Earth magnetic field activity induced variations of the ISS inner radiation belt SAA region

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Outlook

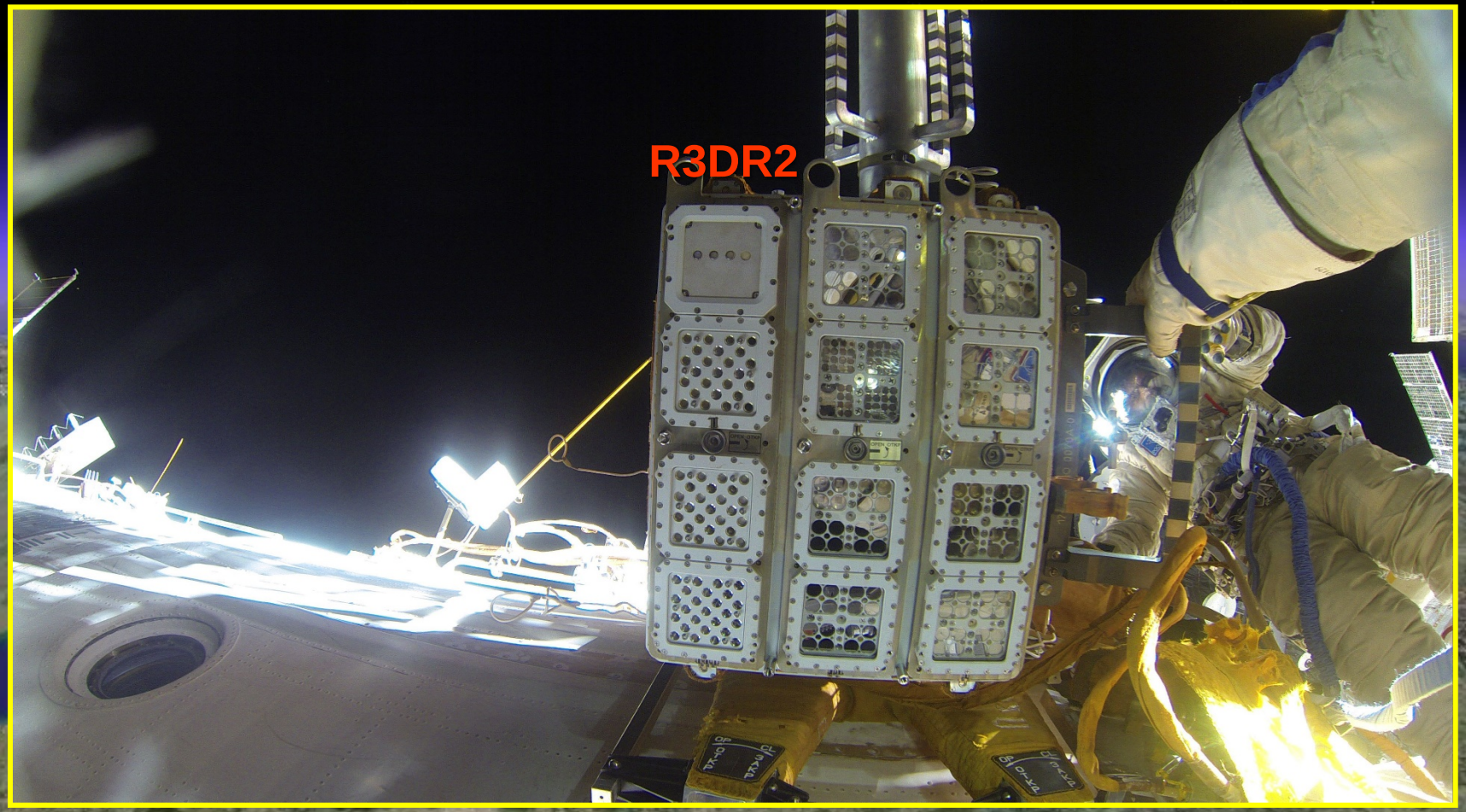
- Introduction
- Definition of the Disturbance Storm Time index - Dsts
- Statistic data
- Conclusions

Introduction

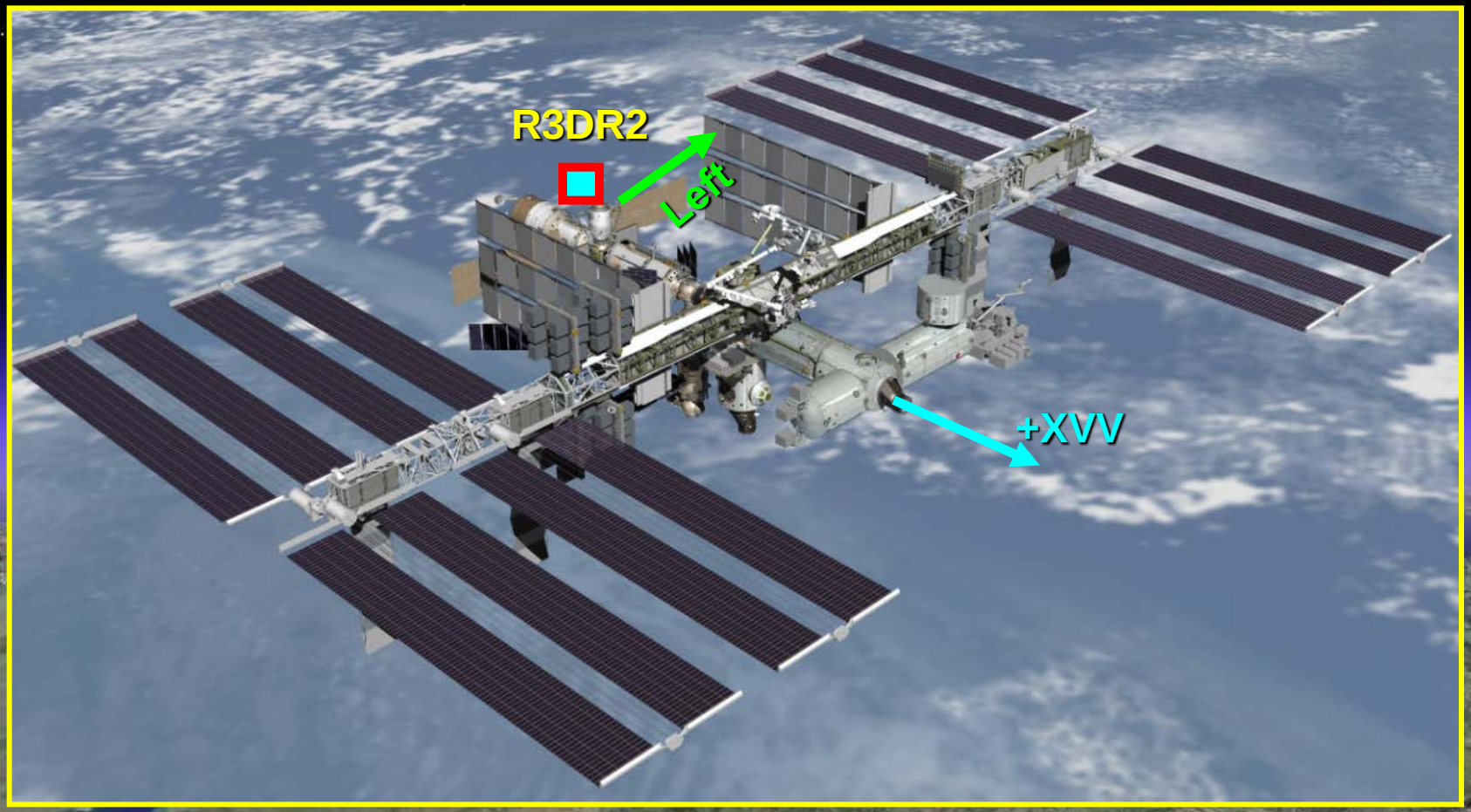
External view of R3DR2 instrument

(The current R3DR2 spectrometer-dosimeter onboard the ISS is the same instrument as flown in the EXPOSE-R facility from 2009-2010, but here is given the extension R2 to distinguish between the data from the previous EXPOSE-R mission.

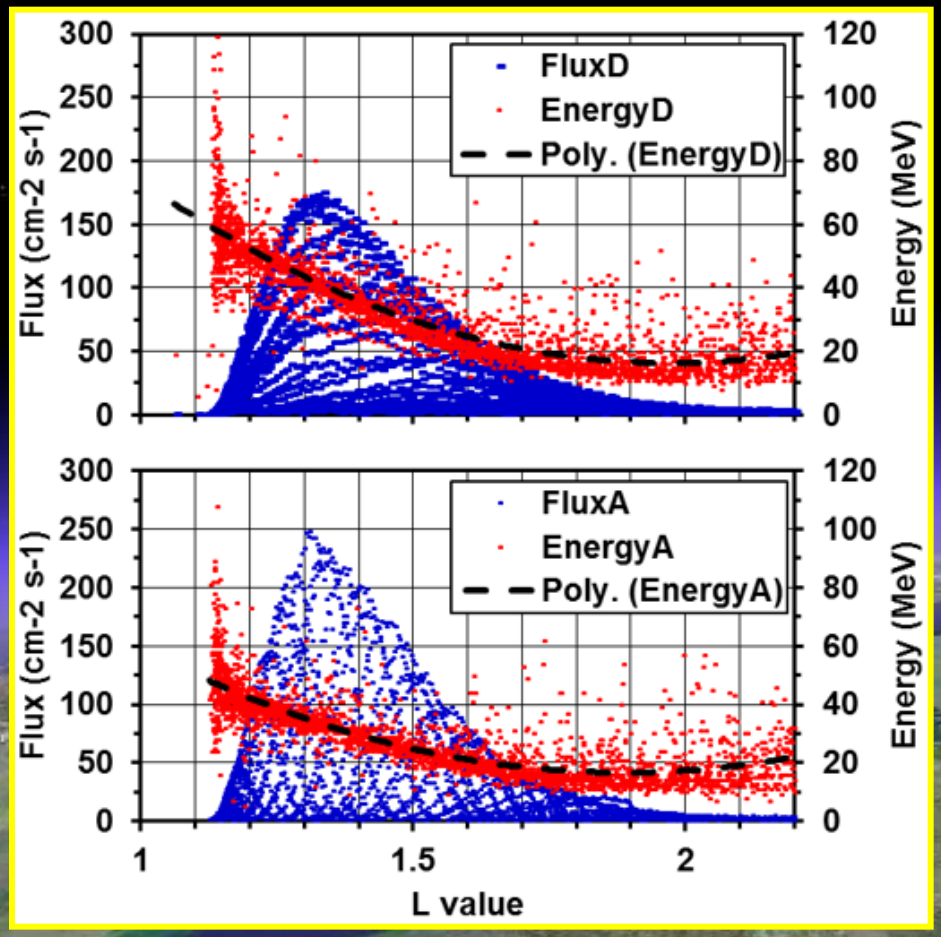
External view of R3DR2 instrument (in the red square) as mounted in the EXPOSE-R2 facility. (Picture taken by Russian cosmonaut G. Pedalka (only his arm is seen in the left-upper corner, while cosmonaut M. Kornienko is seen in the left middle plan) on 15 August 2015 during EVA for examination EXPOSE-R2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

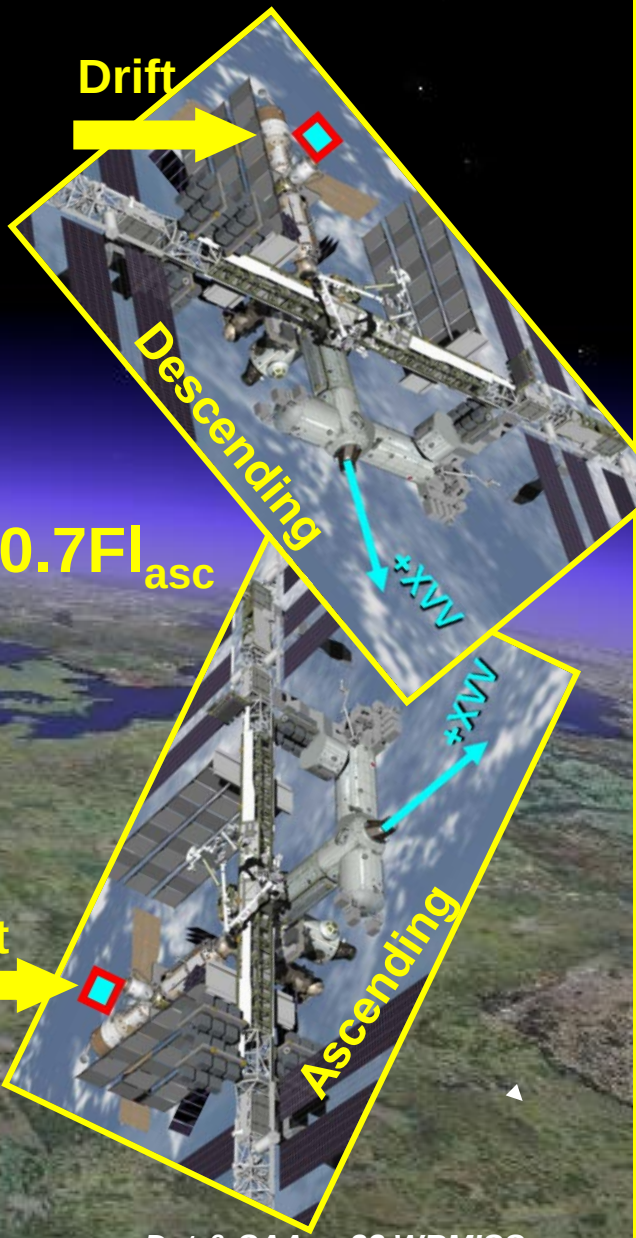


General positions of the R3DR2 instrument in the ISS coordinates



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

The following four primary radiation sources were expected and recognized in the data obtained with the R3DR2 instrument:

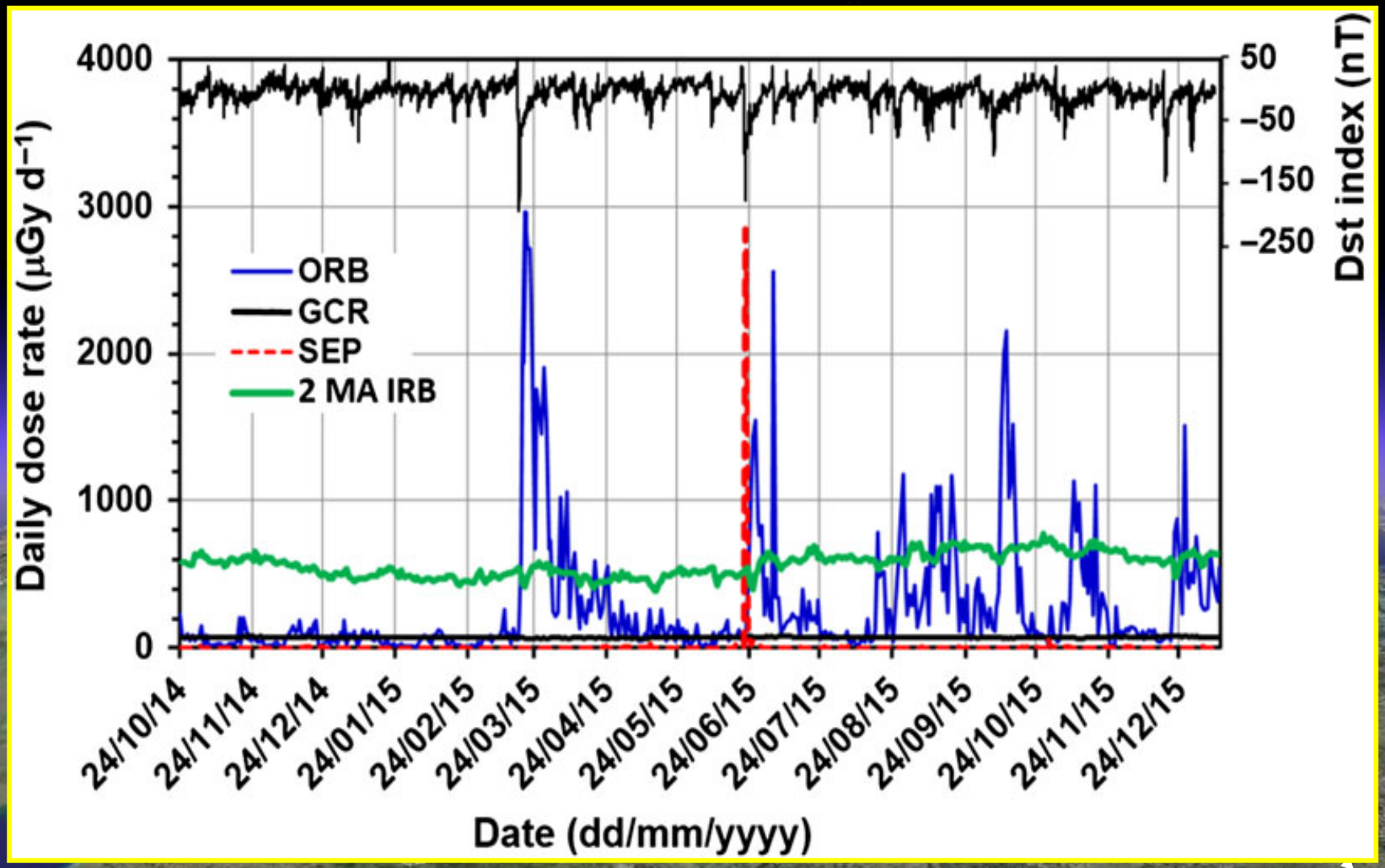
→ Globally distributed GCR particles and those derived from them;

→ Protons in the SAA region of the inner radiation belt (IRB);

→ Relativistic electrons and/or bremsstrahlung in the high latitudes of the ISS orbit where the outer radiation belt (ORB) is situated;

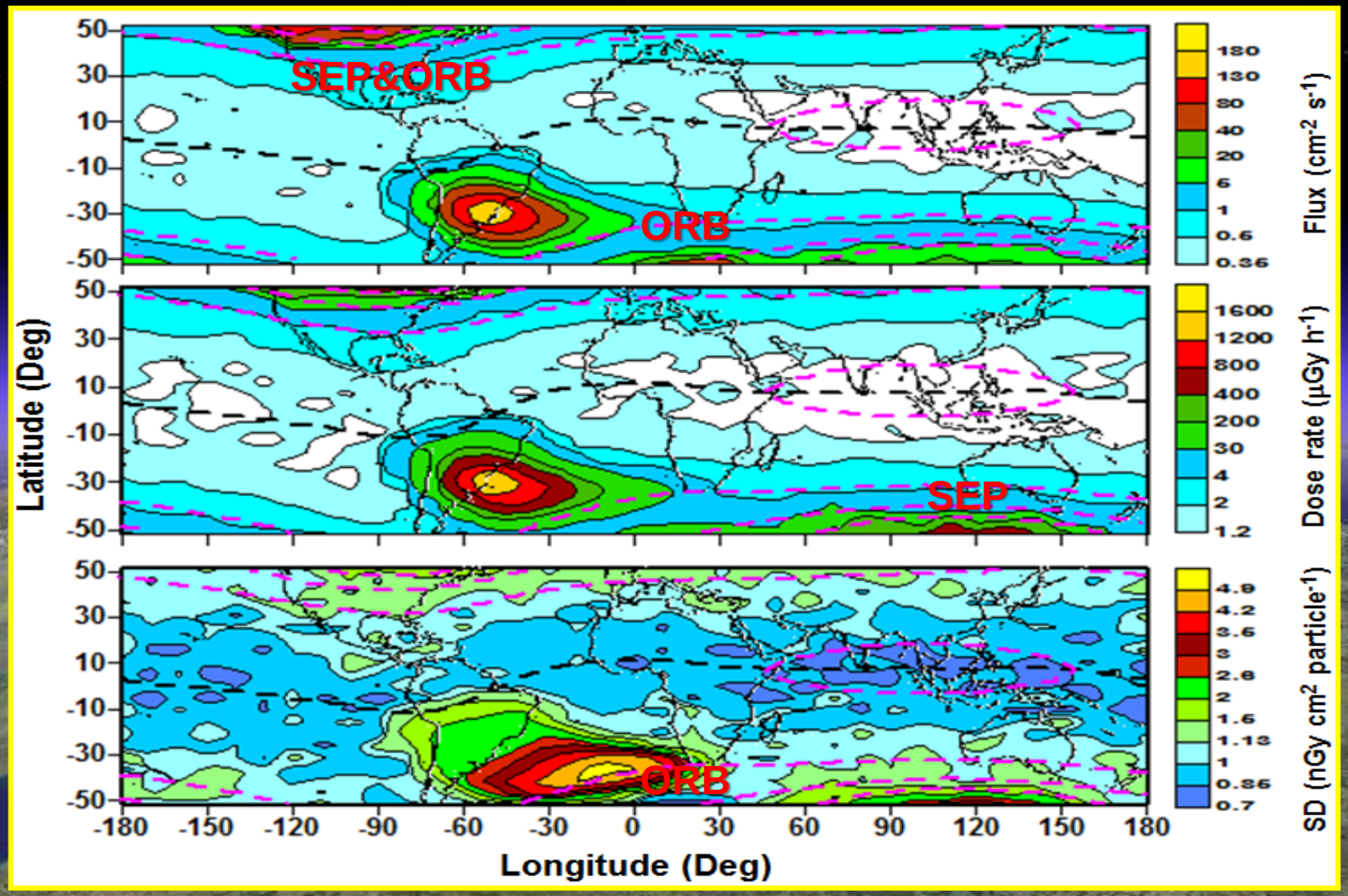
→ Solar energetic particles (SEP) in the high latitudes of the ISS orbit. Together with the real SEP particles, a low flux of what were likely to be mostly secondary protons (SP) were observed in the data.

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

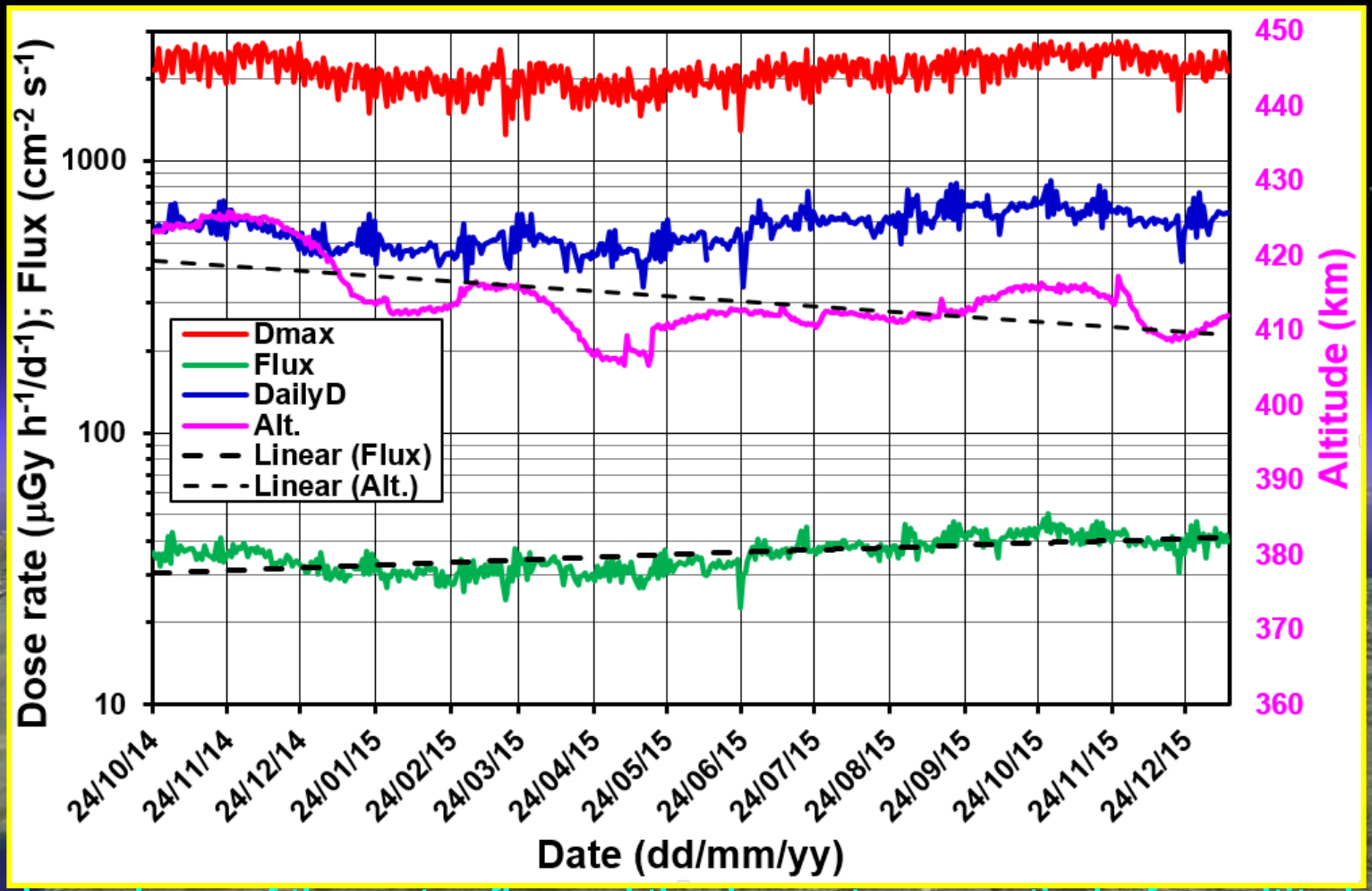


Dachev, T. P., N. G. Bankov, G. Horneck, D.-P. Häder; Letter to the Editor. Radiat Prot. Dosimetry, 174 (2), 292-295, 2017, https://doi.org/10.1093/rpd/ncw123 .

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



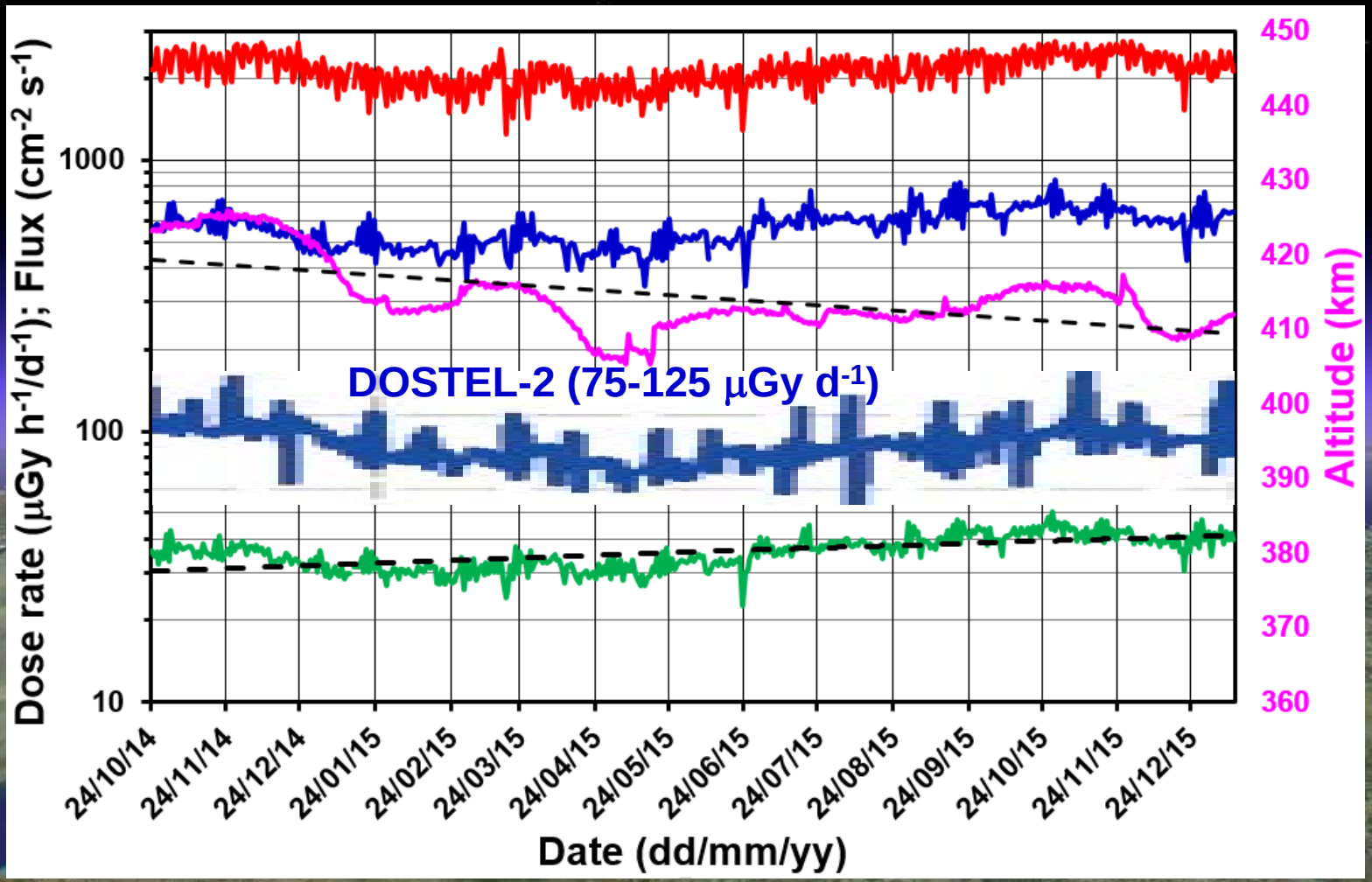
Comparison of the variations of the R3DR2 daily average dose rate, average flux and maximal dose with the averaged at the IRB measurements altitude of ISS



The dependence of the proton flux and the dose rate, respectively, from altitude in SAA is caused by the enhanced frequency of Coulomb collision between the IRB trapped protons and enhanced atmospheric neutral density at lower altitude, resulting to the extra losses of the inner belt protons.

Comparison of the variations of the R3DR2 daily average absorbed dose rate, flux and maximal dose with the measured daily absorbed dose rate for the contribution of the SAA for the DOSTEL-2 instrument*.

The oscillating spikes in the daily SAA dose rate are explained also by Berger et al. (2017)



Berger T, et al., DOSIS & DOSIS 3D: radiation measurements with the DOSTEL instruments onboard the Columbus Laboratory of the ISS in the years 2009–2016. J. Space Weather Space Clim., 7, A8, 2017, DOI: 10.1051/swsc/2017005.

Definition of the Disturbance Storm Time index - Dst

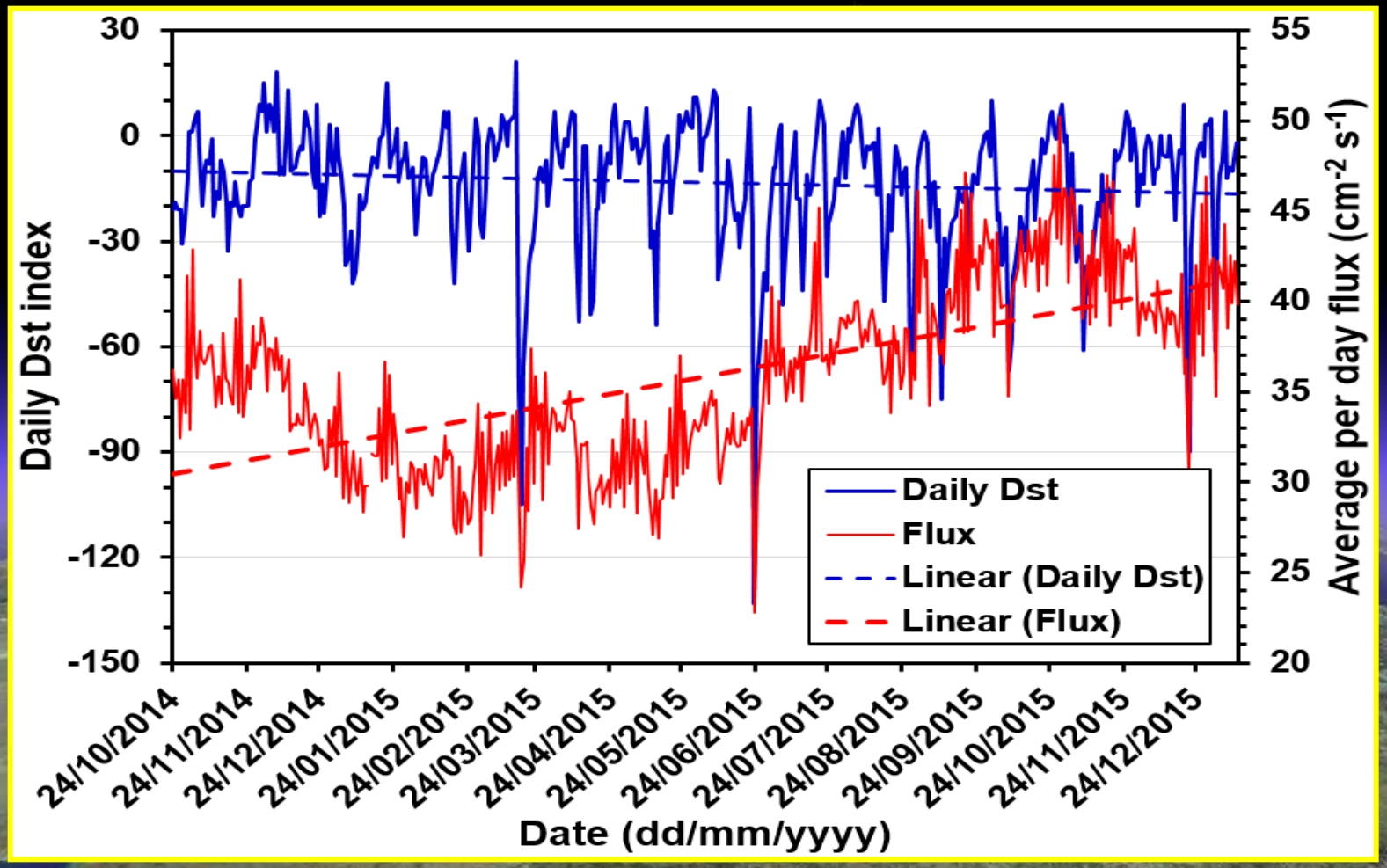
The Dst index represents the axially symmetric disturbance magnetic field at the dipole equator on the Earth's surface. Major disturbances in Dst are negative, namely decreases in the geomagnetic field. These field decreases are produced mainly by the equatorial current system in the magnetosphere, usually referred to as the ring current.*

In the magnetosphere, a region of current that flows from east to west in a in the outer of the Van Allen radiation belts. The current is produced by the gradient and curvature drift of the trapped charged particles. The ring current is greatly augmented during magnetic storms because of the hot plasma injected from the magnetotail. This increase in the ring current causes a worldwide depression of the horizontal geomagnetic field during a magnetic storm.**

Finally the Dst index is connected with the solar wind density and velocity.

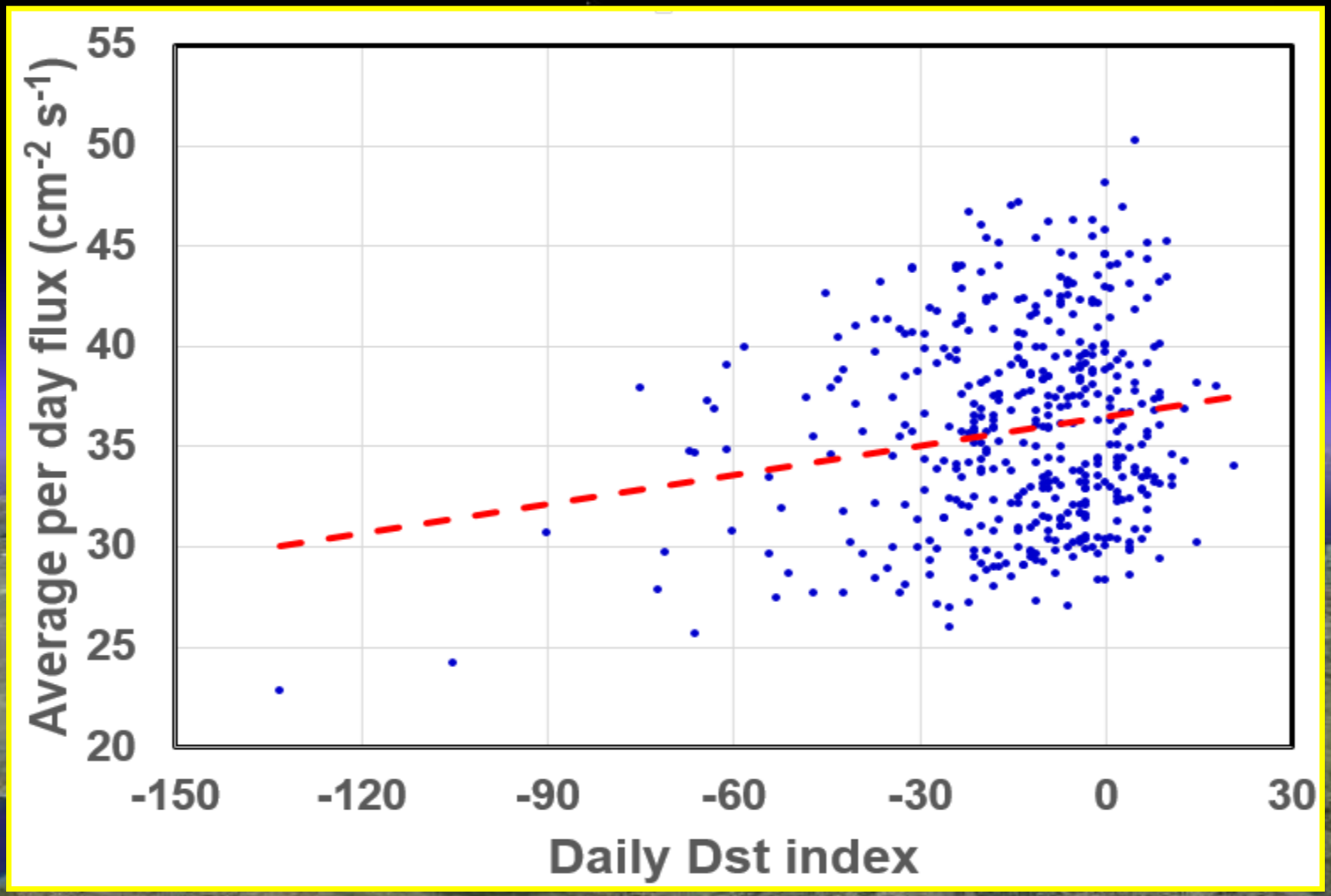
*http://wdc.kugi.kyoto-u.ac.jp/dstdir/dst2/onDstindex.html
**http://www.swpc.noaa.gov/content/space-weather-glossary#d

Comparison of the short-term R3DR2 average per day flux variations with the daily Dst index

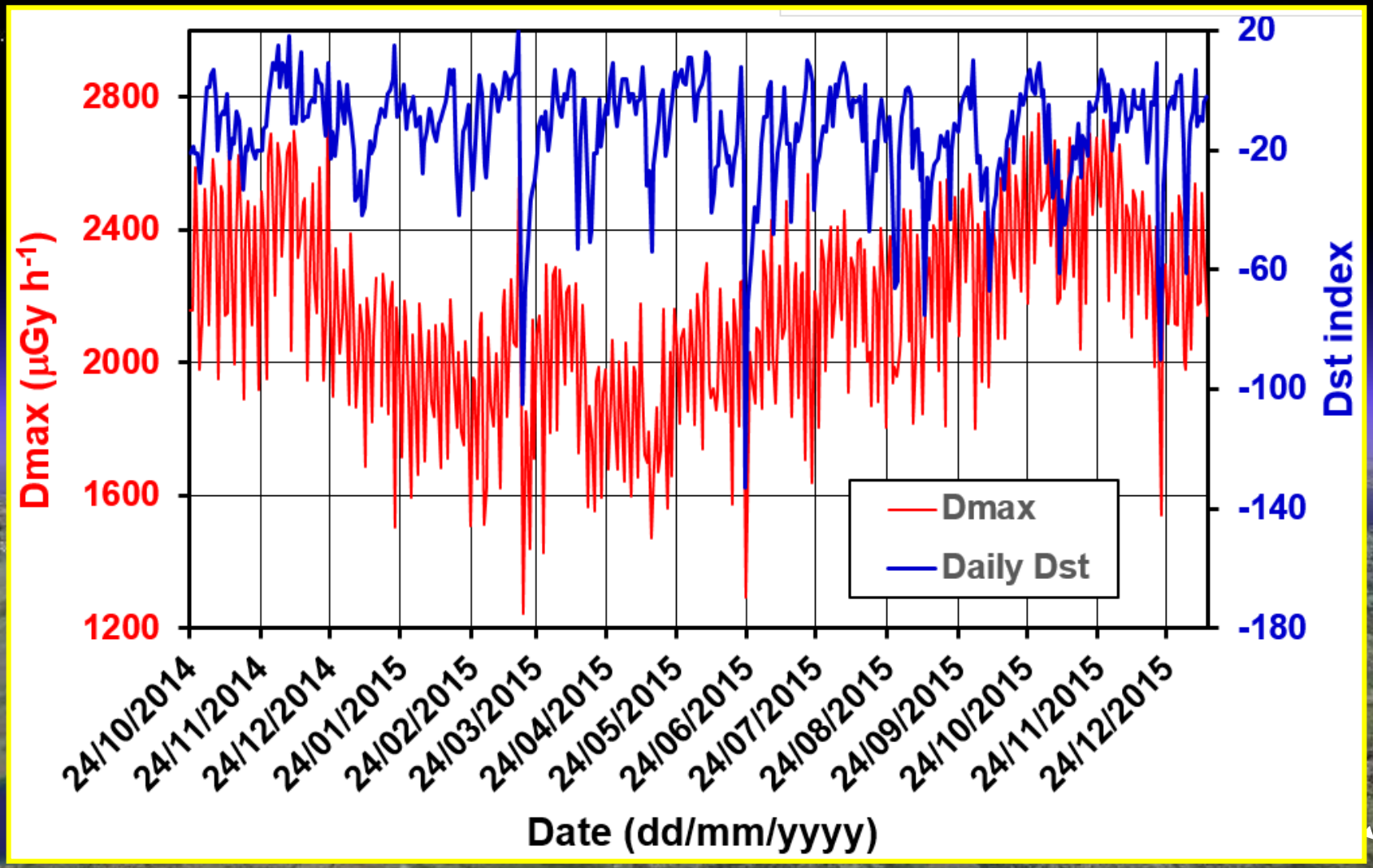


The decrease of the proton flux near the center of SAA is caused by the enhanced frequency of Coulomb collision between the IRB trapped protons and enhanced atmospheric neutral density during the magnetic storm, resulting to the extra losses of the inner belt protons.

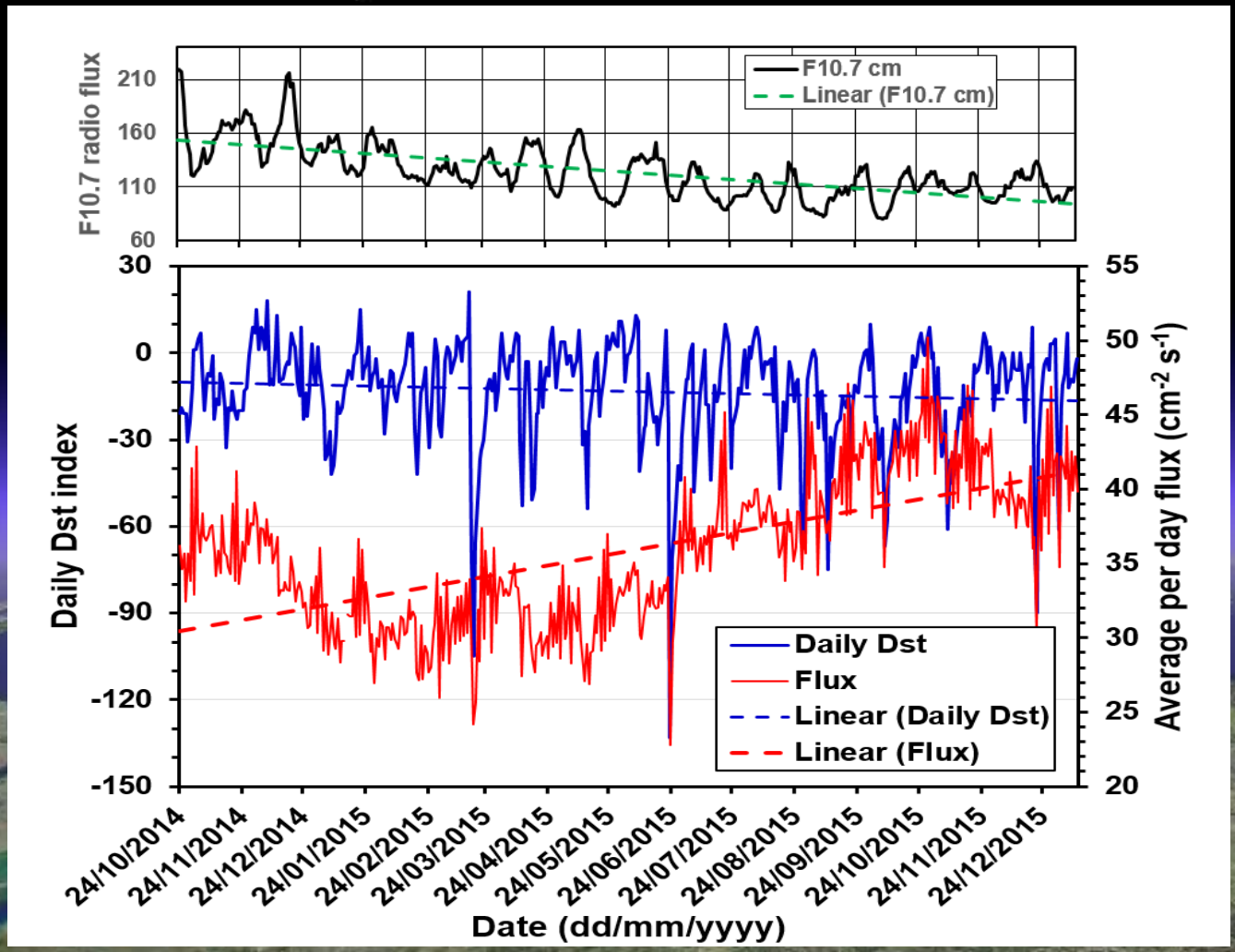
Linear dependence between the averaged per day flux and Dst index



Short-term variations of the R3DR2 maximal per day dose rate and the daily Dst index

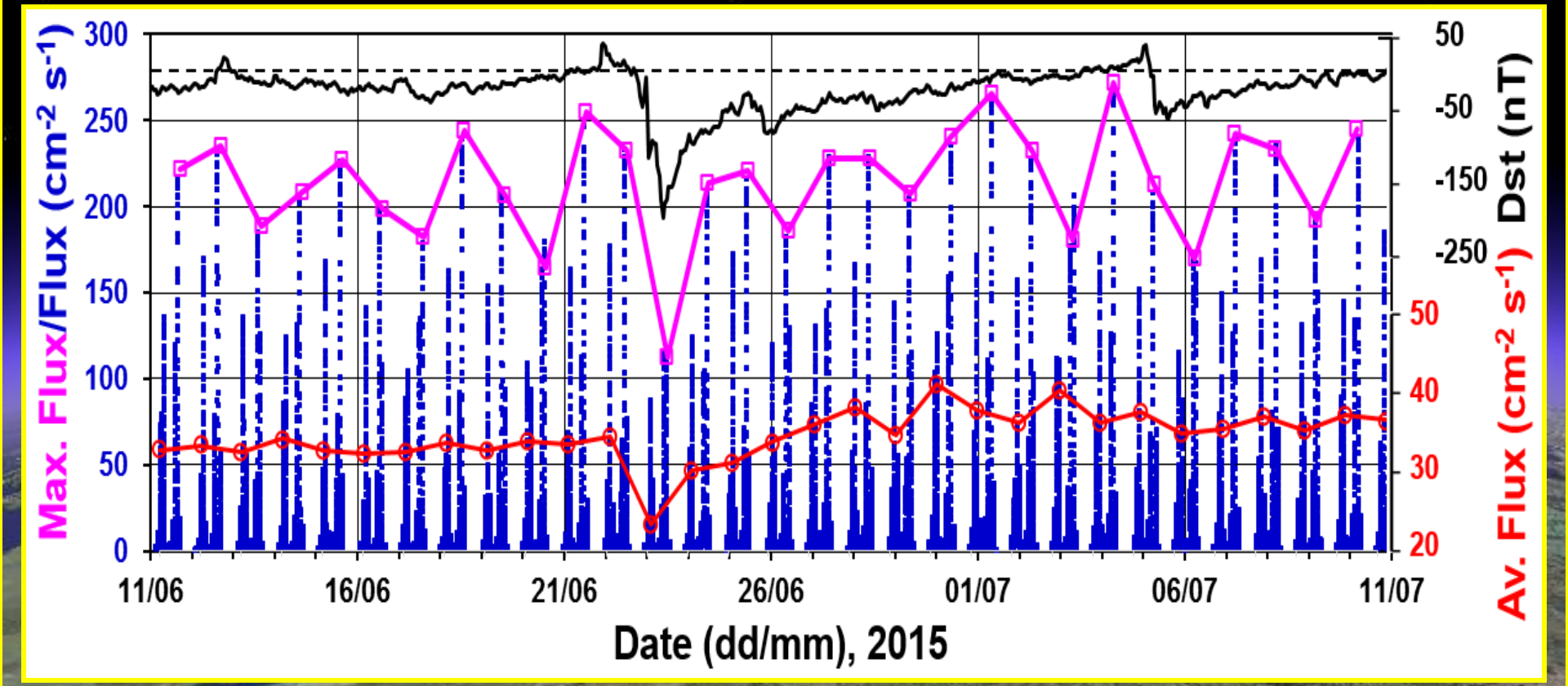


Long-term variations of the R3DR2 average per day flux, daily Dst index and F10.7 radio flux

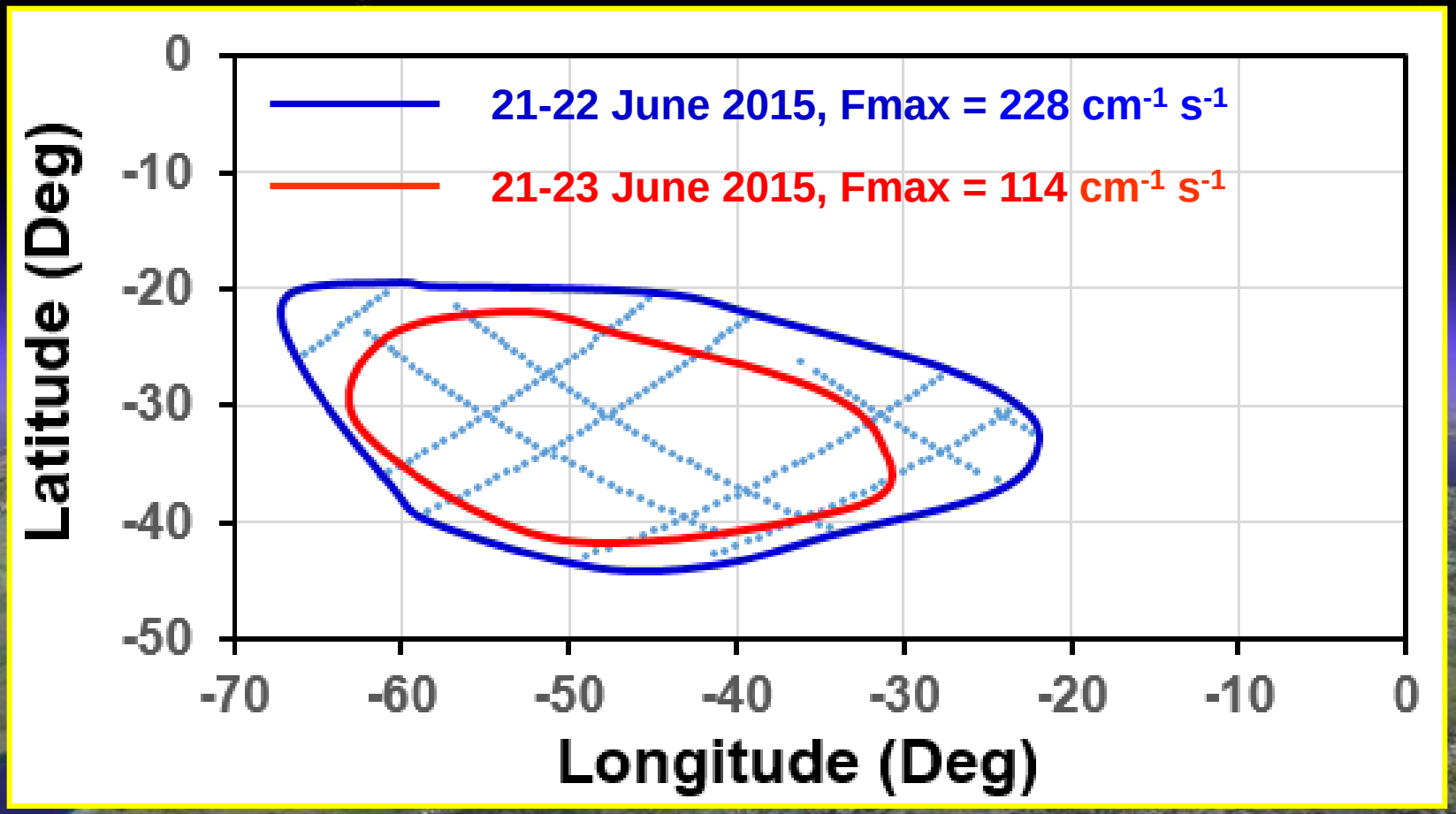


The F10.7 radio flux decrease means lower solar activity, which leads to decrease of the neutral temperature and respectively neutral density decrease at the altitudes of ISS and below. Lower Dst indexes also leads to decrease of the neutral density. Both effects caused increase of SAA proton flux never the less than small altitude decrease.

Comparison of the flux variations with the Dst index for the period 11 June – 11 July 2015

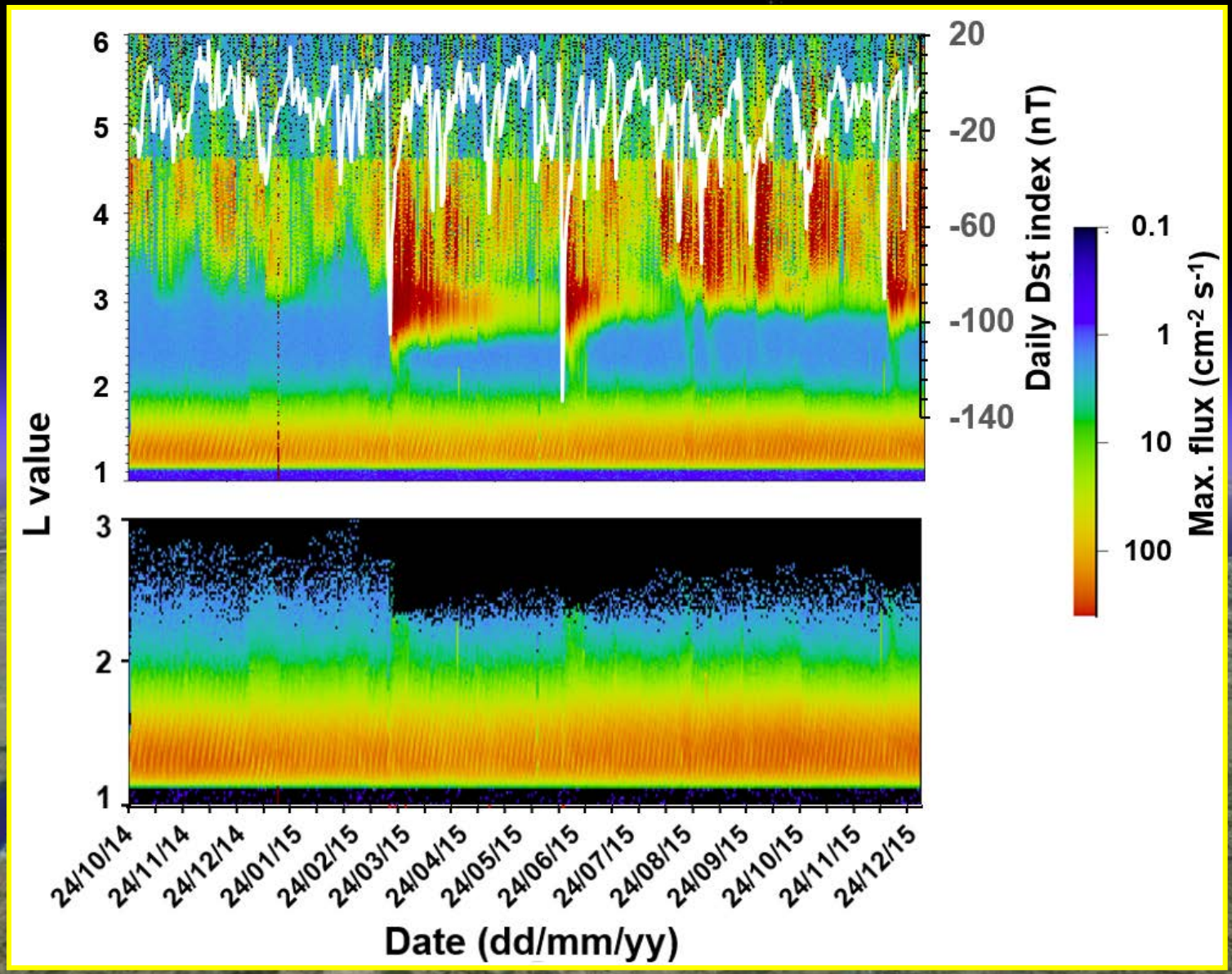


Comparison of the shapes of isolines for the flux more than 60 cm^{-1} s^{-1} before the storm on 21-22 June and during the storm on 23 June 2015. Similar decreases in the maximal flux and area of the SAA was published by Zou et al., (2015).*

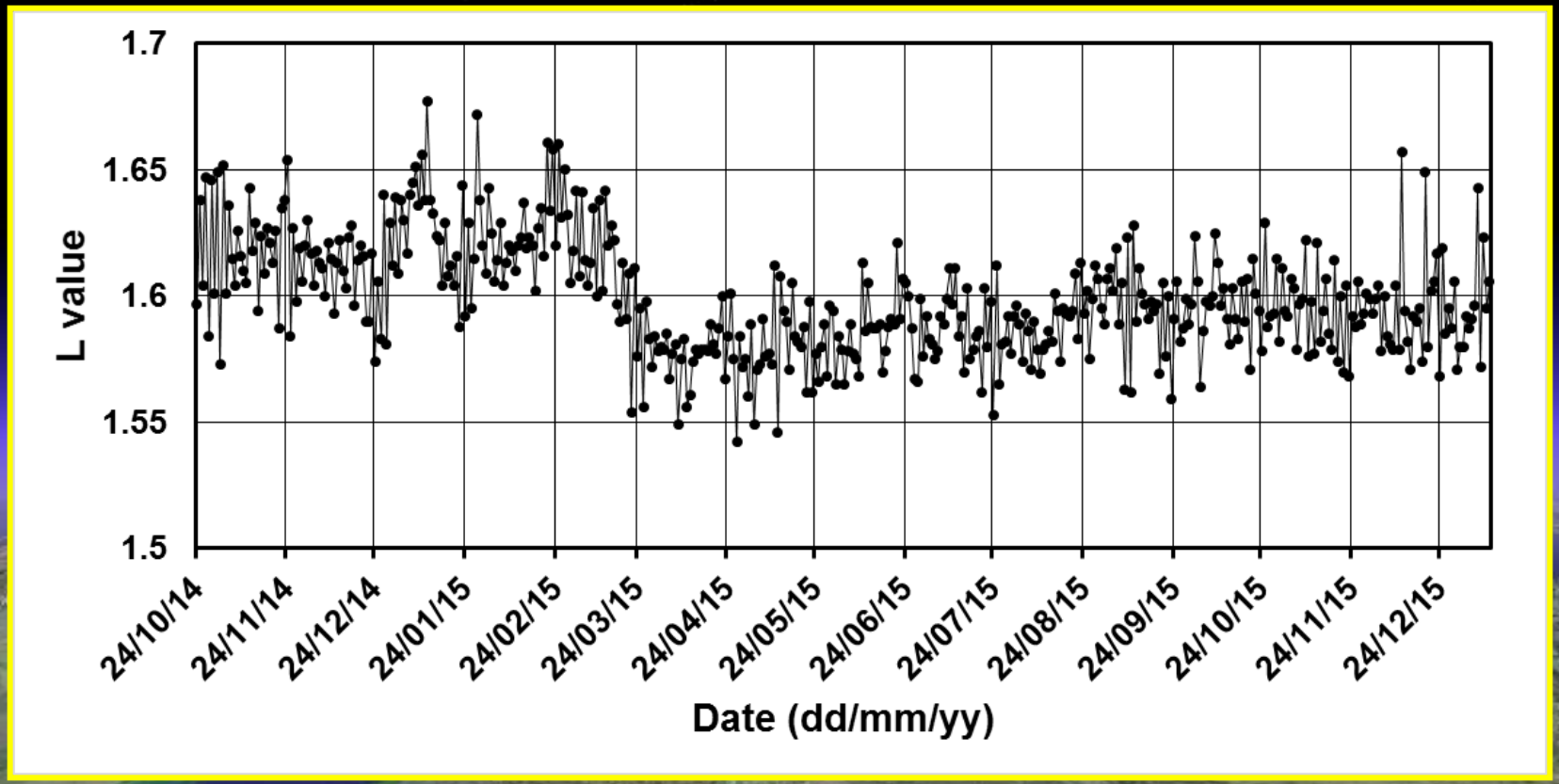


* Zou, et al., Short-term variations of the inner radiation belt in the South Atlantic anomaly, Journal of Geophysical Research: Space Physics, 120, 2015, doi:10.1002/2015JA021312.

The dynamics of the whole magnetosphere is more complicated than of single belts

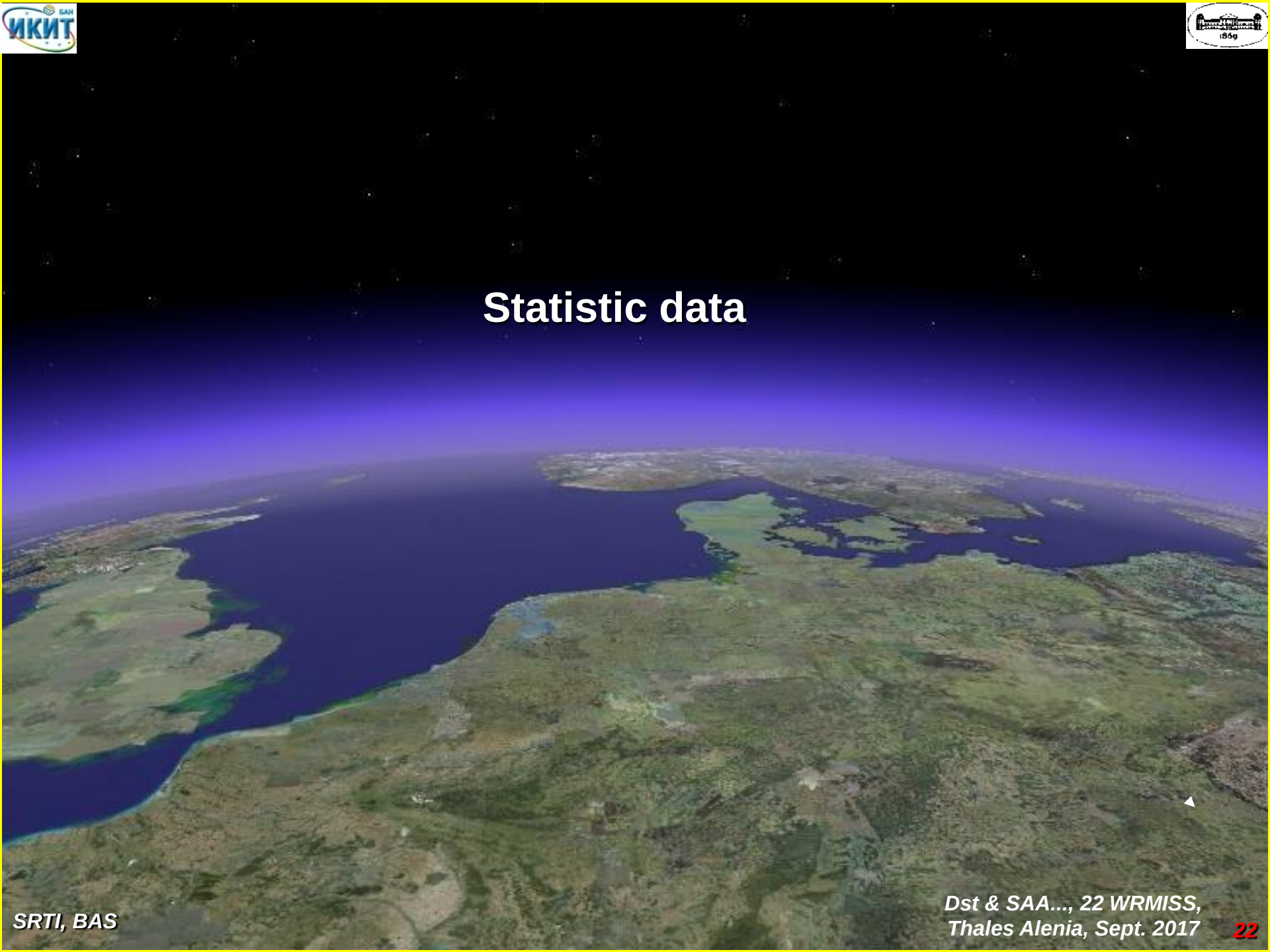


Average L value of the points where IRB source was obtained



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

Statistic data



Statistics for the sources observed during the Expose-E/R/R2 missions

IRB parameter	Minimum value	Average value	Maximum value
Hourly average flux rate (cm^{-2} s^{-1}) (measured and obtained per each day)	22.8	35.8	50.2
Hourly average absorbed dose rate (μGy h^{-1}) (measured and obtained per each day)	218.6	355.4	470.3
Daily absorbed dose rate (μGy d^{-1})	342	567	844
Maximum observed flux rate (cm^{-2} s^{-1} sr^{-1}) (measured in 10 s and obtained per each day)	18.5	36	48.4
Maximum observed dose rate (μGy h^{-1}) (measured in 10 s and obtained per each day)	1,244	2.151	2,748

Because the highest altitude during the EXPOSE-R2 all the of IRB SAA region parameters shows maximal values.

Comparison of the daily averaged absorbed dose rates measured during the EXPOSE-E/R and R2 missions

Daily averaged absorbed dose rate (in Si) (μGy d^{-1}) R3DE/R/R2 prel./R2 final	Minimum (μGy d^{-1})	Average (μGy d^{-1})	Maximum (μGy d^{-1})
GCR	76/79/**68**/71.2	91.1/81.4/**71.6**/71.2	102/90/**82**/77
IRB	110/326/**340**/342	426/506/**567**/567	685/704/**844**/844
ORB	0.25/0.64/**1.66**/2.16	8.64/89/**278**/278	212/2348/**2960**/2962
SEP (only in R3DR2 data)	**0**	**9**	**2846 (on 22/06/2015)**

Comparison of the accumulated absorbed dose rates measured with R3DE/R/R2 instruments

Measured accumulated dose (mGy)			
Source	R3DE	R3DR	R3DR2
IRB	181.1 for 425 days	144.7 for 263 days	250.7/250.6 for 442 days
ORB	3.2 for 432 days	22.9 for 286 days	123.1/123.1 for 443 days
GCR	39.4 for 394 days	23.3 for 286 days	31.8/31.6 for 444 days
SEP (incl. second. protons)			4.04 for 444 days
Total (mGy)	223.7	190.9	409.5

Discussion and conclusions

- The most important achievement of the paper is the discovery and proof of the existence of short term variations in the energetic proton fluxes of IRB SAA region outside ISS during the EXPOSE missions in the period 2008-2016;
- During the main phase of the magnetic storm was observed decreases in the maximal flux and area of the SAA region;
- The correlation between the SAA fluxes and maximal dose rates and Dst confirm the existence of fast mechanism for control most probably trough the magnetic activity induced decreases of the neutral density;
- The paper puts an end to the long-held postulate that there is no dynamic in the inner radiation belt and that it does not change.

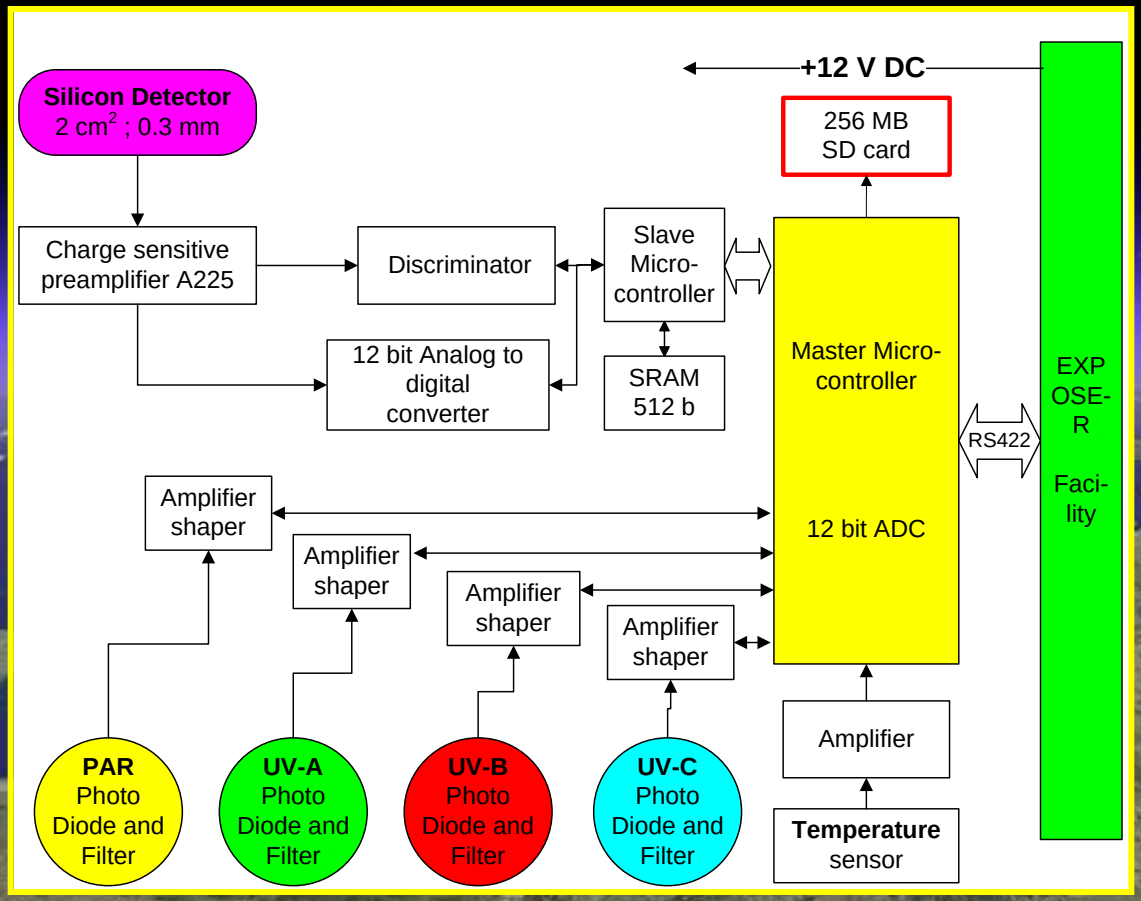
Acknowledgements and data availability

This work was partially supported by Contract No. 4000117692/16/NL/NDe funded by the Government of Bulgaria through an ESA Contract under the Plan for European Cooperating States (PECS).

The R3DR2 data used in this paper are part of the above mentioned contract entitled: “DOSIMETRY: Dosimetry science payloads for ExoMars TGO & surface platform; Unified web-based database with Liulin-type instruments’ cosmic radiation data”. This is the reason why the R2DR2 dose rate and flux data and some time-spatial coordinates of the ISS are currently available online at the following URL: http://esa-pro.space.bas.bg/node/23. Later they will be part of the database.

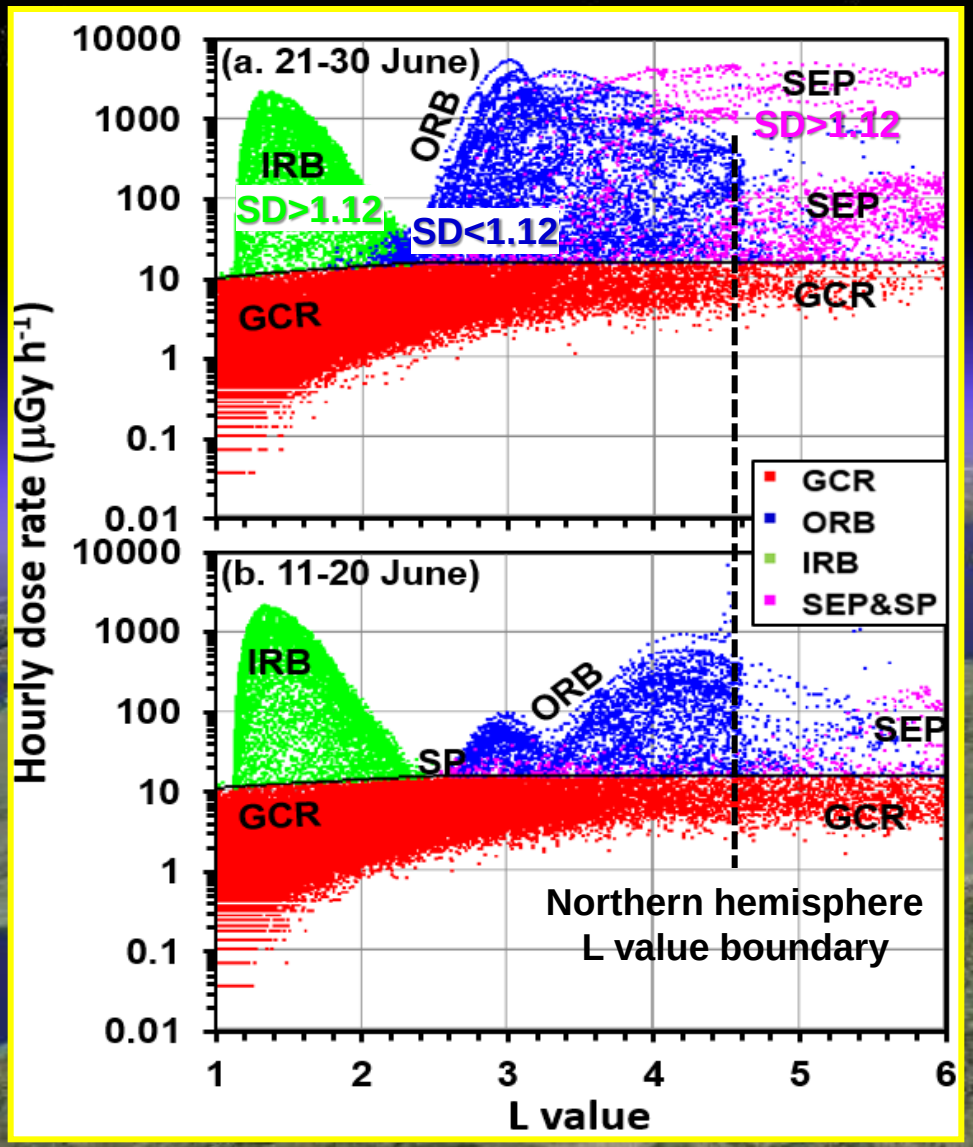

Thank you for your attention

The R3DER2 instrument is active, low mass (170 g) and small consumption (150 mW) device, which measure solar radiation in 4 channels and space ionizing radiation in 256 channels. Measurements have 10 s. time resolution. The spectrometers were mutually developed with University of Erlangen, Germany



Block schema of the R3DE/R/R2 devices

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.

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