Overview of the ISS radiation environment observed during EXPOSE-R2 mission in 2014-2016

T.P. Dachev[a], N.G. Bankov[a], B. T. Tomov[a], Yu. N. Matviichuk[a], Pl. G. Dimitrov[a], D.-P. Häder[b], G. Horneck[c]

[a]Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria

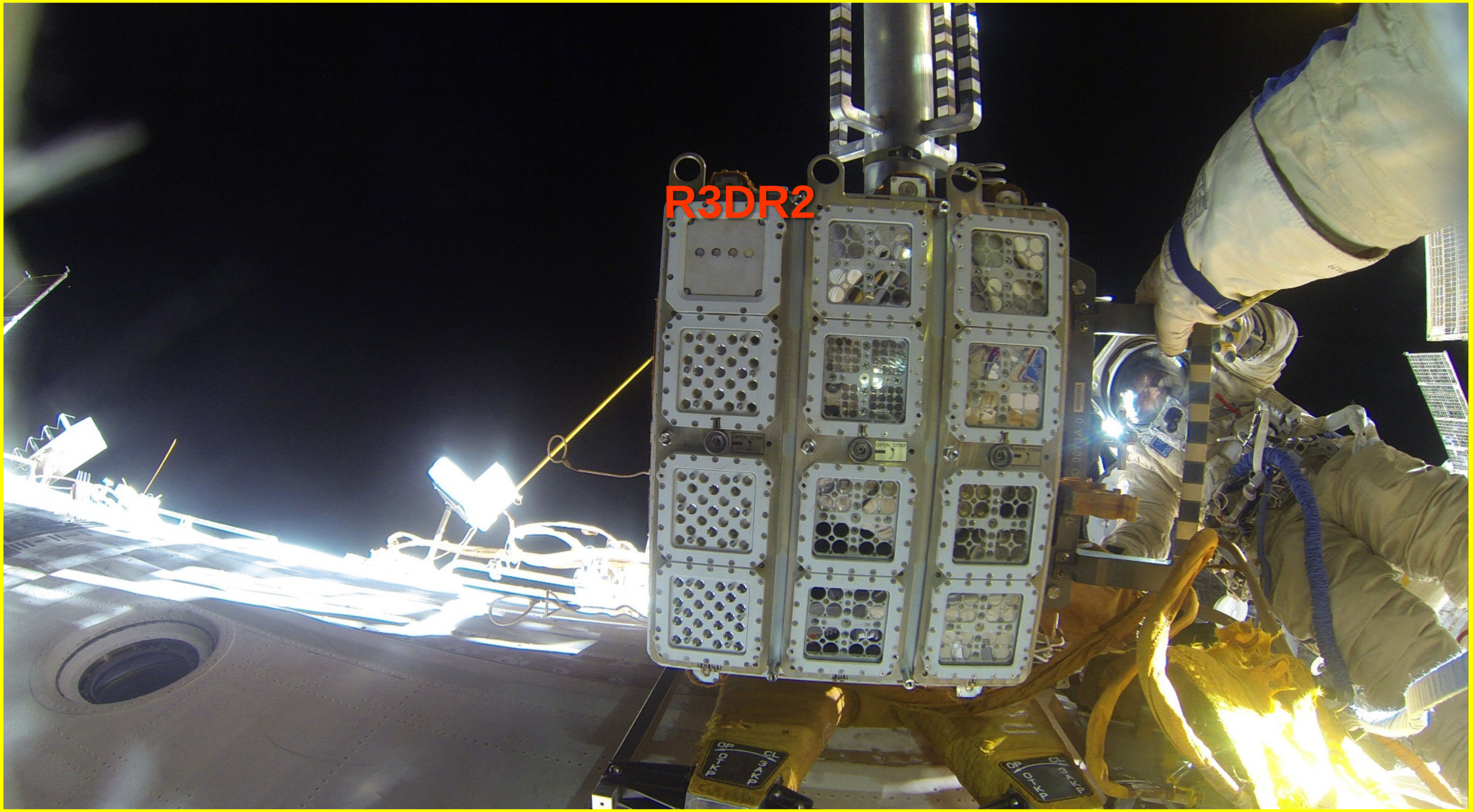
[b]Neue Str. 9, 91096 Möhrendorf, Germany

[c]DLR, Institute of Aerospace Medicine, Köln, Germany

Outlook

- Introduction
- Liulin radiation sources selection methods
- The ISS radiation environment observed during EXPOSE-R2 mission in 2014-2016:
  - R3DR2 data selection in 4 radiation sources by the Hefner's dose to flux formulas;
  - Results from the selection:
    - GCR;
    - IRB;
    - ORB & precipitation bands;
    - SEP
- Conclusions

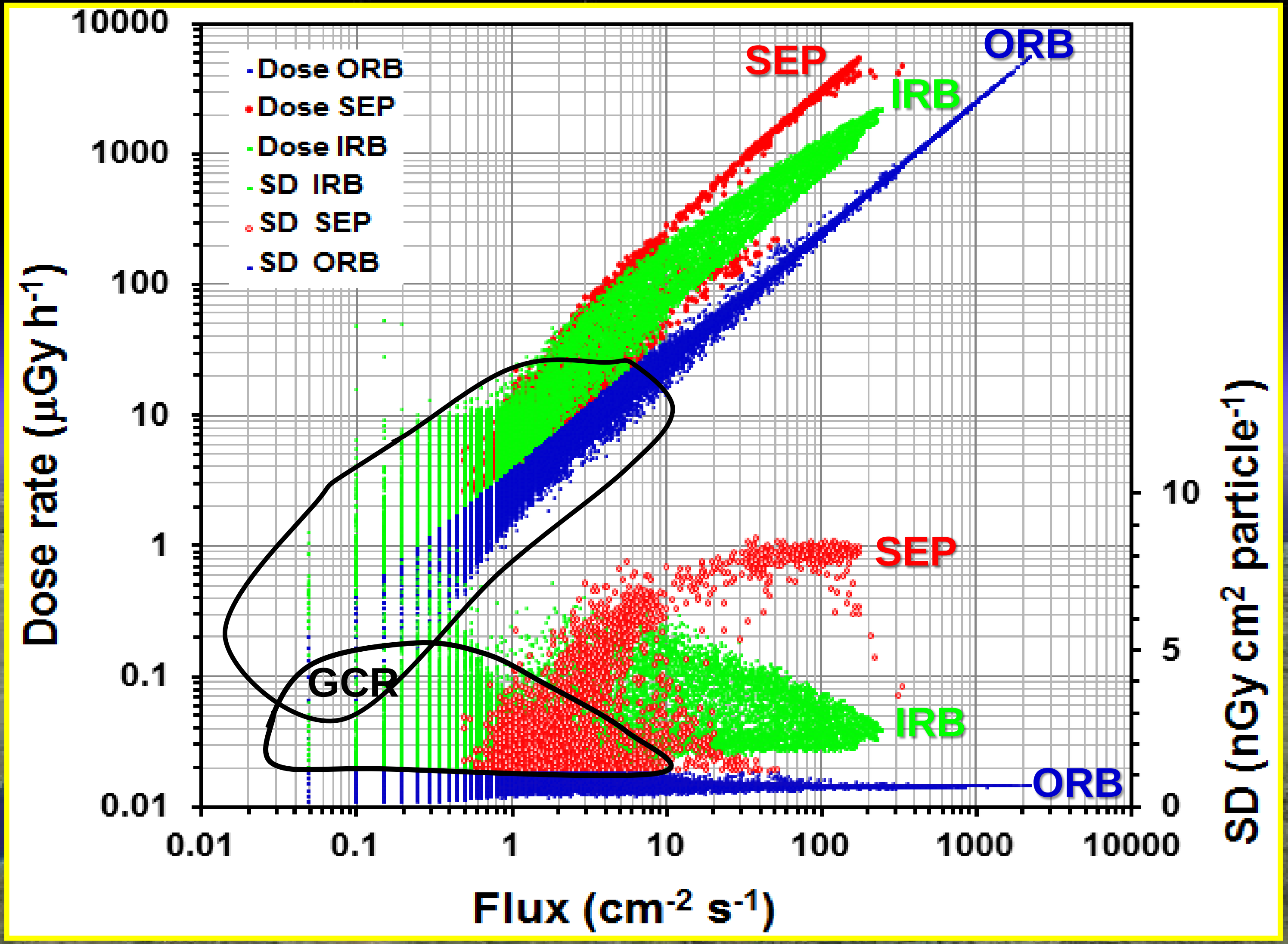
External view of R3DR2 instrument (in the red square) as mounted in the EXPOSE-R2 facility. (Picture taken by Russian cosmonaut G. Pedalka (only his arm is seen in the left-upper corner, while cosmonaut M. Kornienko is seen in the left middle plan) on 15 August 2015 during EVA for examination EXPOSE-R2 facility outside Russian “Zvezda” module.) (Picture credit of ESA/RKA).



Liulin radiation sources selection methods

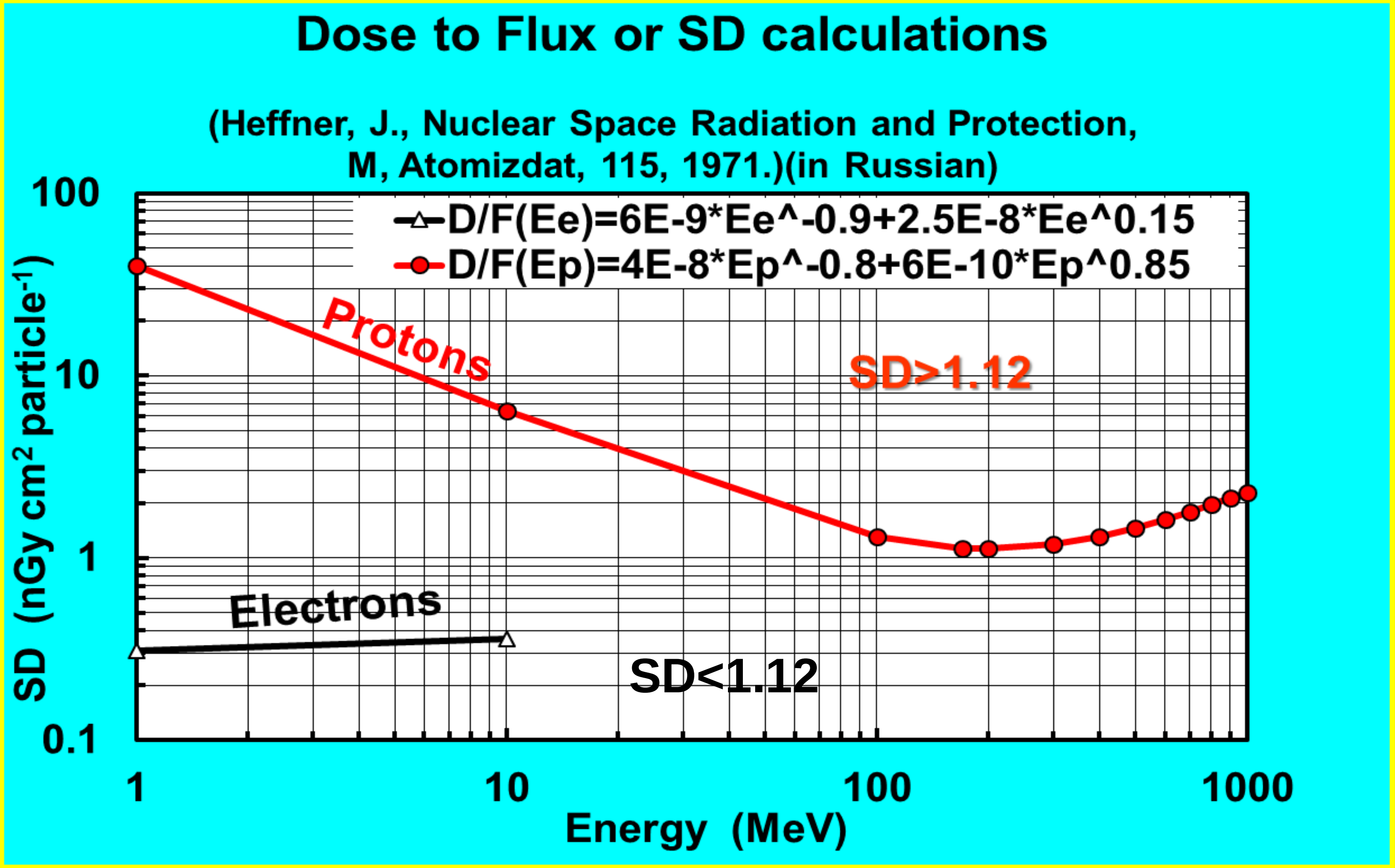
- By the dose dependencies from flux;
- By the deposited energy spectrum shape;
- By the Hefner’s dose to flux formulas.

Selection of the R3DR2 predominant radiation sources by the dose rate from flux and specific dose (SD) from flux dependencies during the period 17–30 June 2015



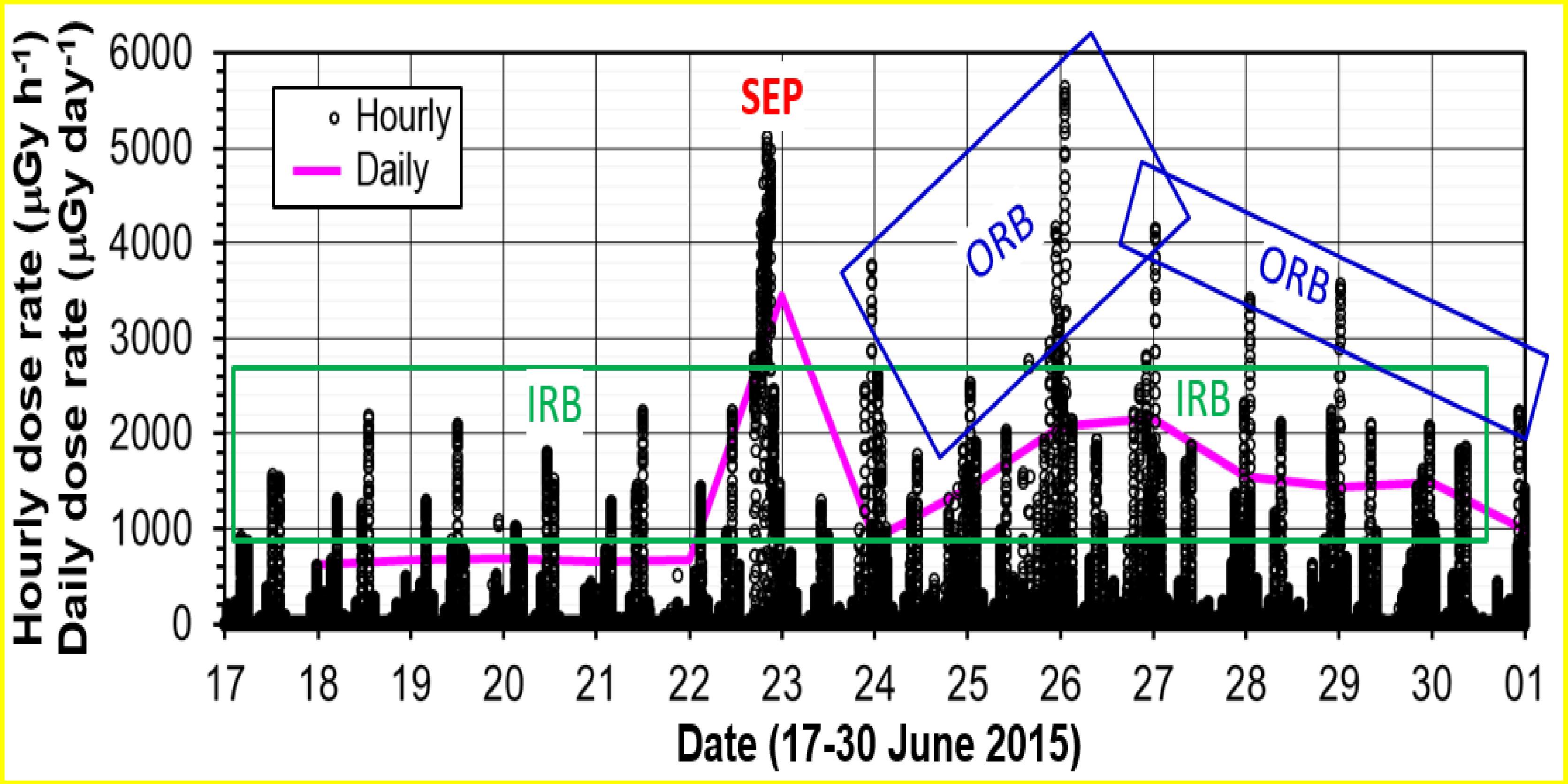
R3DR2 data selection in 4 radiation sources by the Hefner’s dose to flux formulas

The Heffner's experimentally obtained formulae (Heffner, 1970)*, recently published by Dachev (2009)**

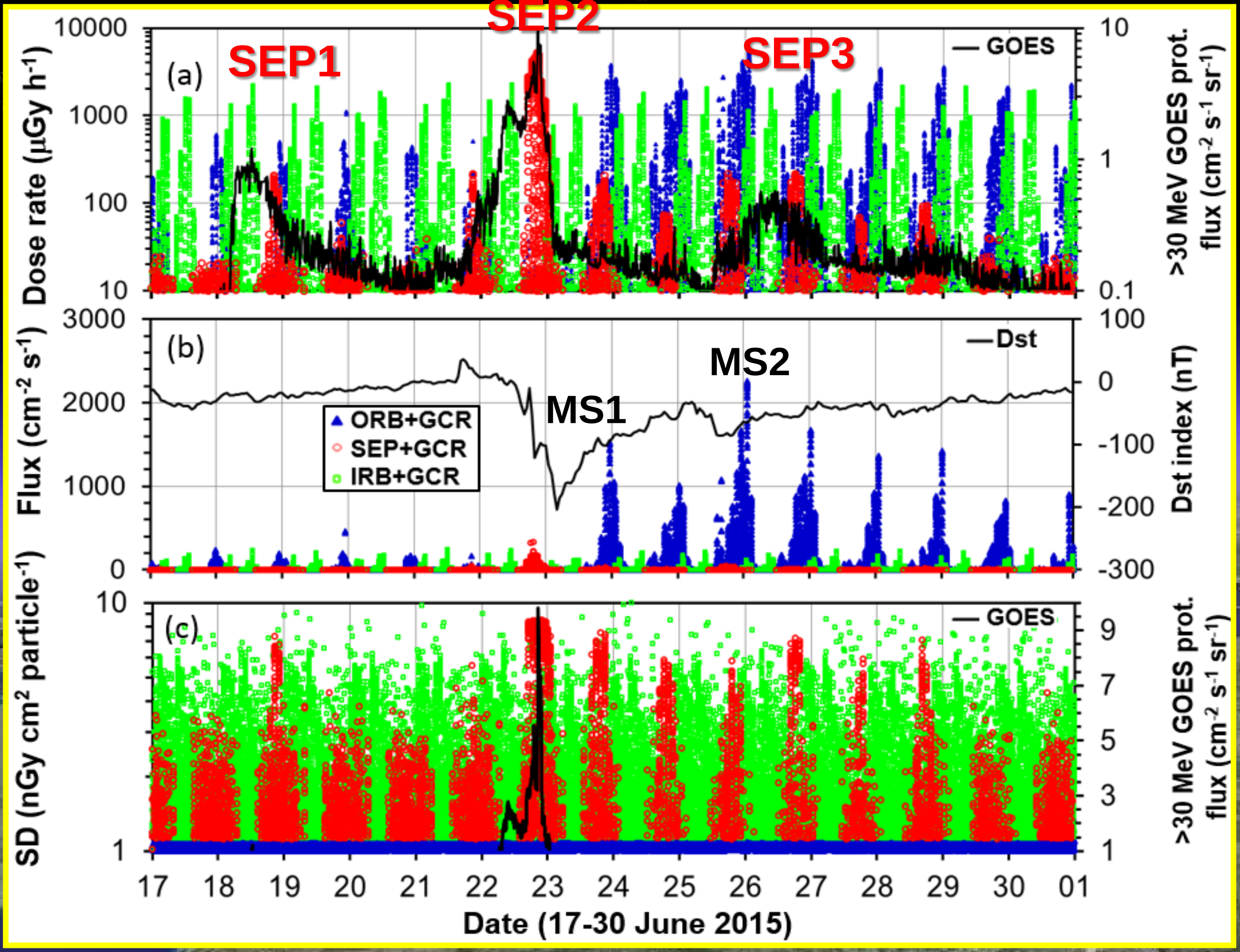


*Heffner, J., Nuclear radiation and safety in space. M, Atomizdat, 1971, pp 115. (in Russian)
**Dachev, Ts.P., Characterization of near Earth radiation environment by Liulin type instruments, Adv. Space Res., 44, 1441-1449, 2009. http://dx.doi.org/10.1016/j.asr.2009.08.007 .

Example for unselected by the radiation source R3DR2 dose rate data for the period 17-30 June 2015



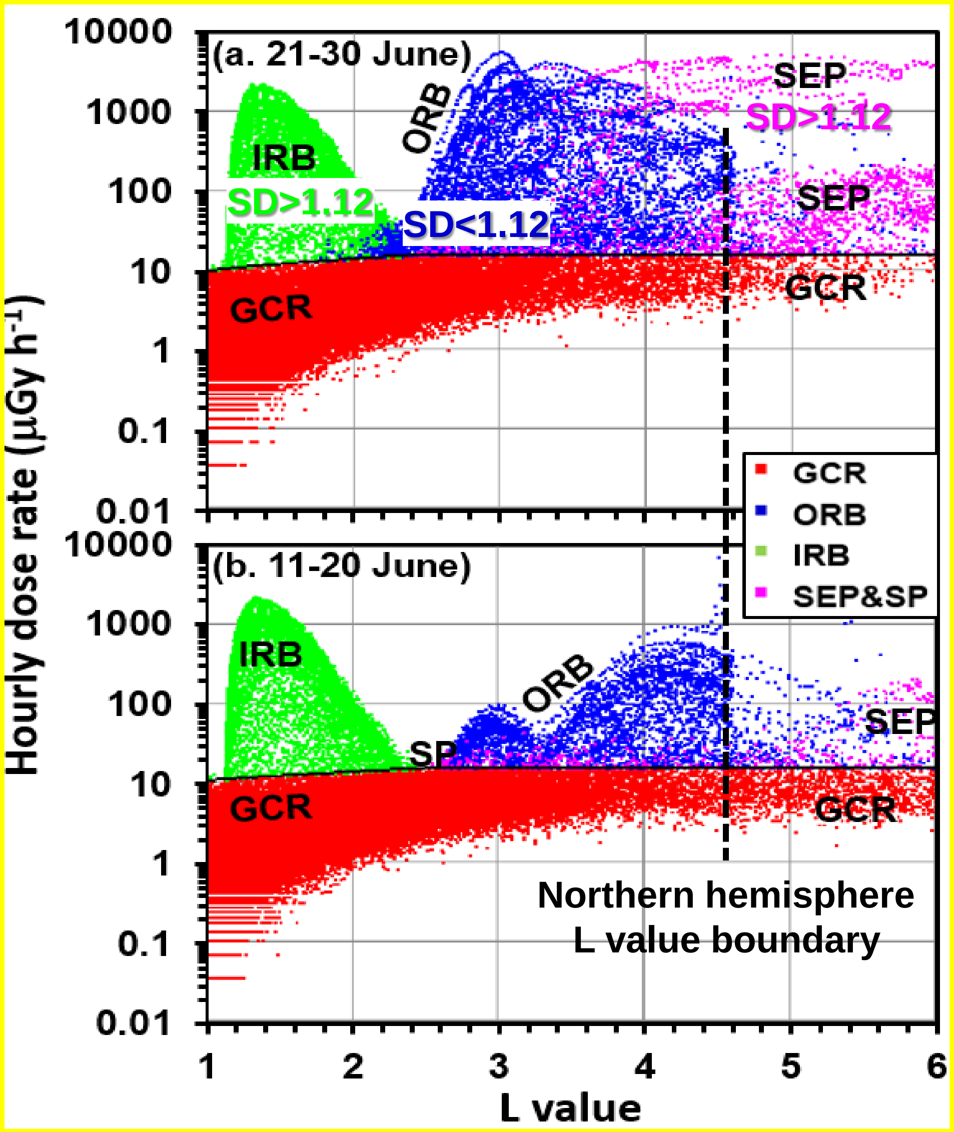
Example for selected with Hefner's formulae R3DR2 dose rates, fluxes and SD variations for the period 17-30 June 2015*



The GCR source is seen in the bottom of the dose rate bars for dose rates below 20 μGy h^{-1}

*Dachev, T.P., B. T. Tomov, Yu. N. Matviichuk, Pl. G. Dimitrov, N.G. Bankov, High dose rates obtained outside ISS in June 2015 during SEP event, Life Sciences in Space Research, LSSR_2015_11 (2016). available online at http://dx.doi.org/10.1016/j.lssr.2016.03.004

Examples of the selected 10 days latitudinal distribution profiles of the dose rates measured with the R3DR2 instrument against McIlwain's L values for the period 10-20 and 21-30 June 2015



- These 10 days plots were used for the selection of the all 441 days data;

- The selection curve is the black line in the middle of the plots;

- Galactic cosmic rays (GCR) are situated by red points in the lower part of each figure;

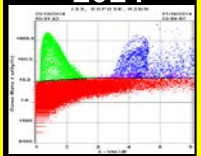
- The maximum in the centrum plotted with blue points (ORB) is generated by high-energy electrons;

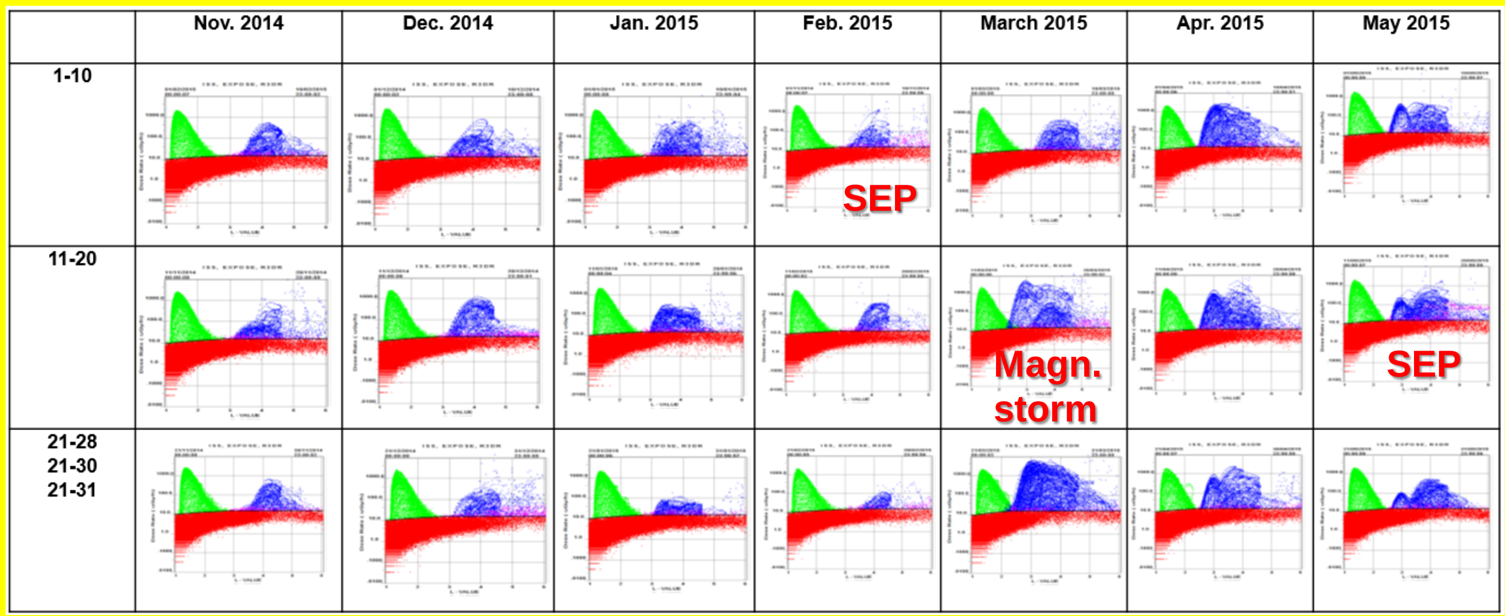
- The maximum in the upper left corner of the figure plotted by green points (IRB) is created by high-energy protons when the ISS crosses the region of the SAA;

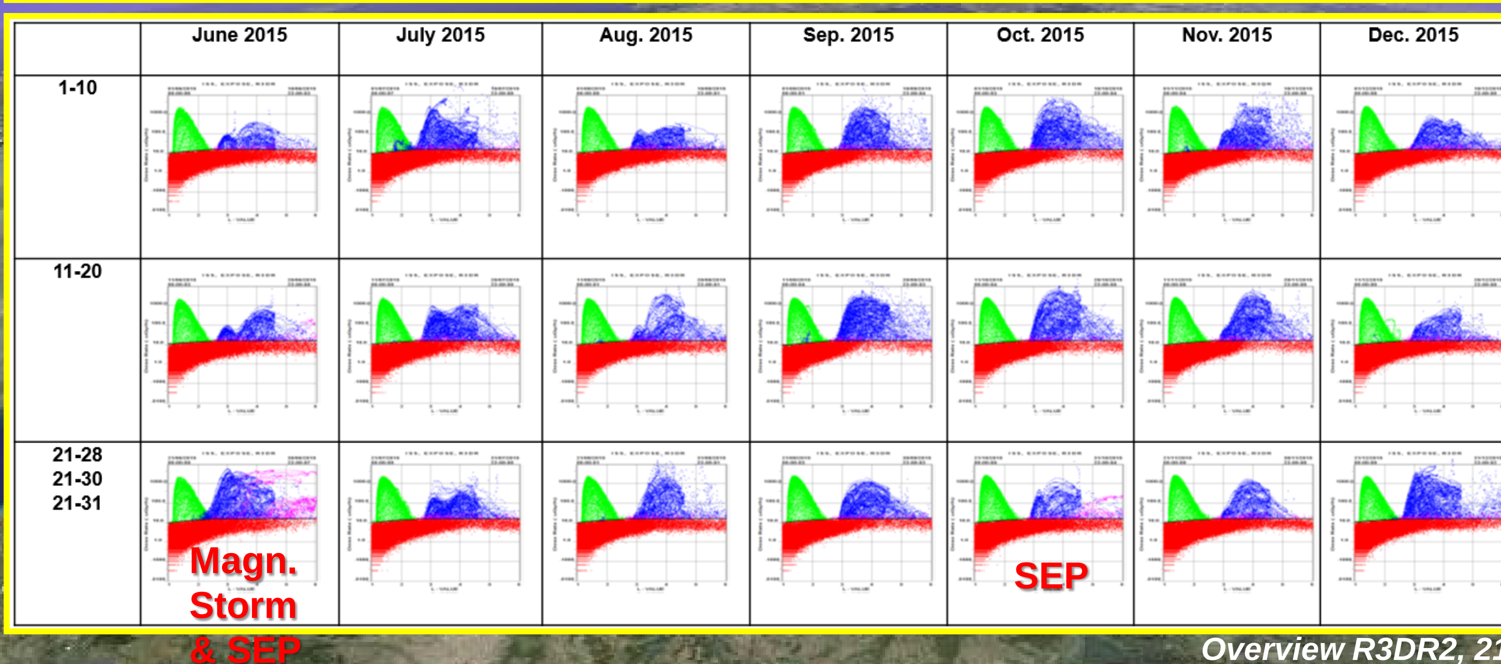
- The magenta points spread from the center toward right side visualize the distribution of the SEP high energy protons.

Separation result for 42+ ten days R3DR2 data sets

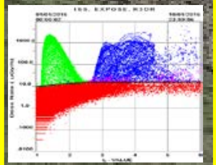
23-31 Oct. 2014



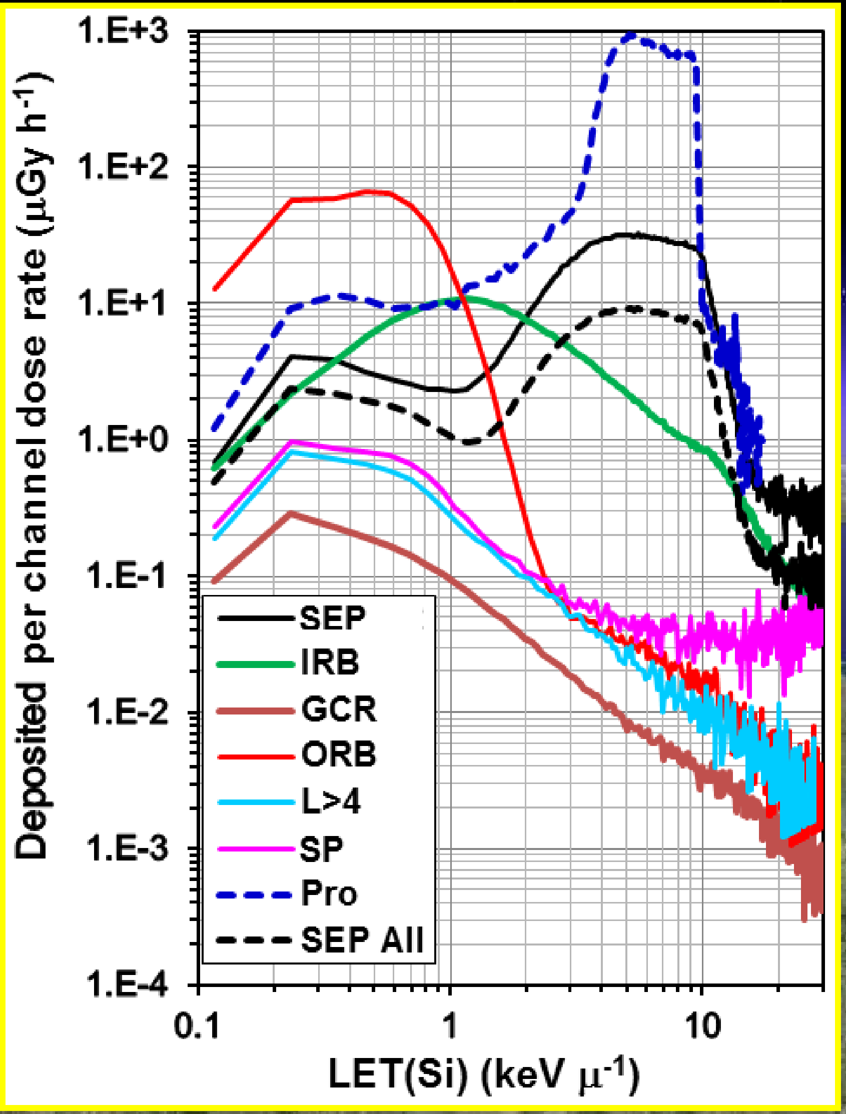




1-10 Jan. 2016

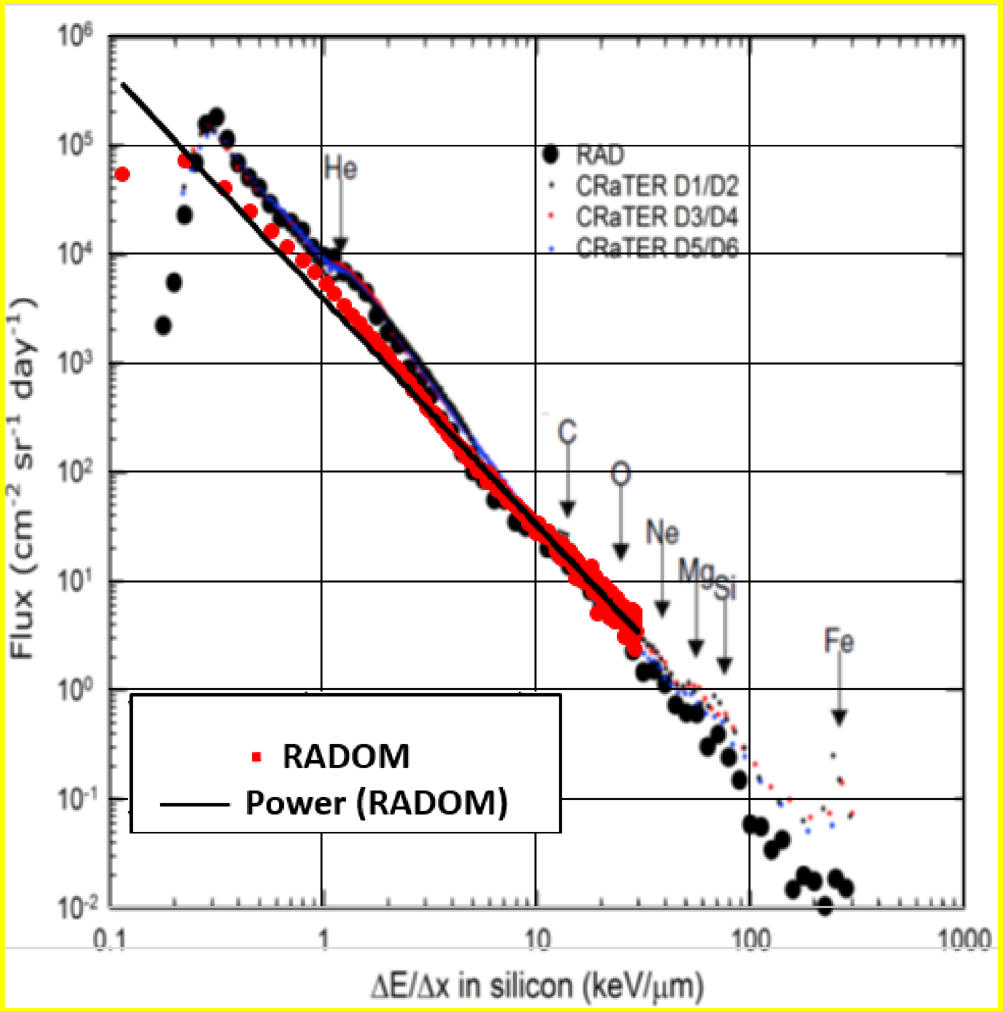


Verification of the radiation sources selection procedure with the form and shape of the energy deposition spectra



- (1) $$D = K\sum_{i=1}^{255} ik_i A_i M D^{-1}$$
- The deposited dose rate according to formulae (1) is the area between the abscissa and the curve of the deposited energy spectrum;
- Each source did have well defined curve in the expected LET(SI) range;
- The high energy deposition part of the "SEP"s spectra are similar to the "Pro" spectrum, which was obtained during the calibrations of Liulin instruments with 7.8 MeV monoenergetic proton beam at the cyclotron facility at the University of Louvain, Belgium;
- The "knee" at 9-10 keV μ^{-1} deposited energy corresponds to the place where the incident energy of the protons impinging normally on the 0.3-mm thick detector is equal to the deposited energy.

Comparison of the RADOM GCR free space spectra with RAD and CRaTER spectra*



Zeitlin, C., 2014. Results from the MSL-RAD Experiment on the Curiosity Mars Rover, Nineteenth WRMISS, Krakow, Poland, 9-11 September 2014. http://wrmiss.org/workshops/nineteenth/Zeitlin_MSL-RAD.pdf

Results from the selection

The separation statistics of the R3DR2 data shows the following results:

- 441 days were really covered;
- 3,810,240 points were separated;
- 2398 were lost (0.062%) or in average less than 6 points per day;
- 313 points were counted twice.

- The average source counts per day were:

GCR=7636 points, IRB=573 points, ORB=383 points, SEP counts per 27 days were 148 points; average SP counts per 414 days (days without real SEP) were 34 points.

Totally the number of the daily averaged measurements for the "stable" presented sources is: 7636+573+383+34 or 8626 measurements, which were selected from a total of 8640.

Selected dose rate results

The predominant radiation source in the R3DR2 data were sorted into four separate categories:

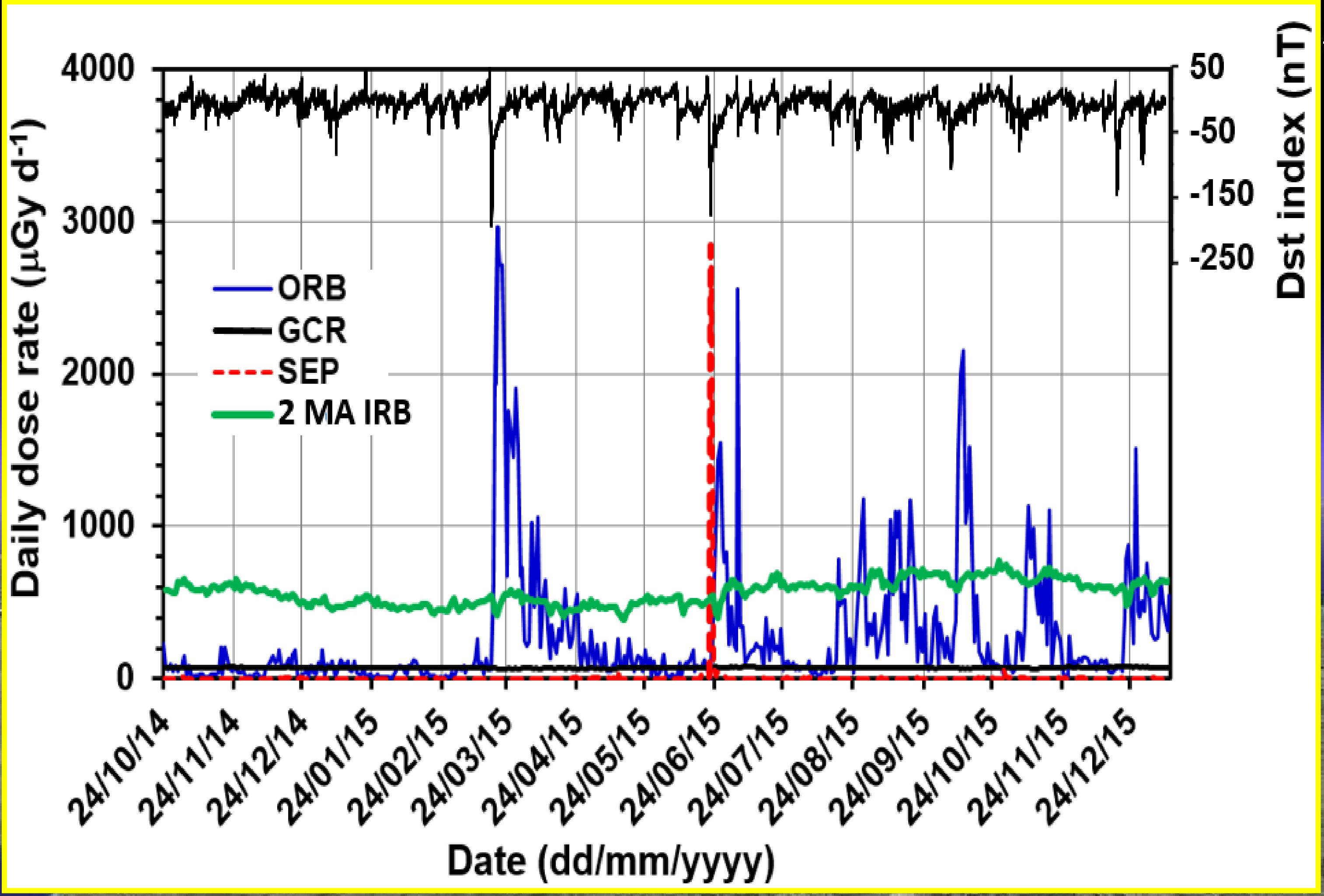
- galactic cosmic ray (GCR) particles and their secondary products with an average daily dose rate of 71.6 μGy d^{-1};

- protons in the South Atlantic Anomaly (SAA) region of the inner radiation belt (IRB) with an average daily dose rate of 567 μGy d^{-1};

- **relativistic electrons and/or bremsstrahlung in the ORB with an average daily dose of 278 μGy;**
- **the average daily dose rate of all SEP events plus SP source is 9.3 μGy d^{-1};**
- **the average daily dose rate only of SP source is 1.9 μGy d^{-1}.**

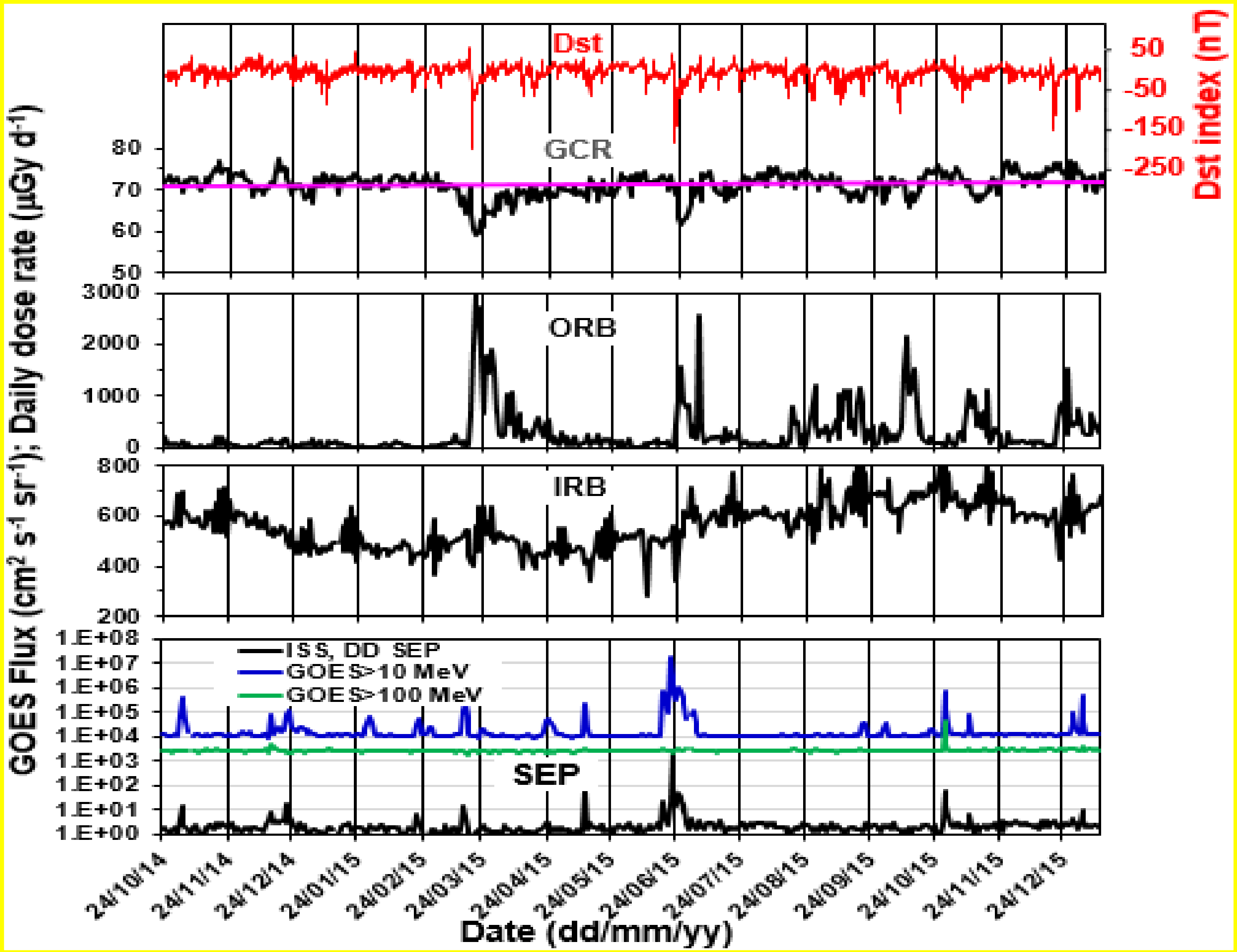
The total average daily dose rate is the sum of above:
71.6+567+278+9.3=925.9 μGy d^{-1}.

Preliminary result of the separation of the R3DR2 instrument data for the period 24 October 2014-11 January 2016 in four radiation sources*



*Dachev T.P., N. G. Bankov, G. Horneck, D.-P. Häder, Letter to the Editor, EXPOSE-R2 cosmic radiation time profile (Preliminary results), Radiation Protection Dosimetry, (Advance Access published May 31, 2016), http://dx.doi.org/10.1093/rpd/ncw123.

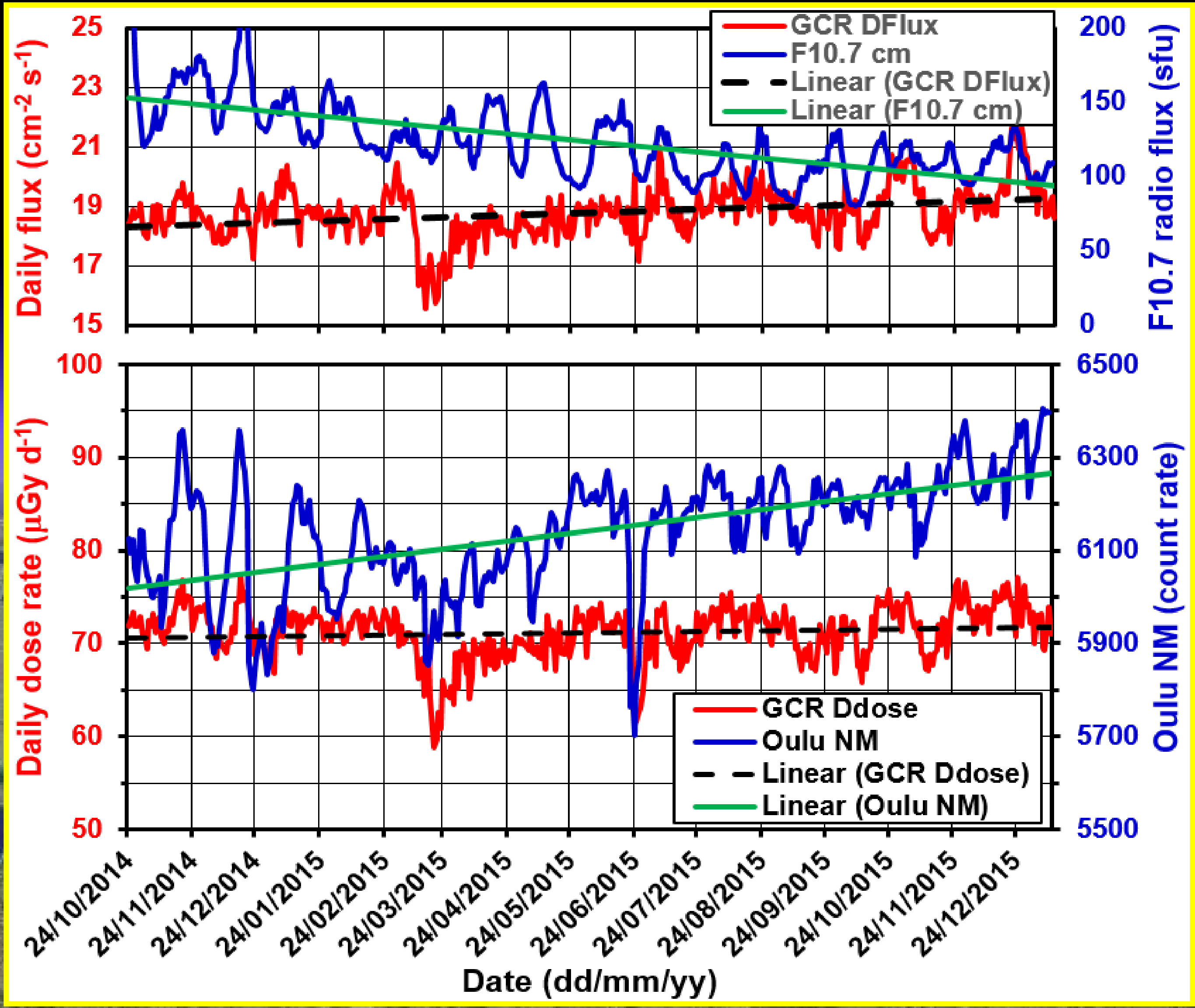
Final result of the separation of the R3DR2 instrument data for the period 24 October 2014-11 January 2016 in four radiation sources



SRTI, BAS

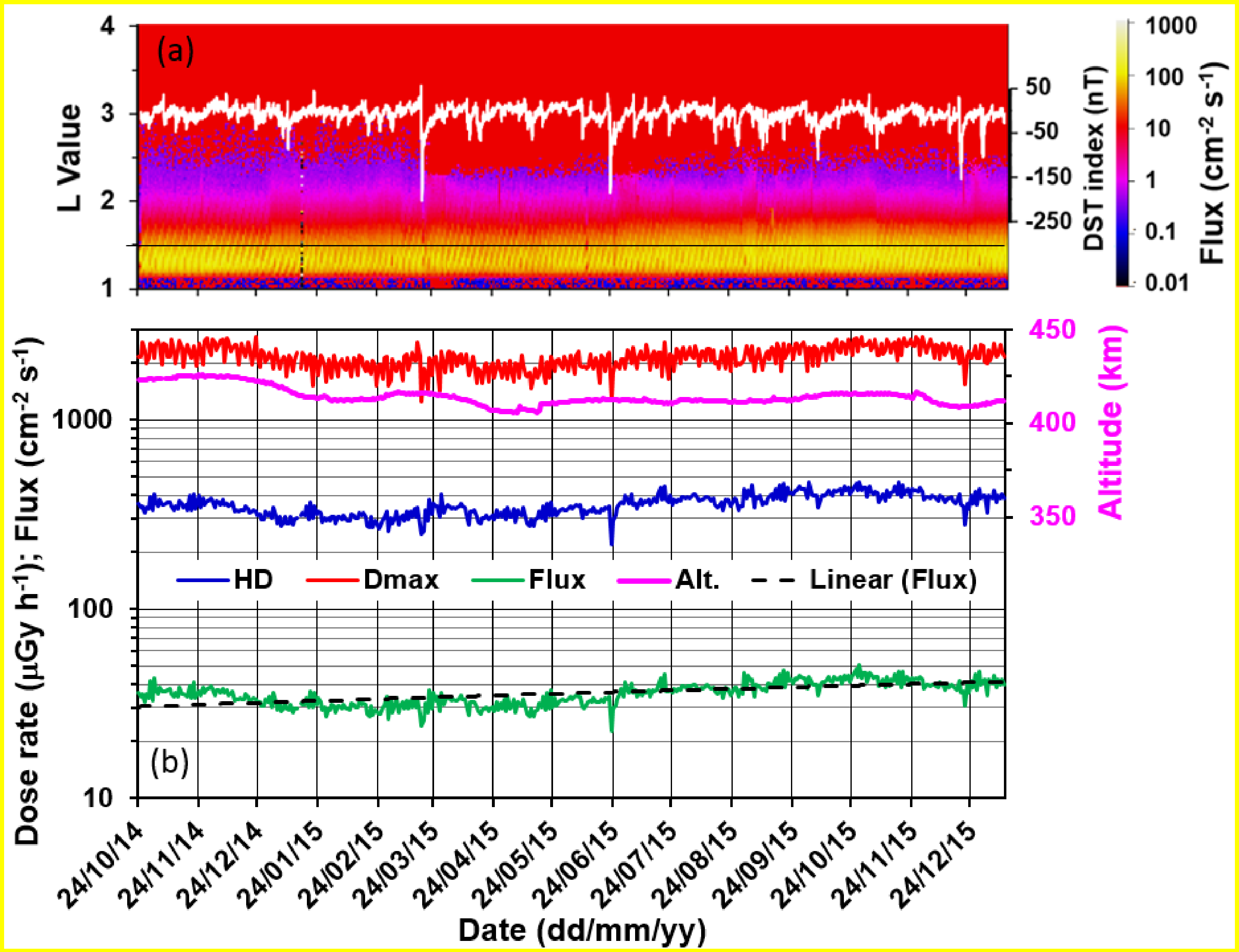
Overview R3DR2, 21 WRMISS, ESTEC, September 2016

Variations of the GCR daily averaged dose rates and flux in the period 24 October 2014-11 January 2016

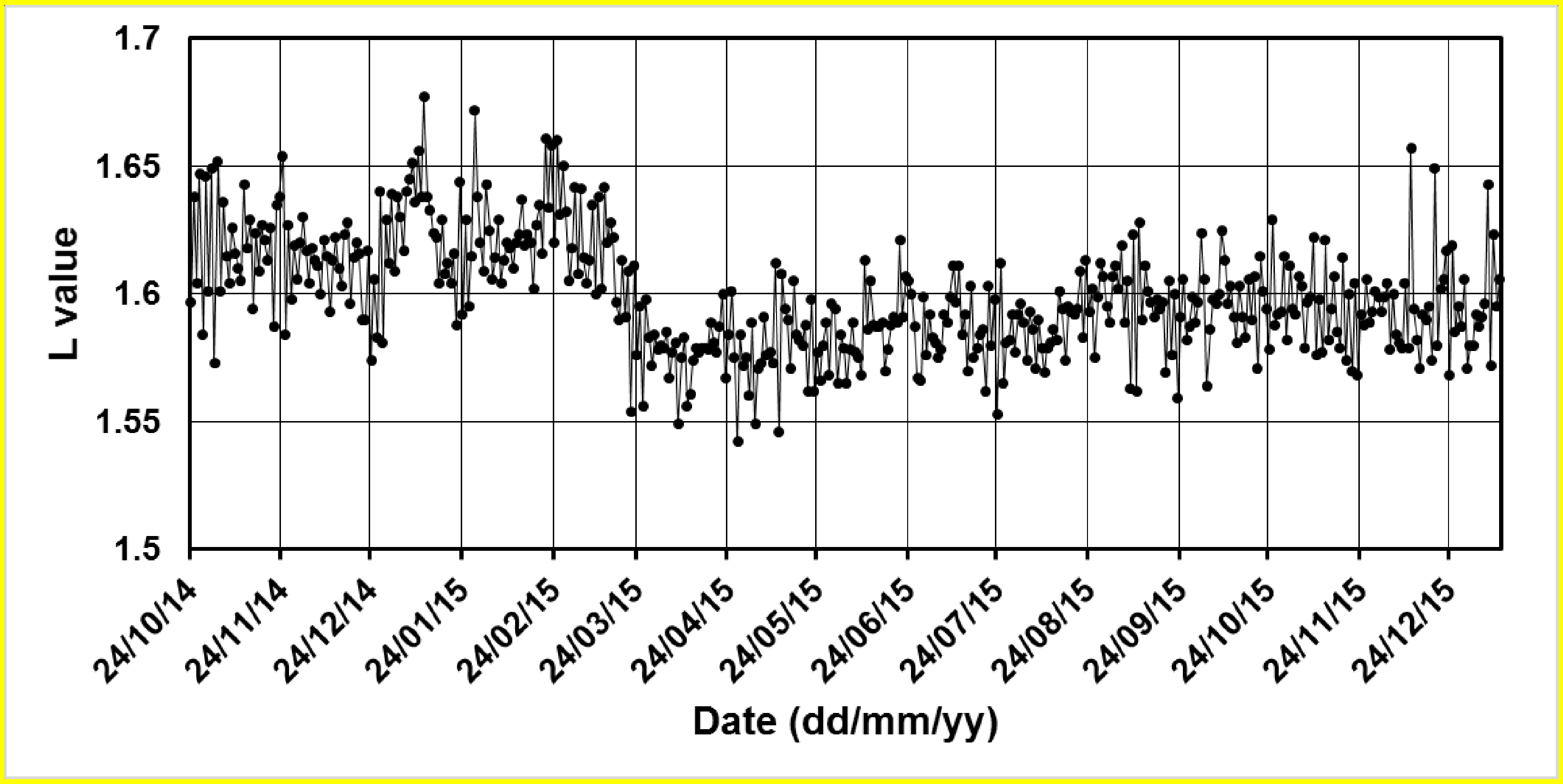


IRB

Variations of the IRB daily averaged dose rates and flux in the period 24 October 2014-11 January 2016

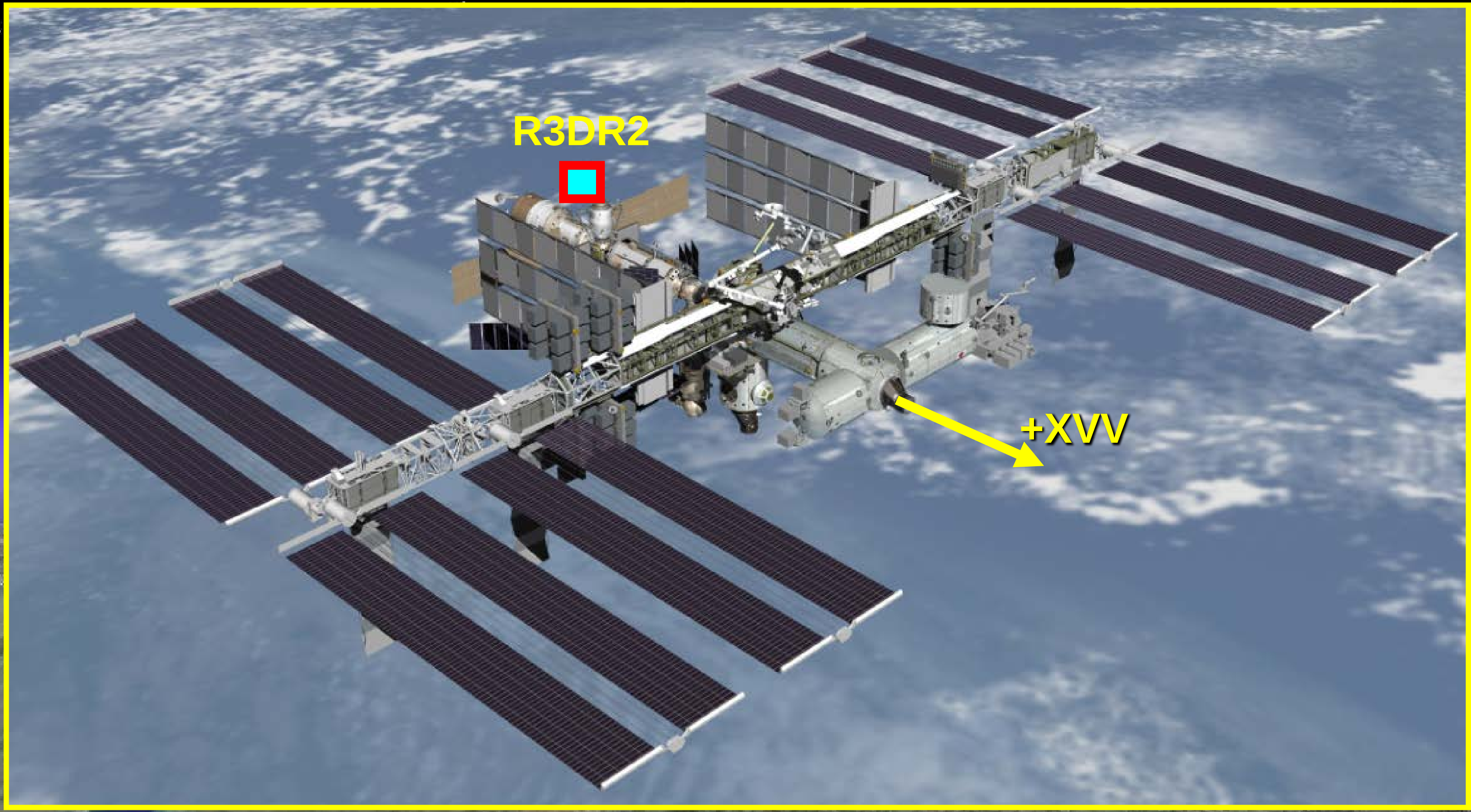


Average L value of the points where IRB source was obtained

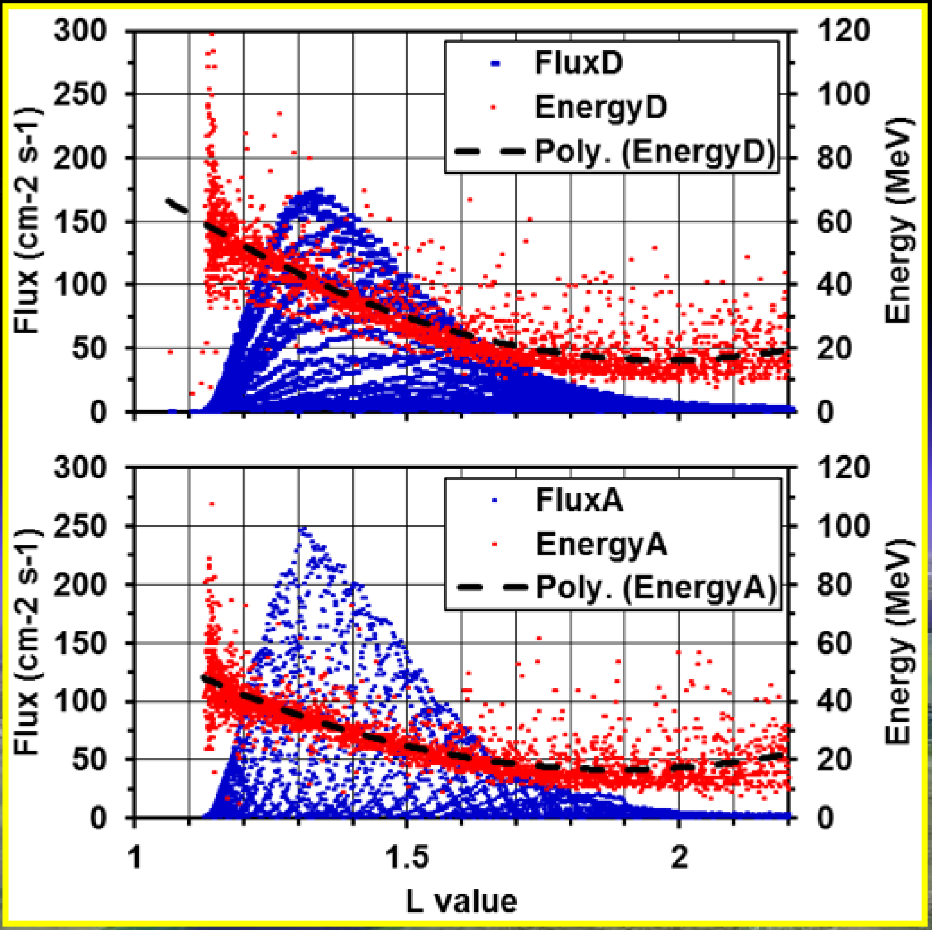


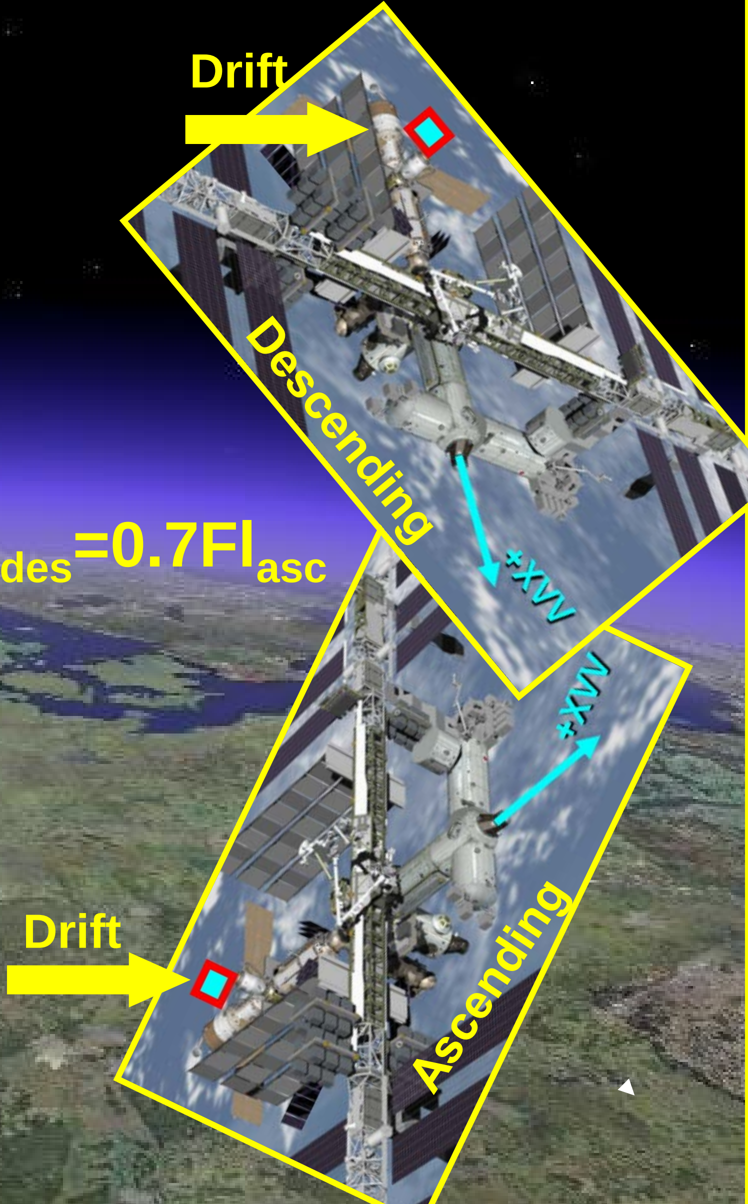
The picture shows that the inner belt size was reduced after the magnetic storm on 15 March 2015 and later slowly returns.

Position of the R3DR2 instrument in the ISS coordination system



Comparison of the of the descending and ascending fluxes in the region of the SAA





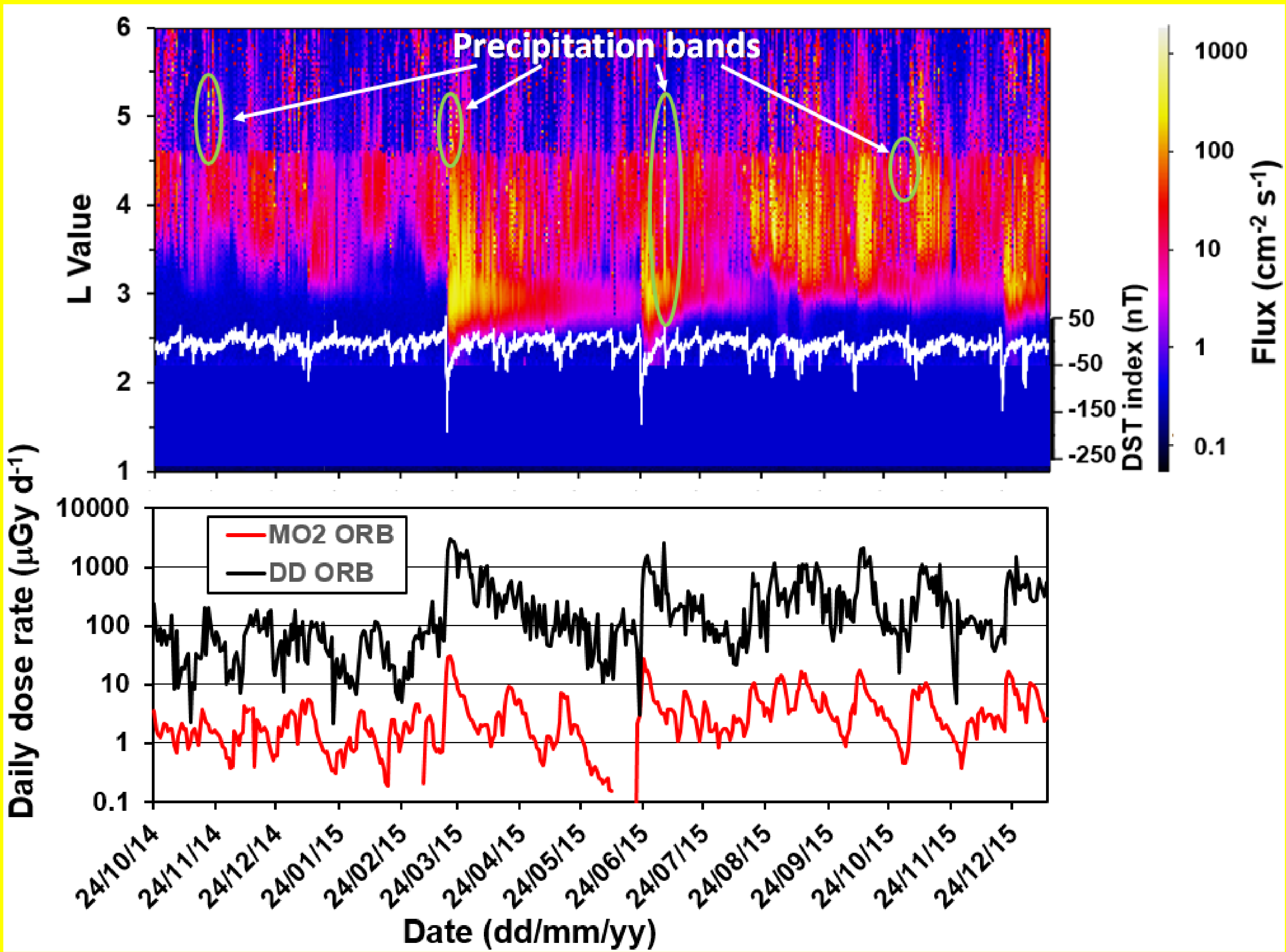
$Fl_{des}=0.7Fl_{asc}$

The R3DR2 detector that was located on the left side of the ISS "Zvezda" module against the ISS vector of velocity, was heavier shielded by the "Zvezda" module body on the descending orbits from west to east drifting inner belt protons, when the ISS was in the nominal "+XVV" orientation

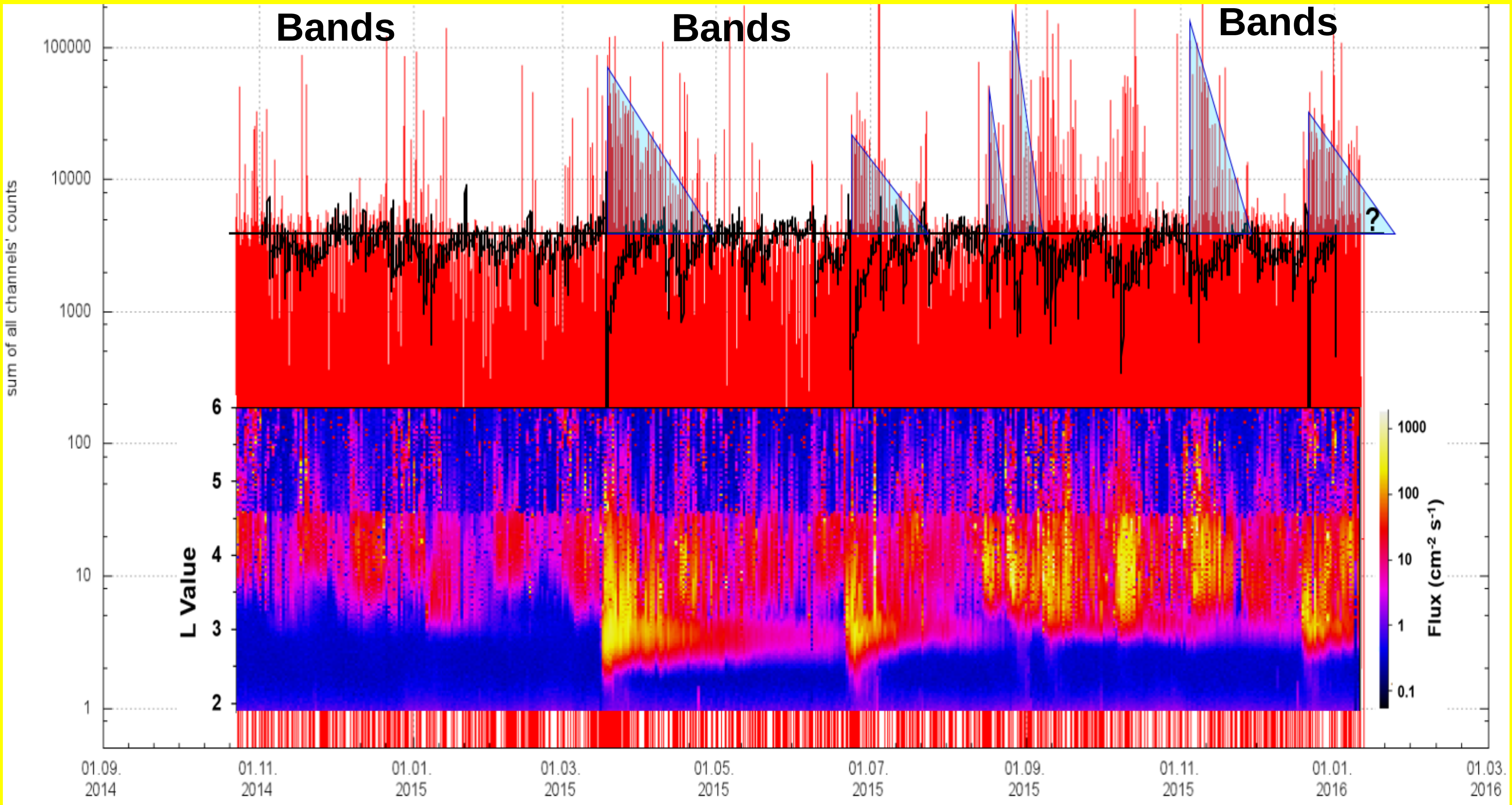
ORB & precipitation bands

“Particle precipitation into the atmosphere is a critical part of radiation belt electron loss; without quantified understanding of this loss mechanism, we are unable to fully understand acceleration mechanisms”.*

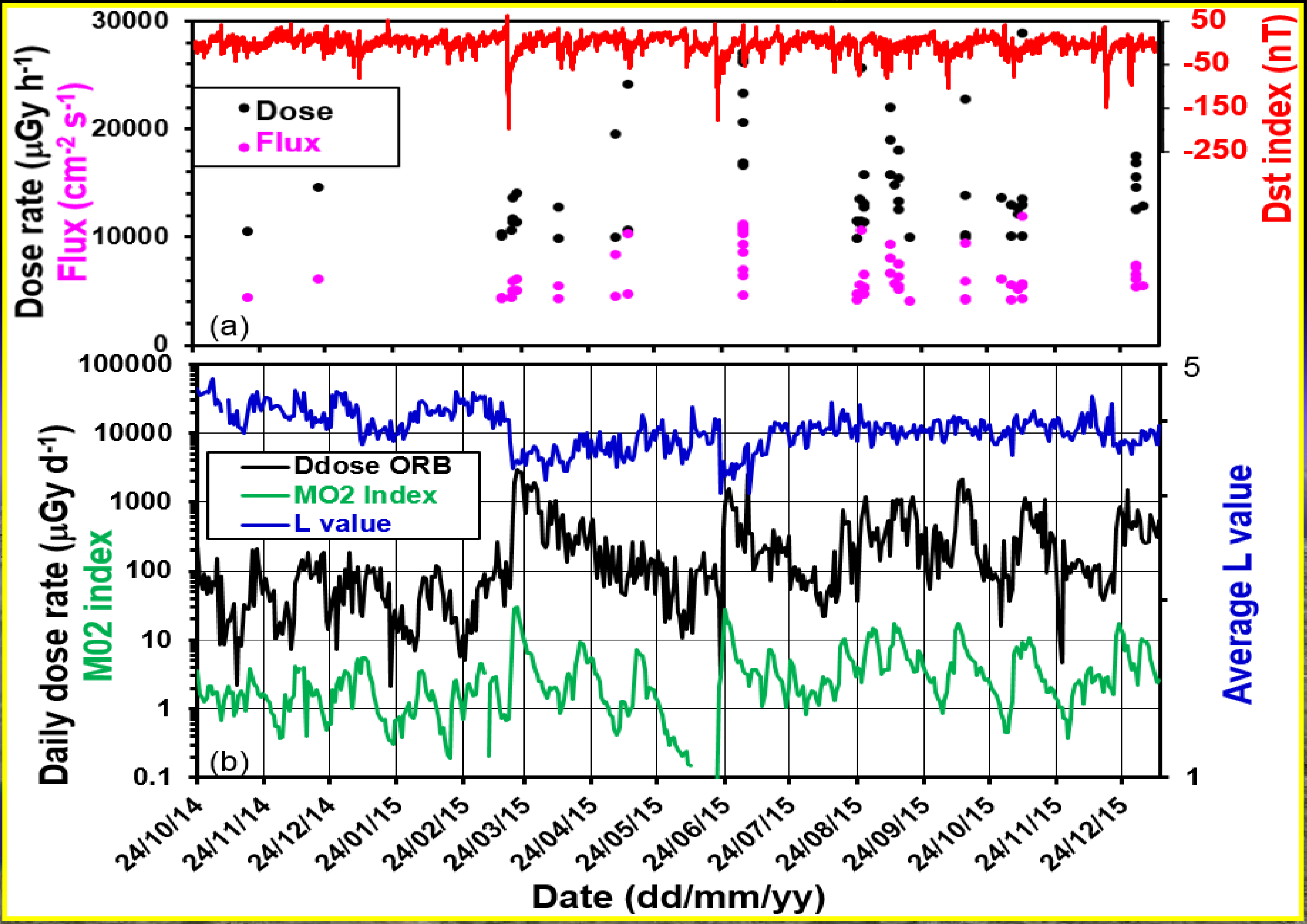
*Blum, L. W., Q. Schiller, X. Li, R. Millan, A. Halford, and L. Woodger, (2013) New conjunctive CubeSat and balloon measurements to quantify rapid energetic electron precipitation, J. Geophys. Res. Let., 40, 5833–5837. http://dx.doi.org/10.1002/2013GL058546


Precipitation bands
L Value
6
5
4
3
2
1
50
-50
-150
-250
DST index (nT)
1000
100
10
1
0.1
Flux (cm-2 s-1)
Daily dose rate (µGy d-1)
10000
1000
100
10
1
0.1
MO2 ORB
DD ORB
24/10/14
24/11/14
24/12/14
24/01/15
24/02/15
24/03/15
24/04/15
24/05/15
24/06/15
24/07/15
24/08/15
24/09/15
24/10/15
24/11/15
24/12/15
Date (dd/mm/yy)

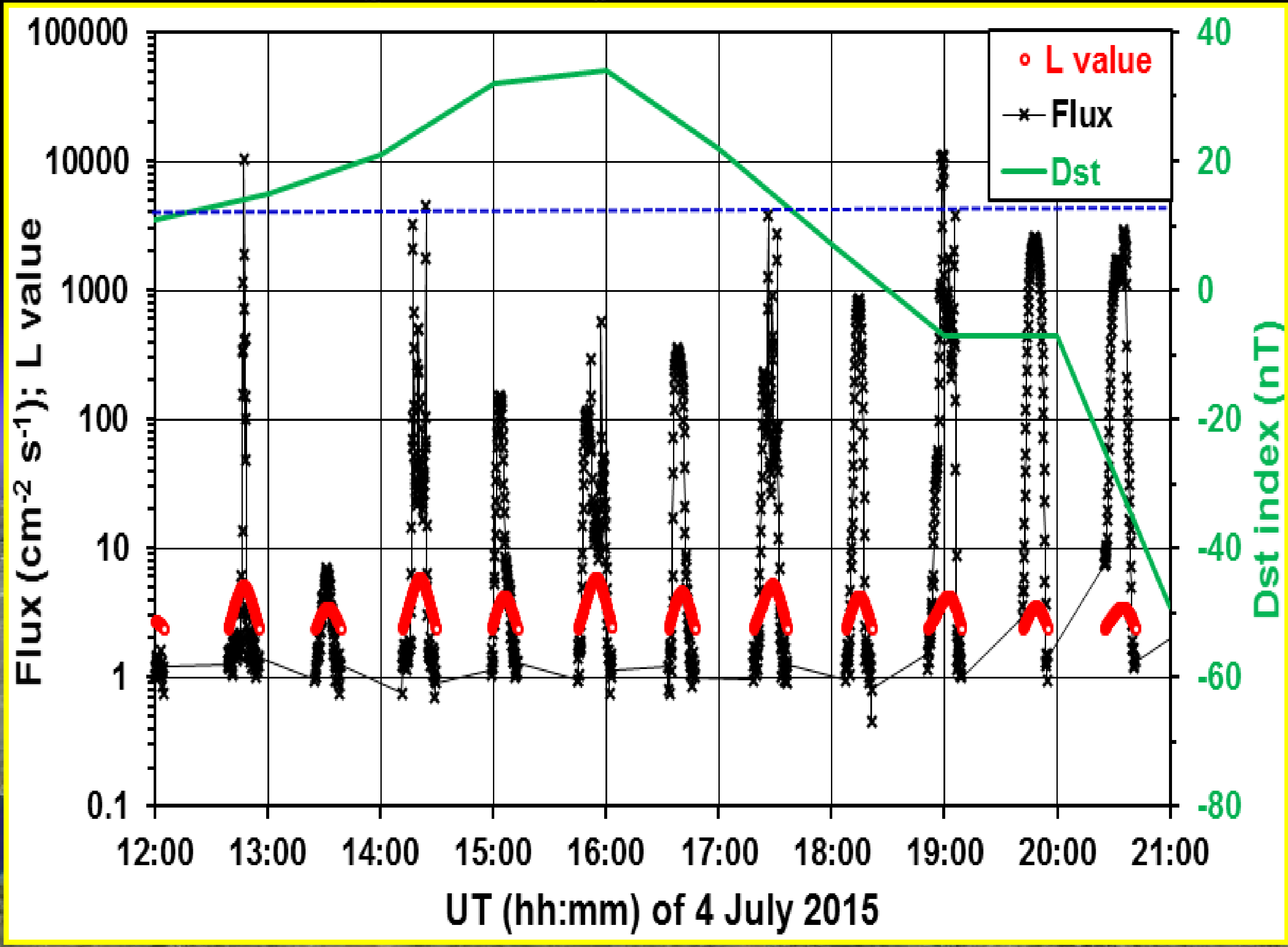
Comparison of the R3DR2 ORB data with the sum of counts in all channels as presented by Dr. Wolfgang Schulte, OHB, Bremen, Germany



Variations of the ORB daily averaged dose rates and flux in the period 24 October 2014-11 January 2016

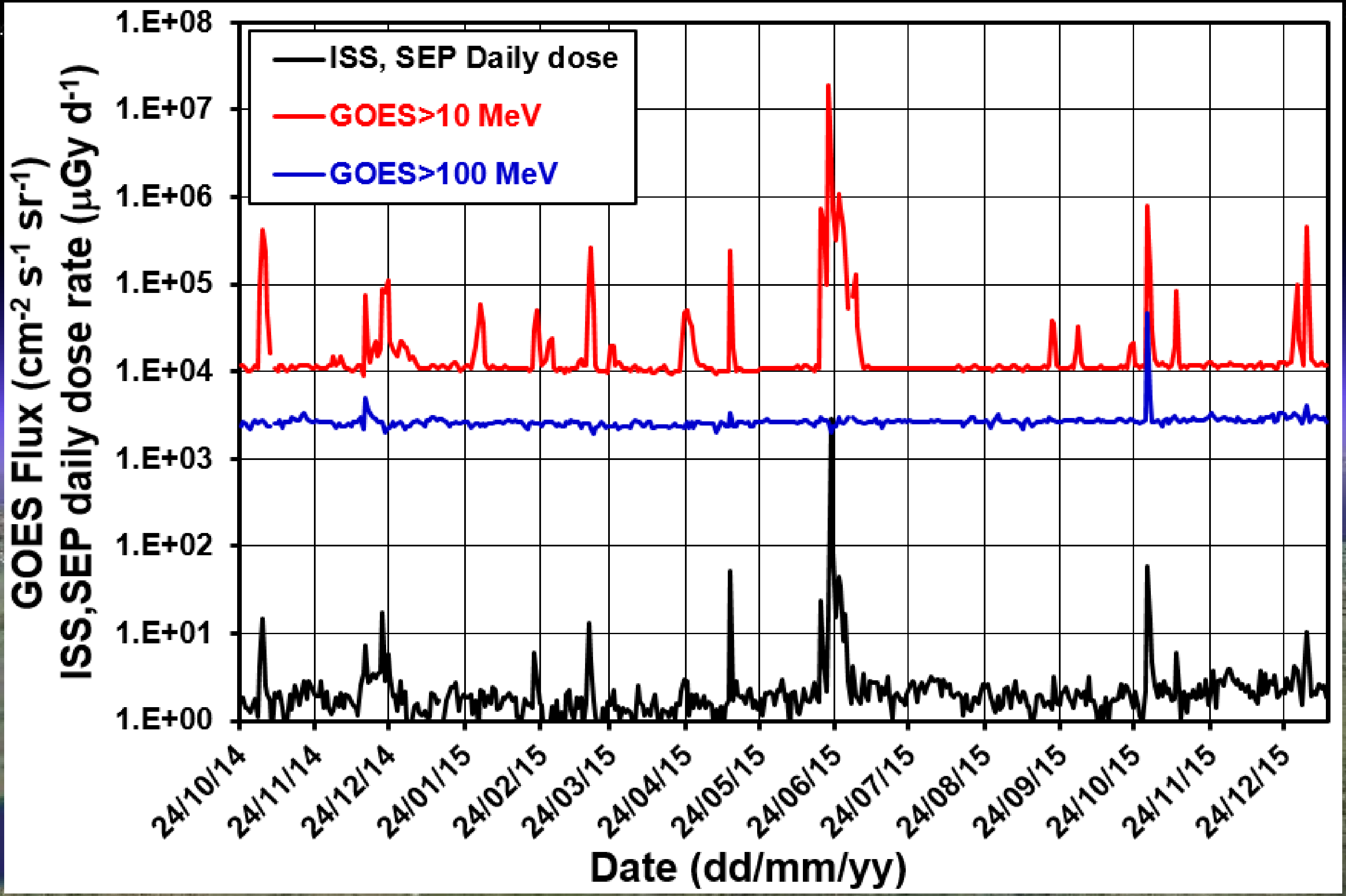


Example of the meaning of "radiation bands with the variations of the ORB flux in the period 12:00-21:00 hour UT on 4 July 2015



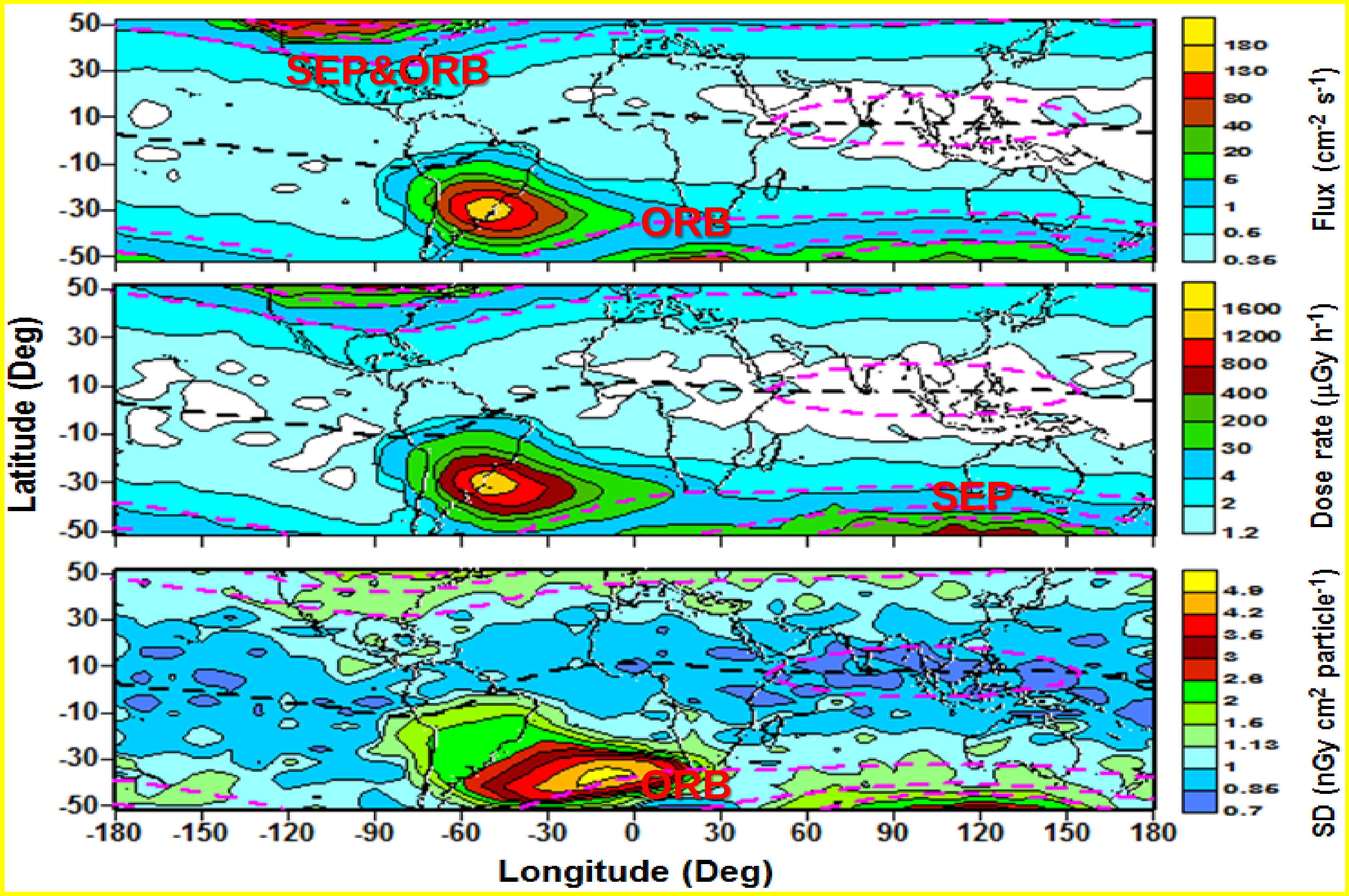
SEP

Variations of the SEP daily averaged dose rates and flux in the period 24 October 2014-11 January 2016

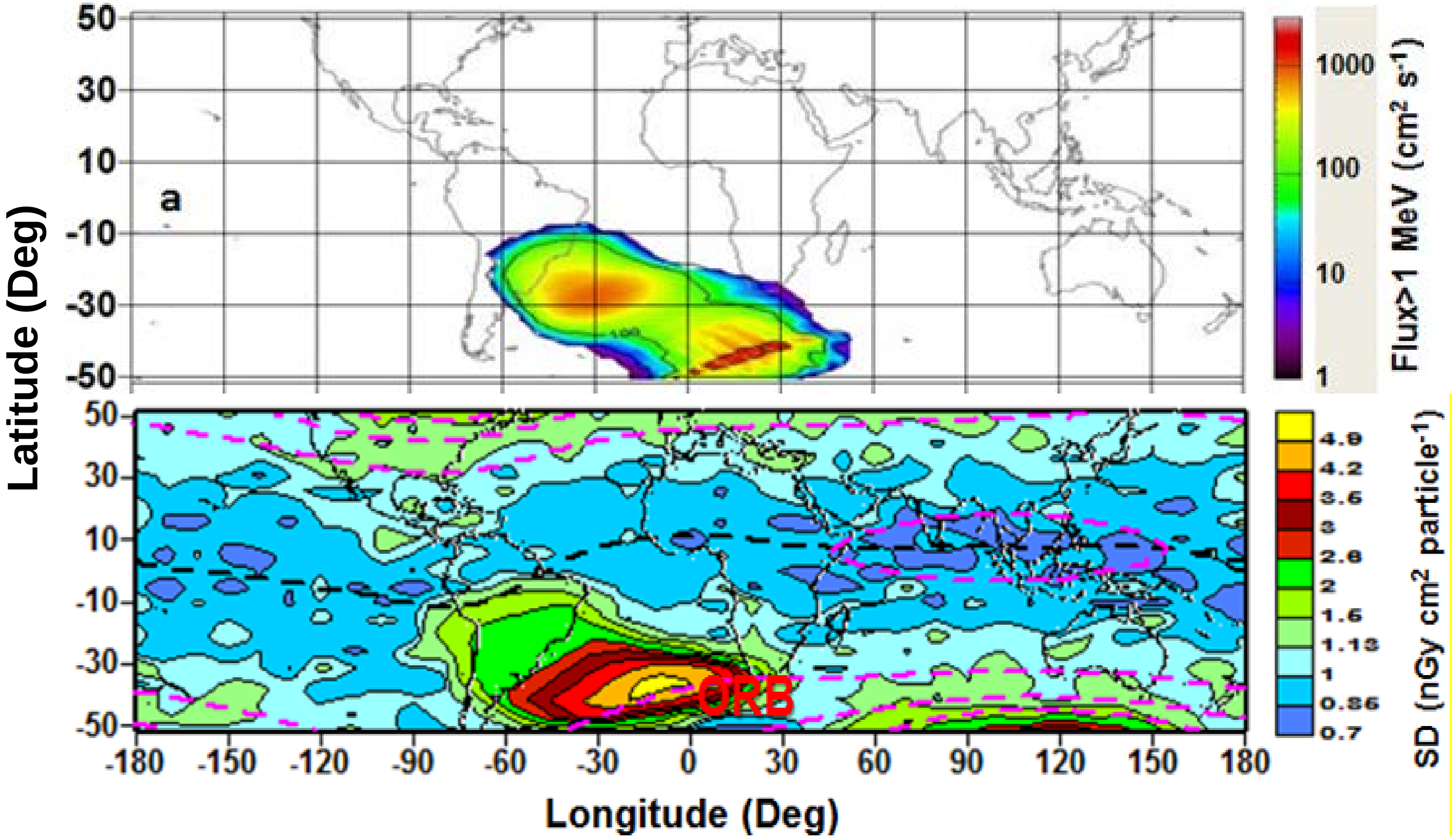


Global views

Global view of the R3DR2 flux and dose rate data for the period 18-30 June 2015



The global R3DR2 dose rate and specific dose data are compared with the world map of the 1 MeV energy proton flux predicted by the AP8 MAX model at 420 km altitude



Conclusions

- The EXPOSE-R2 mission (2014-2016) GCR daily averaged dose rate of 71.6 mGy d^{-1} is the smallest in comparison with the EXPOSE-E (2008-2009; 91.1 mGy d^{-1}; and EXPOSE-R (2009-2010, 81.4 mGy d^{-1}; missions, because the solar modulation lowered the GCR doses;

- The daily averaged IRB doses from the 3 instruments R3D/E/R1/R2 increased as follows: 426, 506, 567 mGy d^{-1}, and the main reason is the raising average altitude of the ISS since 2008;

- The EXPOSE-R2 mission (2014-2016) ORB daily averaged dose rates are the highest in comparison with the other 2 EXPOSE missions onboard of the ISS, because it occurred at the highest solar and geomagnetic activity, which stimulated the acceleration processes in the magnetosphere.

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Thank you for your attention