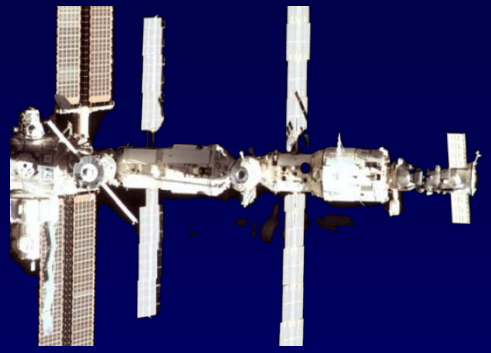
WRMISS22-Torino



# Experiment Liulin-5:
# Results from radiation environment investigations on the International Space Station and interplanetary space with Liulin charged particle telescope

*Variability of radiation characteristics inside ISS*

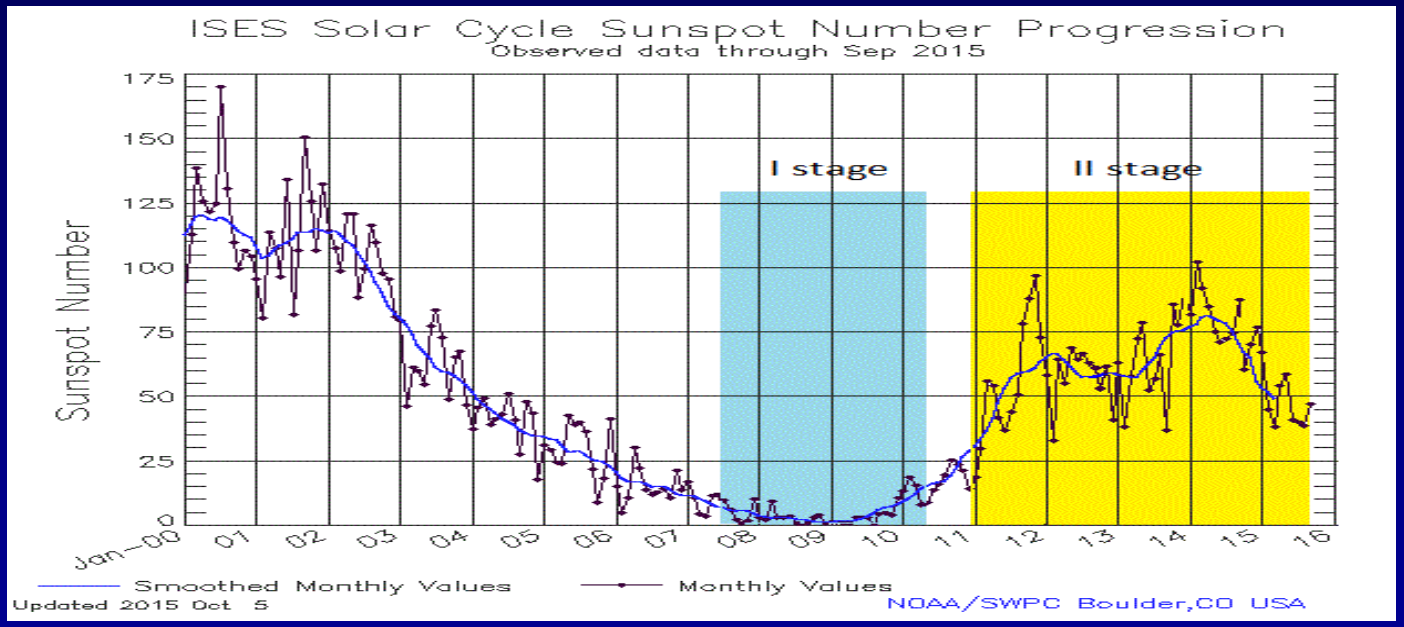

***K. Krastev[1], J. Semkova[1] , R. Koleva[1], St. Maltchev[1], N. Bankov[1], V. Benghin[2], Ts. Dachev[1], V. Shurshakov[2]***

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

***[2] IBMP-RAN, Russia***

# LIULIN – 5

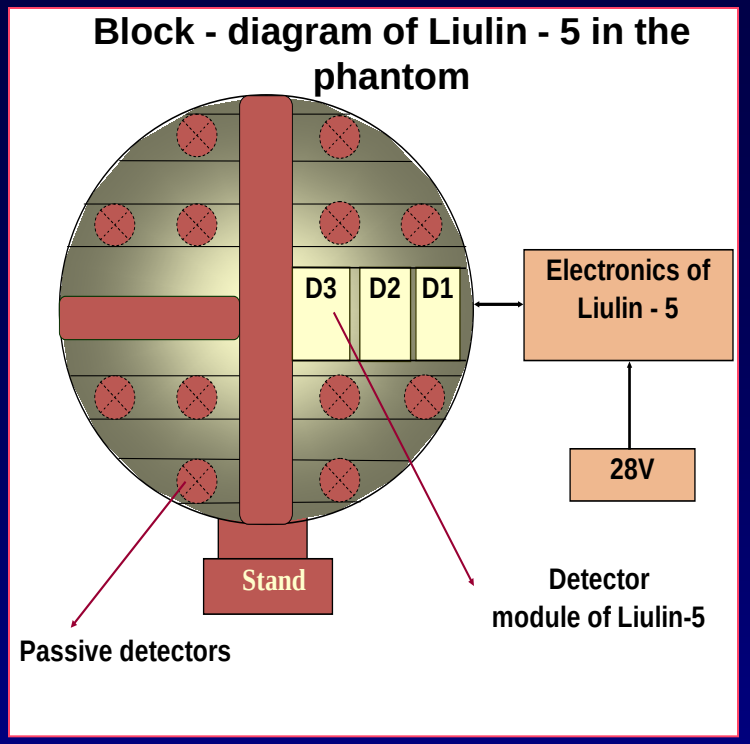
**Experiment Liulin-5 was observing the radiation characteristics in the spherical tissue-equivalent phantom of MATROSHKA-R project on ISS since June 2007 till September 2015 .**




**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**



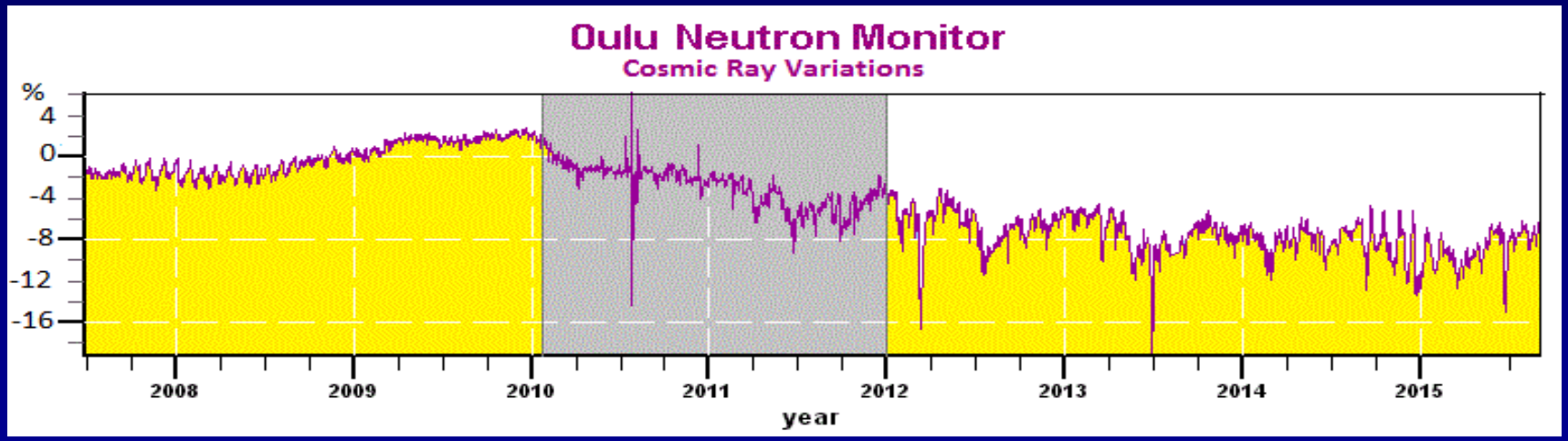

- ✓ **At 3 depths -Energy Deposition Spectra, Dose Rate & Particle flux** - then Absorbed Dose D;
- ✓ **The Linear Energy Transfer (LET) spectra in silicon -** then assessment of LET($H_2O$), Q=f(LET), Dose Equivalent $H=\sum Q(LET).D(LET)$.

- 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 %***

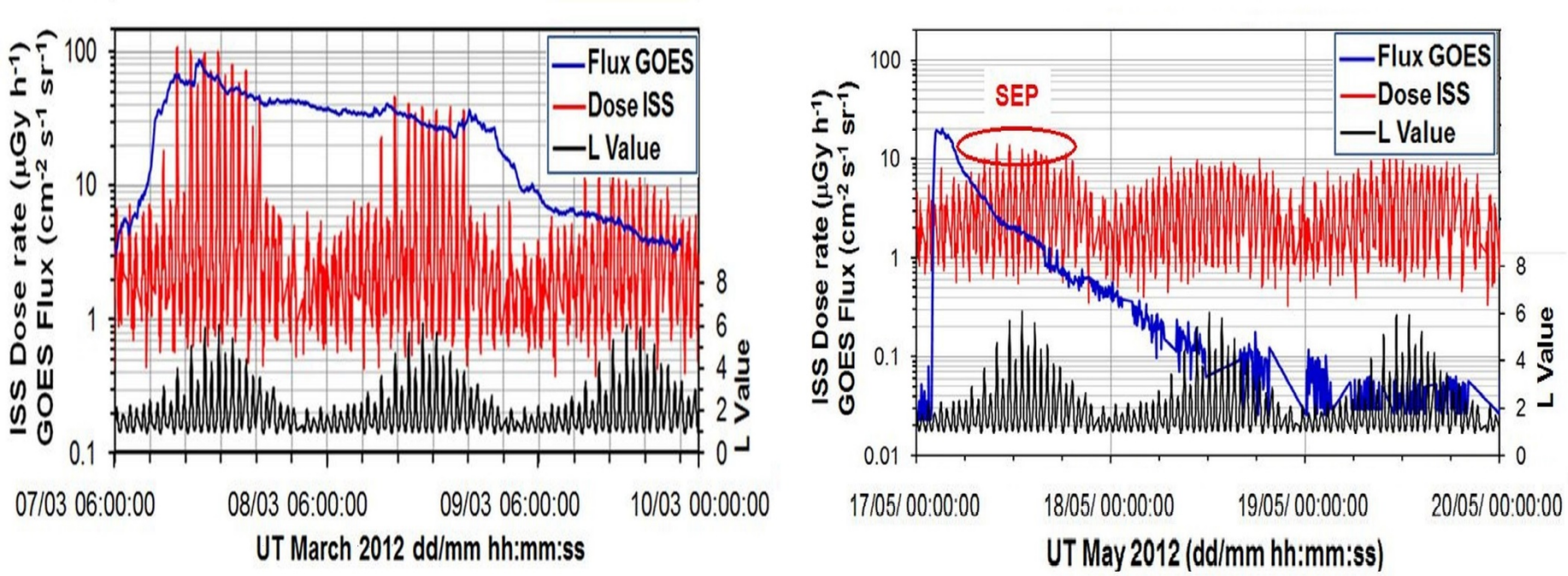
# *27 Solar Proton Events (SPE) in 2012 – September 2015*

***To be observed inside ISS :***

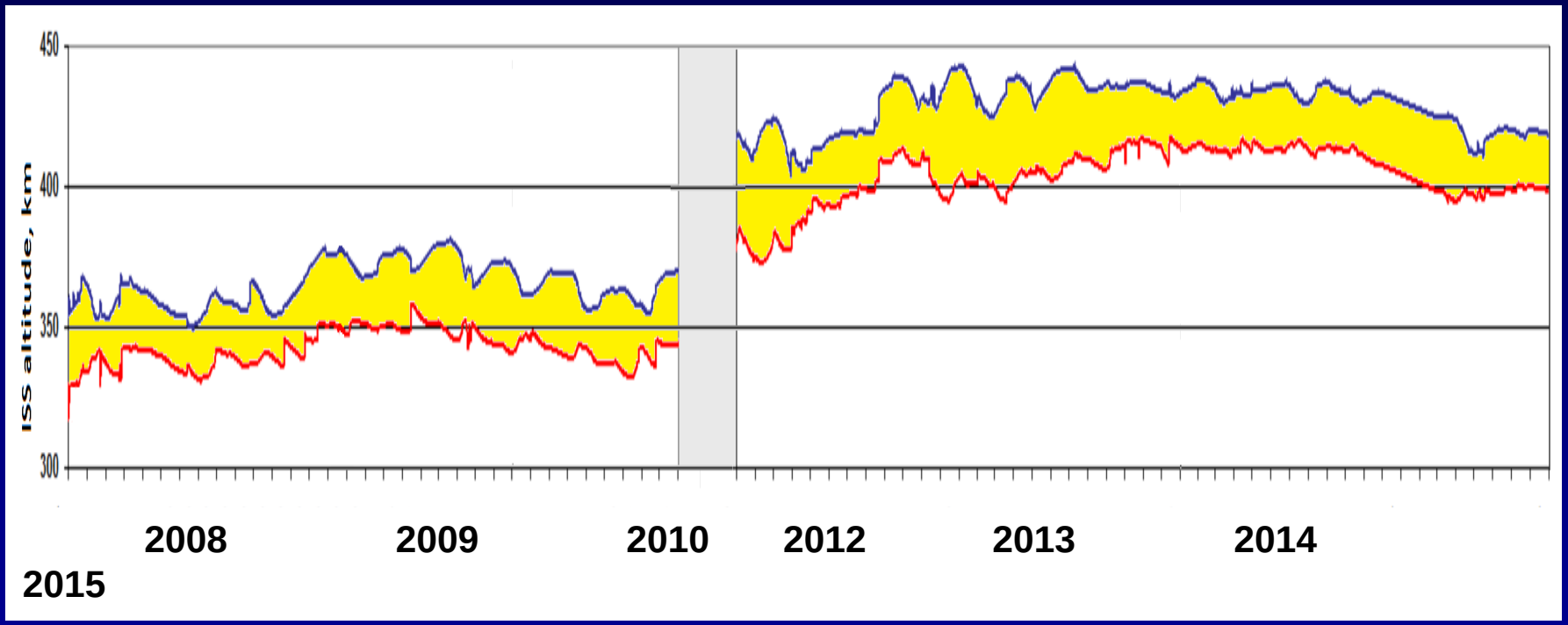
***- Energy > 100 Mev***

***- intensity above the threshold of 10 p/cm$^{-2}$s$^{-1}$sr$^{-1}$***

***- long duration***



# II. Different altitude of the International Space Station

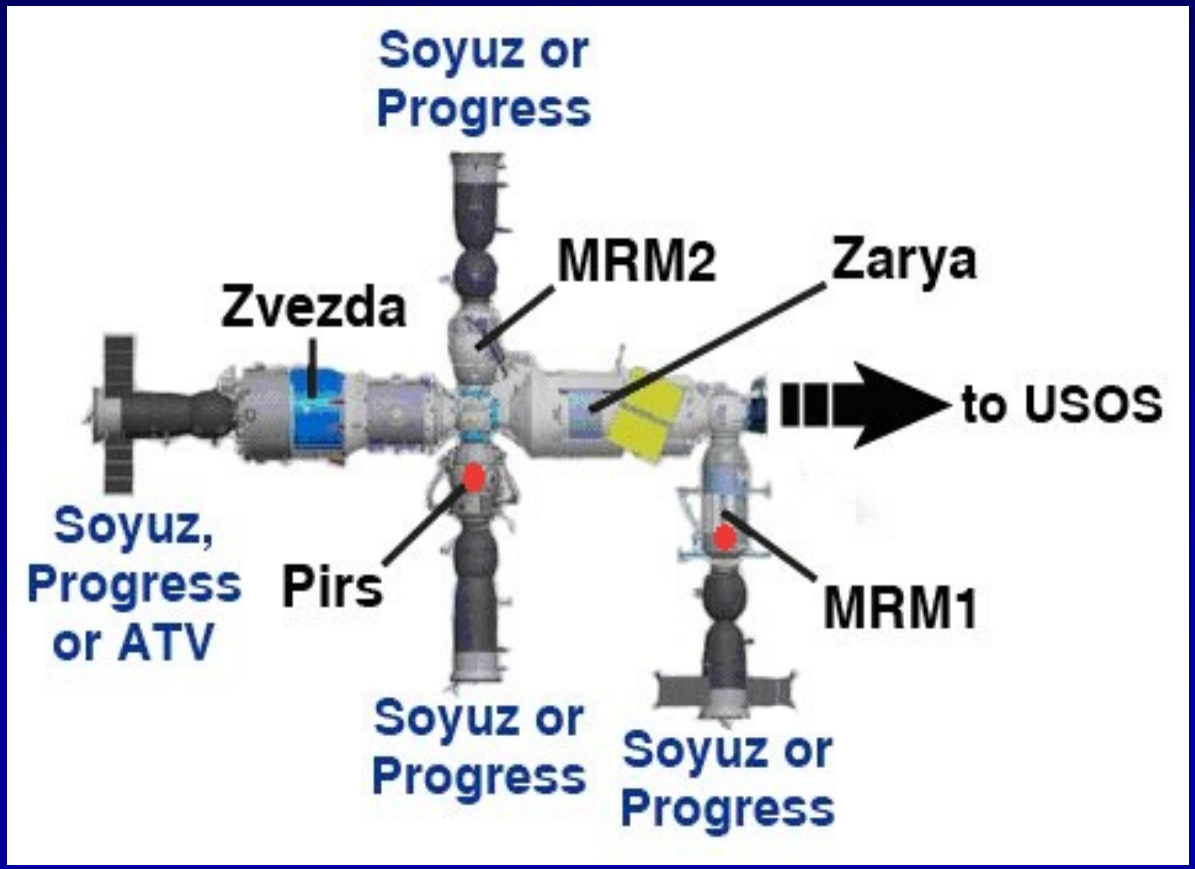



*I stage - 330 – 380 km*

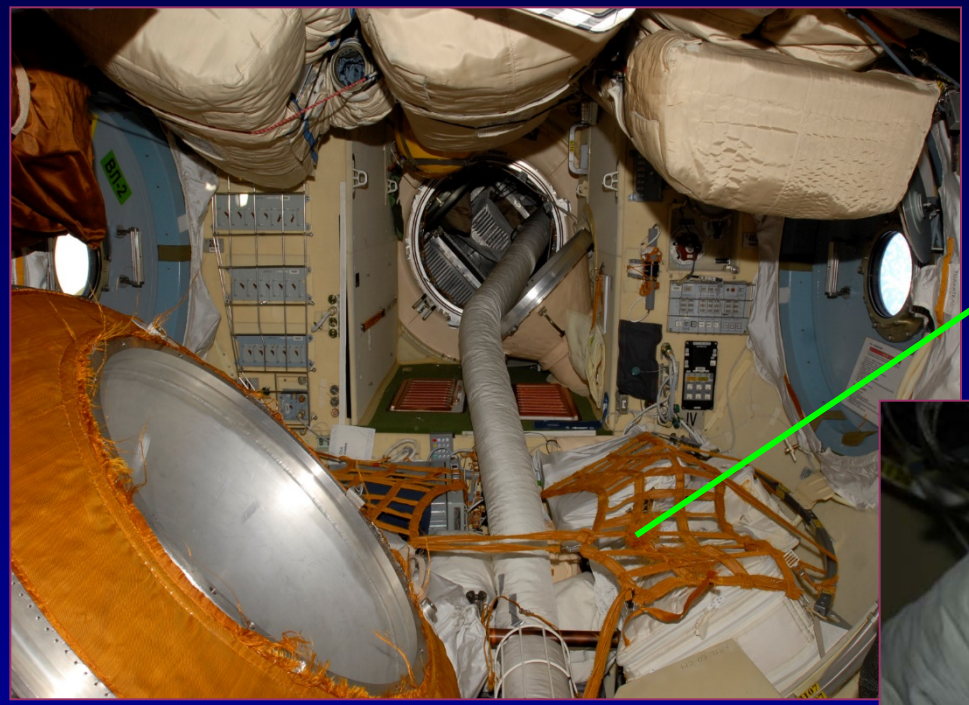
*II stage – 380 – 445 km*

# III. Different location = different shielding

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



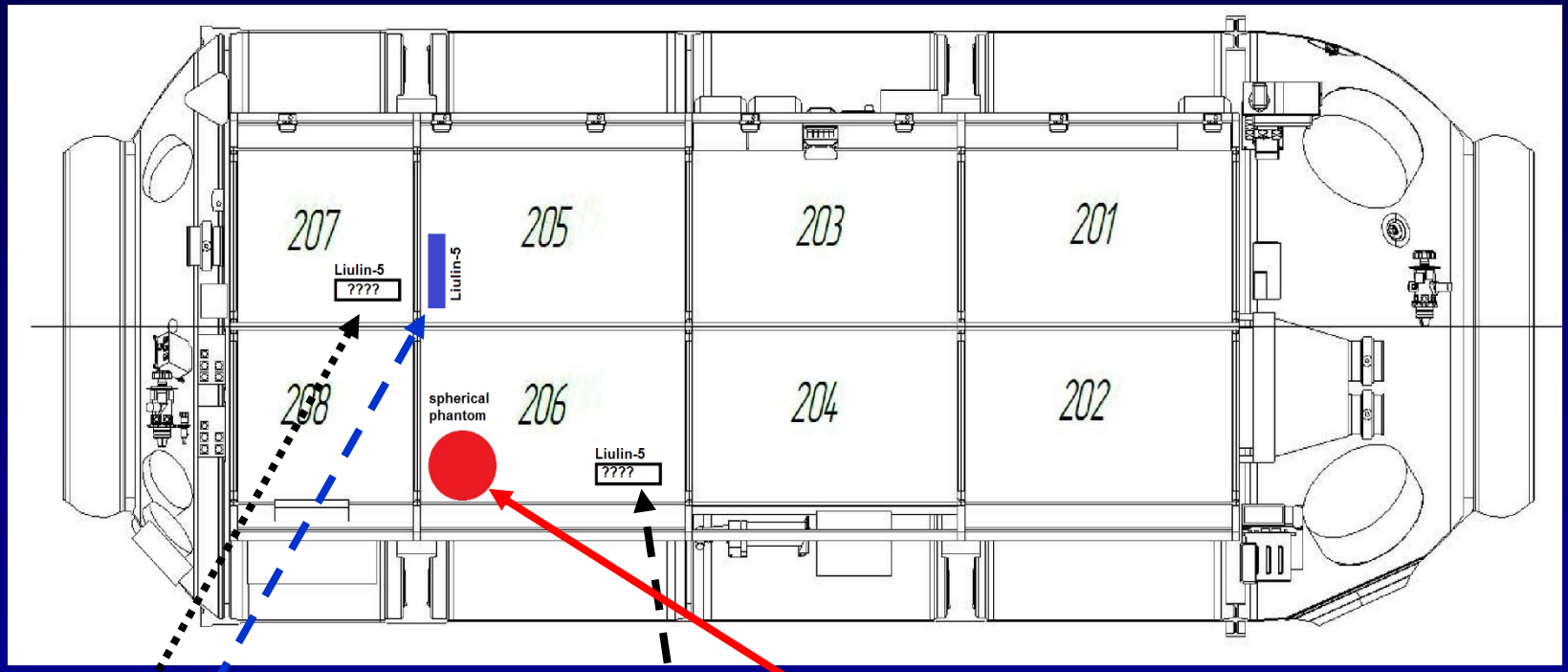
# LIulin -5 in the Spherical Phantom on ISS
# I stage - 2007 - 2009



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

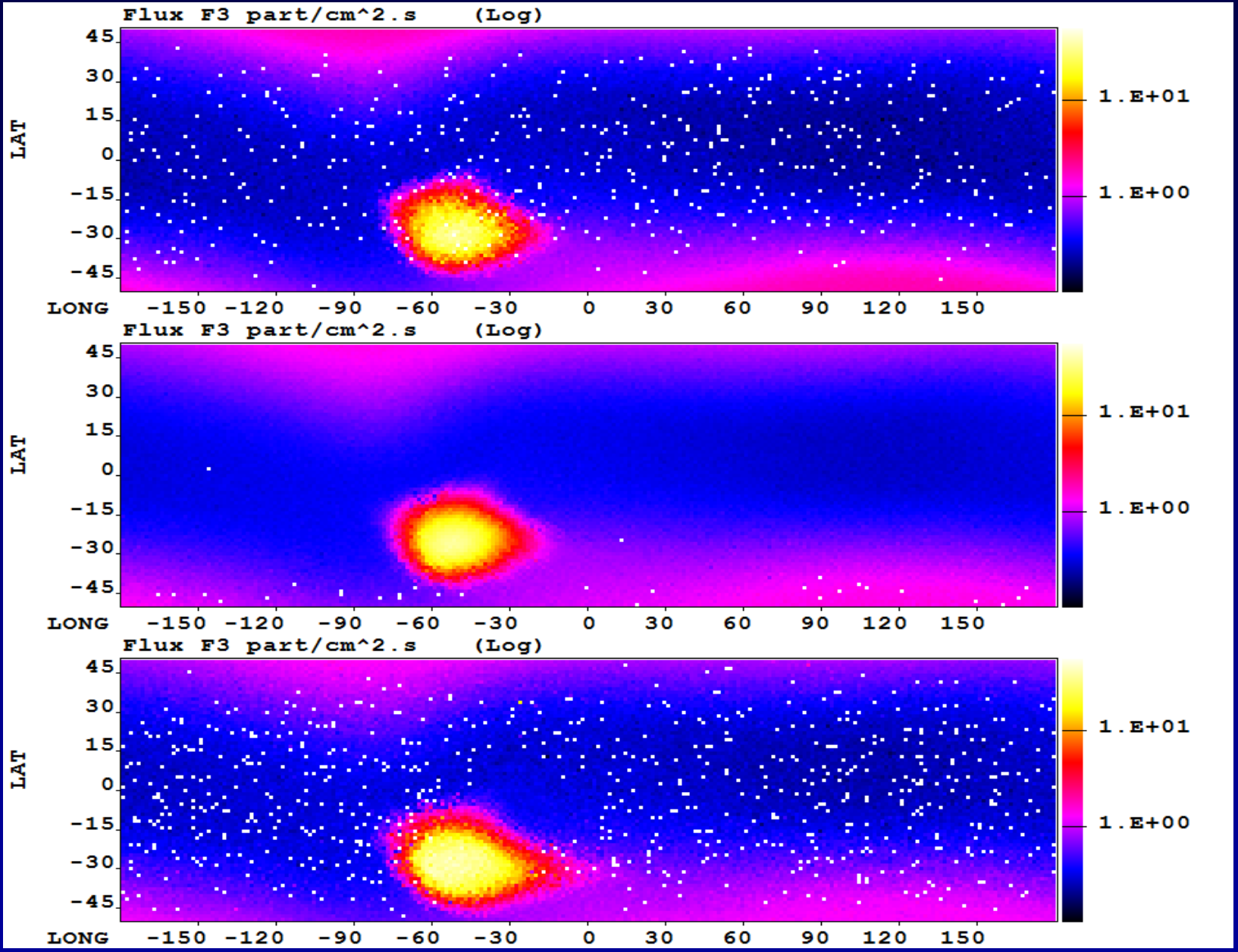
**The Liulin-5 *(white rectangle)* located behind the panel 205 in MRM1 module of ISS**

# Geographical distribution of ionizing particles

I stage

II stage inside

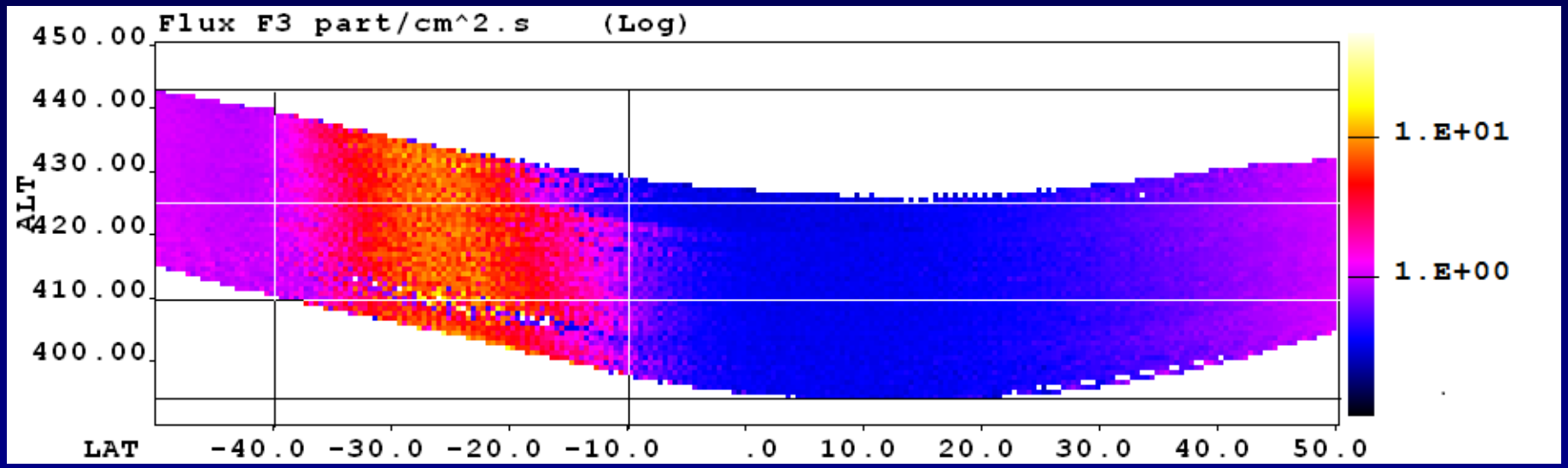
II stage outside

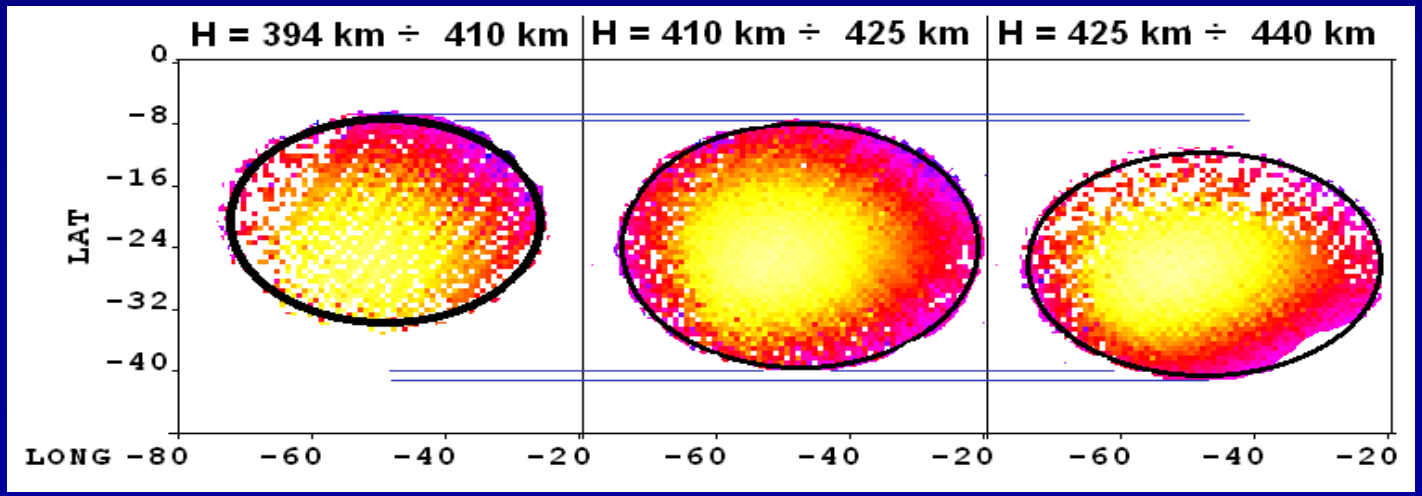


# Altitudinal distribution

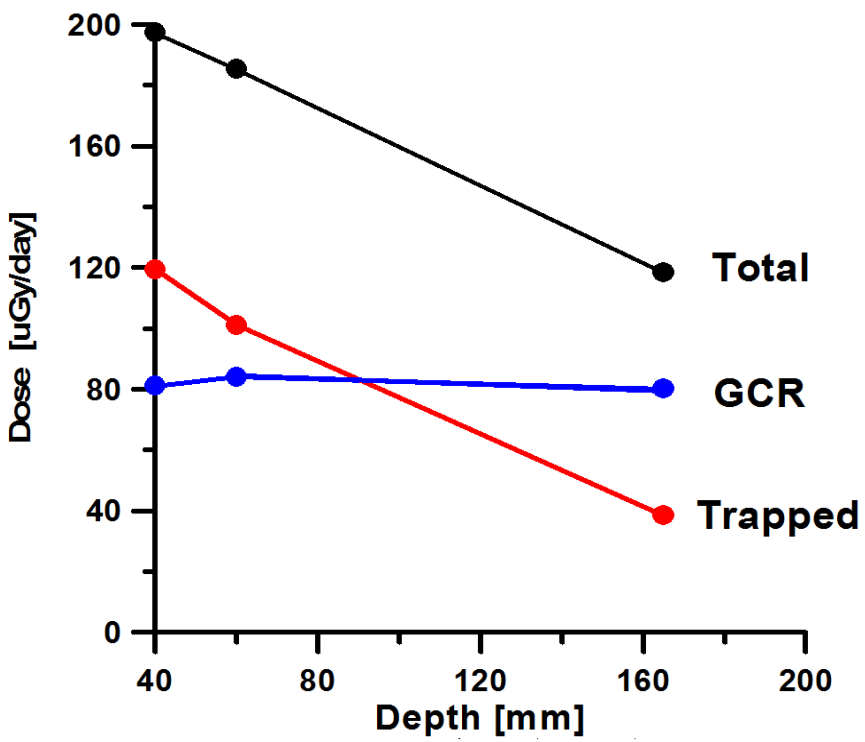
## 394 – 410 km; 410 – 425 km; 425 – 440 km

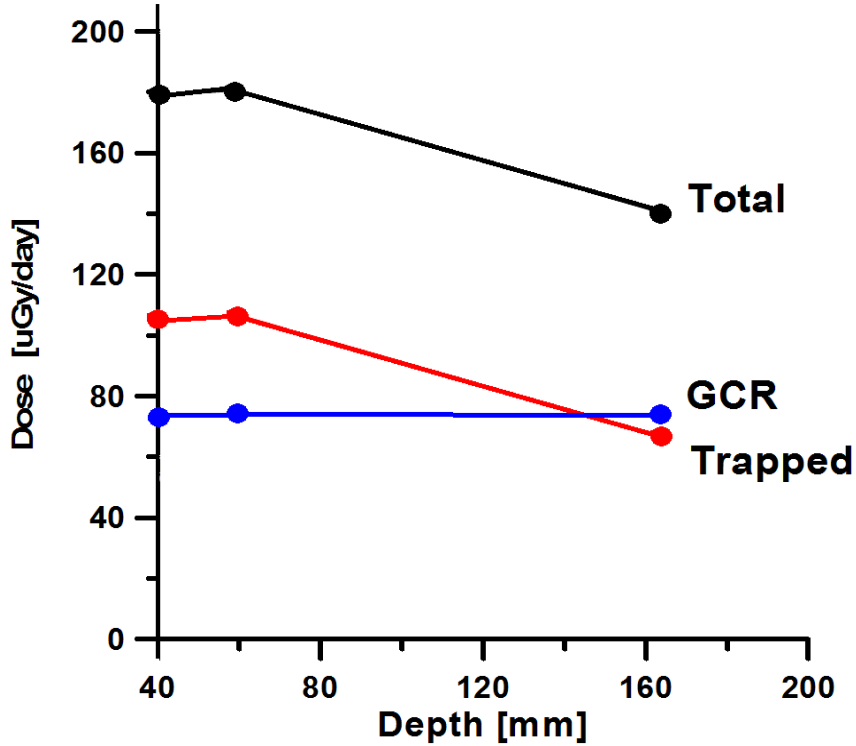
***Distribution of the flux rate measured in D3 for the period 01.10.2012 - 09.05.2013***



# Dose depth distribution



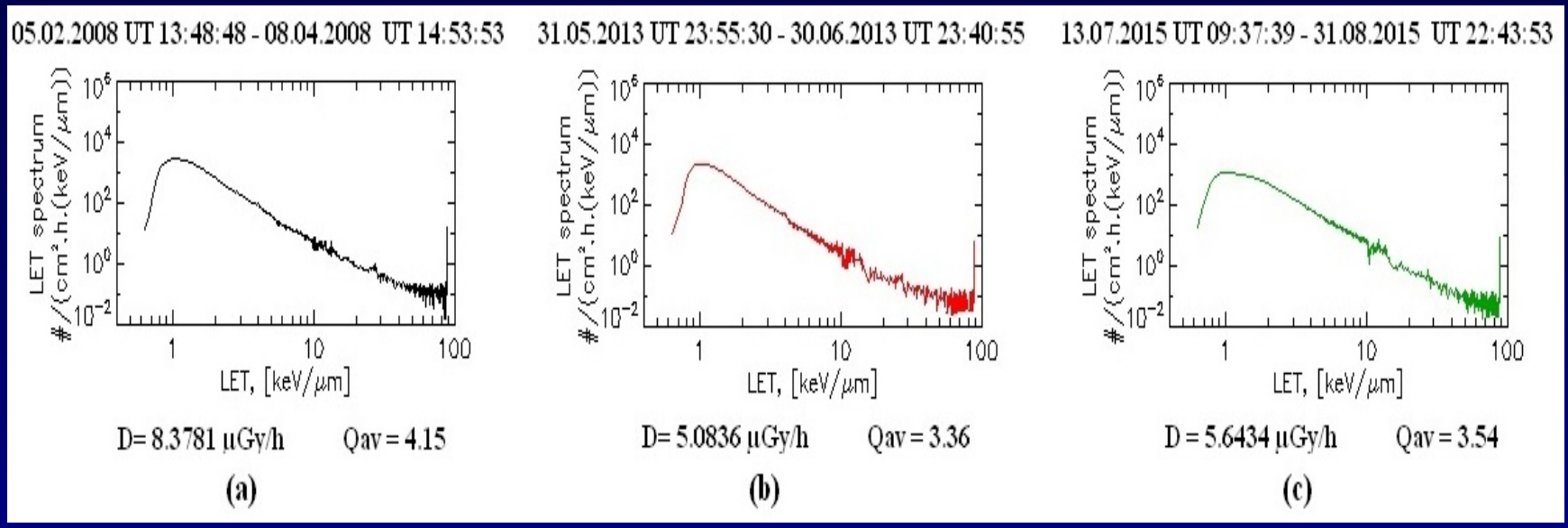



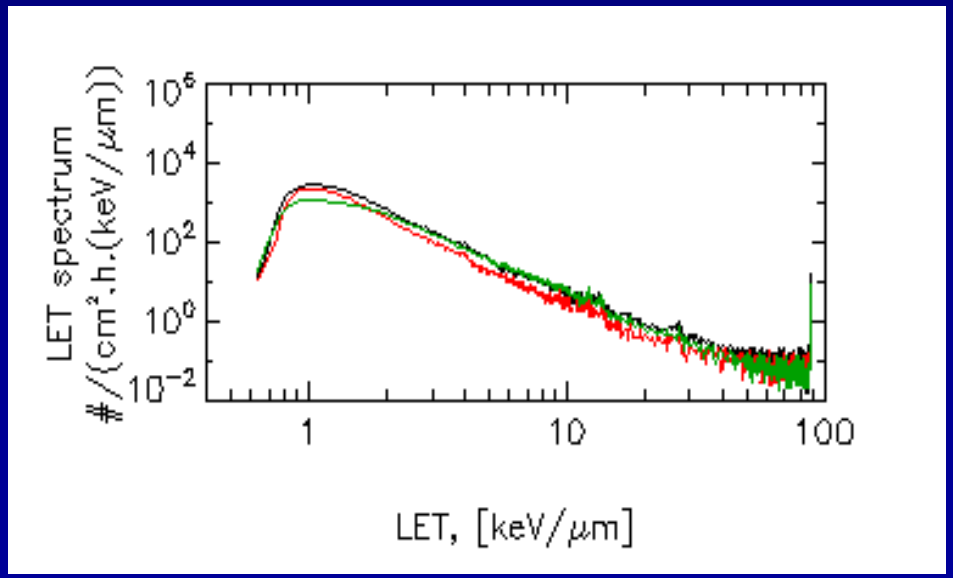

18-23.11.2007, h ~ 349 km

1.06 - 30.06 2013, h ~ 422 km

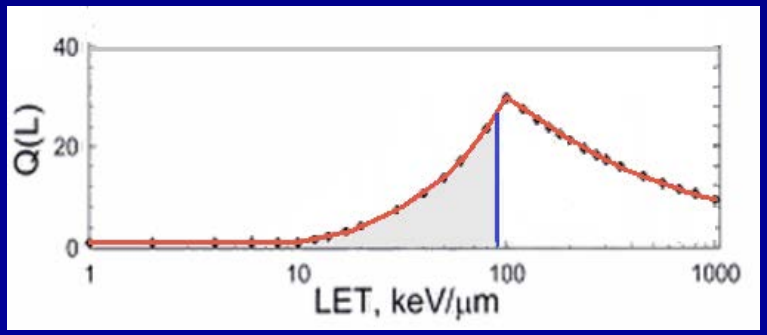
**Typical depth dose distributions in the phantom illustrating the contribution of the GCR and the trapped protons**

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

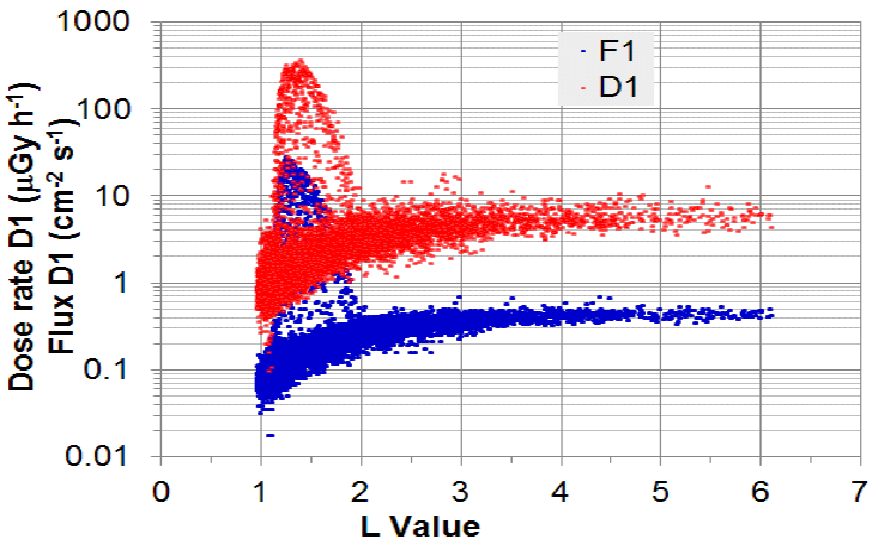


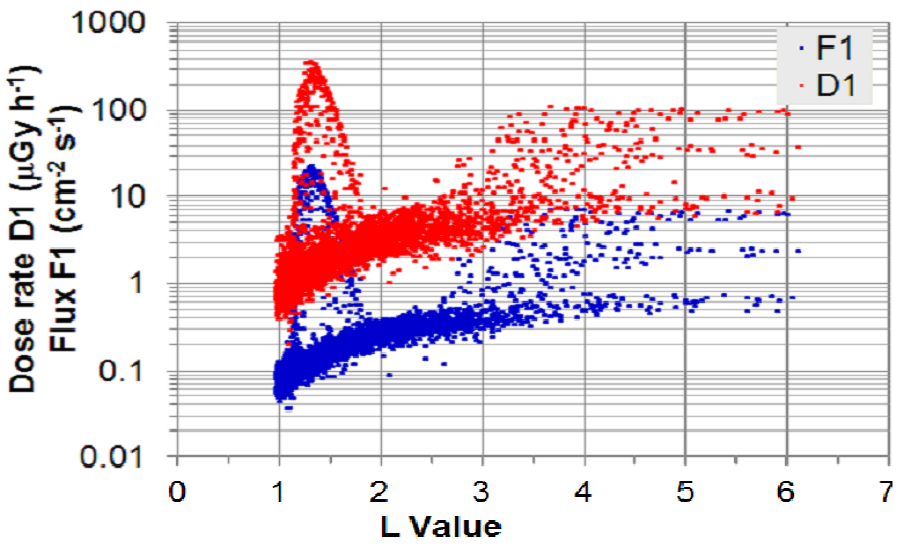

**Q=f(LET),**
**H=∑Q(*LET*)*D(*LET*) [ Sv]**



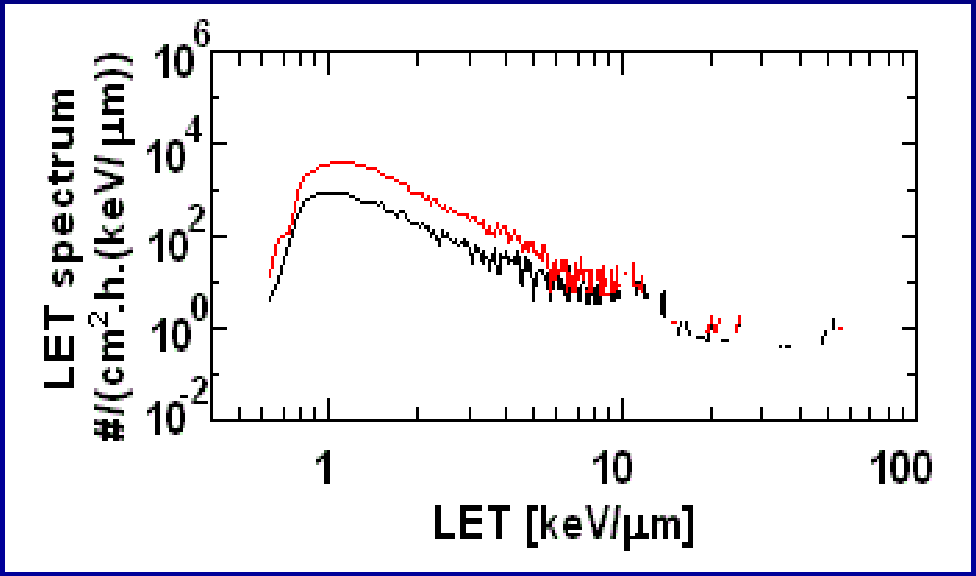
## Distribution of particle flux F1 (blue) and dose rate (red) in D1 detector located at 40 mm depth in the phantom as a function of L




*quiet conditions*




*SPE*



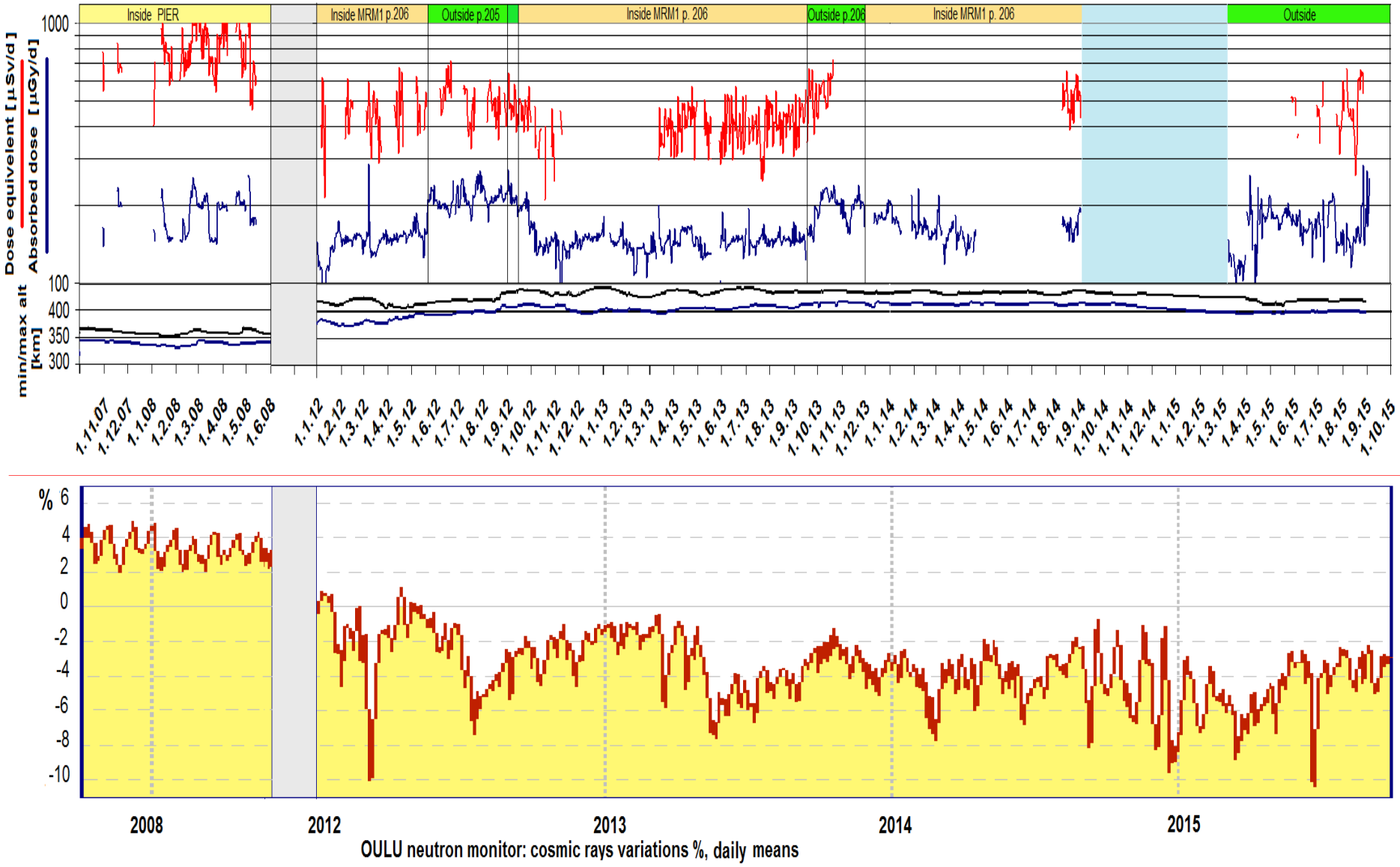

## LET spectra for orbits not crossing SAA

**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.***

# OVERVIEW OF LIULIN-5 DATA







OULU neutron monitor: cosmic rays variations %, daily means

# 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*.**

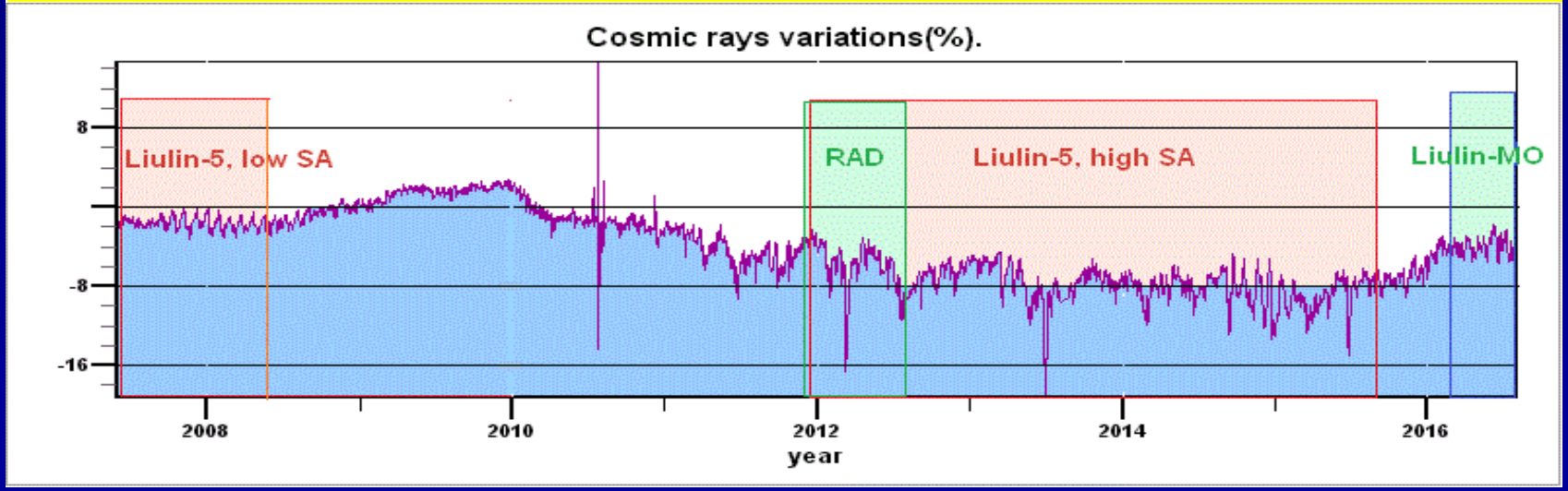
- **Height dependence.** ***The SAA shape and dimensions vary with the altitude of ISS.***

- **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 23$^{th}$ solar cycle and the small number of SPE with increased flux of >100 MeV protons close to the maximum of the 24$^{th}$ 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<br>~ 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!