Analysis of the EVA Doses Observed by Liulin-Type Instruments on ISS

Ts.P. Dachev[1], B.T. Tomov[1], Pl.G. Dimitrov[1], Yu.N. Matviichuk[1], N.G. Bankov[1], O. Ploc[2] , J. Kubancak[2]

Space and Solar-Terrestrial Research Institute, Bulgarian Academy of Sciences, Sofia Bulgaria, tdachev@bas.bg

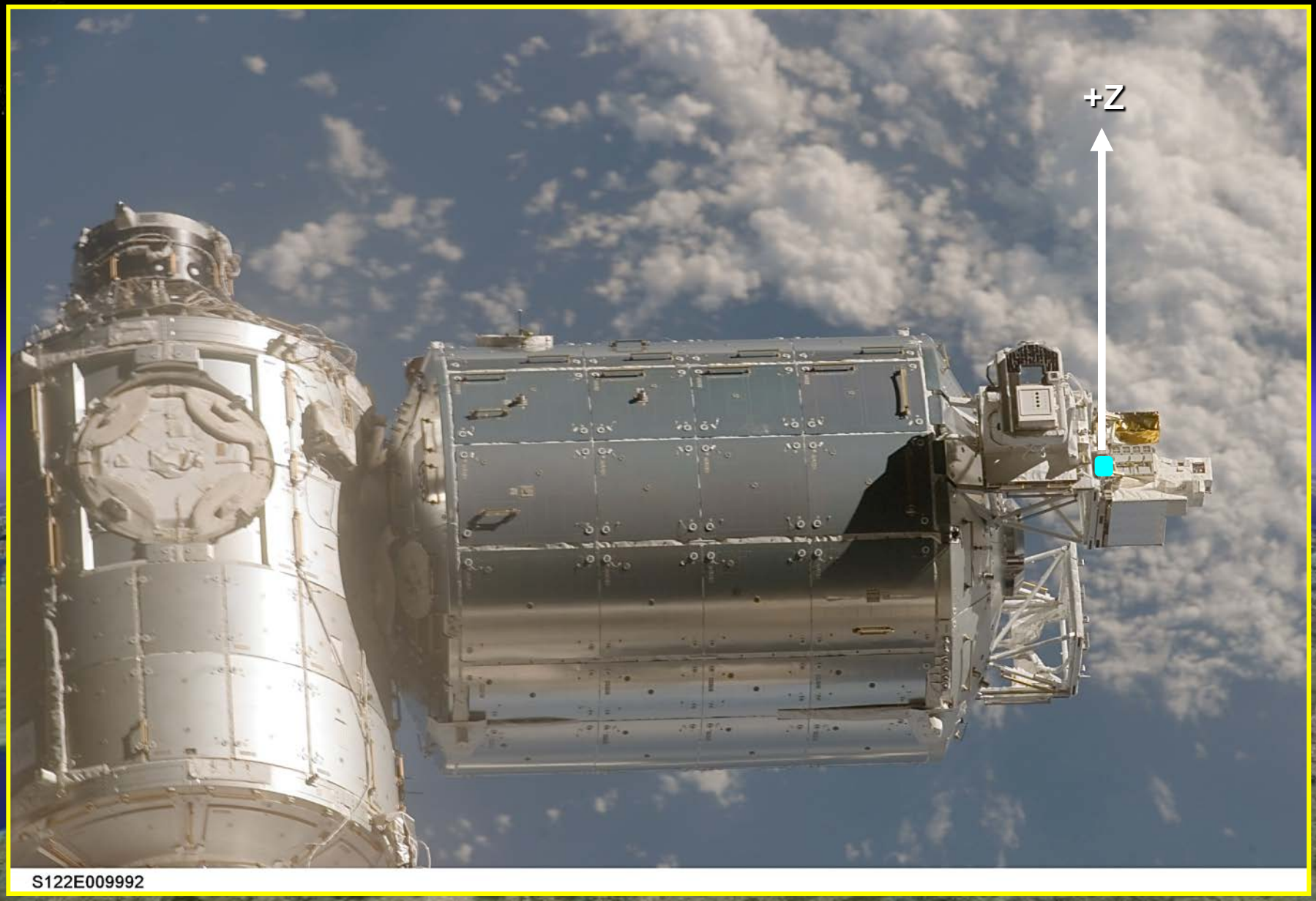
[2] *Department of Dosimetry, Nuclear Physics Institute of AS CR, Na Truhlarce 39/64, 180 86 Praha 8, Czech Republic*

Outlook

- Introduction
- Presentation of the instruments and data obtained
- EVA data inside intense relativistic electrons precipitation from outer radiation belt (ORB)
- EVA data collected simultaneously by R3DE, Pille and TEPC instruments with crossings of the SAA region
- EVA data collected simultaneously by R3DE R3DR and TEPC instruments
- Empirical model of the ISS radiation environment
- Conclusions

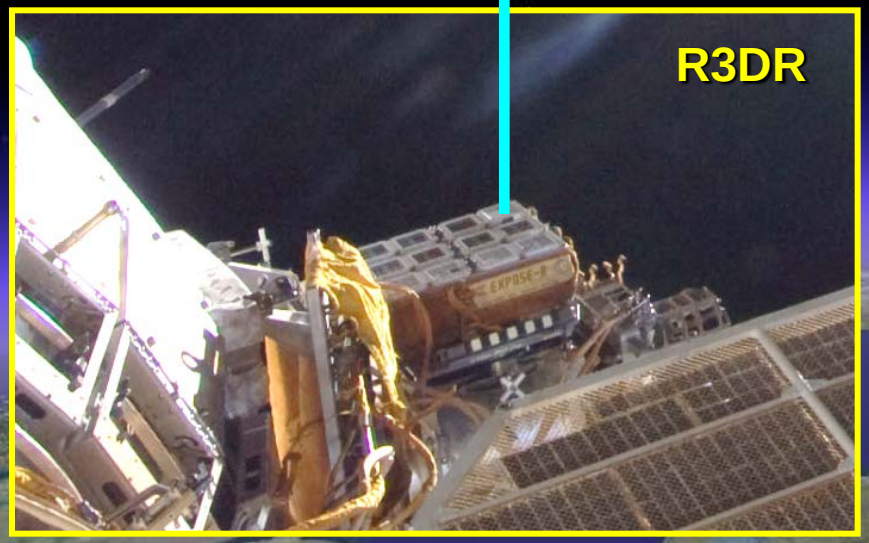
Presentation of the instruments and data obtained

Location and orientation of the R3DE instrument



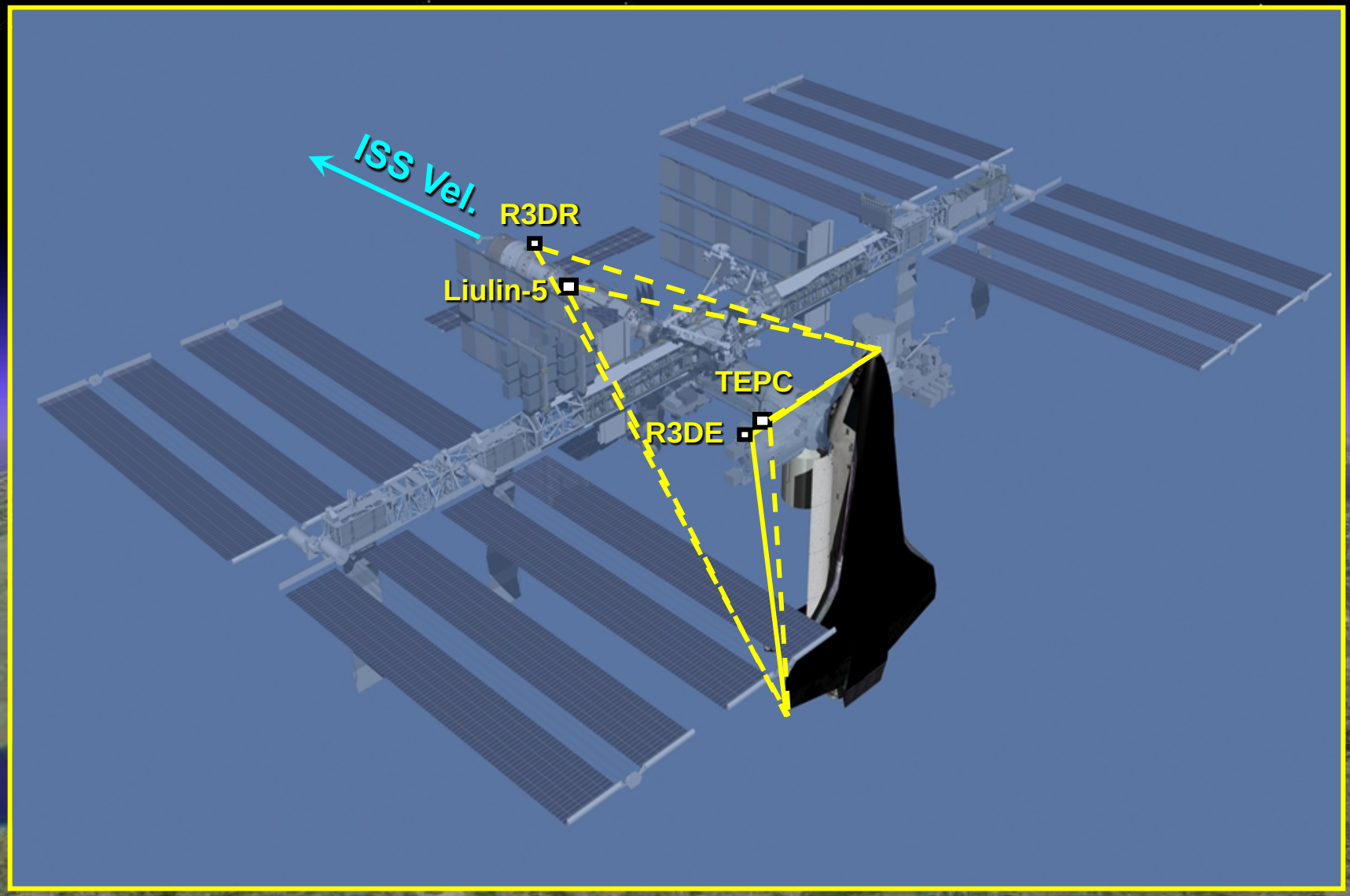
Location and orientation of the R3DR instrument

Comparison of the R3DE and R3DR positions



- Both instruments are in same way shielded from the EXPOSE-E/R platforms in forward and backward 2π angles;
- R3DR instrument is less shielded by surrounding construction elements than R3DE by EUTeF facility. That is why the R3DR SAA doses are larger than R3DE SAA doses.

Places of all instruments used in the presentation together with the docked Space Shuttle



What kind of particles with which energies can reach the detectors of the R3DE/R instruments?

The detectors of R3DE/R instruments are shielded by less than 0.4 g/cm^2 material including: 1 mm aluminum + 0.1 mm cuprum +0.2 mm plastic.

This allows direct hits on the detector by electrons with energies larger than 0.78, MeV and protons with energies larger than 15.8 MeV

Classification of the EVA

WHO?

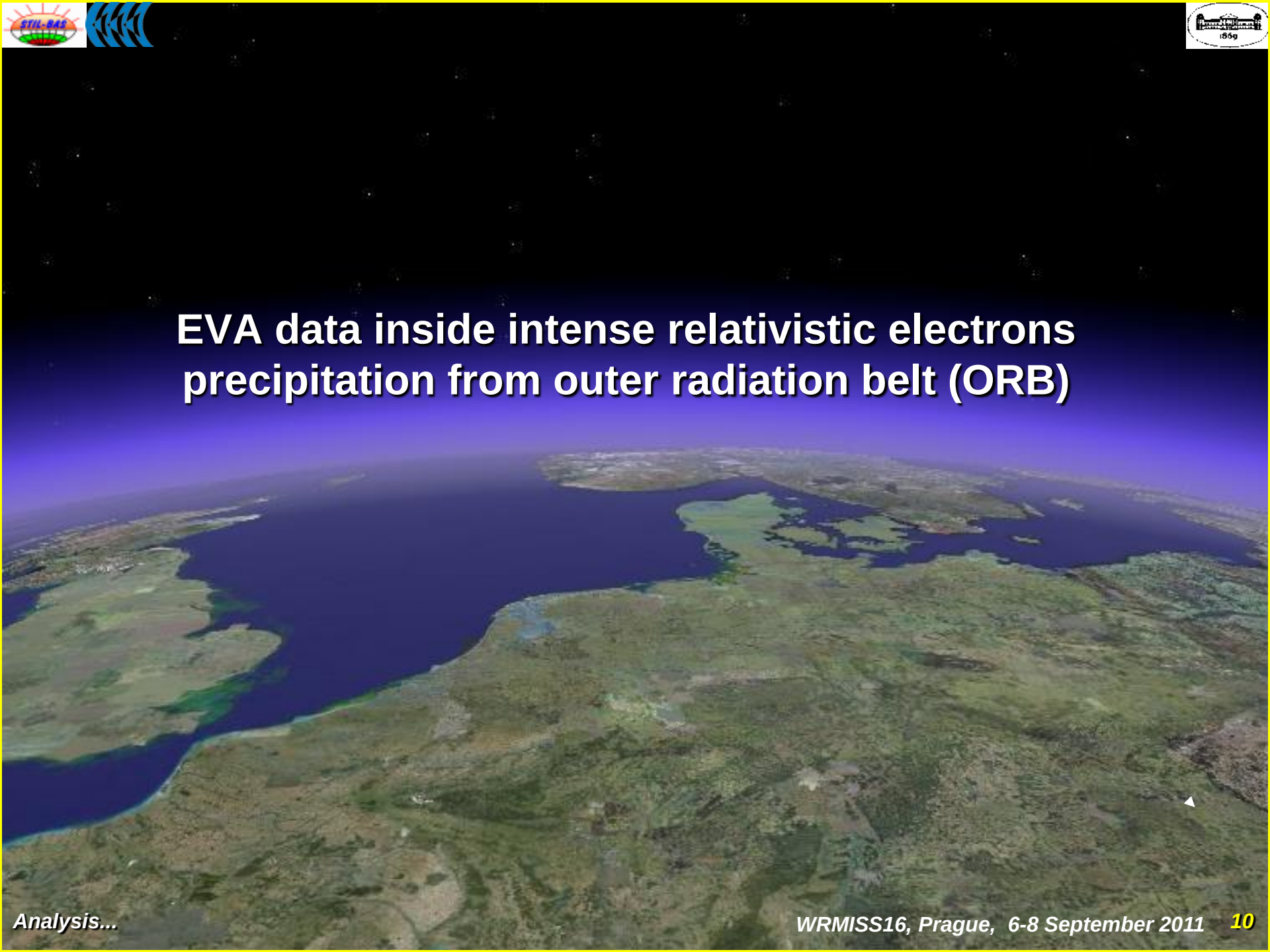
- EVA performed by the ISS crew for maintenance of the station;
- EVA performed by the Space Shuttle crew for building of the ISS;

WHEN?

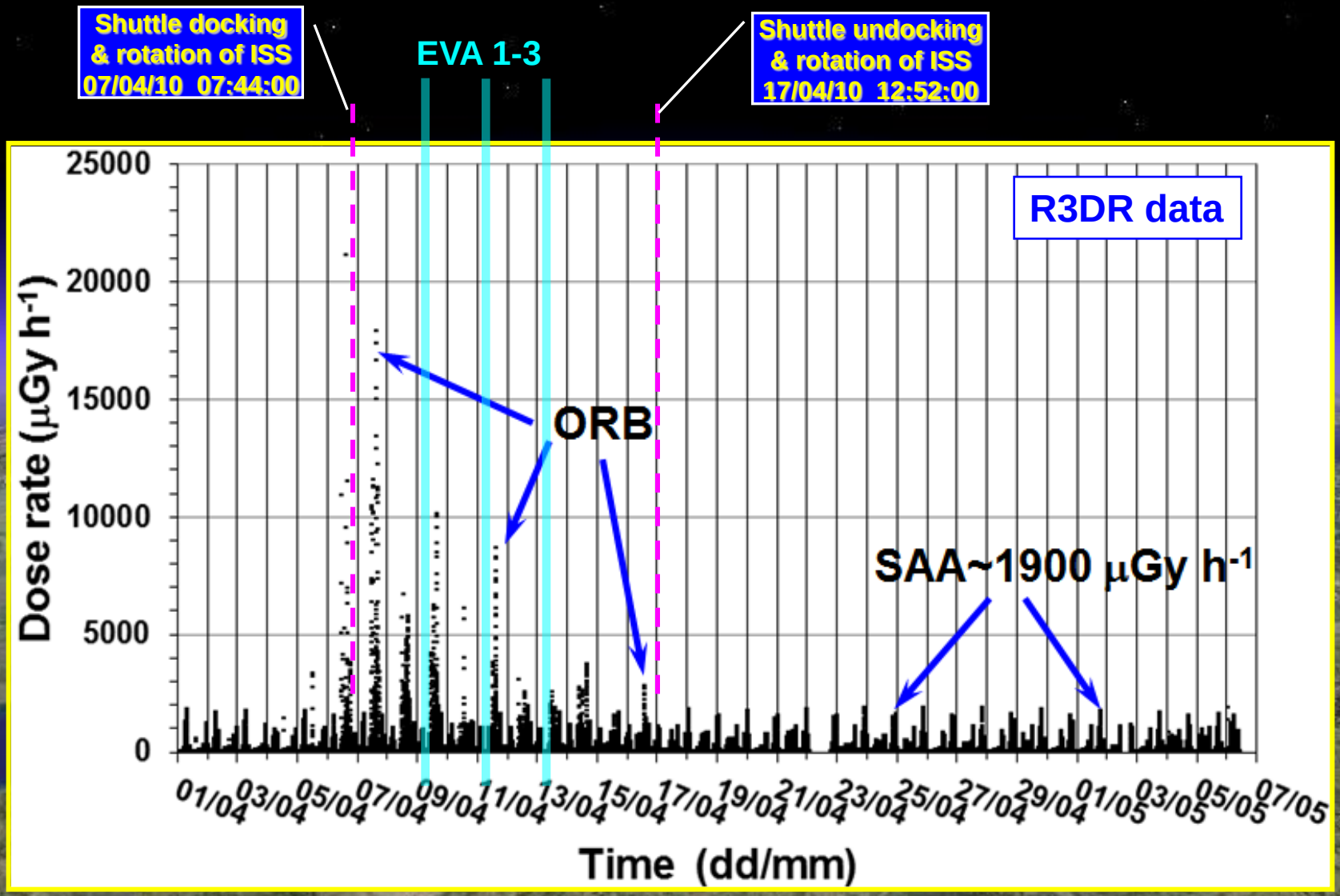
- EVA performed during quite geomagnetic conditions;
- EVA performed during solar proton events and during/after outer radiation belt enhancements in presence of relativistic electrons;

WHERE?

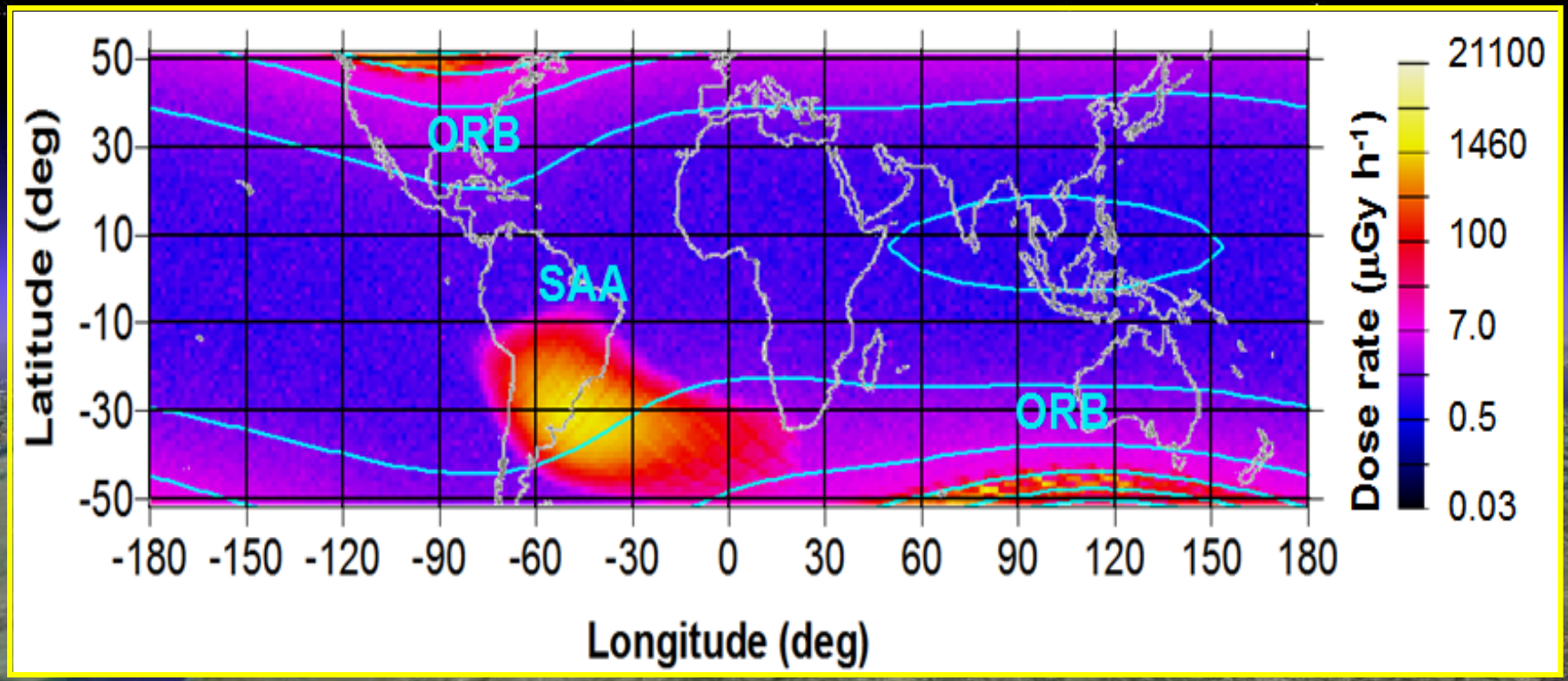
- EVA paths not crossing the SAA region;
- EVA paths crossing the SAA region;


EVA data inside intense relativistic electrons
precipitation from outer radiation belt (ORB)

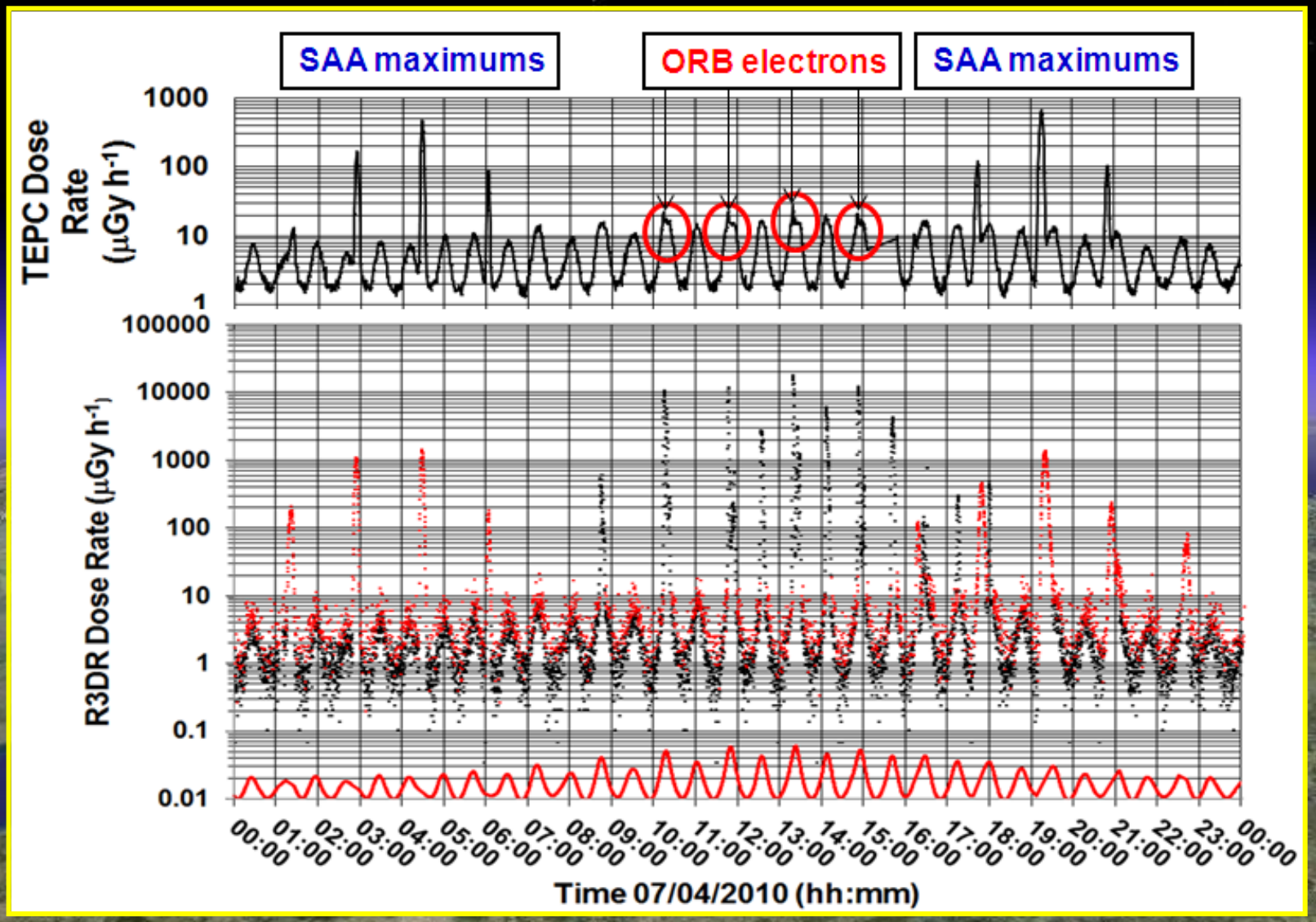
Time dependent presentation of the data between April 1st and May 7th 2010. The ordinate is specially choose to be linear to emphasize the real dynamic of the "killer electrons" dose rates



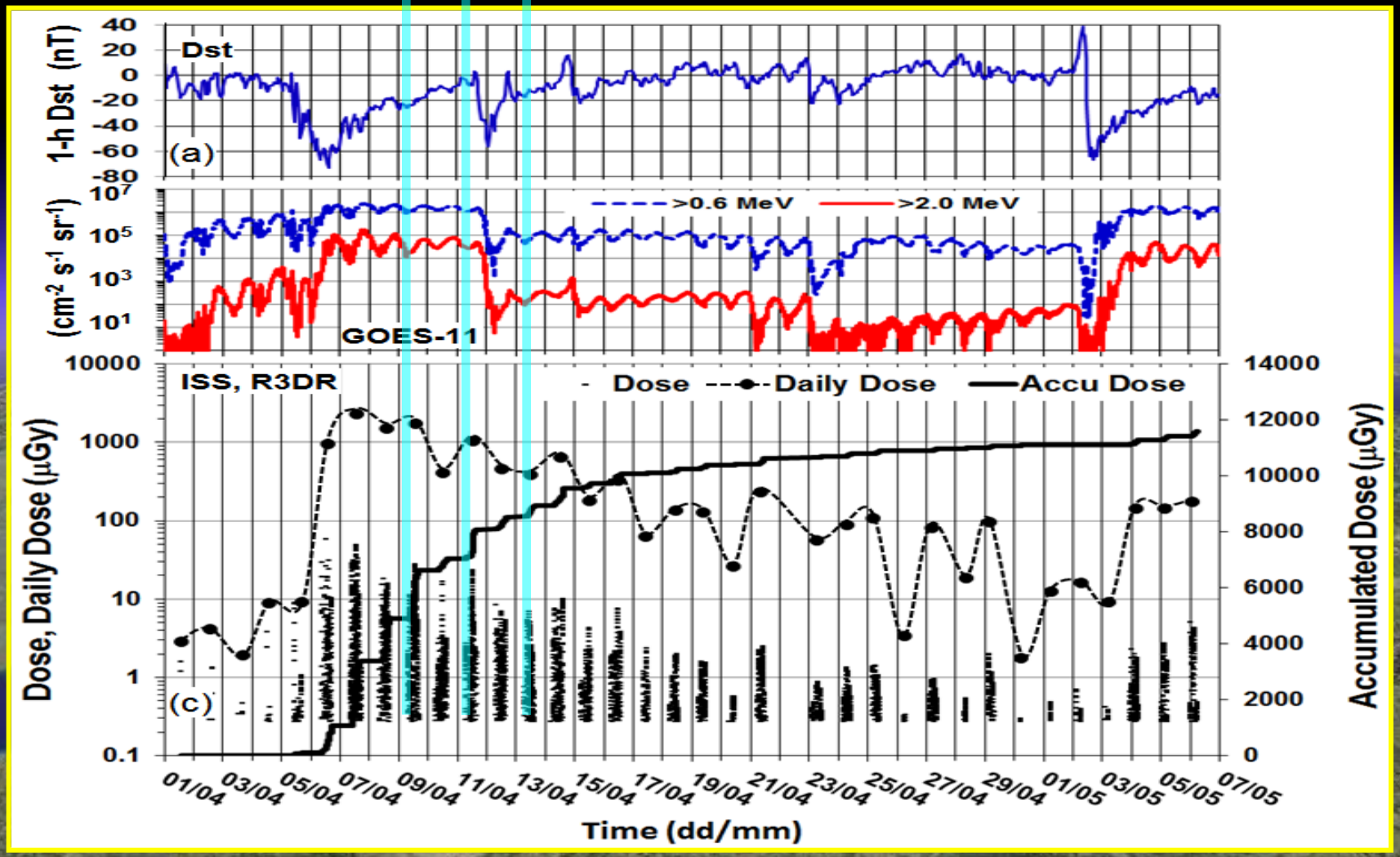
3D geographic distribution of the dose rate data. The white (white blue) curves represent equal L-parameter values. South and North ORB regions are situated at 4.5<L<3.5



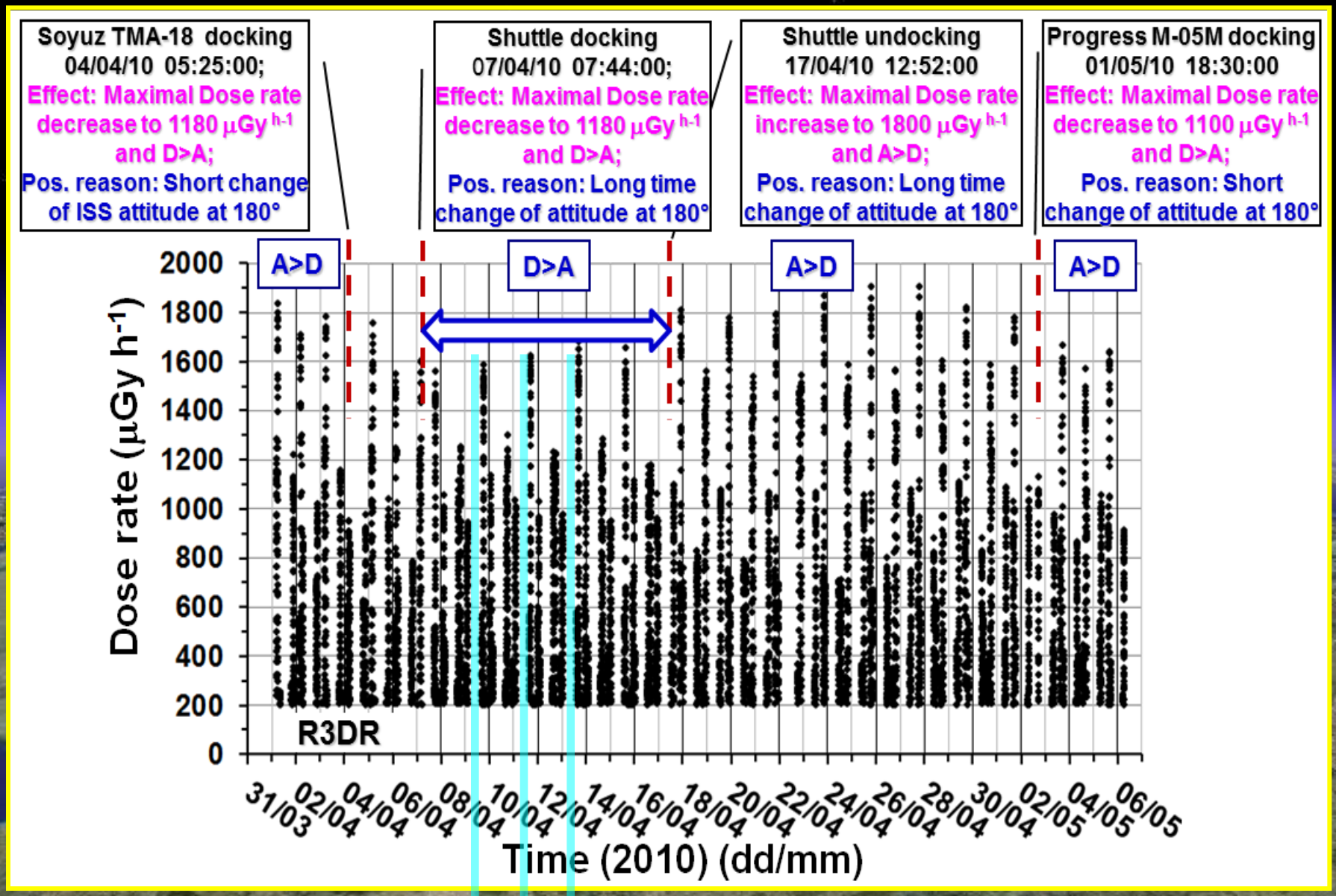
Comparison of the data between R3DR and TEPC for 7th of April 2010 data (Zapp, 2011) http://cdaweb.gsfc.nasa.gov/



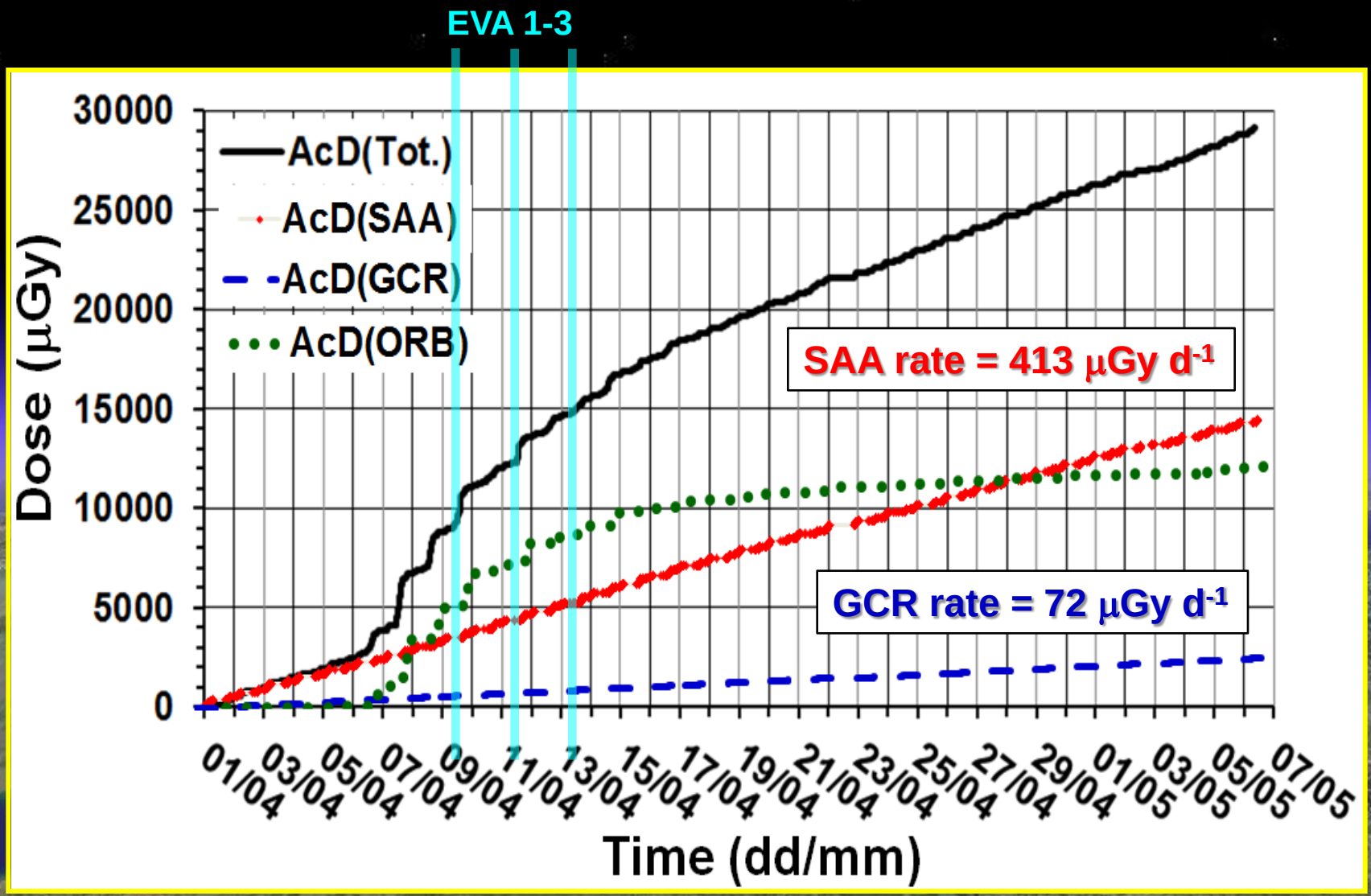
Combined plot of R3DR data ((c) panel) with GOES-11 energetic electrons more than 0.6 and 2.0 MeV ((b) panel) and Dst variations ((a) panel) for the period 01/04/2010-07/05/2010



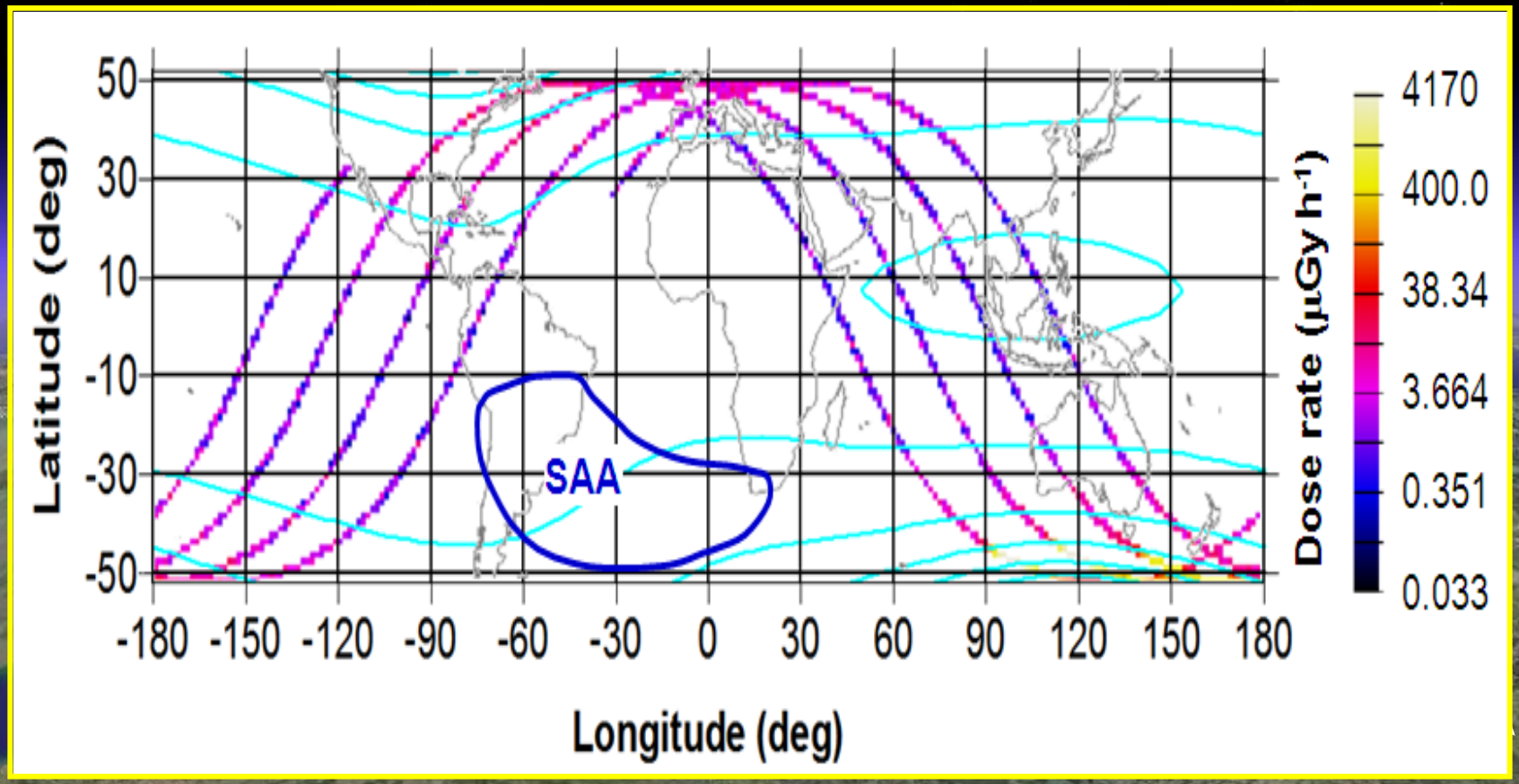
The measures by R3DR SAA dose rates indicate well each attitude and configuration change of ISS



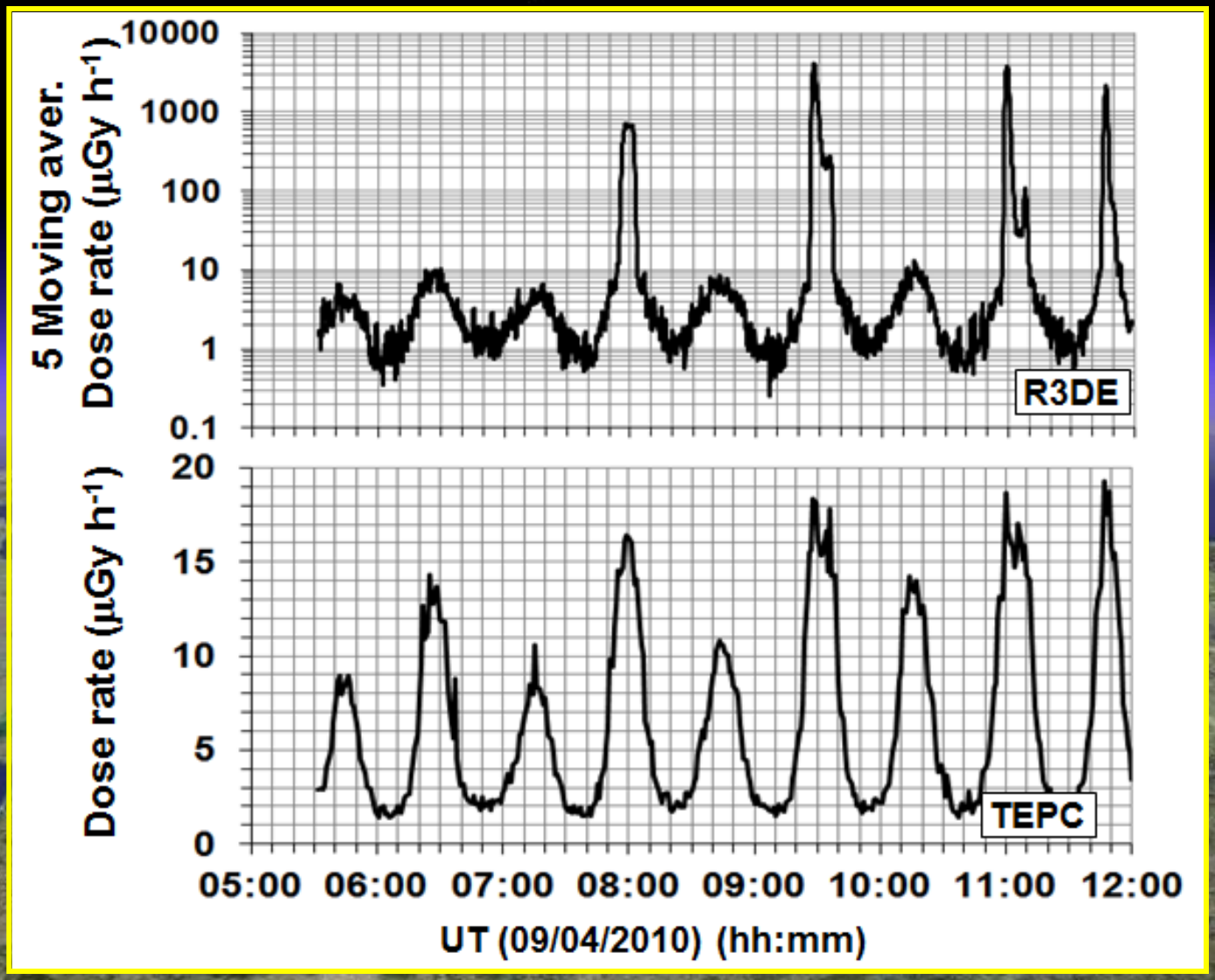
Accumulation of different dose sources in the period 1 April-7 May 2010



Color coded dose rates along the trajectory of the ISS during the first EVA on 9th of April 2010. It is seen that the carefully choose time of the EVA avoid SAA crossings. Highest dose rates are seen in the longitudinal range 90-150° in Sothern Hemisphere



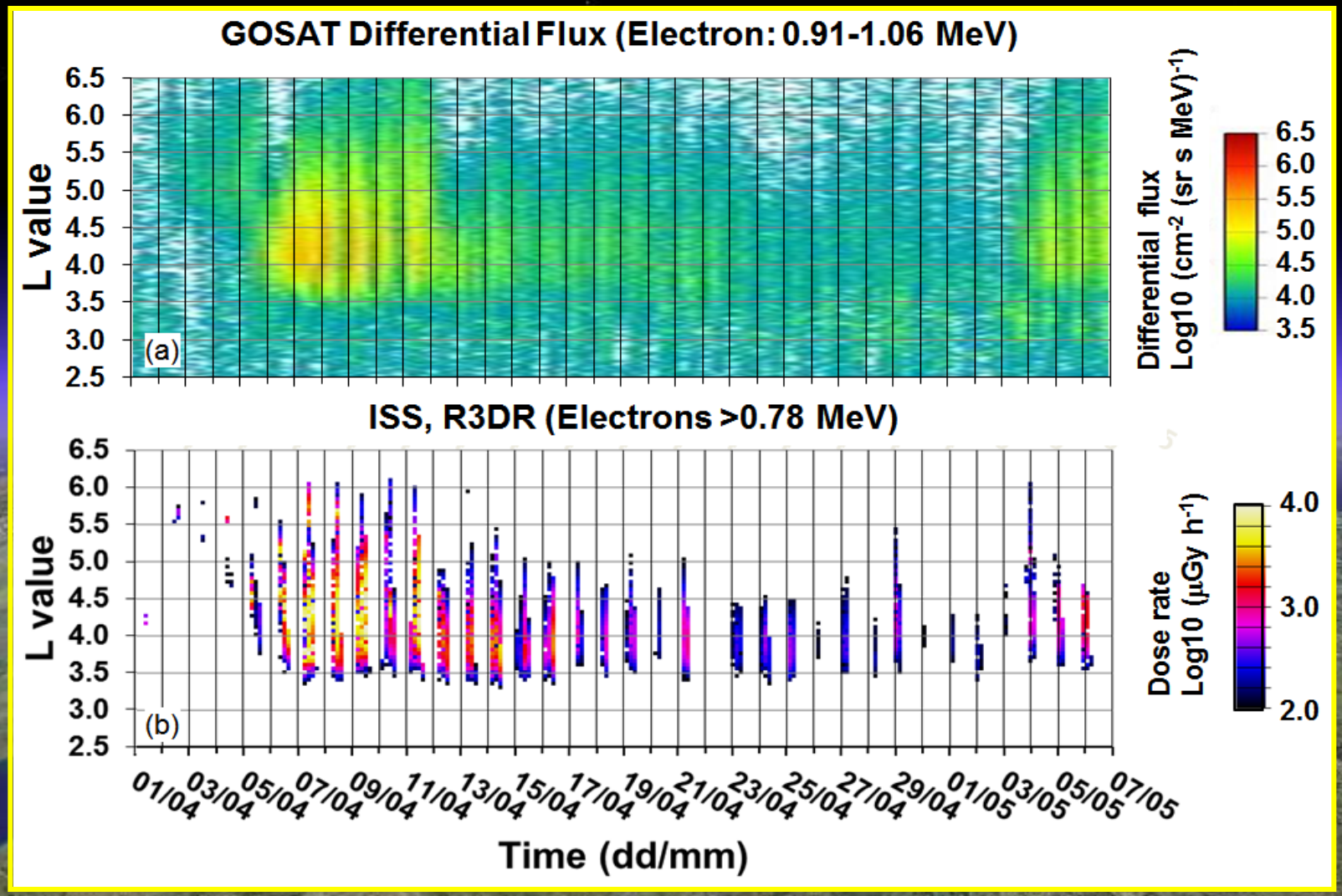
The dose rate dynamics observed by R3DR and TEPC instruments during EVA1 of Expedition 18 on April 9, 2010 between 05:31 and 11:58 for 6 h and 27 m



The R3DR additional dose data for the NASA astronauts Rick Mastracchio and Clayton Anderson collected during the three EVAs (see Table 1.) is 1067 mGy or an enhancement of 38.6% in comparison with the astronauts inside ISS. The equivalent additional dose according to R3DR data is 1170 mSv or an enhancement of 17.6%

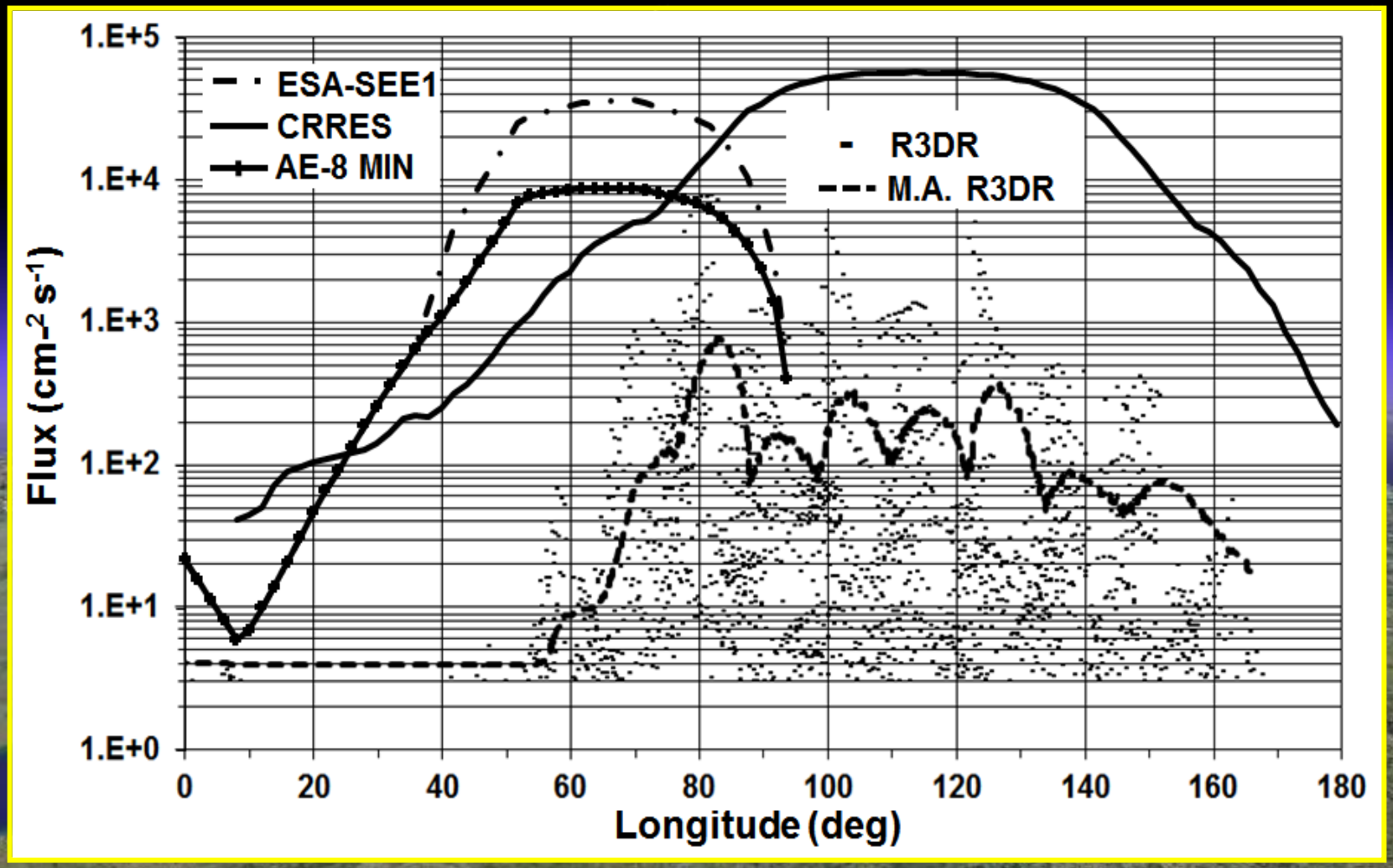
Absorbed doses/Equivalent doses					
R3DR					TEPC (Zapp, 2011)
STS-131 EVA number	UTC from-to	GCR dose μGy/μSv	ORB dose μGy/μSv	Total μGy/μSv	Total = GCR μGy/μSv
EVA-1 6 h. and 27 m.	09/04/2010 05:31-11:58	17.6/49	443/443	461/492	41/138
EVA-2 7 h. and 26 m.	11/04/2010 05:30-12:56	18.6/53	269/269	288/322	49/163
EVA-3 6 h. and 24 m.	13/04/2010 06:14-12:36	18.1/56	299/299	318/355	45/144
Total 20 h. and 27m.		54.3/158.4	1012/1012	1067/1170	135/445

Comparison of the R3DR dose rate data with the GOSAT 0.91-1.06 MeV relativistic electrons data* for the period 01/04/-07/05/2010

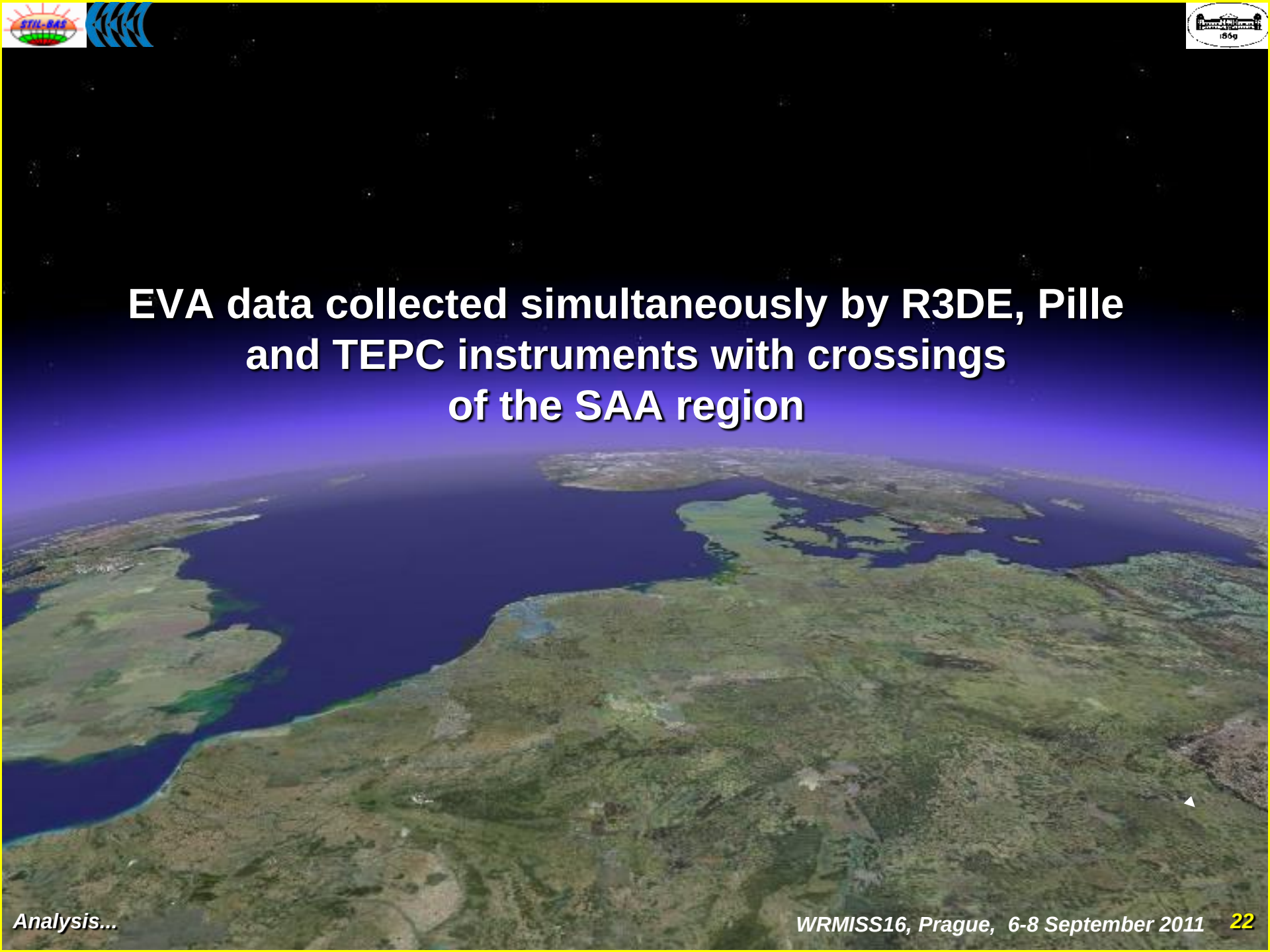


*Obara, T., Space Environment Measurements by JAXA Satellites and ISS, 7th European Space Weather Week, 15-19 November, 2010 - Brugge, Belgium, 2010. http://www.sidc.be/esww7/presentations/2.5.ppt

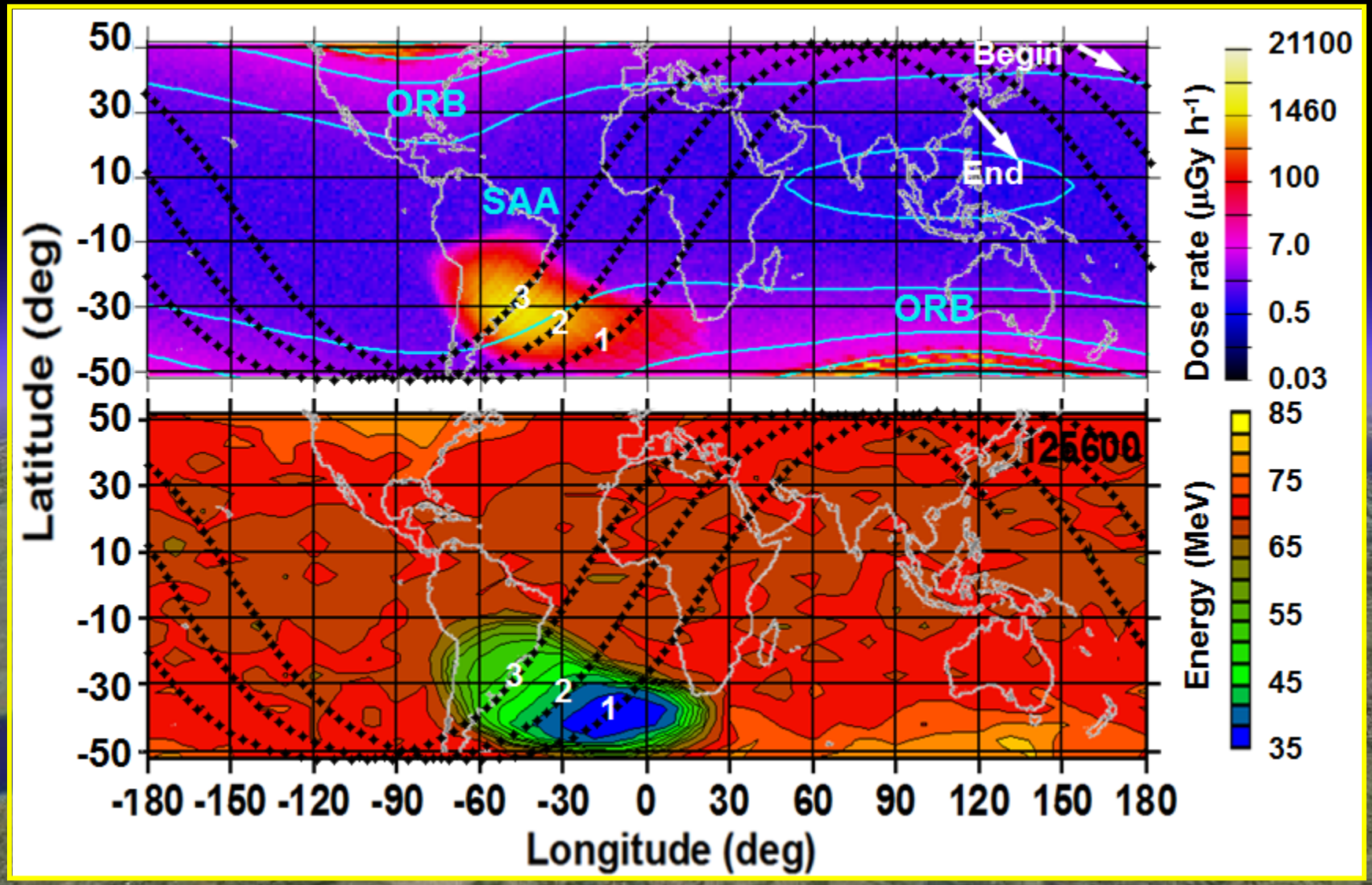
Comparison of the R3DR data with the AE-8 MIN, ESA-SEE1 and CRRES/ELE models* on the longitudinal profile at 48°S latitude



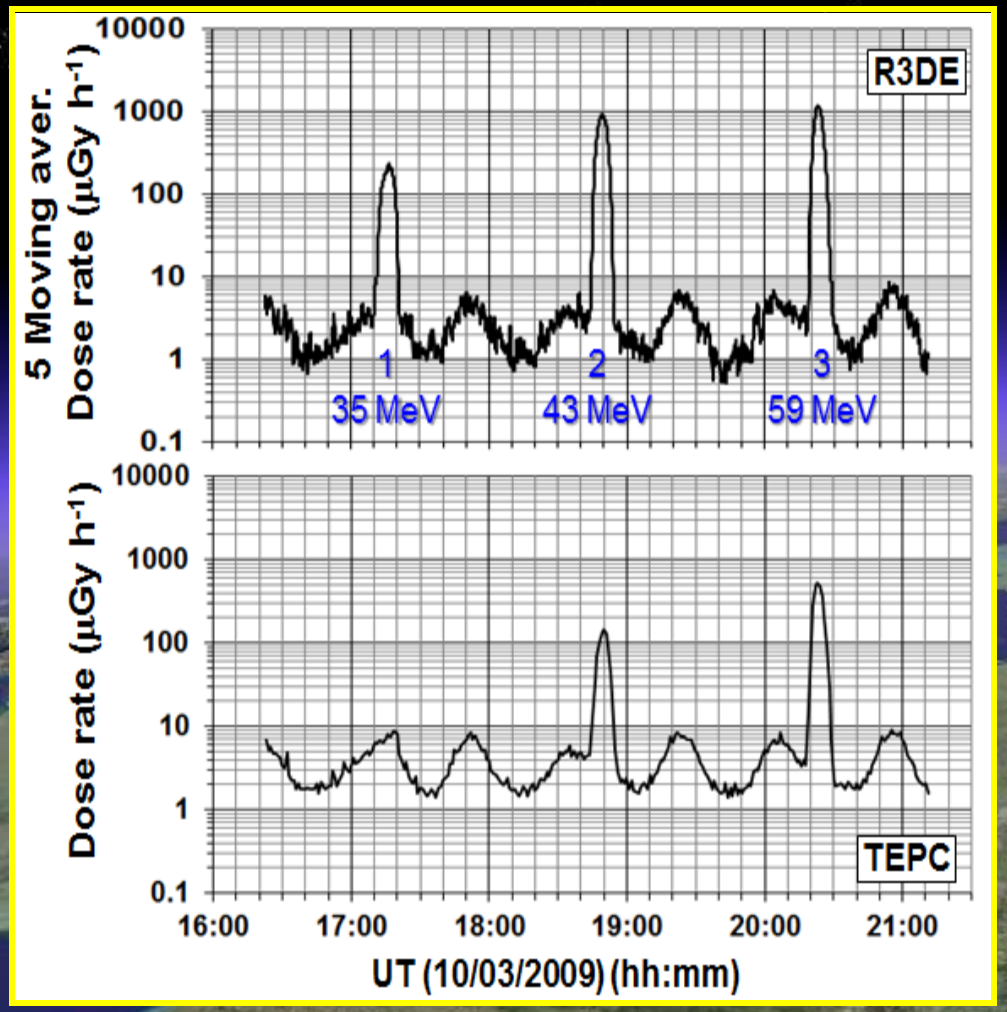
*(http://www.spenvis.oma.be/)


EVA data collected simultaneously by R3DE, Pille
and TEPC instruments with crossings
of the SAA region

The orbit path during EVA 2 of Expedition 18 on March 10, 2009 between 16:22 and 21:11 for 4 h and 49 m (Installation of EXPOSE-R facility)



The dose rate dynamics observed by R3DE, TEPC and Pille instruments during EVA2 of Expedition 18 on March 10, 2009 between 16:22 and 21:11 for 4 h and 49 m



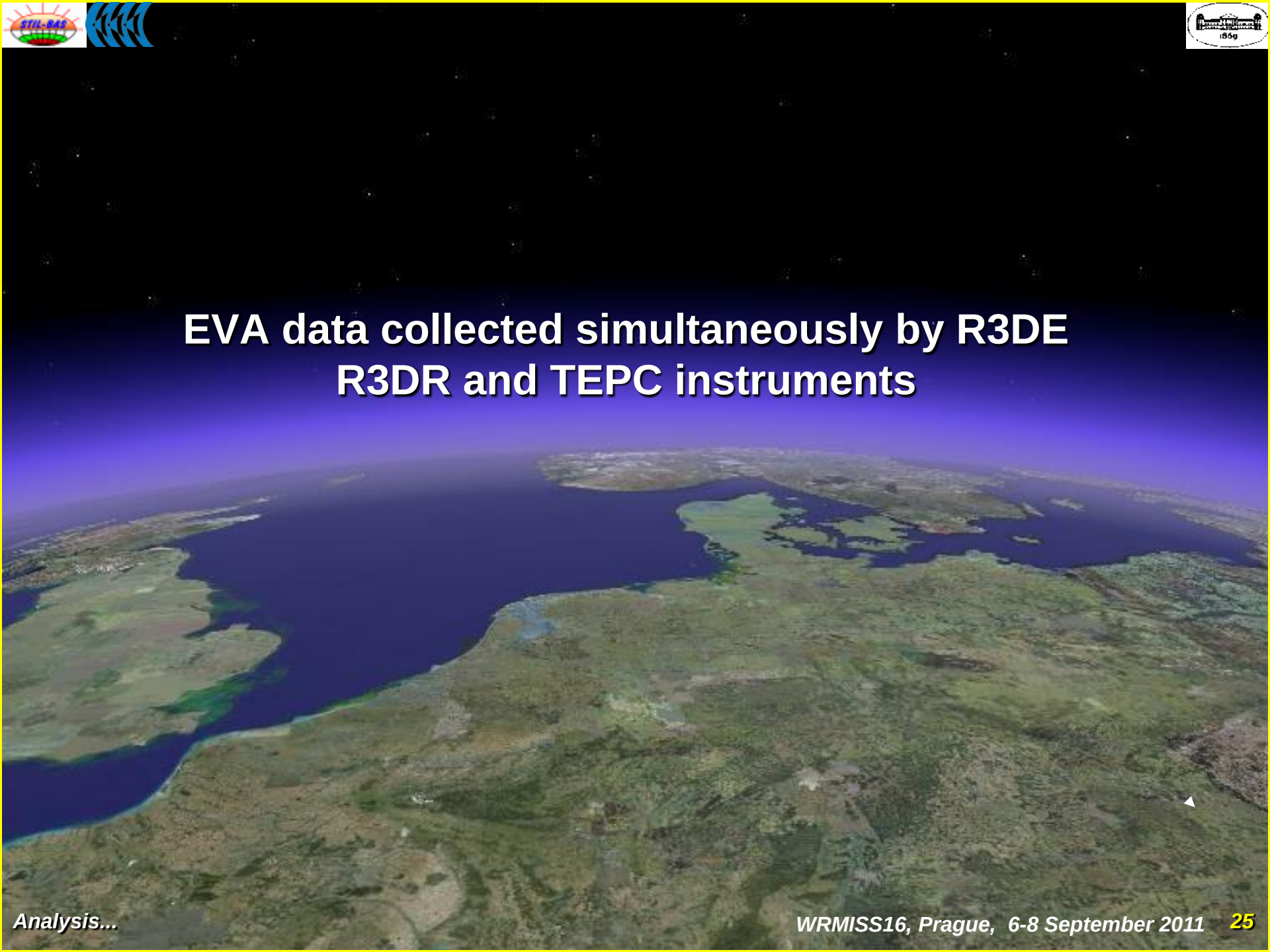
R3DE values:
Total AD/ED dose = 191 μGy/268 μSv
GCR AD/ED dose = 11 μGy/27 μSv
SAA AD/ED dose = 180 μGy/241 μSv

TEPC values:
Total AD/ED dose = 72 μGy/154 μSv
GCR AD/ED dose = 16 μGy/57 μSv
SAA AD/ED dose = 56 μGy/97 μSv

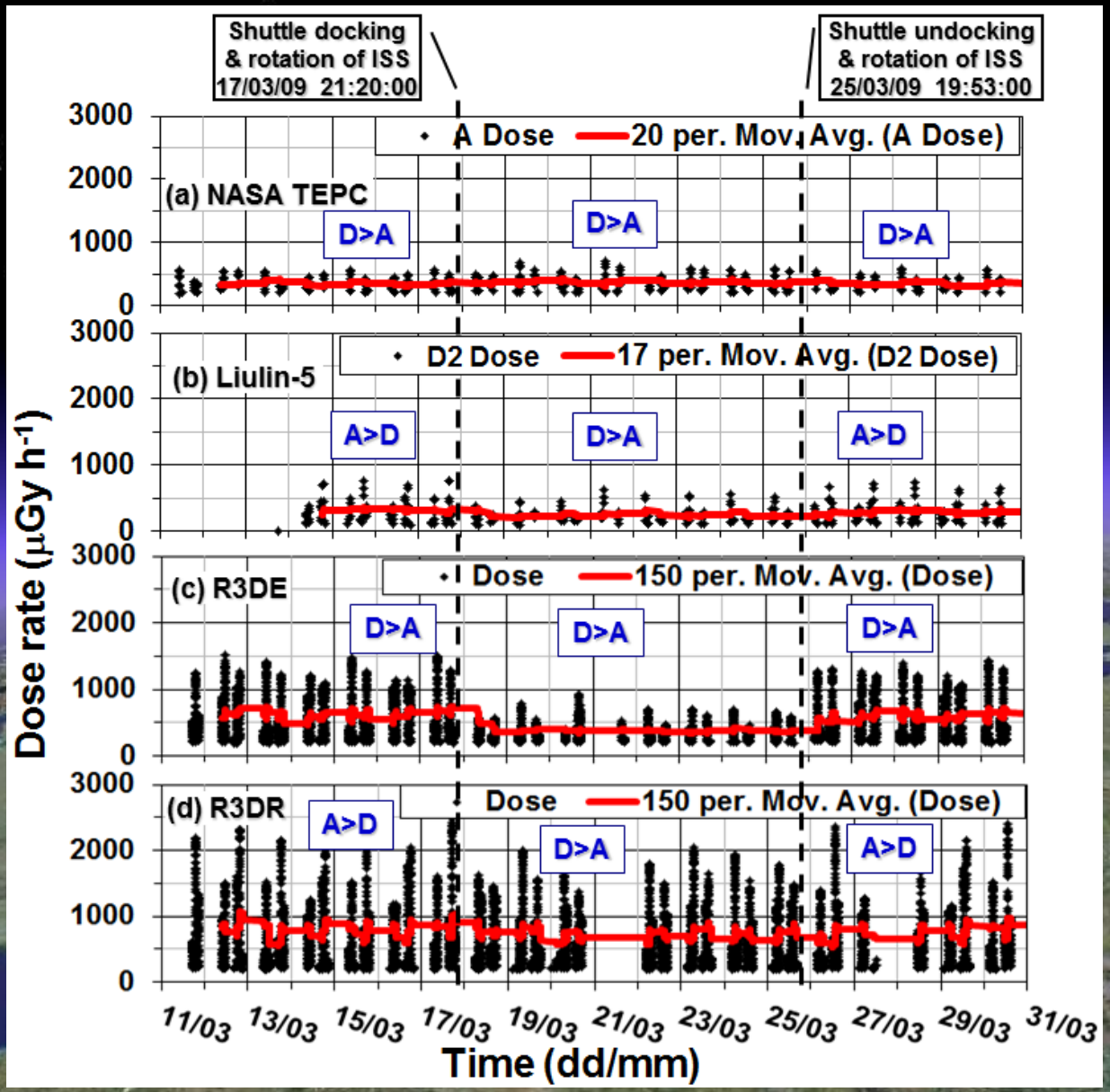
Pille value: 92 μGy first cosmonaut
Pille value: 72 μGy second cosmonaut*

*(Apathy et al., 2010)

Analysis...


EVA data collected simultaneously by R3DE
R3DR and TEPC instruments

Comparison of TEPC*, Liulin-5, R3DE and R3DR data



TEPC being strong shielded don't show dependence in dose rate and asc./desc. amplitude by Shuttle docking

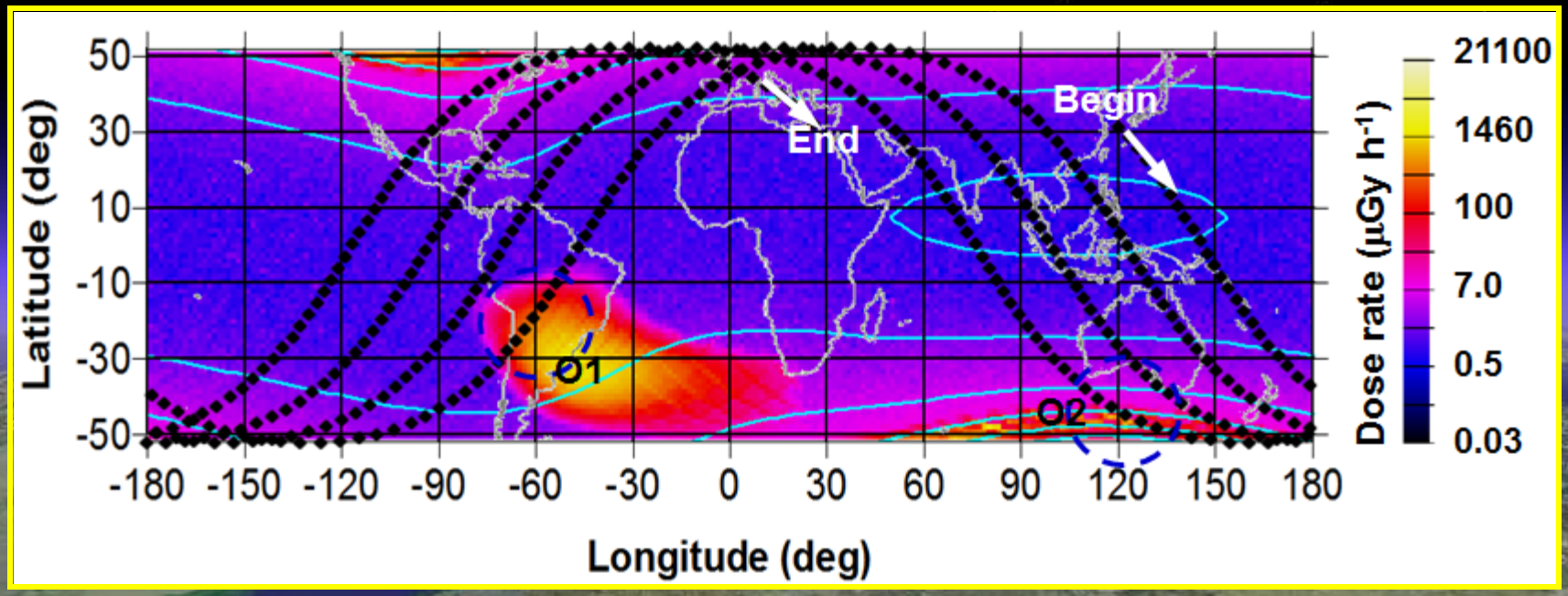
The second detector of Liulin-5 being in Pirs module show relative small dependence by Shuttle docking

R3DE being closer to shuttle respect larger dose rate decrease than R3DE

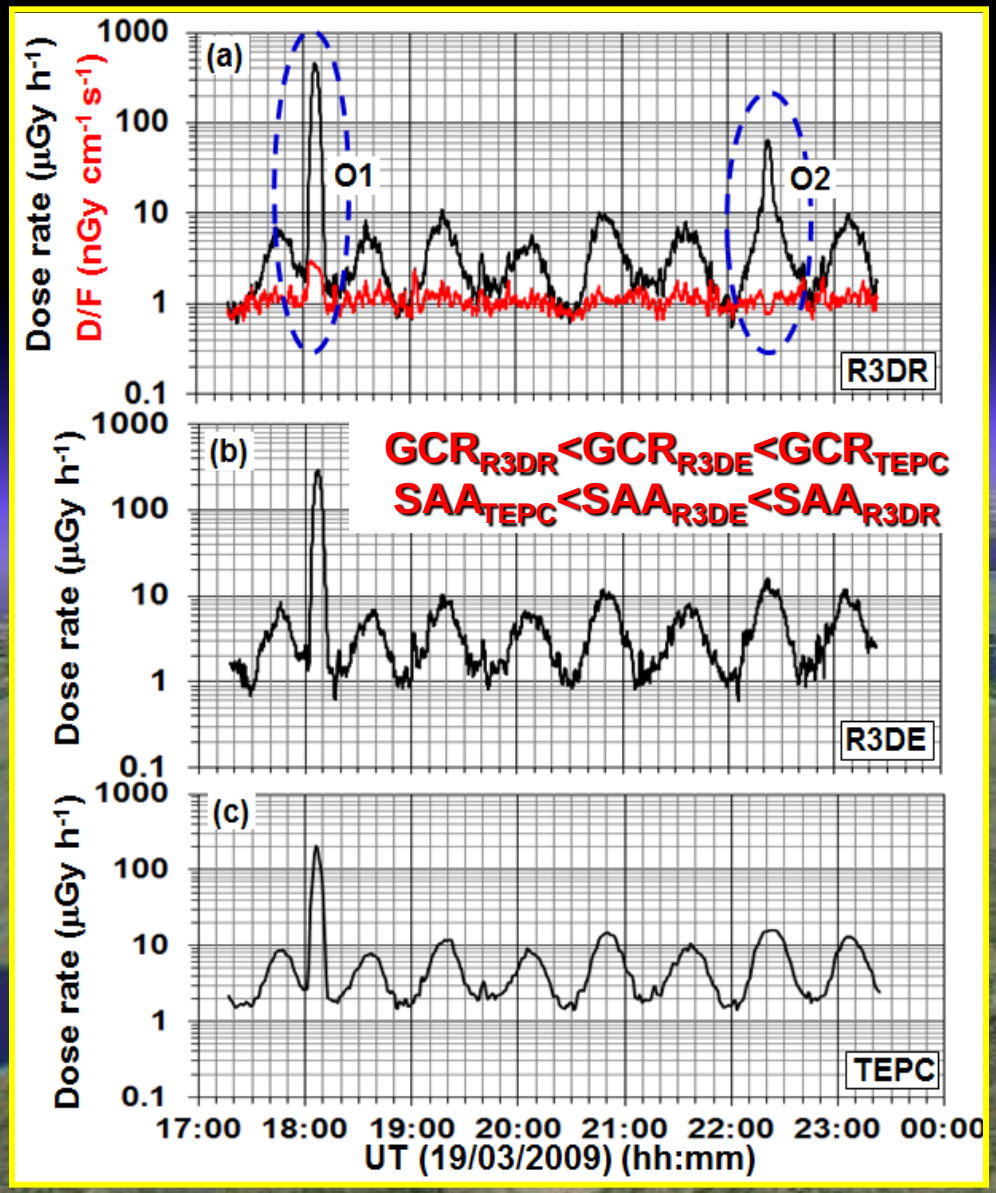
Absolute values of R3DR dose rates is larger than R3DE values because it is less shielded

*Zapp, (http://cdaweb.gsfc.nasa.gov/), July, 2011.

The orbit path during EVA 1 of STS-119 on March 19, 2009 between 17:16 and 23:23 for 6 h and 7 m



The dose rate dynamics observed by R3DR, R3DE and TEPC instruments during EVA 1 of STS-119 on March 19, 2009 between 17:16 and 23:23 for 6 h and 7 m



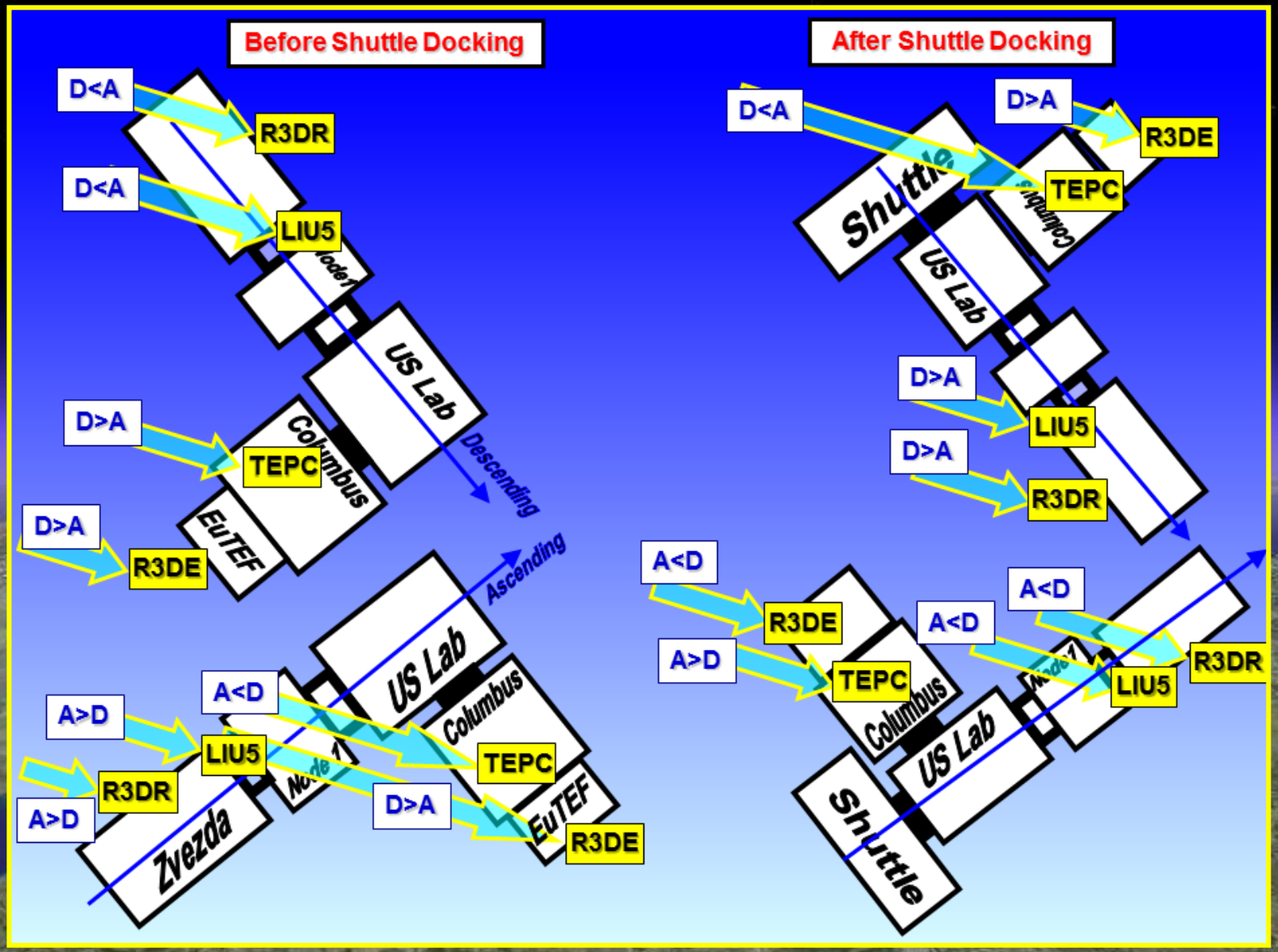
R3DR values:
Total Abs. dose = 57 μGy
GCR Abs. dose = 18.6 μGy
SAA Abs. dose = 32 μGy
ORB Abs. dose = 5.2 μGy

R3DE values:
Total Abs. dose = 45 μGy
GCR Abs. dose = 22 μGy
SAA Abs. dose = 23 μGy
ORB Abs. dose = 0 μGy

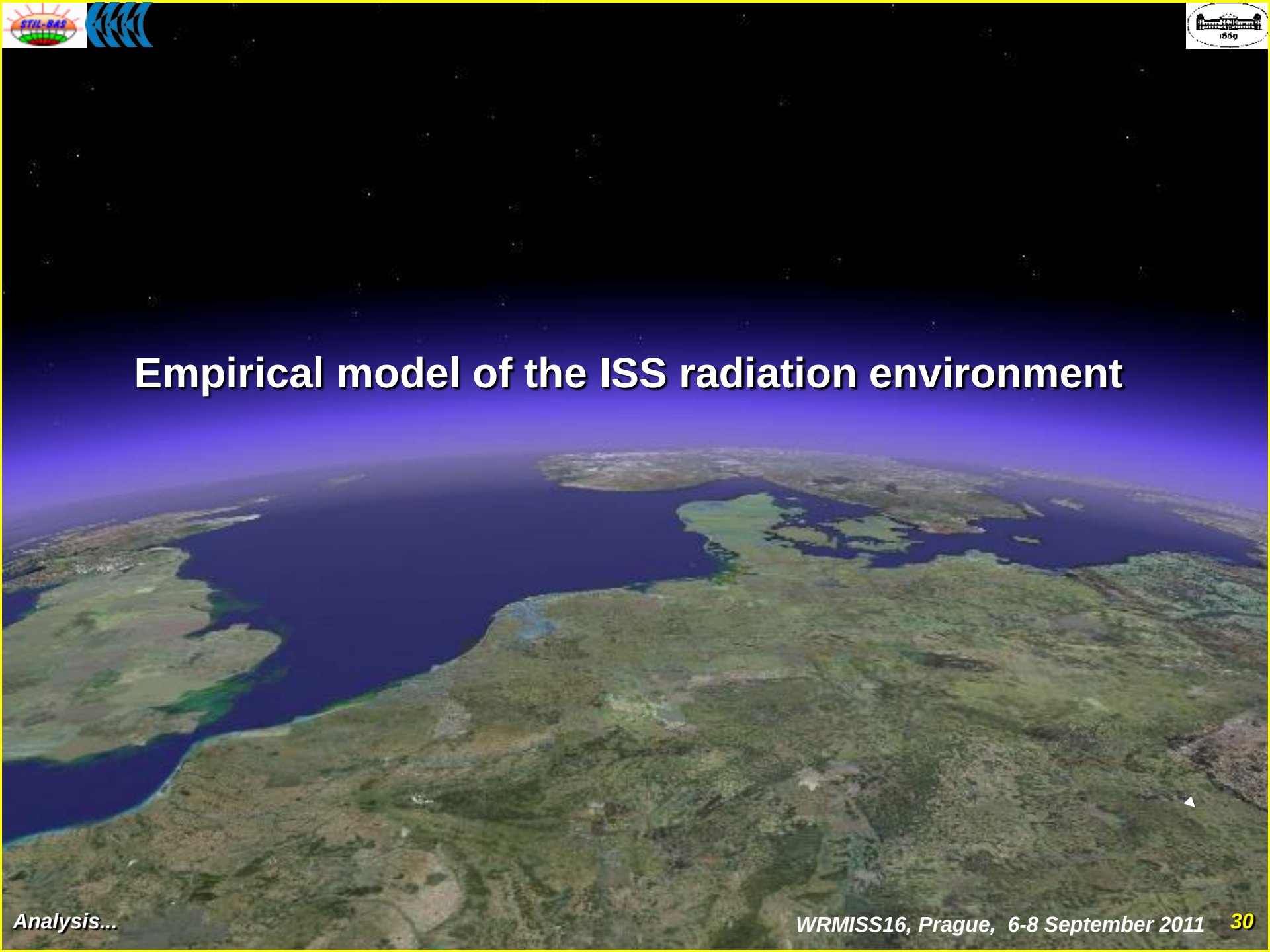
TEPC values:
Total AD/ED dose = 47 μGy/142 μSv
GCR AD/ED dose = 31 μGy/114 μSv
SAA AD/ED dose = 16 μGy/28 μSv
ORB AD/ED dose = 0 μGy/0 μSv

Analysis...

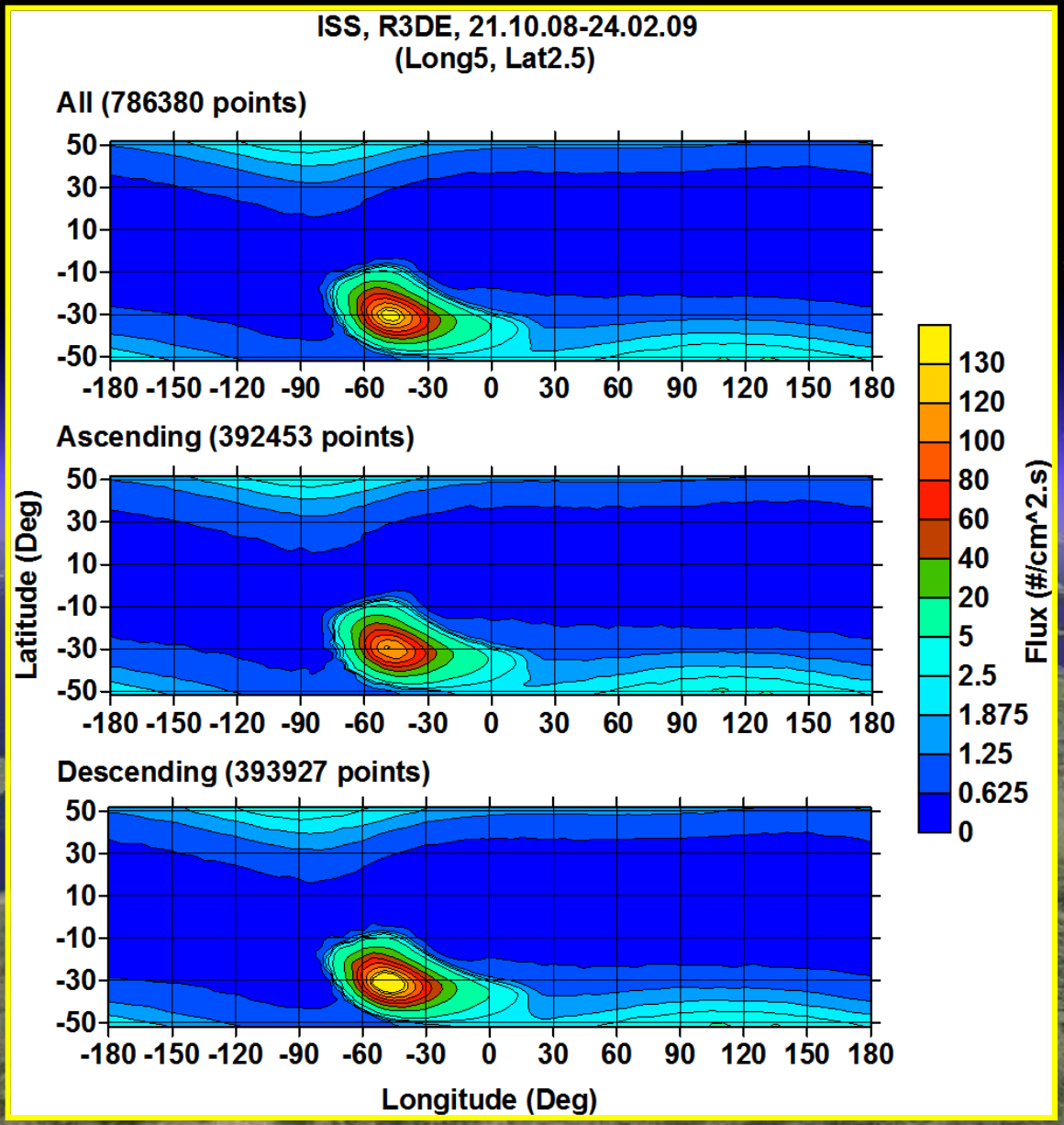
Explanation of the R3DE and TEPC ascending/descending doses with predominant East/Down drift of protons in SAA



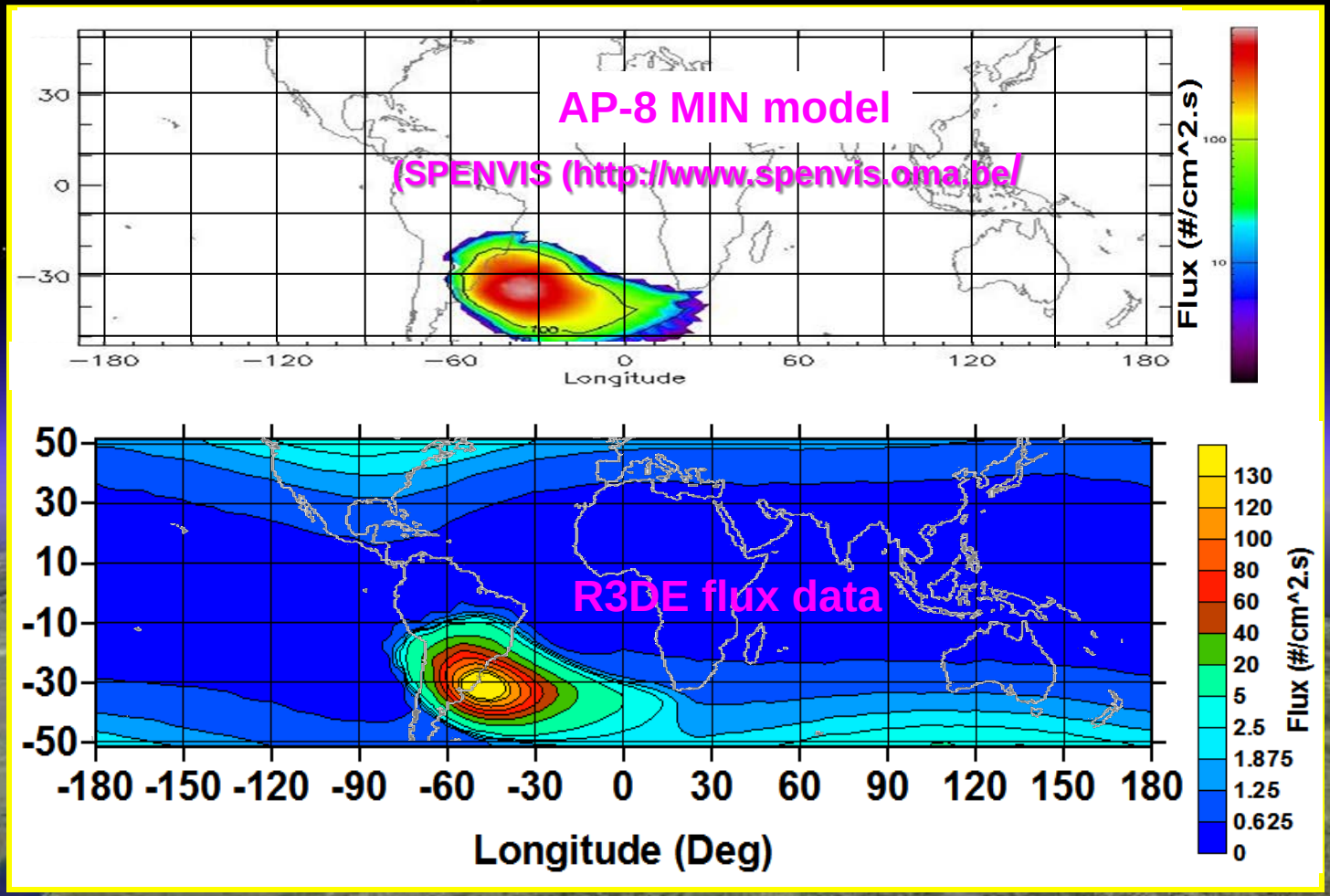
Empirical model of the ISS radiation environment



R3DE flux data



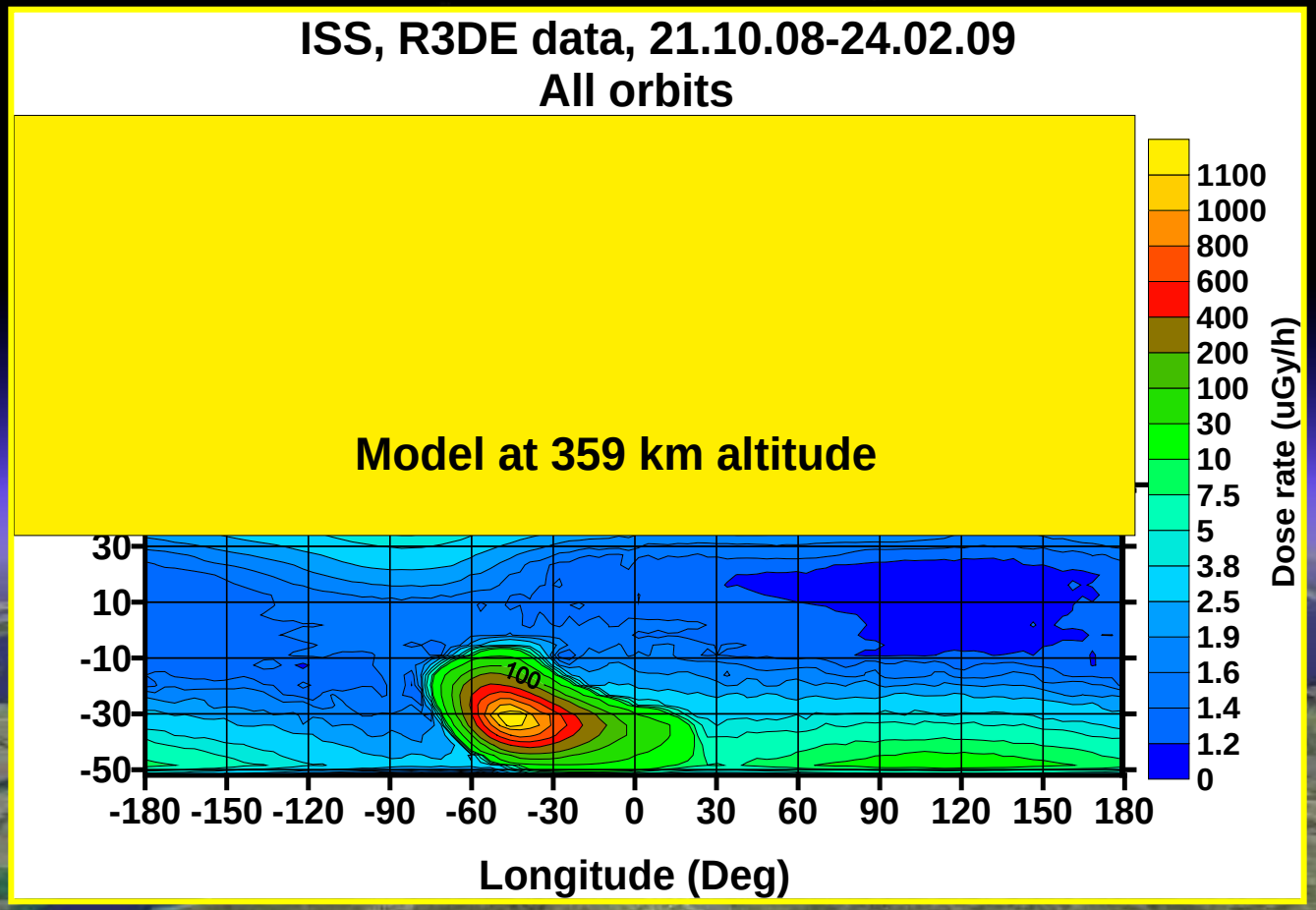
Comparison between R3DE flux data and AP-8 MIN model* (359 km, >15.8 MeV protons)



The coordinates of SAA flux central location are at -50° west longitude -30° south latitude. These values are in comparison with AP-8 MIN model (Vette, 1991) epoch 1970 moved with -12° (0.3° per year) to the west and with 2° (0.05° per year) to the north.

*(http://www.spenvis.oma.be/)

Comparison between measured data and preliminary version of model for prediction the doses developed by N. Bankov



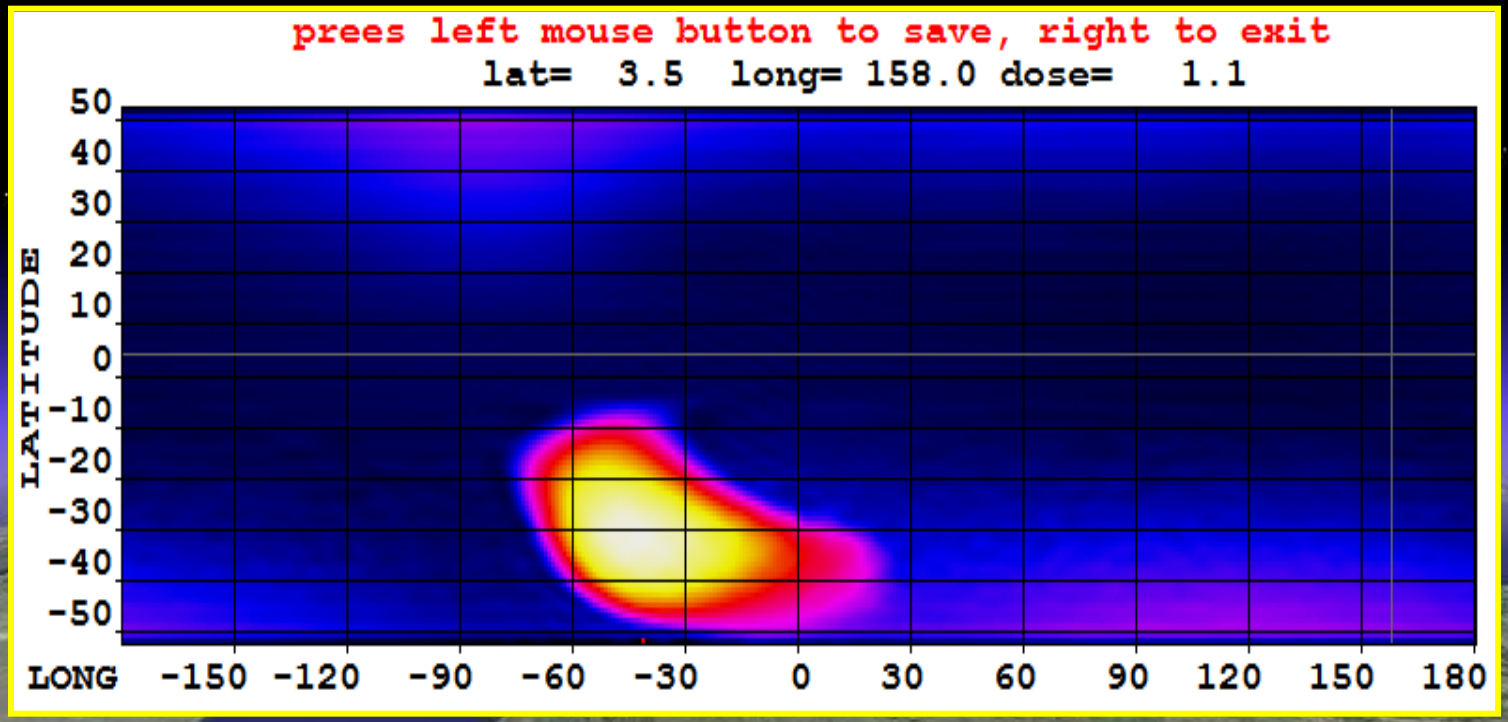
Model values were obtained by approximating dose data [11.07.08-31.12.08] by:

$$f(r,\theta,\varphi)_{r=r_0} = f_0(\theta,\varphi) = \sum_{n=0}^{90}\sum_{m=0}^{n}(A_{nm}\cos m\varphi + B_{nm}\sin m\varphi)P_{nm}(\cos\theta),$$

where A_{nm}, B_{nm} are Fourier coefficients and $P_{nm}(\cos\theta)$ associated Legendre polynomials

Point Dose rate [μGy/h] model at ISS 359 km altitude

http://www.stil.bas.bg/dwp/R3DE_POINT_model.zip



The model outputs are:

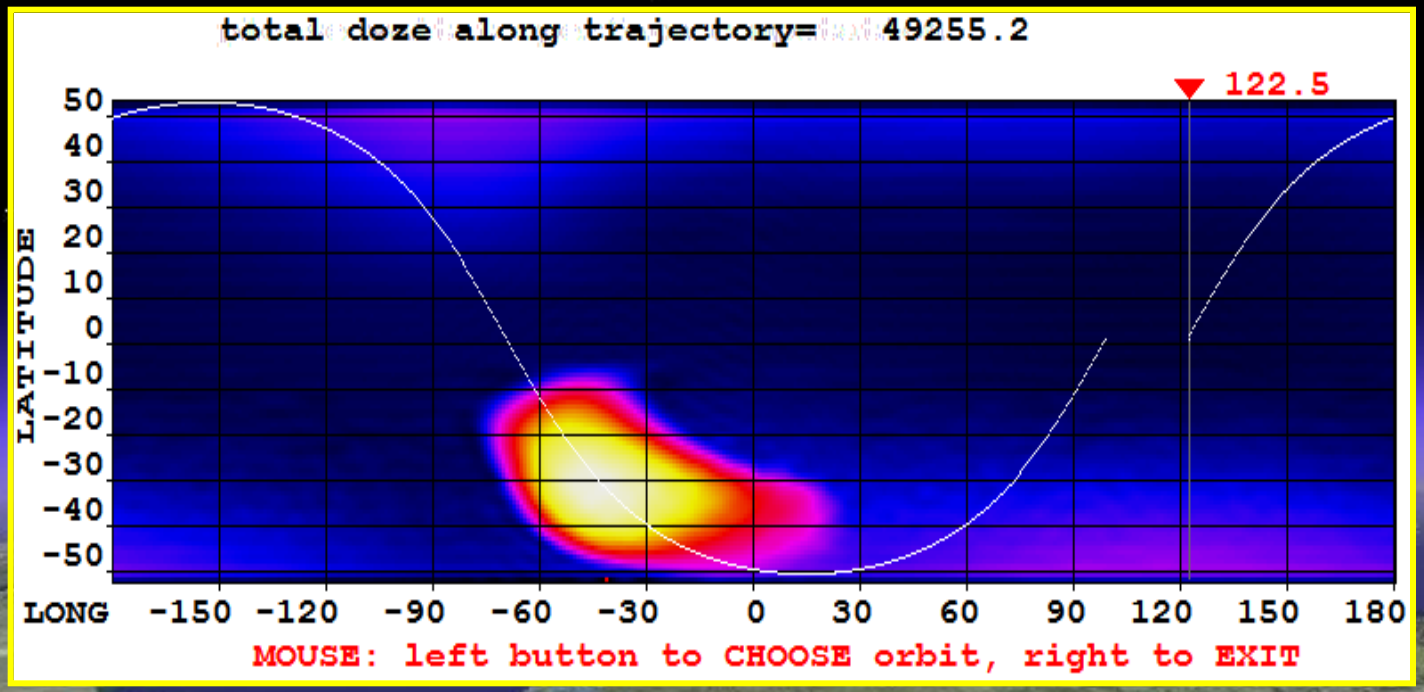
- 1. Seen on the screen with the point dose rate in μGy h^{-1};

If you use the model please reference:

Bankov, N., T. Dachev, B. Tomov, Pl. Dimitrov, Yu. Matviichuk, _Simulation model of the radiation dose measured onboard of the ISS, Fundamental Space Research, Suplement of Comptes Rend. Acad. Bulg. Sci., ISBN 987-954-322-409-8, 147-149, 2010. http://www.stil.bas.bg/FSR2009/pap144.pdf

Orbital Dose rate [μGy h^{-1}] model at ISS 359 km altitude

http://www.stil.bas.bg/dwp/R3DE_ORBIT_model.zip



The model outputs are:

- 1. Seen on the screen with the total accumulated dose rate in μGy h^{-1};

2. Automatically written in ASCII file in the directory where the model is. The file contain 4 columns: Lat. (deg) ; Long. (deg); Dose rate (μGy h^{-1}); Accum. Dose rate (μGy h^{-1});

3. To be calculated the dose it is necessary to divide the dose rates by 360.

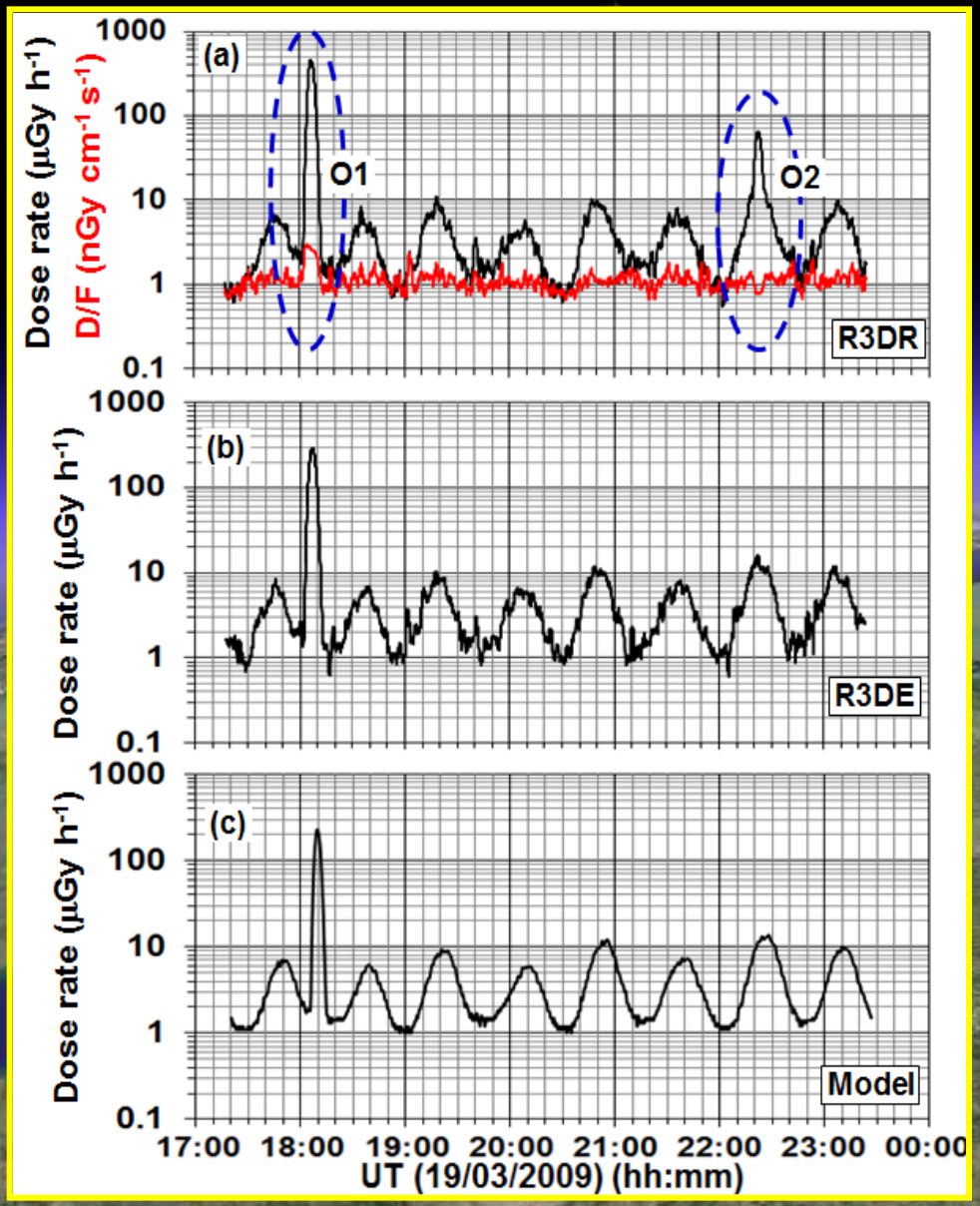
If you use the model please reference:

Bankov, N., T. Dachev, B. Tomov, Pl. Dimitrov, Yu. Matviichuk, _Simulation model of the radiation dose measured onboard of the ISS, Fundamental Space Research, Suplement of Comptes Rend. Acad. Bulg. Sci., ISBN 987-954-322-409-8, 147-149, 2010. http://www.stil.bas.bg/FSR2009/pap144.pdf

Advantages of the Empirical model

- **Recent!** The position of the centrum of the SAA moved from the time of AP-8 MIN model toward Northwest with more than 12°;
- **Free!** Everyone can download and use it;
- **Compact!** Each of the versions is less than 1 MB volume and can be used directly in the users computer without Internet connection;
- **Easy!** All user interface is on the screen with few simple commands;
- **Calculates directly dose rates!** (Most of the other models including AP-8/AE-8 calculated the flux.);
- **Calculates the dose rates from all sources at once.**

Comparison of the measured with the calculated with the model data

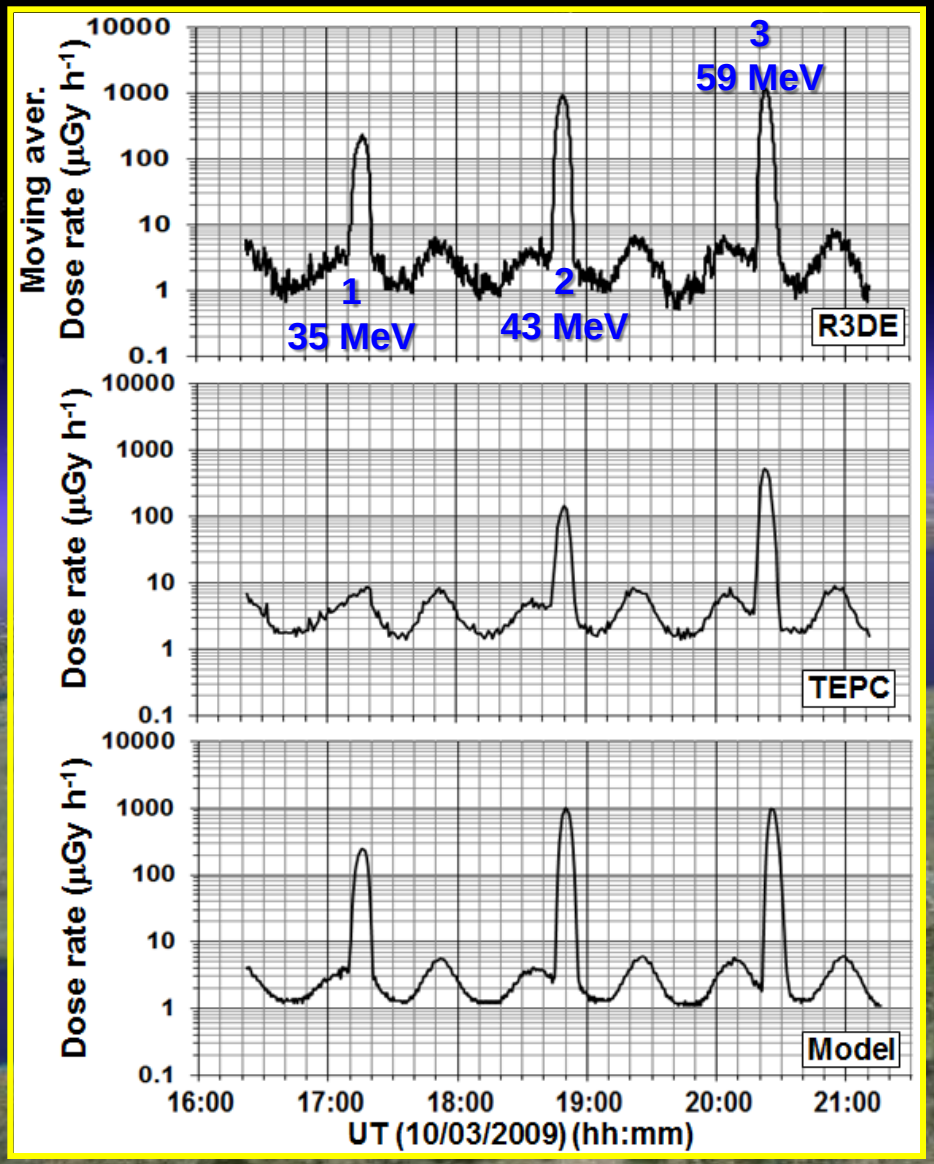


R3DR values:
Total Abs. dose = 57 μGy
GCR Abs. dose = 18.6 μGy
SAA Abs. dose = 32 μGy
ORB Abs. dose = 5.2 μGy

R3DE values:
Total Abs. dose = 45 μGy
GCR Abs. dose = 22 μGy
SAA Abs. dose = 23 μGy
ORB Abs. dose = 0 μGy

Model values:
Total Abs. dose = 37 μGy
GCR Abs. dose = 23 μGy
SAA Abs. dose = 14 μGy
ORB Abs. dose = 0 μGy

The dose rate dynamics observed by R3DE, TEPC and Pille instruments during EVA2 of Expedition 18 on March 10, 2009 between 16:22 and 21:11 for 4 h and 49 m



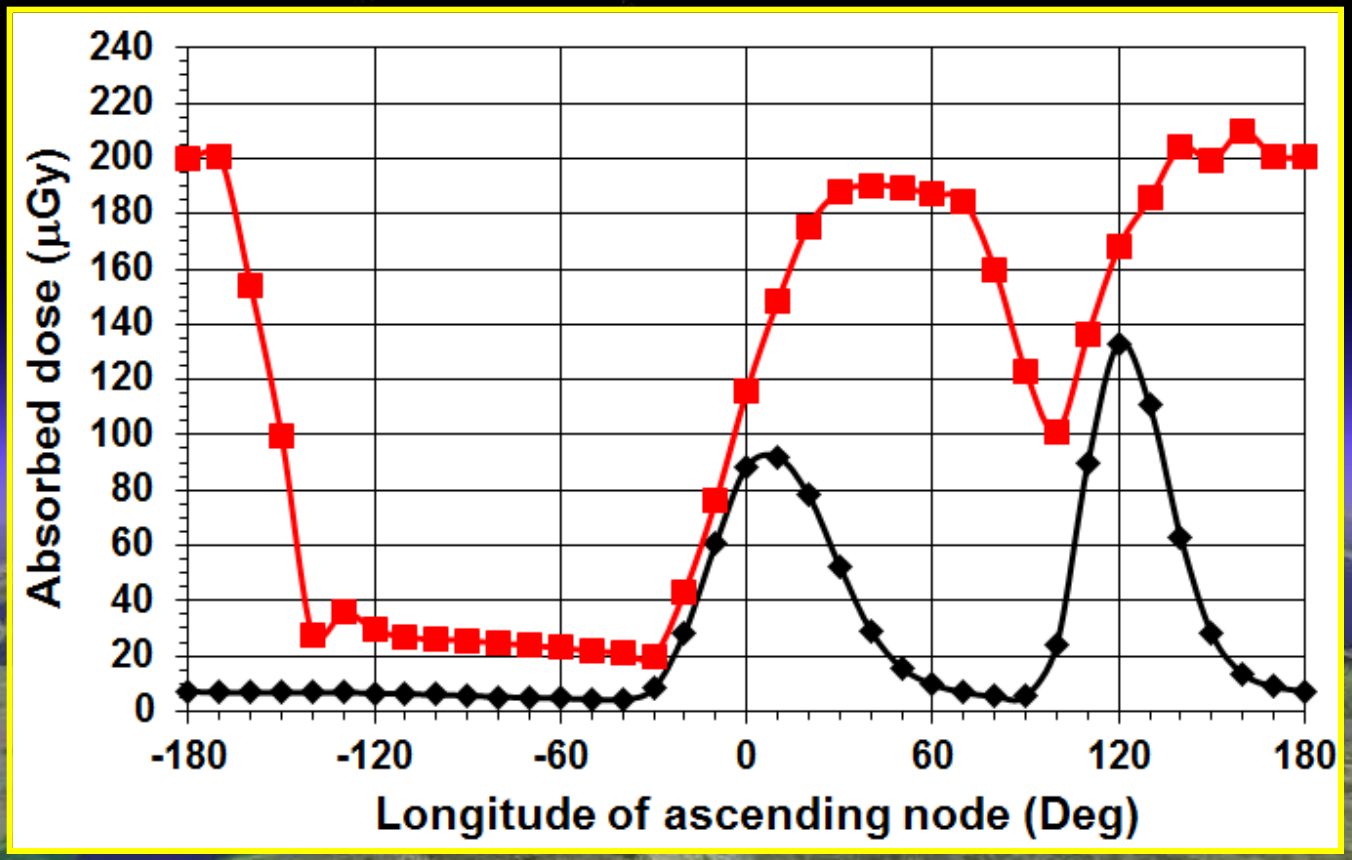
R3DE values:
Total AD/ED dose = 191 μGy/268 μSv
GCR AD/ED dose = 11 μGy/27 μSv
SAA AD/ED dose = 180 μGy/241 μSv

TEPC values:
Total AD/ED dose = 72 μGy/154 μSv
GCR AD/ED dose = 16 μGy/57 μSv
SAA AD/ED dose = 56 μGy/97 μSv

Model values:
Total Abs. dose = 187 μGy
GCR Abs. dose = 11 μGy
SAA Abs. dose = 176 μGy

Analysis...

Predicted by the model accumulated along the orbit dose for 1 orbit (1.5 hours) (black curve) and 4 consequences orbits (6 hours) (red curve)



It is seen that the absorbed doses accumulated during 1 orbit don't exceed 130 μGy, while the doses during 6 hours (about the nominal EVA duration) don't exceed 210 μGy. Keeping in mind that the daily absorbed doses outside ISS are at least 400 μGy we may conclude that even worst case EVA don't poses extreme risk for the astronauts.

Future work for the development of the empirical model

The model is under development and the next planned steps are:

- To be divided in 3 levels of altitude;
- To to be considered mechanism for transformation of the calculated values for larger shielding . The data from another Bulgarian build instrument (Liulin-5) inside of ISS is planned to be used;
- To be solved the problem with very small solar activity of the existing model by incorporation of new data base obtained with the analogical R3DR instrument on ISS in period with larger solar activity till August 2010;
- To be considered mechanism for transformation of the absorbed dose rates to Ambient dose equivalent rates.

Conclusions

- Space agencies when planning the EVA are trying to avoid crossings of the SAA region, which in a case of magnetosphere enhancements leads to enhanced “killer electrons” doses;
- Even worst case EVA don’t poses extreme risk for the astronauts;
- EVA dose dynamic is too complicated to be predicted by instruments situated inside of the station;
- Passive measurements with Pille type instruments are very useful but don’t give opportunity to be developed EVA strategy which will minimize the doses;
- Only small active personal dosimeters, which are able to distinguish between different kinds of radiation sources can, measure the real astronauts/cosmonauts doses during EVA


Thank you for your attention

Abstract

Data for this paper are collected by the Radiation Risk Radiometer-Dosimeter R3DE during the flight of the instrument at the European Technology Exposure Facility (EuTEF) on the Columbus External Payload Adaptor at the ISS inside of the ESA EXPOSE-E facility in the period February 2008–August 2009 and during the flight of the R3DR instrument inside of the ESA EXPOSE-R facility on the external pallet of the Russian Zvezda module during in the period March 2009-August 2010. The construction of the R3DE/R instruments shows that the total external and internal shielding before the Si detector (0.3 mm thick, 2 cm^2 area) is 0.41 g cm^{-2}. The calculated stopping energy of normally incident particles to the detector is 0.78 MeV for electrons and 15.8 MeV for protons. The developed previously data analysis procedures allow on the base of the dose to flux ratio to be separated predominant different particles depositing the doses. Different EVA paths are selected and analyzed to understand the dose rate and accumulated dose depositions dynamics in different radiation sources: GCR, protons in inner radiation belt (SAA) and electrons from outer radiation belt. The R3DE/R data were compared with the TEPC data http://cdaweb.gsfc.nasa.gov/ (Zapp, 2011) and Pille data presented by (Apathy et al., 2010) during the 15th WRMISS workshop http://wrmiss.org/workshops/fifteenth/Szanto.pdf. Main conclusion from the study is that the EVA dose dynamic is too complicated to be predicted by instruments situated inside of the station. Passive measurements with Pille type instruments are very useful but don't give opportunity to be developed EVA strategy which will minimize the doses. Only small active personal dosimeters, which are able to distinguish between different kinds of radiation sources can, measure the real astronauts/cosmonauts doses during EVA.