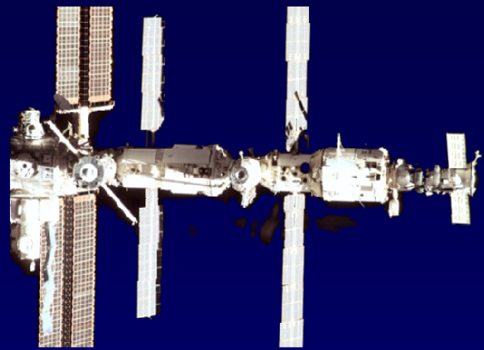
Ninth Workshop "Solar influence on the magnetosphere, ionosphere and atmosphere"



Experiment Liulin-5:

Review of the Measured Radiation Characteristics on Board the International Space Station

Variability of radiation characteristics inside ISS

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[1] ***SRTI-BAS, Bulgaria,***

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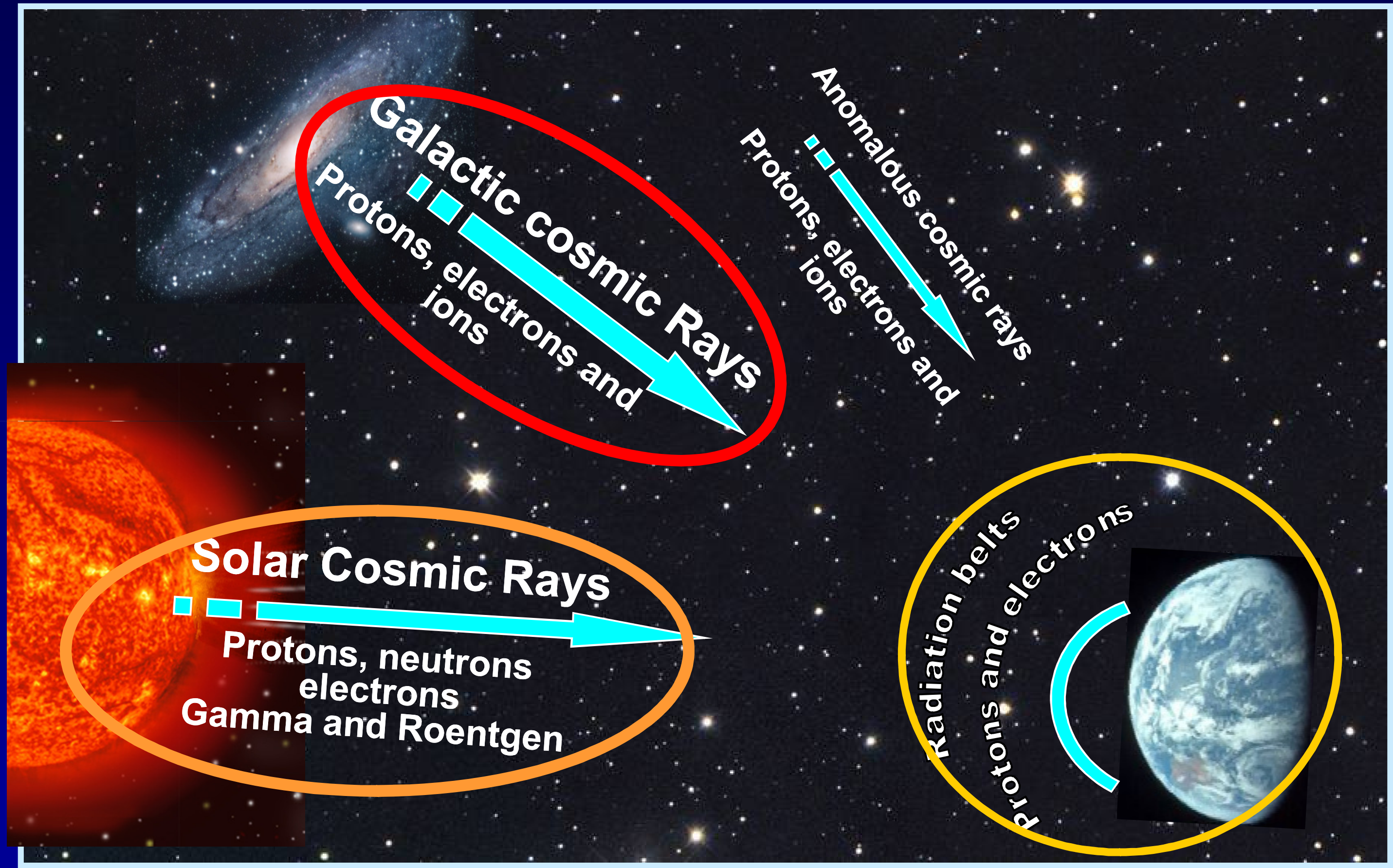
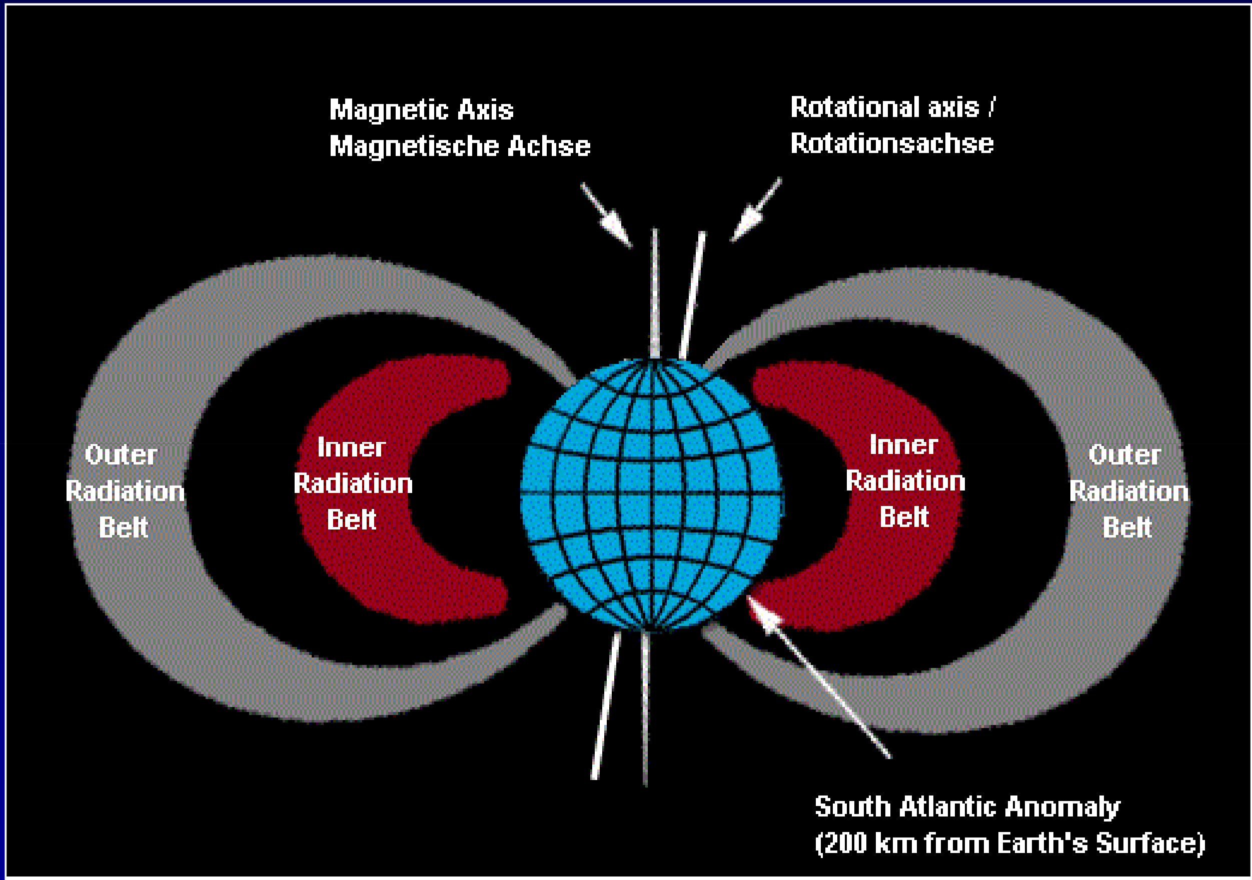
RADIATION SOURCES IN THE HELIOSPHERE



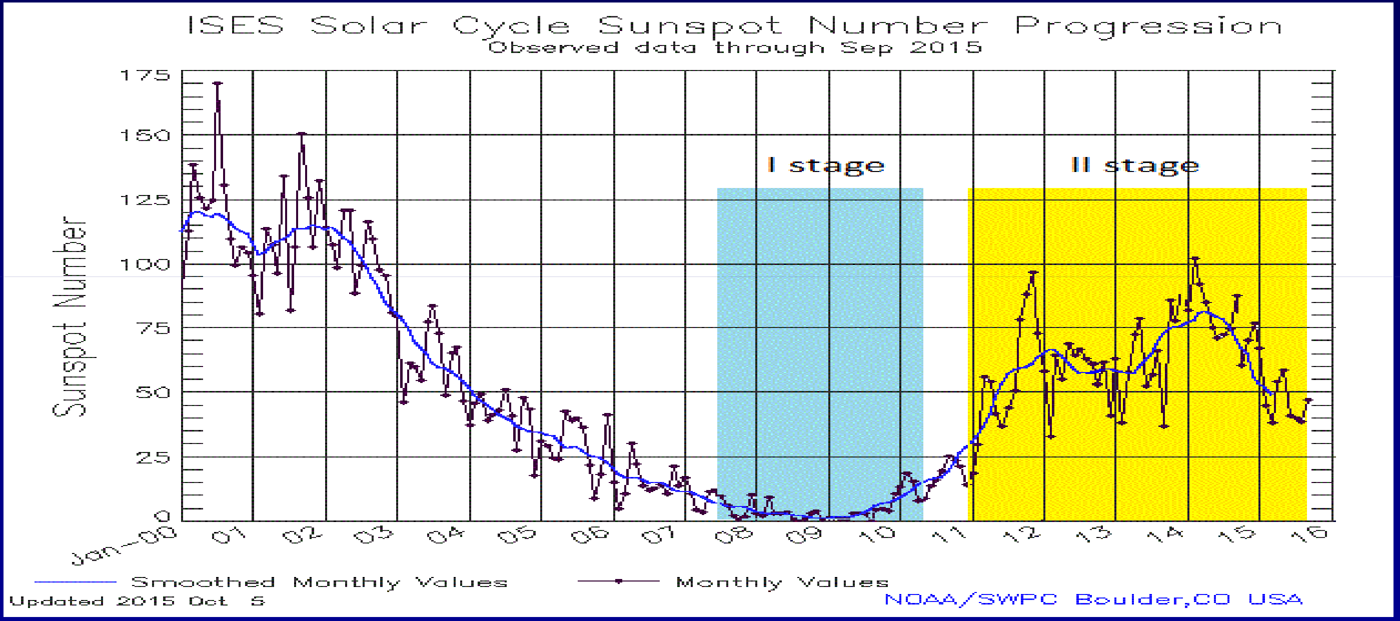
Inside a space vehicle ⟶ + secondary particles

THE EARTH RADIATION BELTS



LIULIN – 5

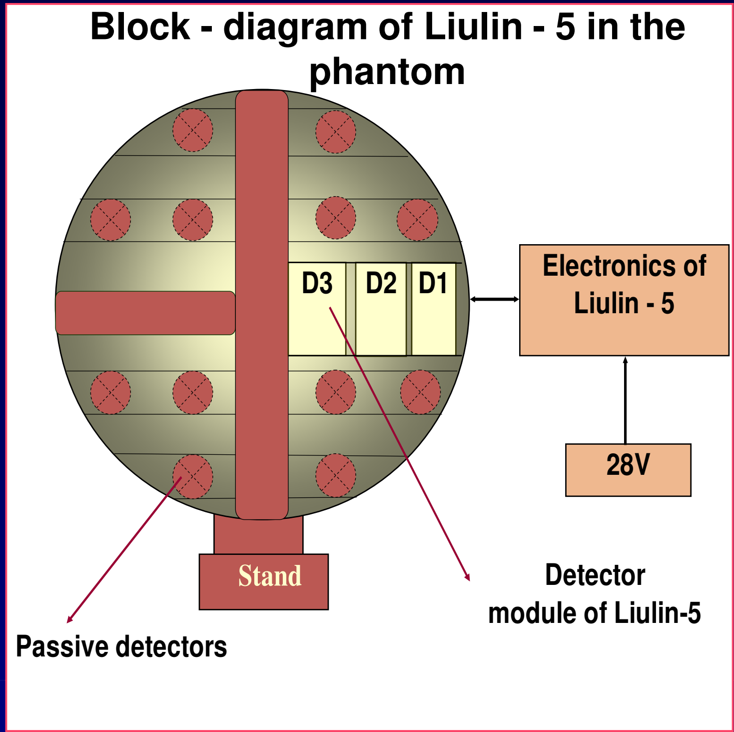
Experiment Liulin-5 was observing the radiation characteristics in the spherical tissue-equivalent phantom of MATROSHKA-R project on ISS since June 2007 till September 2015 .



We present a review of the results obtained during the the two stages of the experiment:

I stage – June 2007 – 2009

II stage – 2012 – September 2015



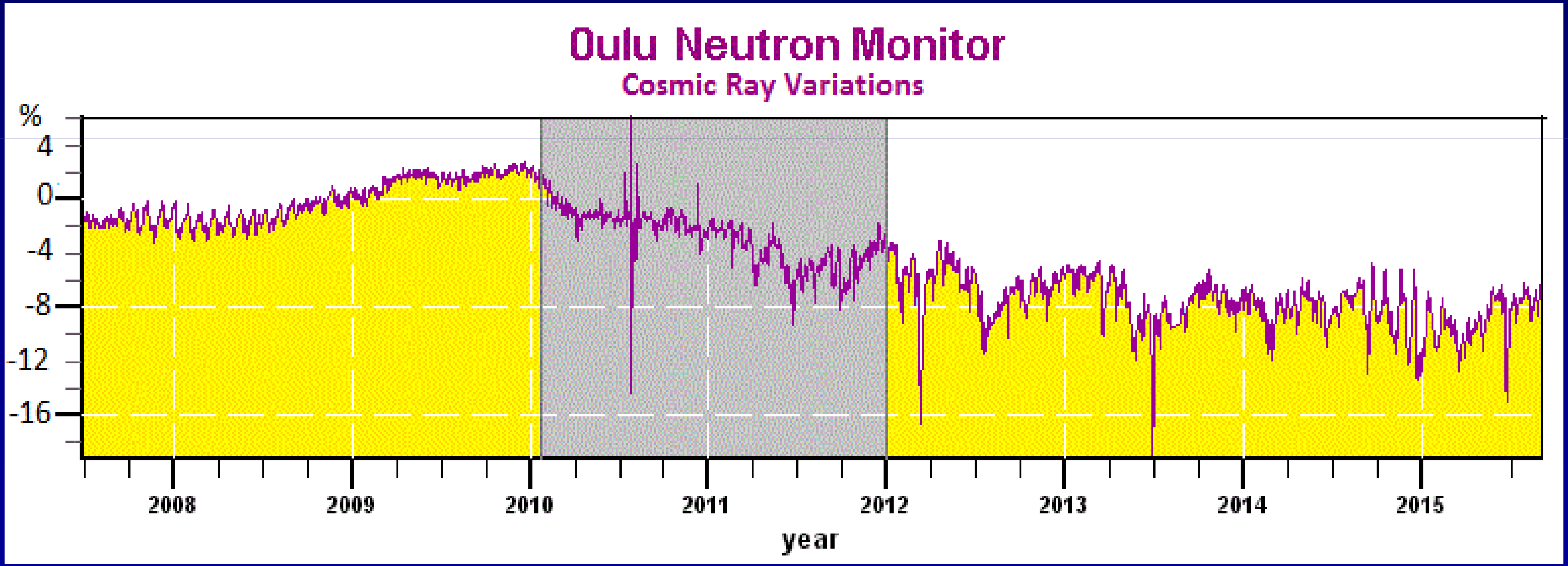
- ✓**At 3 depths -Energy Deposition Spectra, Dose Rate & Particle flux** - then Absorbed Dose D;
- ✓**The Linear Energy Transfer (LET) spectra in silicon** - then assessment of LET(H_2O), Q=f(LET), Dose Equivalent H=∑Q(*LET*).D(*LET*).

- D1 and D2 are at 40 mm and 60 mm from the surface of the phantom – depth, corresponding to the shielding of BFO in human body.
- D3 is at 165 mm depth, close to the center of the phantom.

CONDITIONS of the EXPERIMENT

I. Solar cycle variations

Galactic Cosmic Rays (GCR)

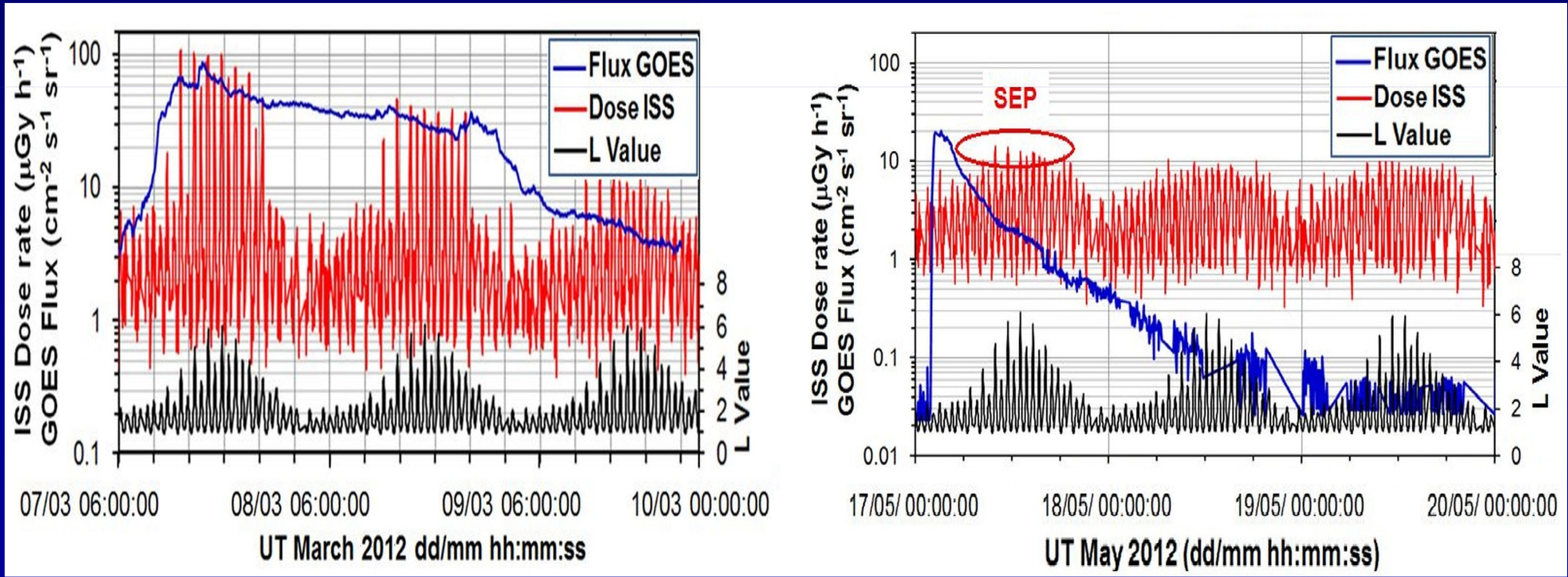


Galactic cosmic ray flux varied by ~7 to 12 %

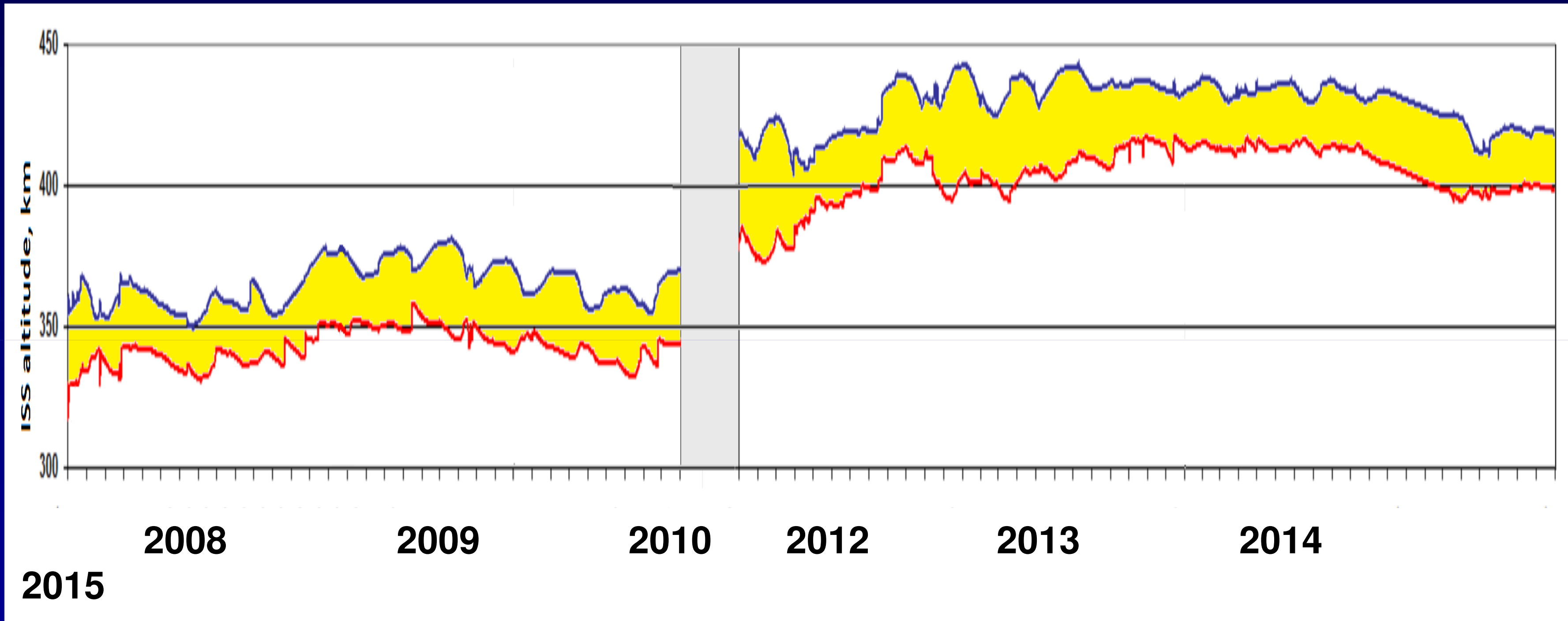
27 Solar Proton Events (SPE) in 2012 – September 2015

To be observed inside ISS :

- ***Energy > 100 Mev***
- ***intensity above the threshold of 10 $p/cm^{-2}s^{-1}sr^{-1}$***
- ***long duration***



II. Different altitude of the International Space Station

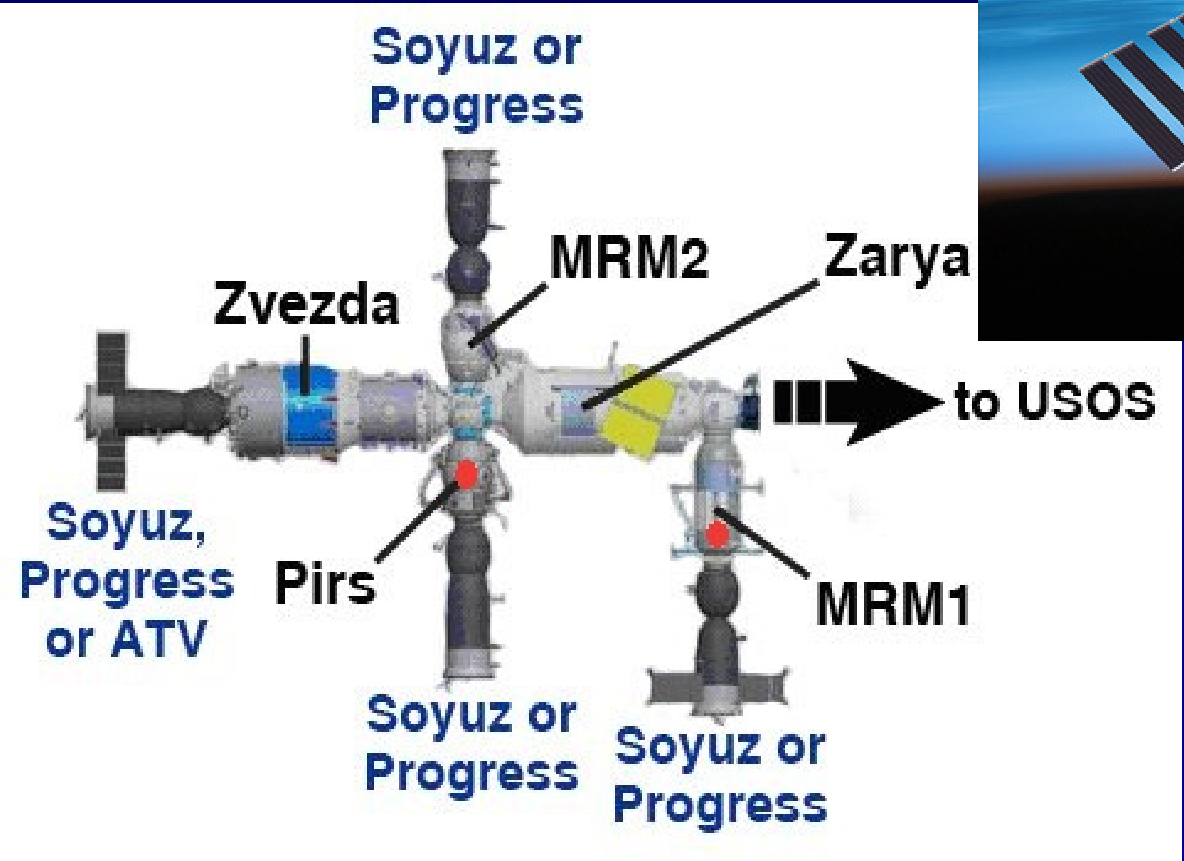


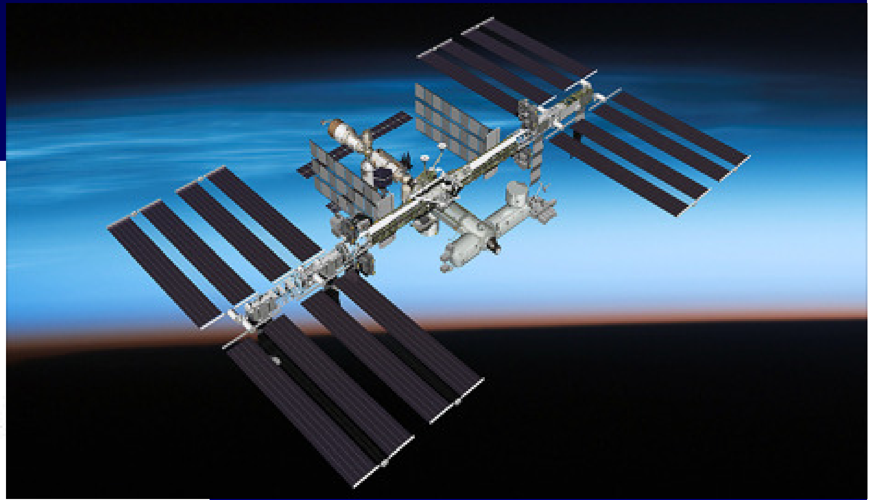
I stage - 330 – 380 km

II stage – 380 – 445 km

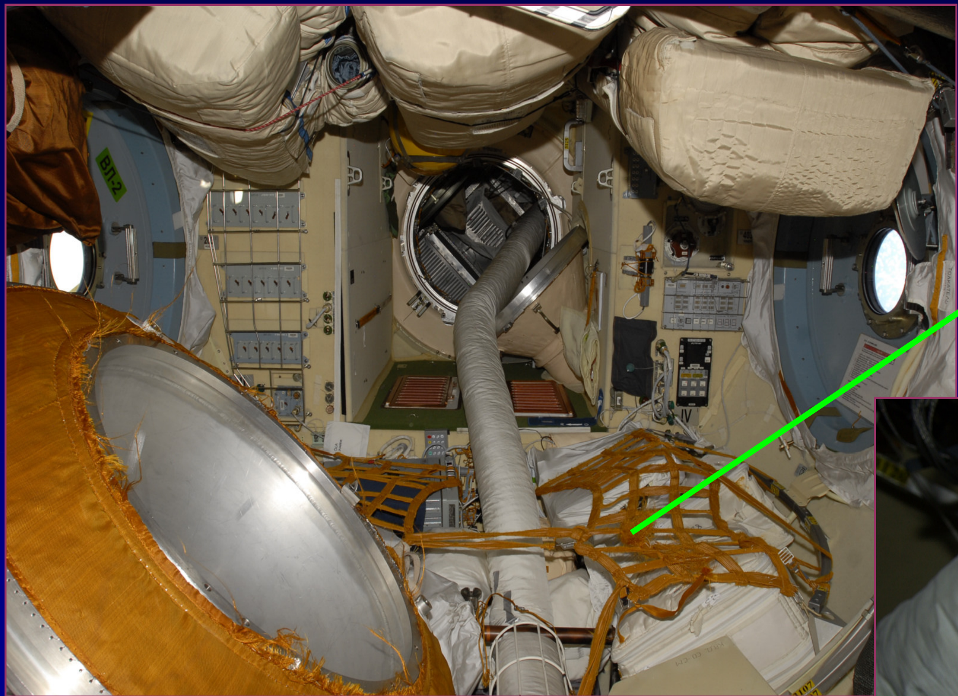
III. Different location = different shielding

ISS configuration with the Pirs and MRM1 module and the spherical phantom





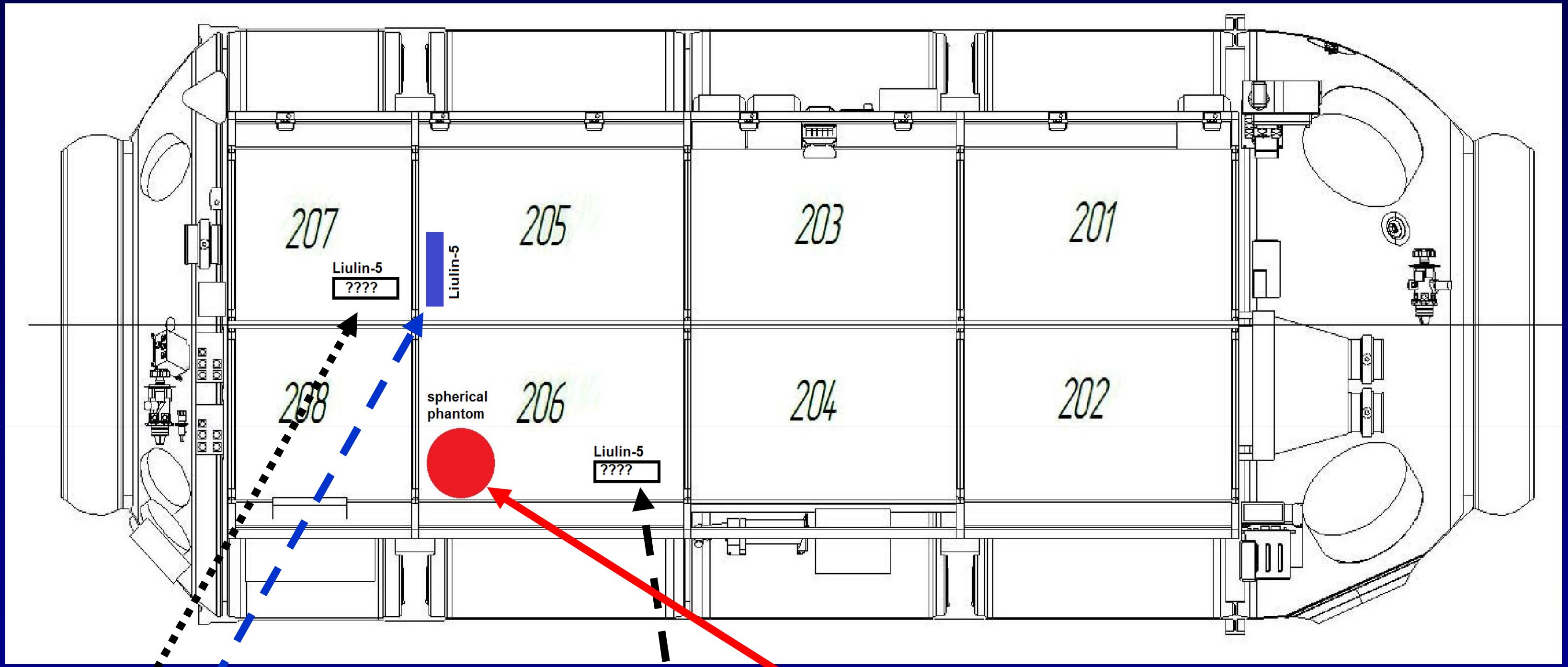
Llulin -5 in the Spherical Phantom on ISS
I stage - 2007 - 2009



Detector module

LIULIN-5 in the Phantom in Pirs module of ISS – activated 28 June 2007.

Position of Liulin-5 during 2012 - 2015 on the right board of MRM1 ISS module (II stage).



Outside the phantom

21.05.2012 - 31.08.2012

31.08.2012 - 12.09.2012

18.09.2013 - 05.09.2015

Inside the phantom

27.12.2011 - 20.05.2012

12.09.2012 - 16.09.2013

Liulin - 5 in the phantom

The spherical phantom on ISS, located in the MRM1 module behind the panel 206. Inside the phantom (behind the label) is the detector module of Liulin-5.

Liulin-5 outside the phantom behind panel 205 in the MRM1 module

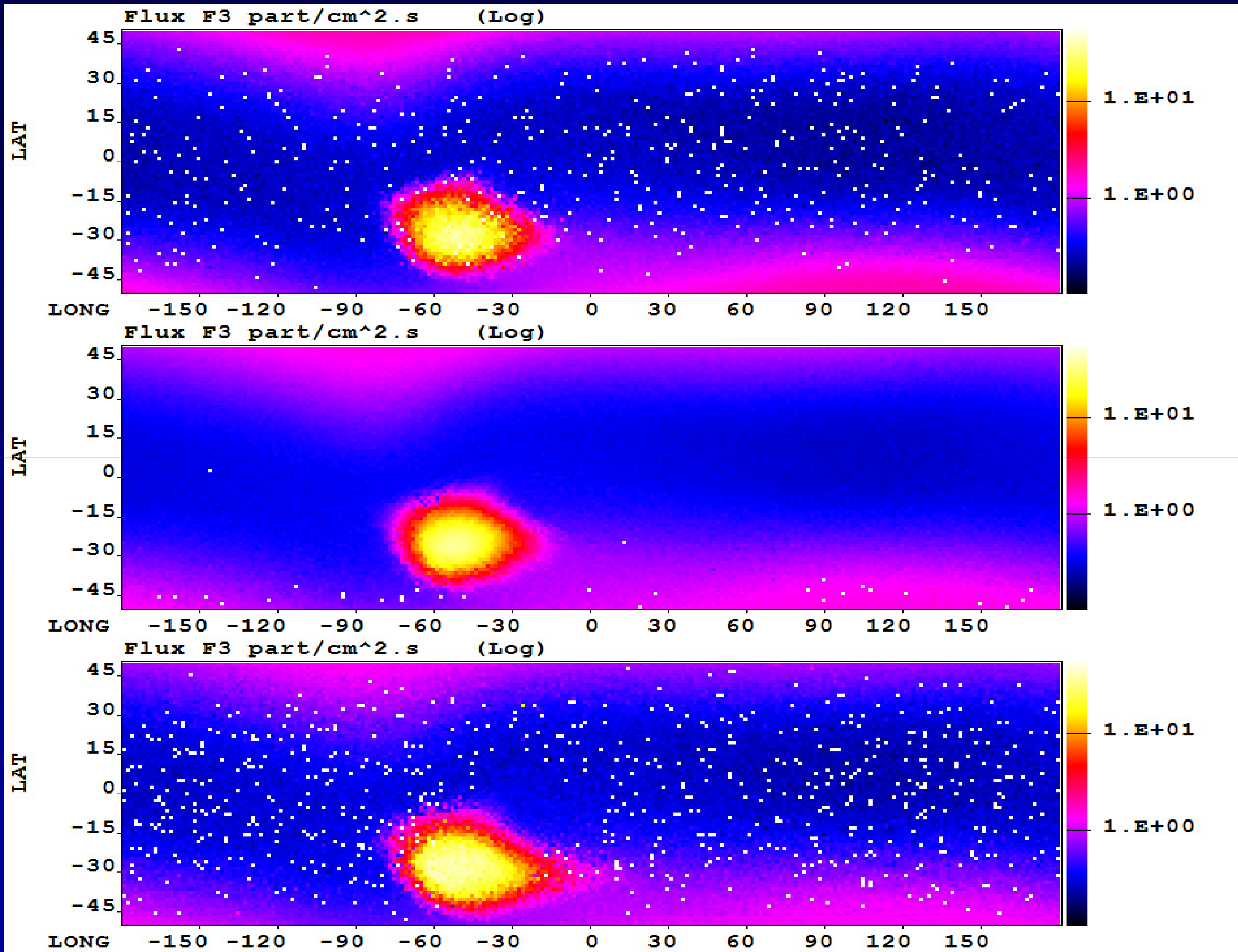
The Liulin-5 *(white rectangle)* located behind the panel 205 in MRM1 module of ISS

Geographical distribution of ionizing particles

I stage

II stage inside

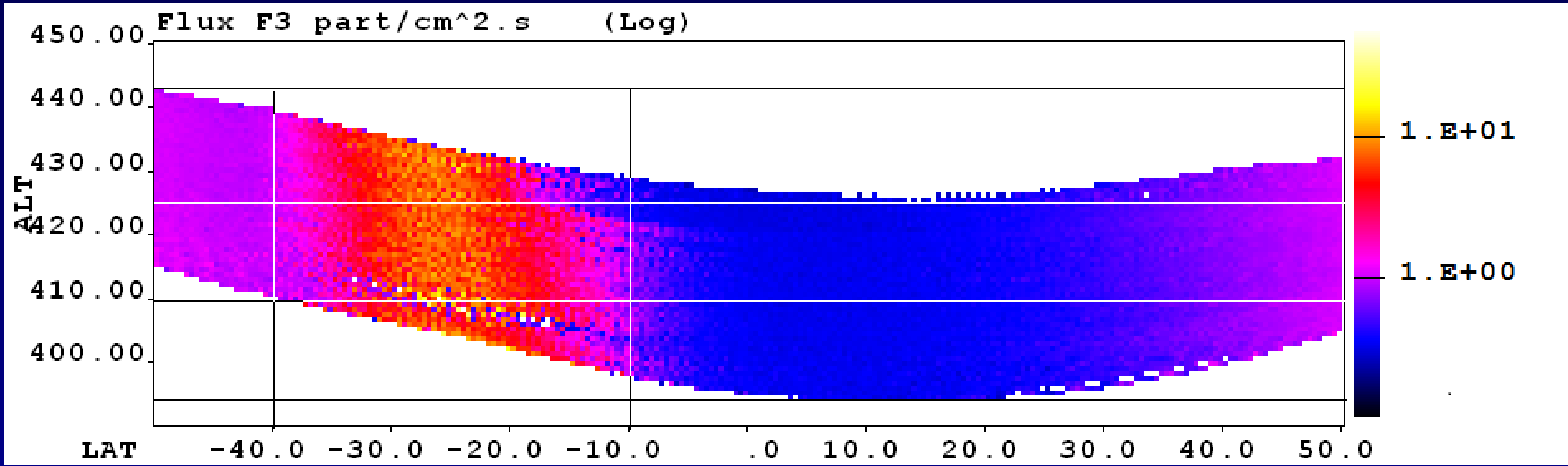
II stage outside

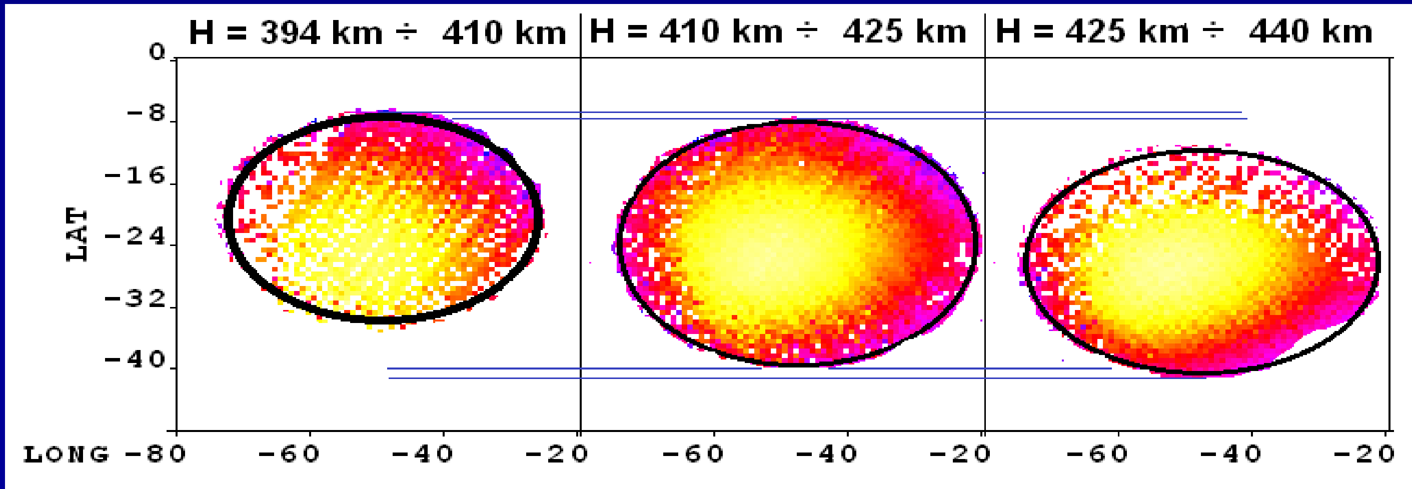


Altitudinal distribution

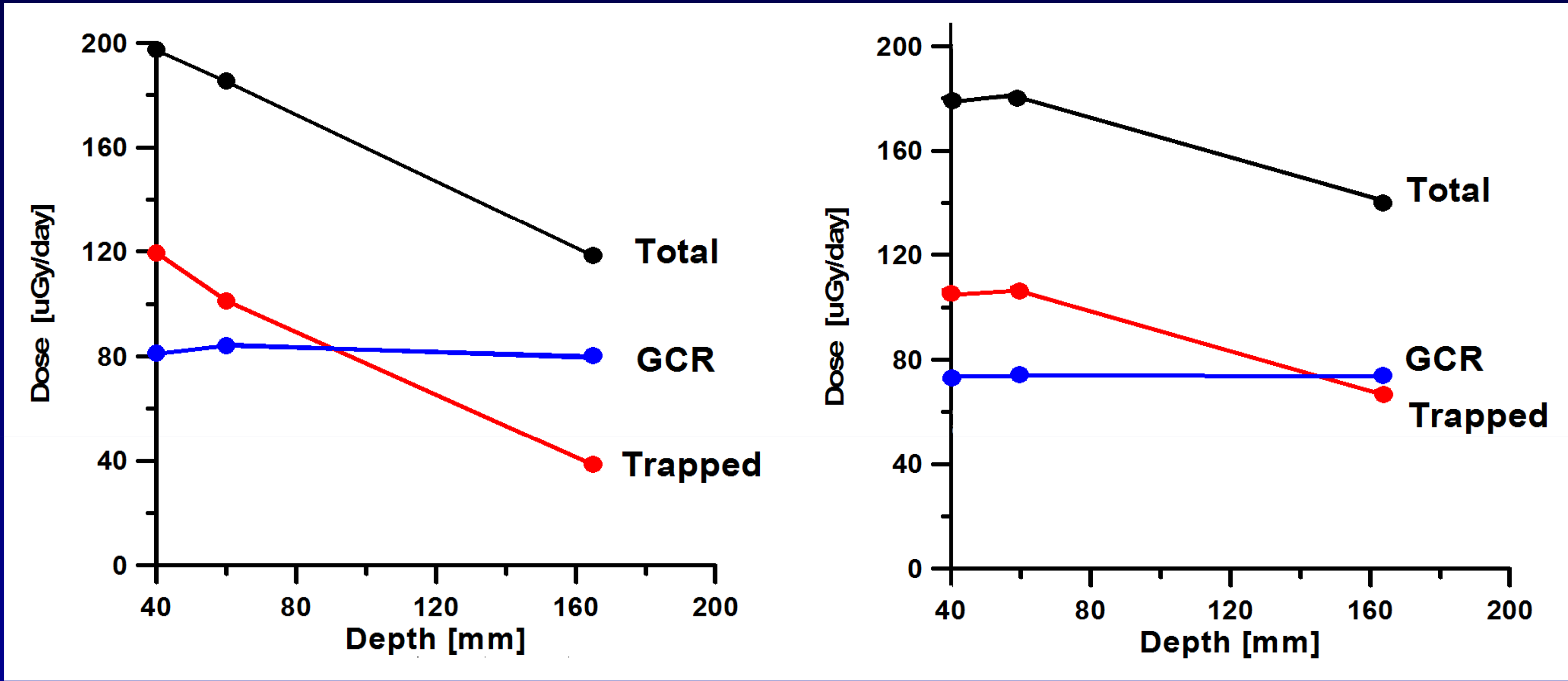
394 – 410 km; 410 – 425 km; 425 – 440 km

Distribution of the flux rate measured in D3 for the period 01.10.2012 - 09.05.2013





Dose depth distribution

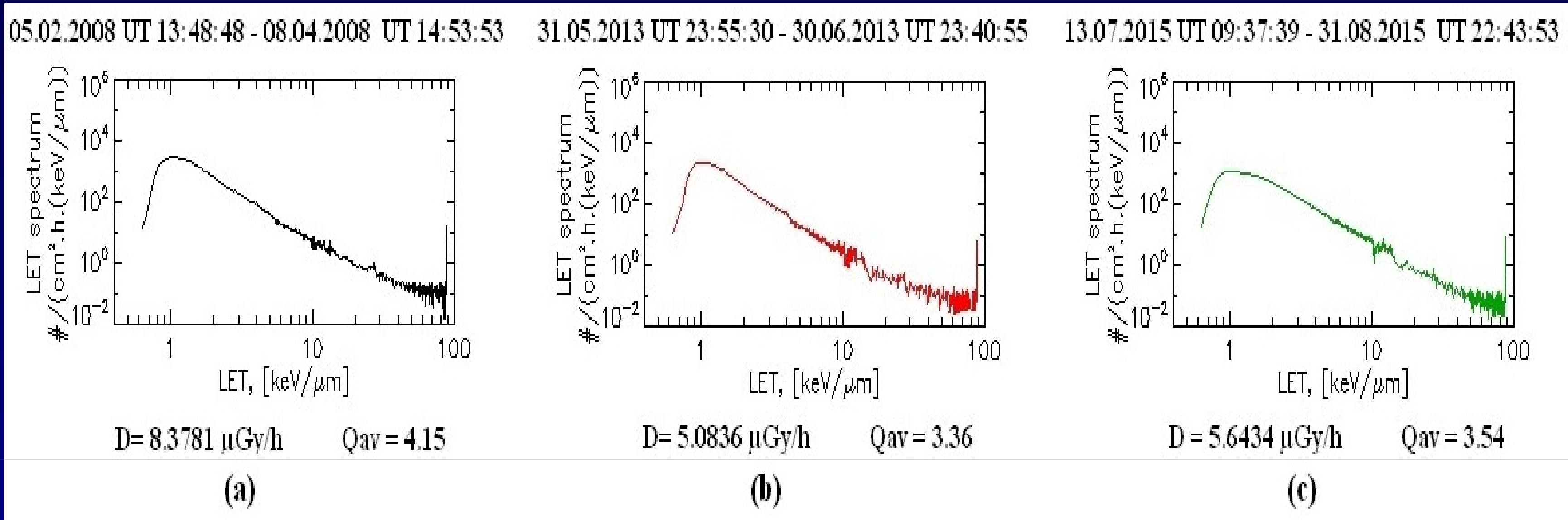


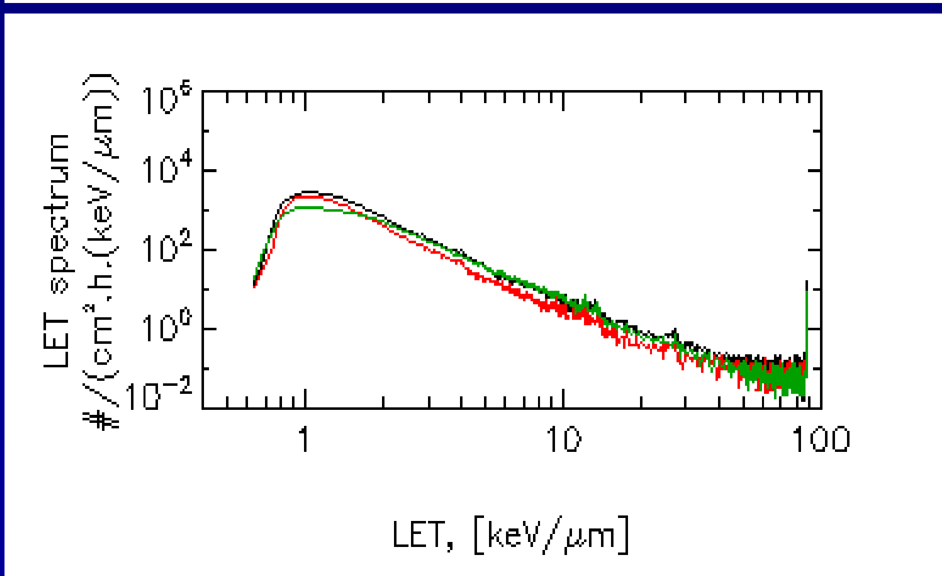
18-23.11.2007, h ~ 349 km

1.06 - 30.06 2013, h ~ 422 km

Typical depth dose distributions in the phantom illustrating the contribution of the GCR and the trapped protons

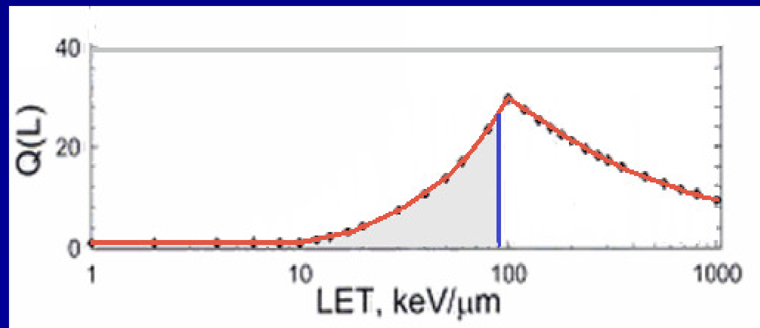
LET *(dE/dX)* spectra and quality factor



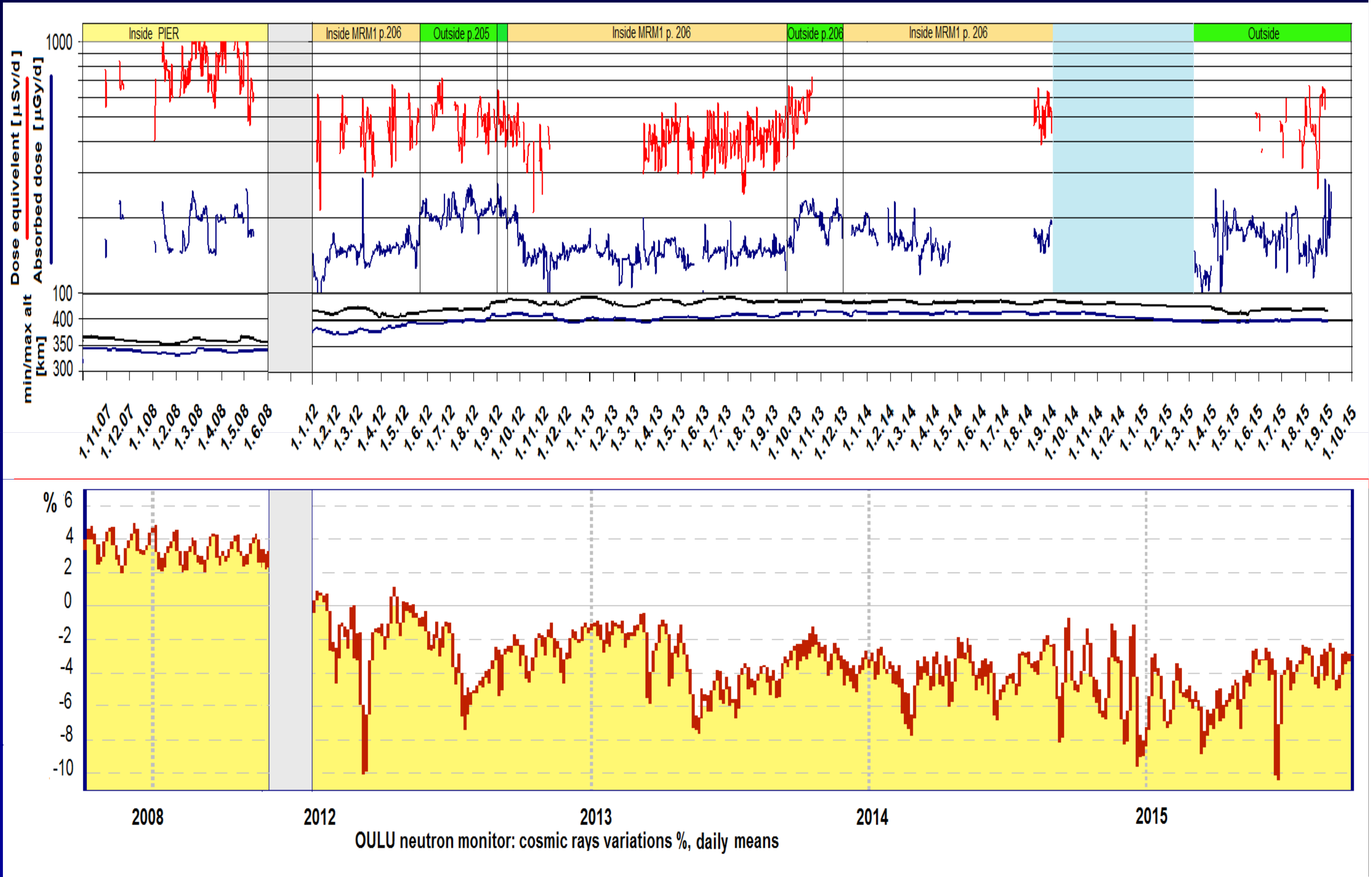


Q=f(LET),

H=∑Q(*LET*)*D(*LET*) [Sv]

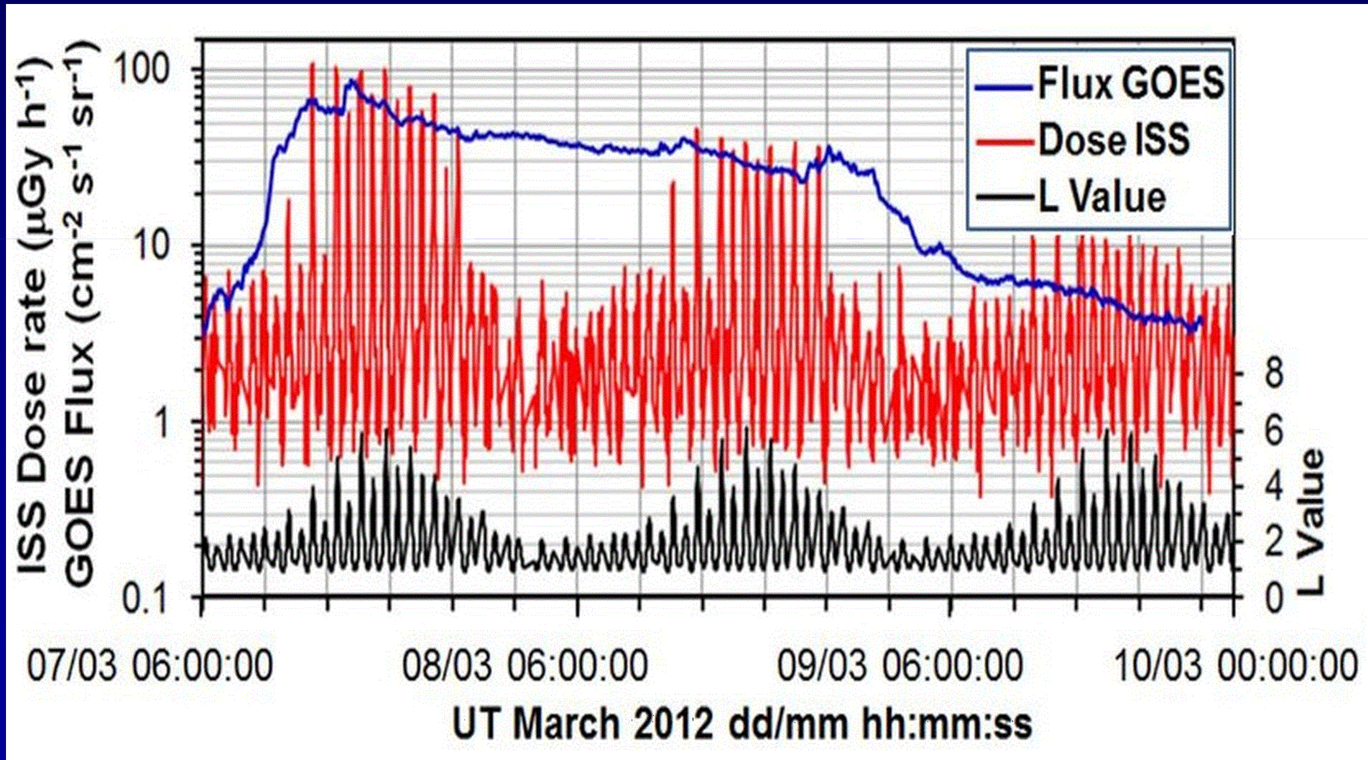


OVERVIEW OF LIULIN-5 DATA



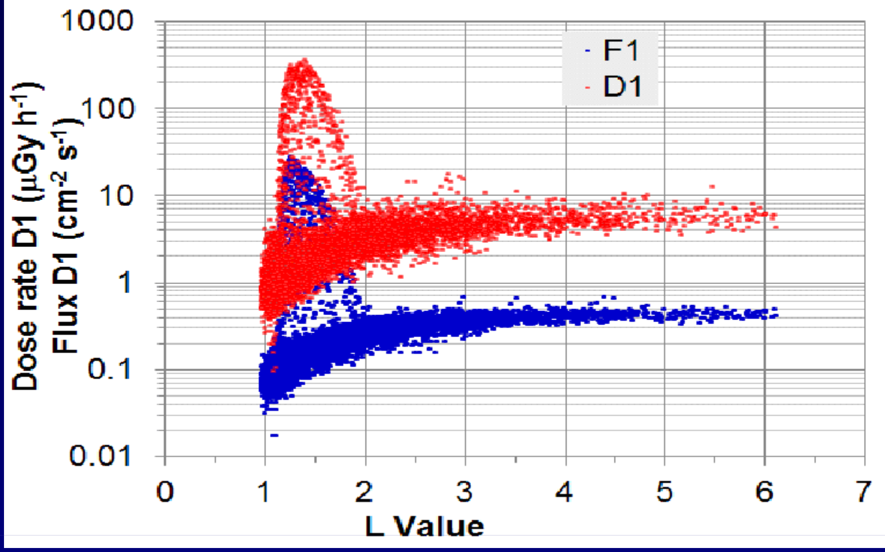
SPE observations

- On 07.03.2012 GOES -13 registered the beginning of two SPE associated with Earth-directed CMEs. A greater than 100 MeV event began at 04:05 UT on 07 March 2012, reached a maximum of 69 part·$cm^{-2}\cdot s^{-1}\cdot sr^{-1}$ at 15:25 UT the same day, and ended at 16:50 UT on 10 March 2012. *(ftp://ftp.ngdc.noaa.gov/STP/swpc_products/weekly_reports/)*

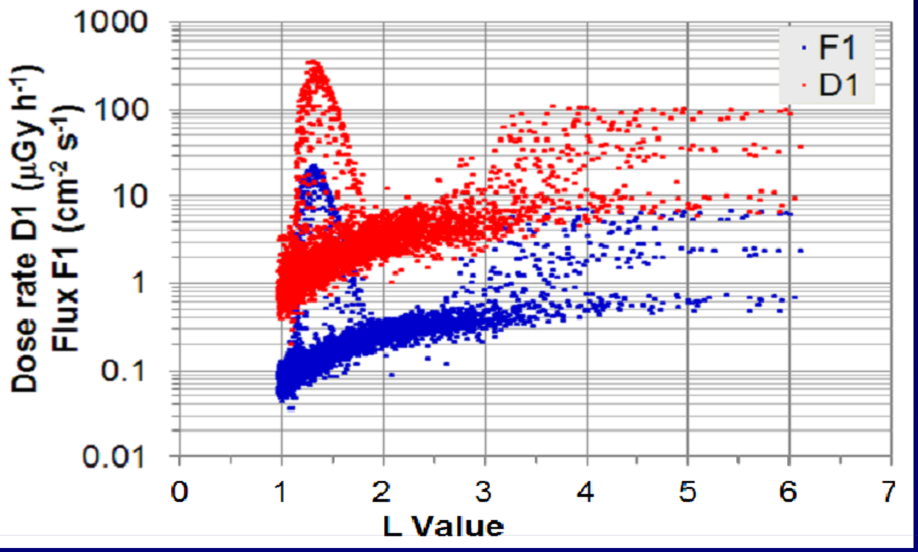


Liulin-5 registered the effect from the SPE from 07.03.2012, at 13:01 UT till 08.03.2012, at 21:31 UT

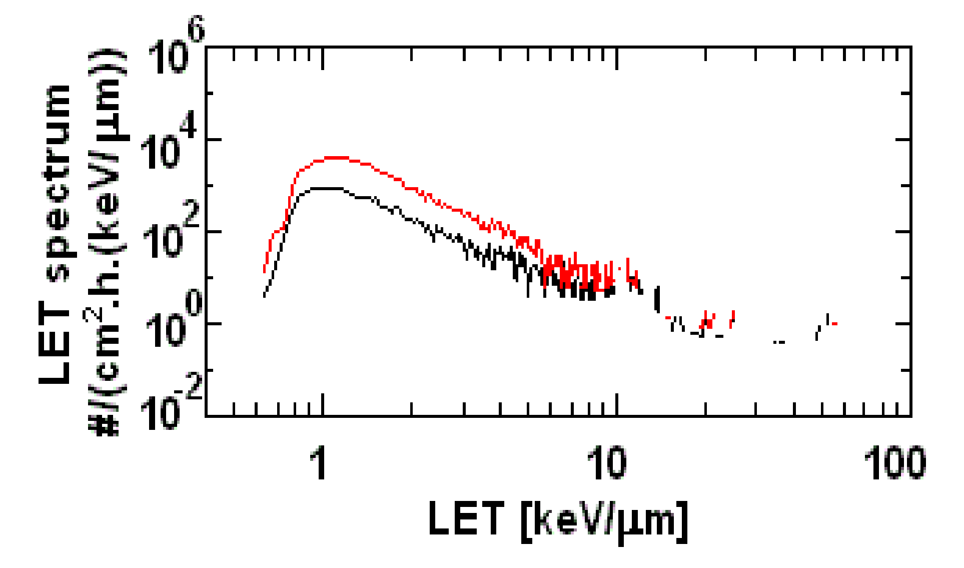
Distribution of particle flux F1 (blue) and dose rate (red) in D1 detector located at 40 mm depth in the phantom as a function of L



quiet conditions



SPE



LET spectra for orbits not crossing SAA

black curve - prior the SPE Q=4.15

red curve - during SPE, Q=2.5

The additional dose equivalent is ~ 450 μSv - comparable to the daily values in the phantom in ISS during quite periods.

CONCLUSIONS (1)

➢ Variability of the radiation environment in ISS

	2007-2009 in the phantom	2012-2015 in the phantom	2012-2015 outside the phantom	SPE 7-10.03.2012 *(at L>3 for 3 days)*
D1	186 – 230 μGy/day	130-220 μGy/day	150-280 μGy/day	+ 180 μGy
D3	83 - 150 μGy/day	120 - 160 μGy/day		
Dose Equivalent	590-880 μSv/day	220-600 μSv/day	300-700 μSv/day	+ 450 μSv

CONCLUSIONS (2)

- **Dose distribution in depth of the phantom**. ***The doses from GCR are practically the same at different depths. At 165 mm depth due to the phantom self-shielding from the trapped protons in SAA a decrease by a factor of 1.6-1.9 of the absorbed doses is found. Near the center of the phantom the GCR contribute about 60% of the total dose*.**

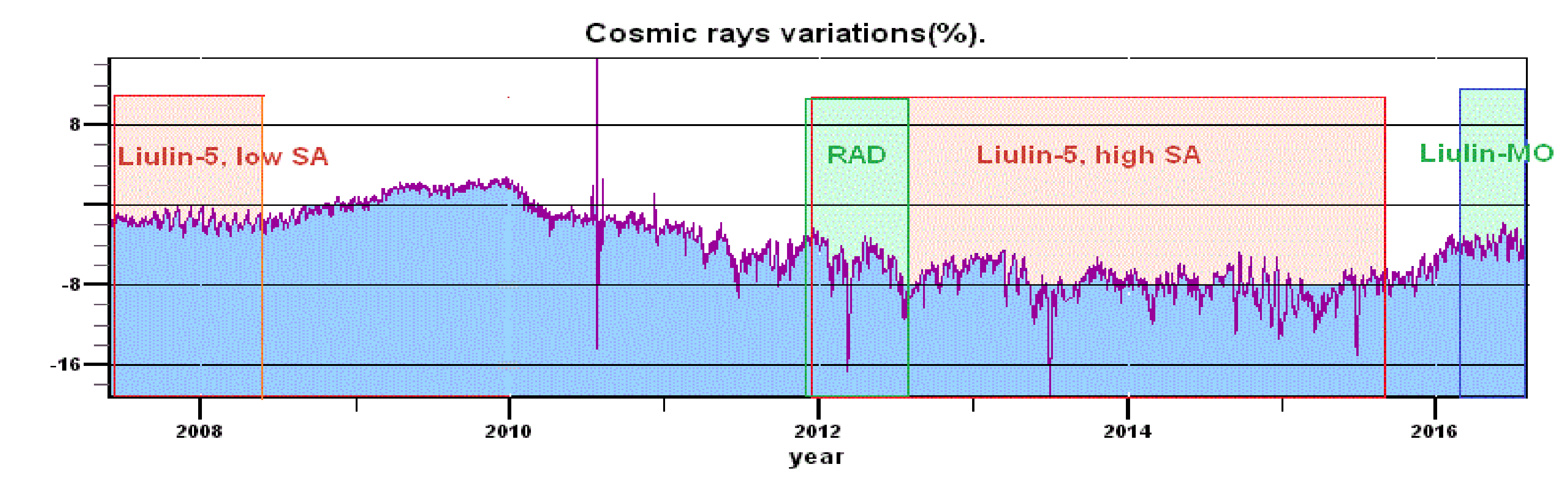
- **Height dependence.** ***The SAA shape and dimensions vary with the altitude of ISS.***

- **Comparison between Liulin-5 data during both stages of the experiment – solar minimum and solar maximum**. ***During the I stage, when the ISS is at higher altitudes, the dose rates at 40 mm depth (BFO) in the phantom are comparable with the dose rates outside the phantom during the II stage. The dose equivalent rates are much higher. This is due to the much higher intensity of the GCR during the minimum of the 23th solar cycle and the small number of SPE with increased flux of >100 MeV protons close to the maximum of the 24th solar cycle.***

SUPPLEMENT: COMPARISON

- ✓ Doses for an round trip to Mars - 1 year, 6 month in each direction
- ✓ One year stay in ISS

	To and from MARS	On ISS – Liulin-5
high SA *without SPE*	RAD: ~ 630 mSv	~ 180 mSv
addition by SEP	RAD: ~24.7 mSv *(5 SPE)*	~ 0.45 mSv
low SA	Liulin-MO: ~ 729 mSv	~ 234 mSv ~ 316 mSv *extreme case*



Acknowledgements

- Agreement between RAS and BAS on space research.
- NIRS - Japan .
- RKK “Energia” and the cosmonauts for the operation of Liulin - 5 aboard ISS.
- Contract No. DID 02/8 with the Bulgarian National Science Fund.

Thank you for your attention!