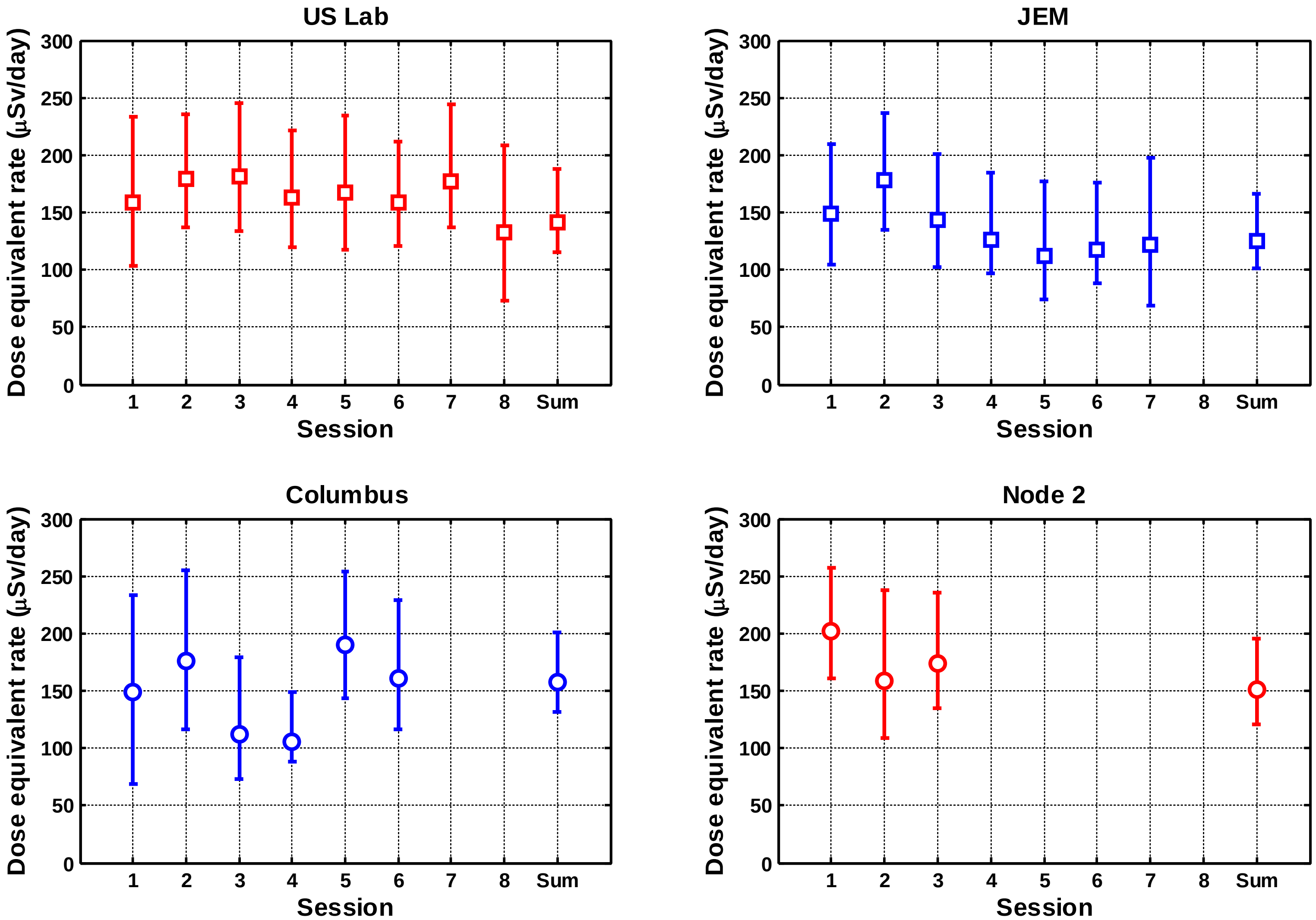
Radi-N2: SPND Dose Rate



Radi-N and Radi-N2: SBDS Data



Radi-N and Radi-N2: SBDS Dose Rate



Radi-N and Radi-N2: SBDS Dose Rate

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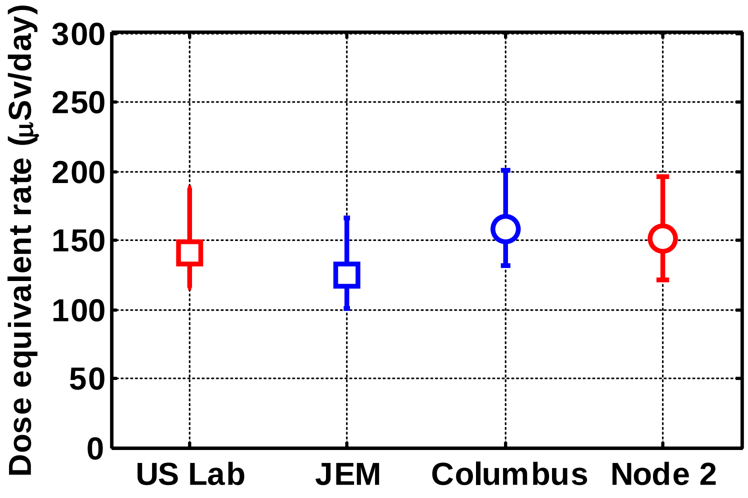
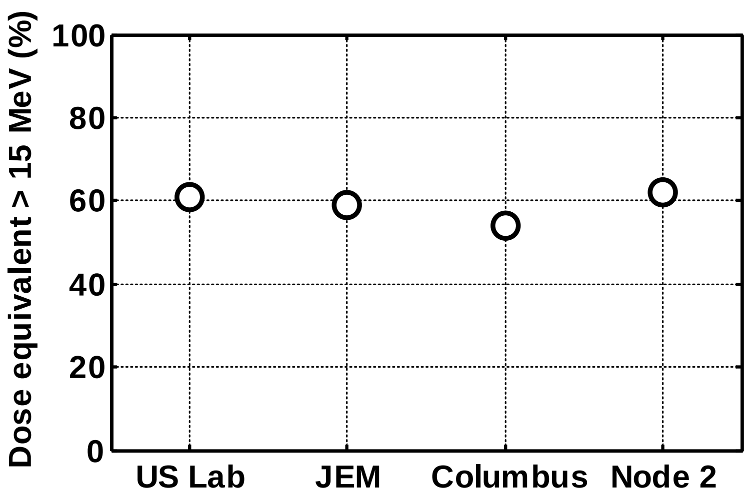
- The SBDS dose rate, summed over all sessions, is very similar in each of the four USOS locations
  - This observation is in good agreement with the SPND data
- The SBDS data suggest that ~60% of the neutron dose is due to neutrons with energy > 15 MeV
  - This number is higher than previously reported
- Changes in solar activity and ISS altitude since 2009 did not have a strong influence on the neutron dose
- Conclusions will be finalized once data have been acquired for a full solar cycle (2009 – 2020)

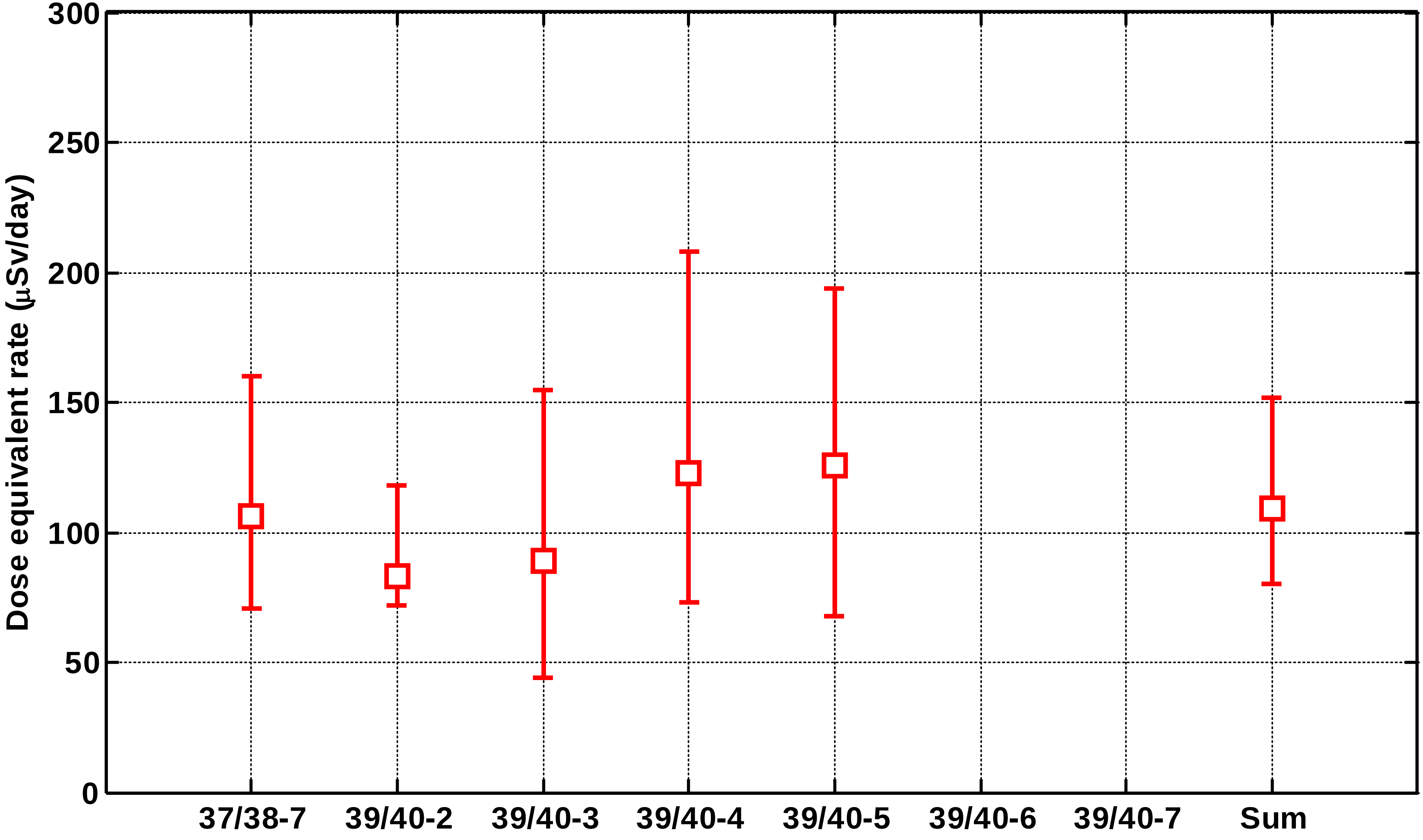




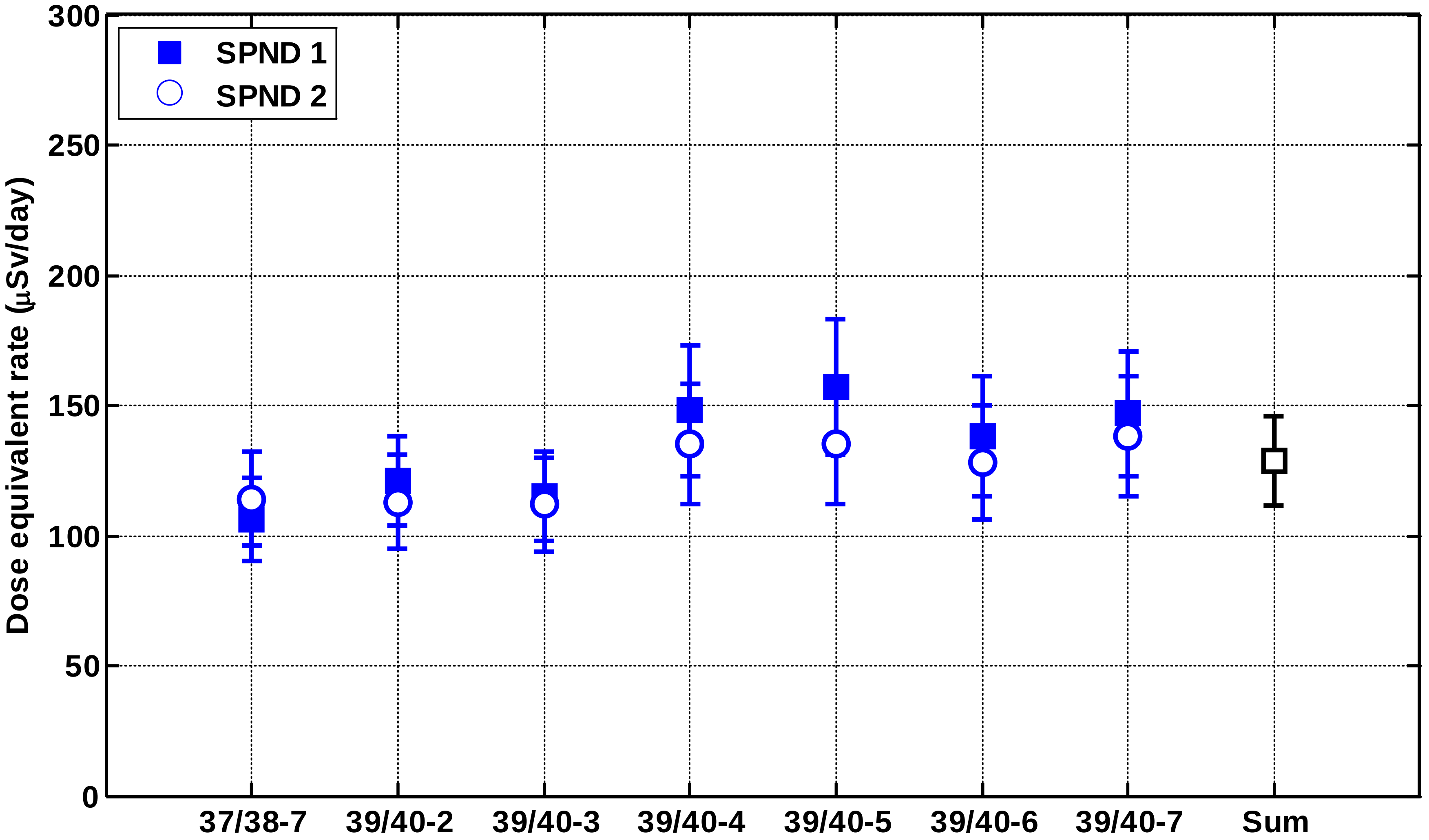
Matroshka-R: ISS-39 to ISS-42

- For Matroshka-R, a total of 17 sessions were conducted during ISS-39/40 and ISS-41/42
- Each used a spectrometer (SBDS) and two dosimeters (SPNDs)
- These measurements included
  - First extensive measurements in Mini Research Module 2 (MRM2)
  - Experiments using the Matroshka-R phantom in MRM1

MRM2: SBDS Dose Rate



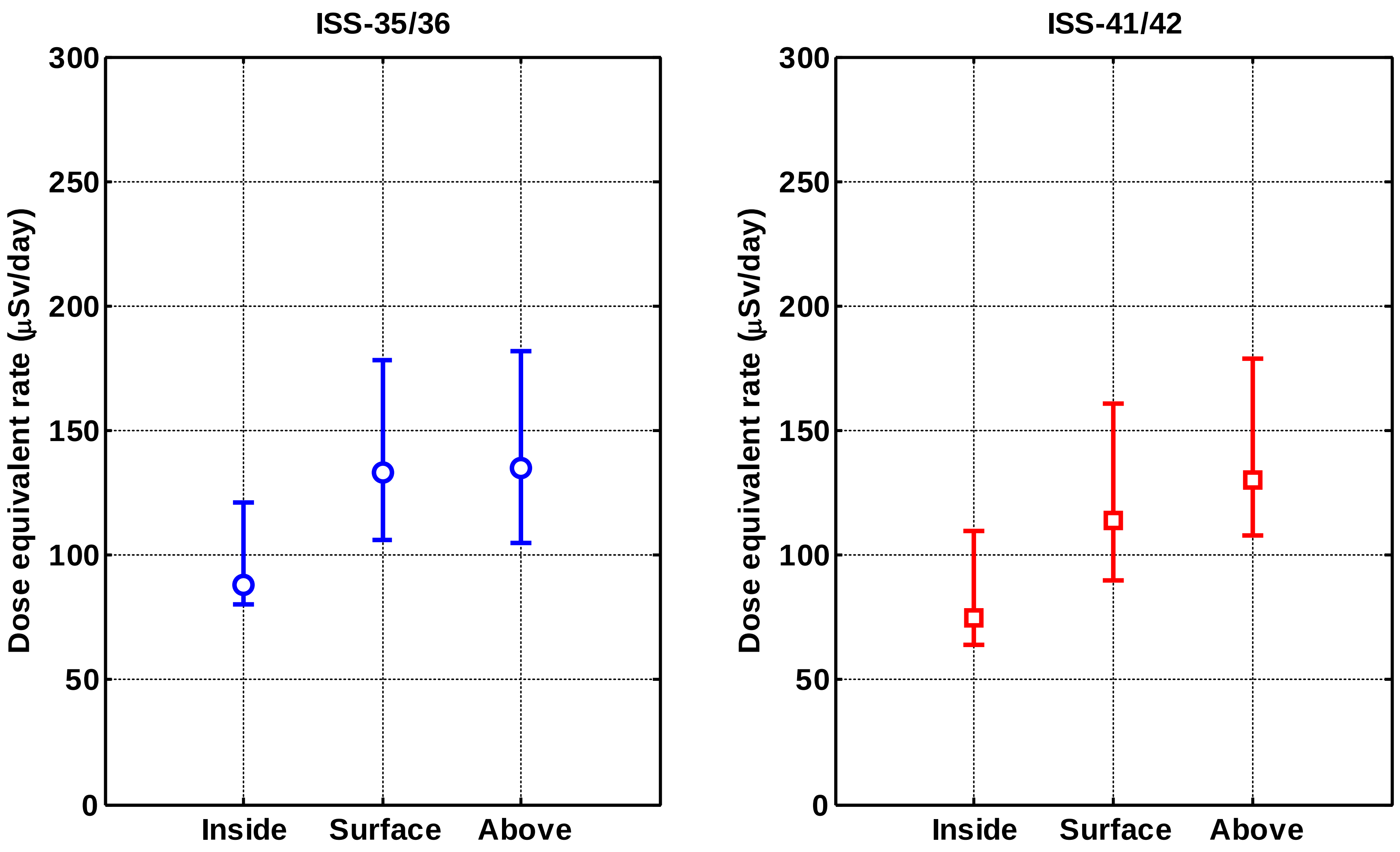
MRM2: SPND Dose Rate



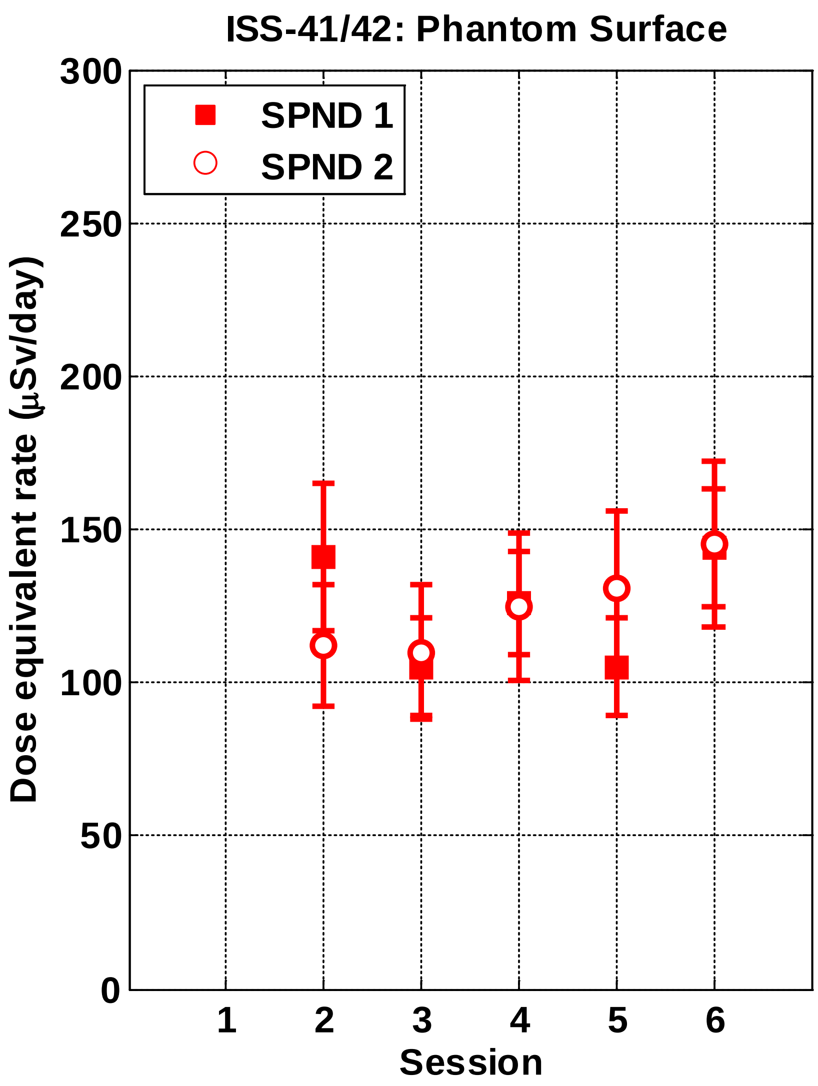
Matroshka-R: Phantom in MRM1

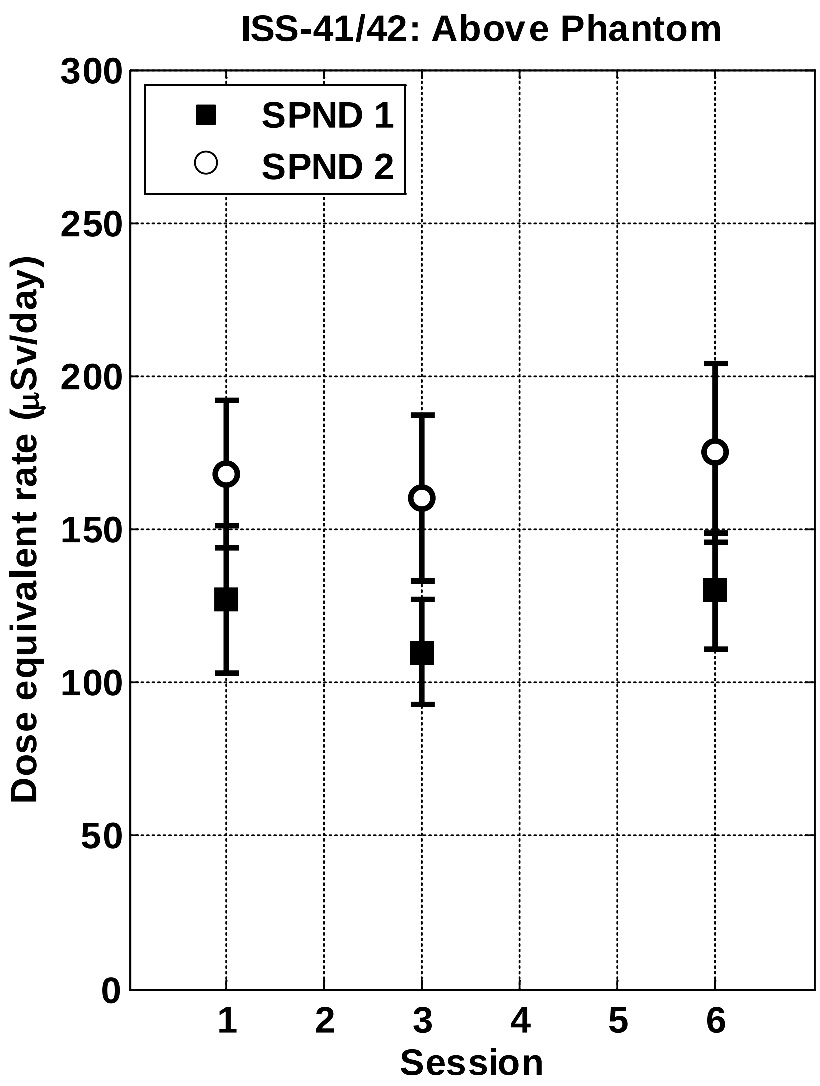
- Measurements aimed to repeat an experiment conducted during ISS-35/36
- The phantom was located behind panel 206 in MRM1, as before
- The back-up SBDS was used inside the phantom and on its surface
  - It was only possible to insert three detectors into the phantom at a time
  - SBDS detectors alternated between the two locations
- The prime SBDS was used to measure the spectrum above the phantom (on panel 206) for three sessions
- SPNDs were also used on the phantom surface and above the phantom

SBDS Phantom Results



SPND Phantom Results





ISS-43/44 and ISS-45/46

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Session	Initialization Date	Retrieval Date	Prime Location	Back-Up Location
43/44-1	24 March 2015	31March 2015	Columbus	Service Module
43/44-2	16 April 2015	23 April 2015	Service Module	Service Module
43/44-3	19 May 2015	26 May 2015	Service Module	Service Module
43/44-4	12 June 2015	18 June 2015	Node 2	Service Module
43/44-5	14 July 2015	21 July 2015	Columbus	Service Module
43/44-6	12 August 2015	19 August 2015	Node 2	Service Module
45/46-1	18 September 2015	25 September 2015	JEM	FGB
45/46-2	16 October 2015	23 October 2015	Node 2	FGB
45/46-3	13 November 2015	20 November 2015	US Lab	FGB
45/46-4	11 December 2015	17 December 2015	JEM	FGB
45/46-5	13 January 2016	20 January 2016	US Lab	FGB
45/46-6	12 February 2016	19 February 2016	JEM	FGB

FGB: Functional Cargo Block

Summary and Conclusions

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- Bubble-detector experiments were performed for Radi-N2 and Matroshka-R during ISS-39/40 and ISS-41/42 (to March 2015)
- For Radi-N2, nine sessions were conducted, including all four USOS locations
  - The measured neutron dose is very similar in each of the four modules
  - SBDS data suggest that approximately 60% of the neutron dose is due to neutrons with energy > 15 MeV
  - Variations in potential influence quantities such as solar activity and ISS altitude seem to have little effect on the neutron dose
- Seventeen sessions were performed for the Matroshka-R experiment
  - First extensive measurements in MRM2
  - Experiments using the Matroshka-R phantom in MRM1, which provided good agreement with the earlier measurements from ISS-35/36
- Experiments are ongoing
  - Six sessions were performed during ISS-43/44 and six are scheduled for ISS-45/46
  - Plans up to 2020 are under discussion

Acknowledgements

- We would like to thank the following for their important contributions
  - The astronauts and cosmonauts who performed the measurements
  - NASA's Space Radiation Analysis Group (SRAG) for supporting the experiments
  - The Canadian Space Agency and the Russian Space Agency for funding the work

- References for recent publications

  - R. Machrafi et al., Radiat. Prot. Dosim. 133(4), 200 – 207 (2009)
  - B.J. Lewis et al., Radiat. Prot. Dosim. 150(1), 1 – 21 (2012)
  - M.B. Smith et al., Radiat. Prot. Dosim. 153(4), 509 – 533 (2013)
  - M.B. Smith et al., Proc. 65th IAC, IAC-14.A1.4.3 (2014)
  - M.B. Smith et al., Radiat. Prot. Dosim., 163(1), 1 – 13 (2015)
  - M.B. Smith et al., Radiat. Prot. Dosim., 164(3), 203 – 209 (2015)
  - M.B. Smith et al., Radiat. Prot. Dosim., doi:10.1093/rpd/ncv181 (2015)

BACK-UP SLIDES

Bubble Detector Response Function

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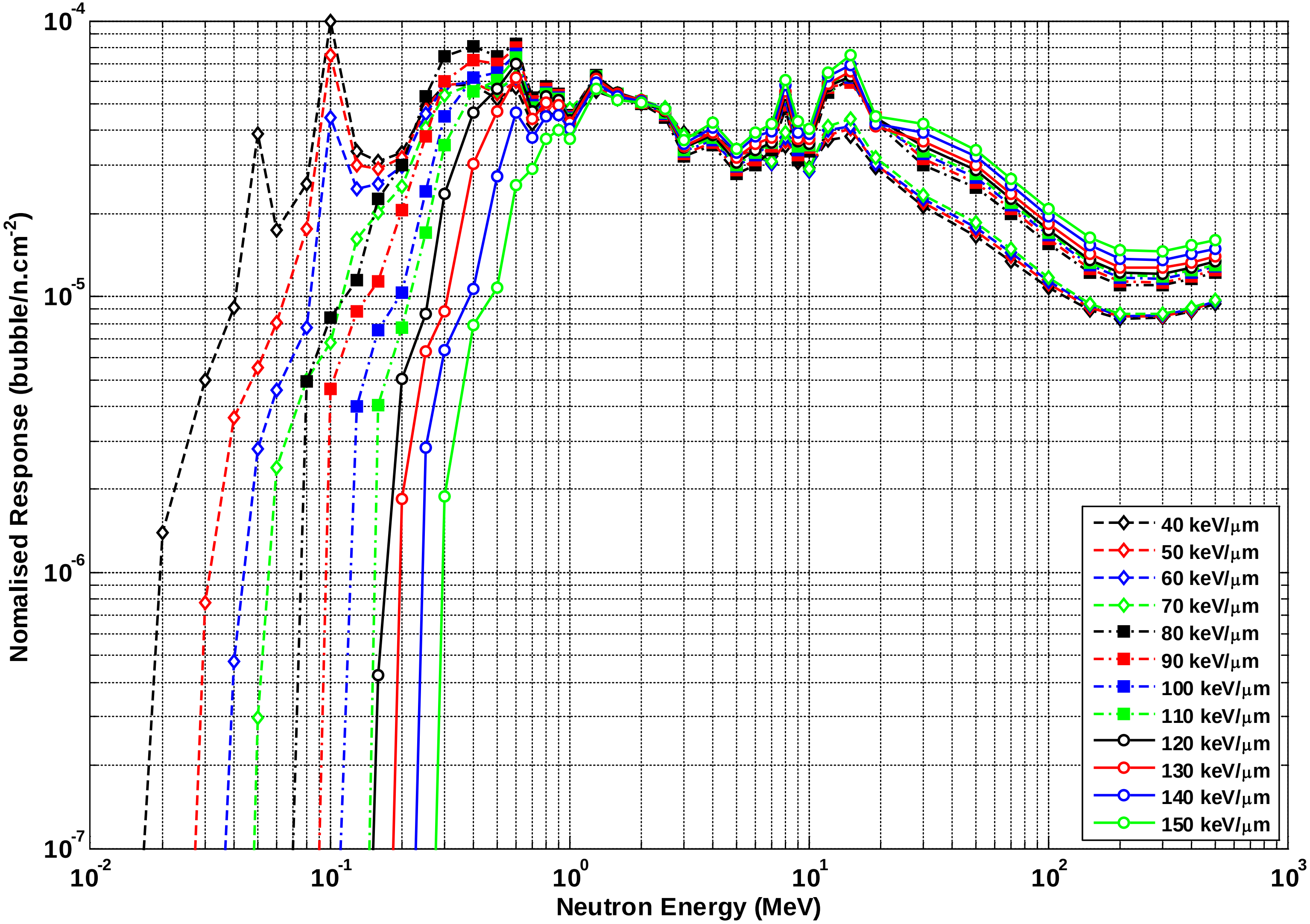

Bubble Detector Response Function

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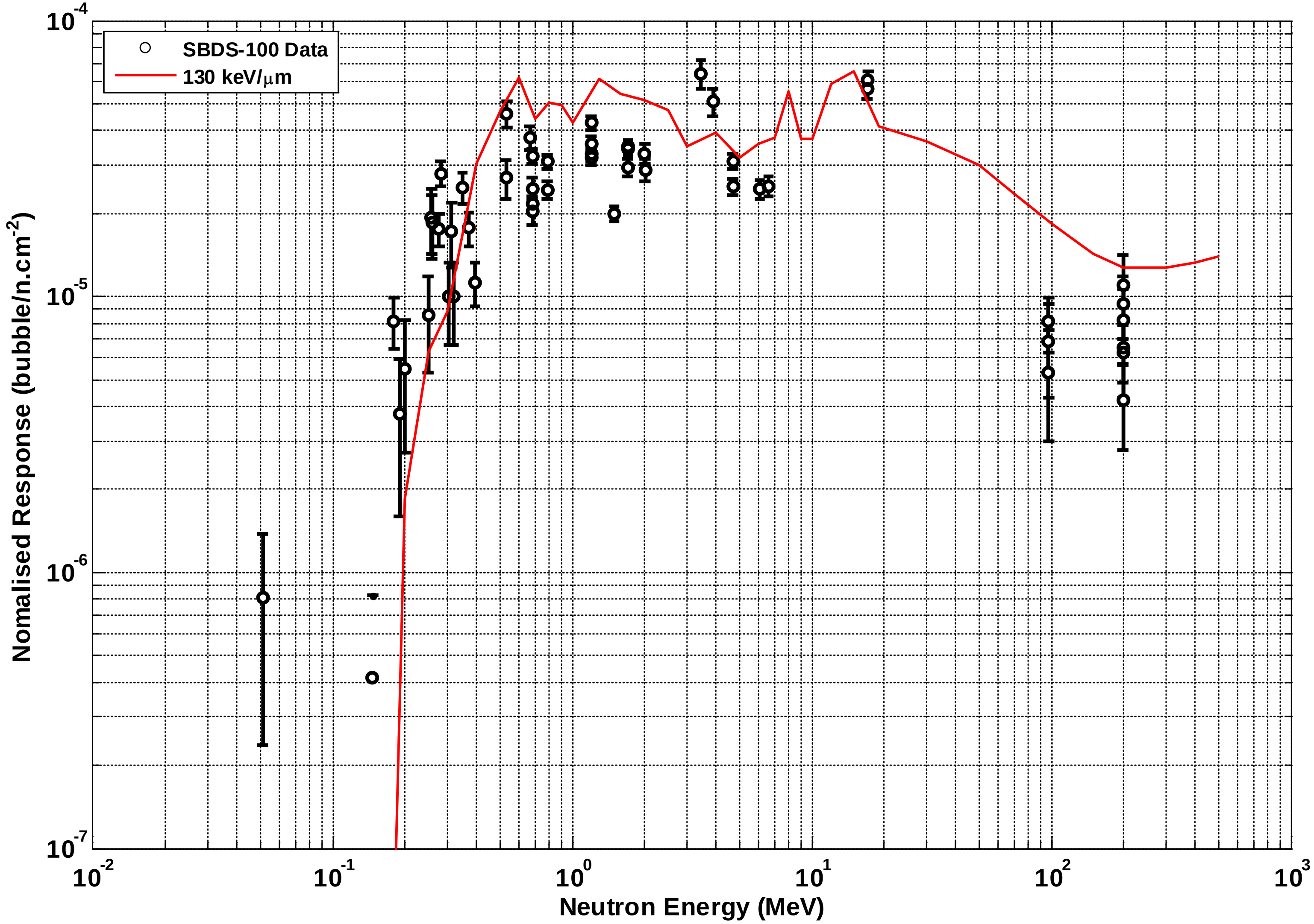
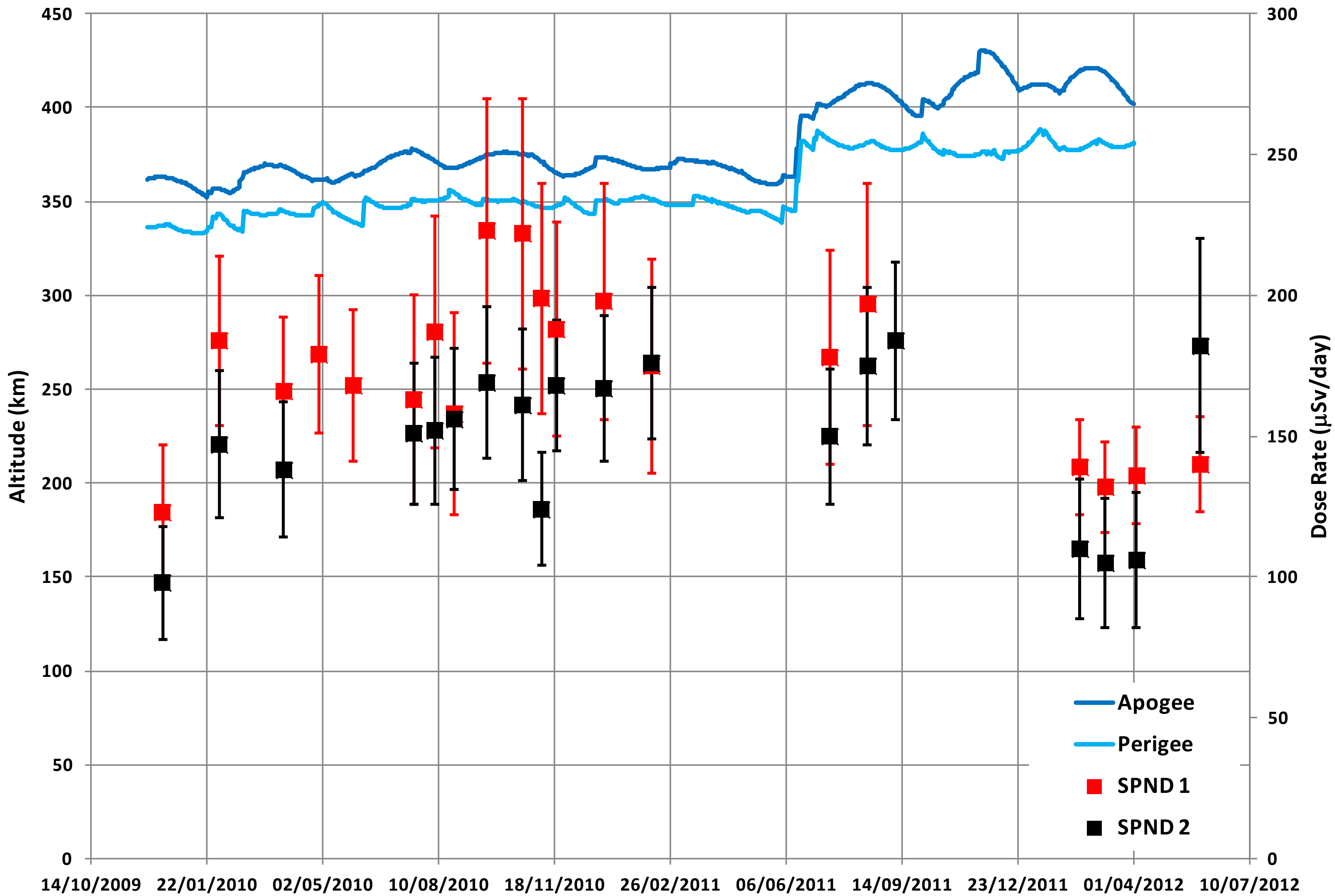


ISS-22 to ISS-33: Altitude



ISS-22 to ISS-33: Solar Activity

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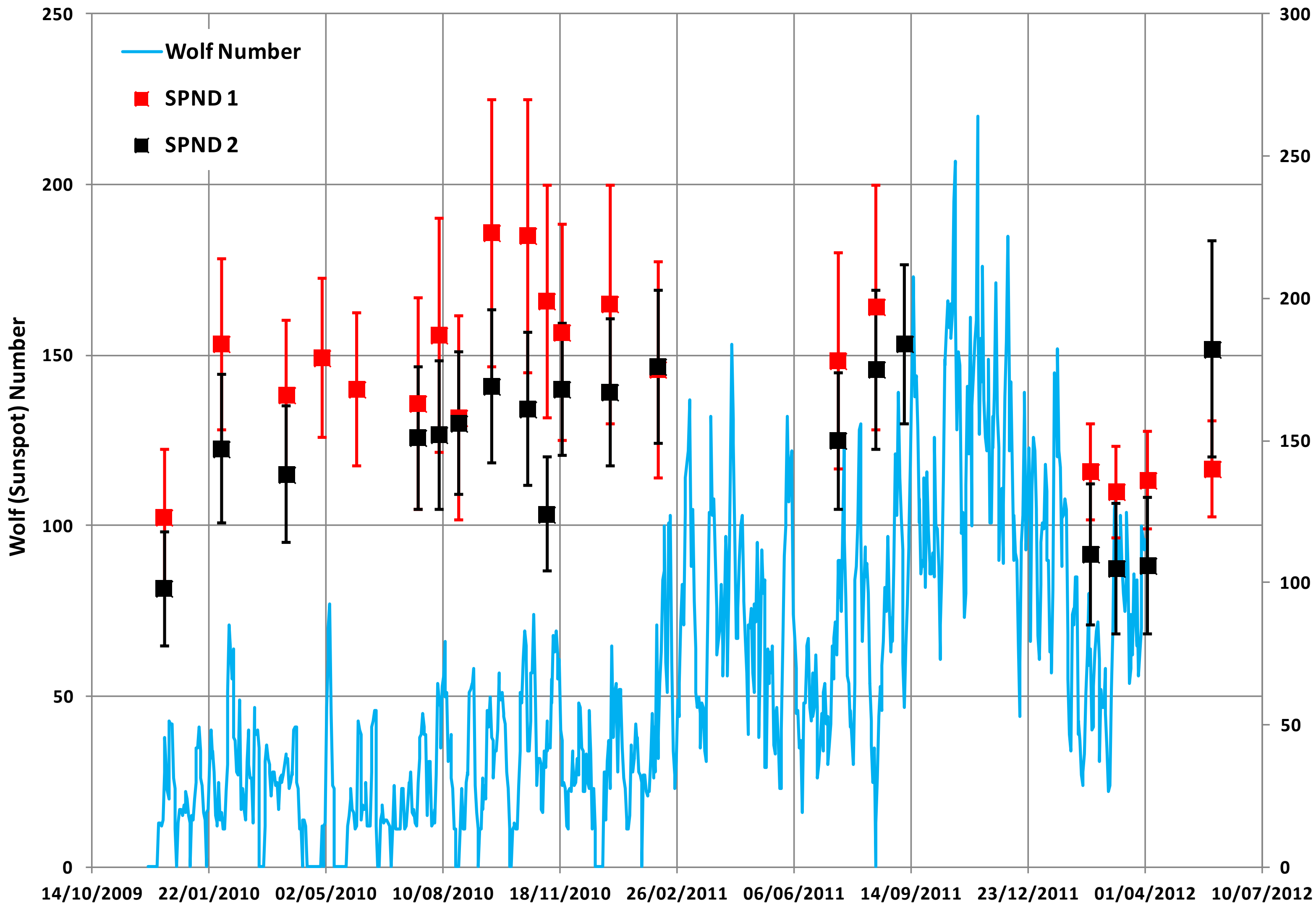

Phantom: Monte-Carlo Simulations

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- Interactions in the phantom were investigated using Geant4 Monte-Carlo simulations
  - Inputs from Armstrong and CREME
  - Results suggest that most neutrons inside the phantom are due to neutron scattering
  - Protons and alpha particles also create neutrons
- Geant4 neutron dose in the phantom is 58% of that at the surface
  - Good agreement with the dose-rate reduction measured by the SBDS (66%) and SPNDs (73±17%)

T.W. Armstrong and B.L. Colborn., Radiat. Meas. 33(3), 229 – 234 (2001)