Earth and Moon Radiation Environment Results Obtained by RADOM Instrument on Indian Chandrayyan-1 Satellite. Comparison with Model

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Outlook

- Introduction
- Instrumentation
- Preliminary results for the Earth radiation environment
- Preliminary results for the Moon radiation environment
- Conclusions

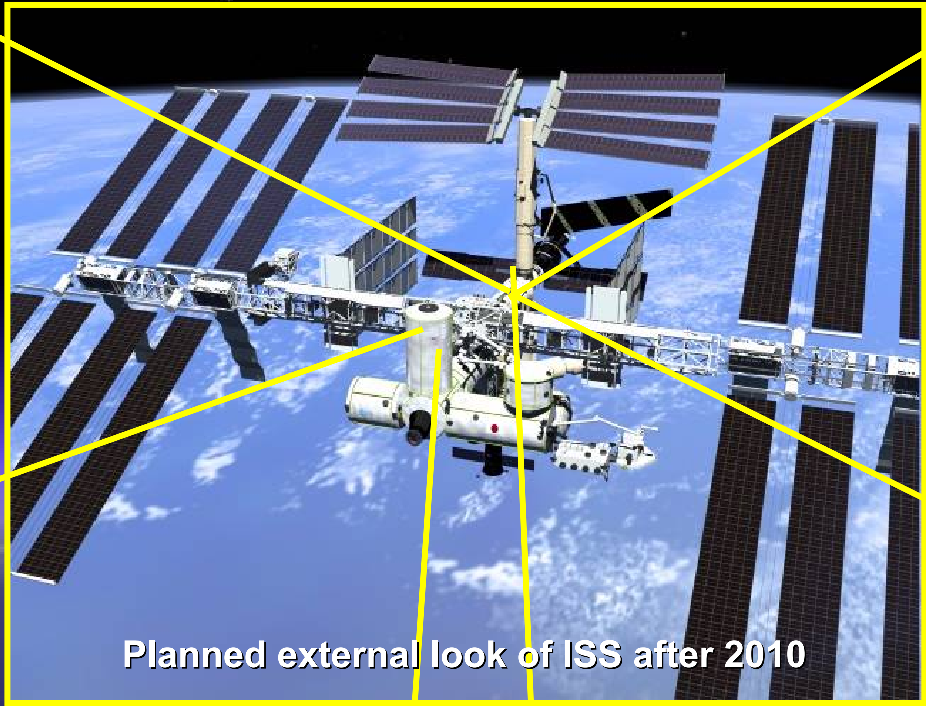
Introduction

STIL-BAS space radiation measurements experiments since 2000

1. Liulin-MDU1, June 14, 2000, ESA balloon flight up to 33 km over Gap, France;
2. Liulin-MDU5, more than 10000 flight hours on Czech airlines aircrafts from 2001 till 2009;
3. Liulin-E094, May-August 2001, ESA-NASA exp. on the International space station (ISS);
4. 2 Liulin-MDU, June 2001, NASA ER-2 flights at 20 km altitude in USA;
5. R3D-B1, October 2002, ESA Foton M1 satellite – unsuccessful launch;
6. R3D-B2, 1-12 юни 2005, ESA Foton M2 satellite;
7. 3 Liulin-MDU, June 11, 2005, NASA balloon flight up to 40 km over New Mexico, USA;
8. Liulin-ISS, ROSCOSMOS, launched to ISS in September 2005 (active now);
9. Liulin-6R, since October 2005 working in Internet (active now);
10. Liulin-Mussala, since June 2006 working in Internet (active now);
11. Liulin-5, ROSCOSMOS, since June 28, 2007 working at ISS (active now);
12. R3D-B3, September 14-26 2007, ESA Foton M3 satellite;
13. Liulin-6S, since October 2007 working at Jungfrau peak in Internet (active now);
14. Liulin-R, January 31, 2008, ESA rocket experiment up to 380 km from Norway;
15. R3DE, since 20 February, 2008, working at ESA Columbus module at ISS (active now);
16. RADOM, since October 22, 2008, Moon satellite Chandrayyan-1 (active now);

Participation of STIL-BAS in experiments on the International Space Station (ISS)

Liulin-ISS, 2005-2019, Russian Segment ISS

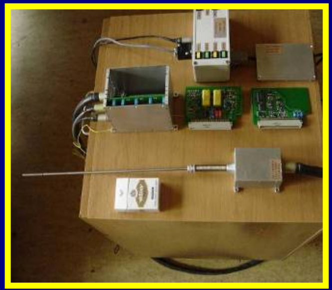


Planned external look of ISS after 2010

Liulin-5, 2007-2009, Russian Segment ISS

Liulin-E094, 2001 US Laboratory module

Langmuir probe, 2009-2019, Russian Segment ISS



R3DE, 2008-2009 ESA- EuTFF, Columbus

R3DR, 2009-2010 Russian Segment ISS

STIL-BAS spin-off produced Liulin type spectrometers for measurements of the space radiation on aircrafts are used by scientists from Japan, USA, Germany, France, Canada, Spain, Australia, Poland, Russia, Czech Republic and others

GPS receiver;
Li-Ion batteries;
Galvanically ins. 20-35 V DC
1 GB SD/MMC card.

Weight: 470 g*
Size: 100x100x45 mm

Internet based instrument

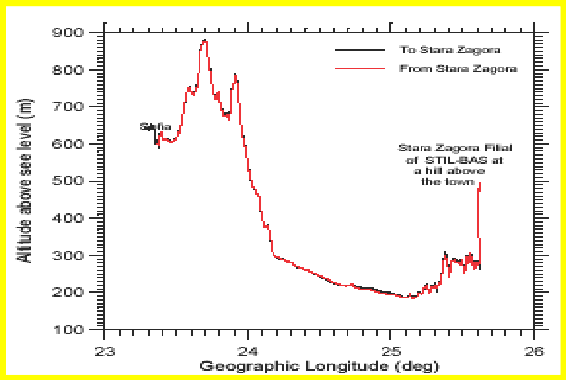
Weight: 120 g*
Size: 95x85x55 mm

More than 4 days working time from Li-Ion accumulator

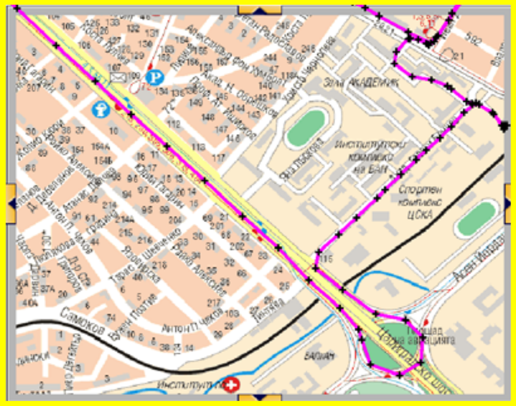
Weight: 115 g*
Size: 124x40x20 mm

Spectrometer with GPS receiver and display for monitoring of the space radiation doses by aircraft pilots

Weight: 280 g
Size: 110x80x45 mm



Altitude above the see level as measured by Liulin type spectrometer on the route Sofia-St. Zagora town



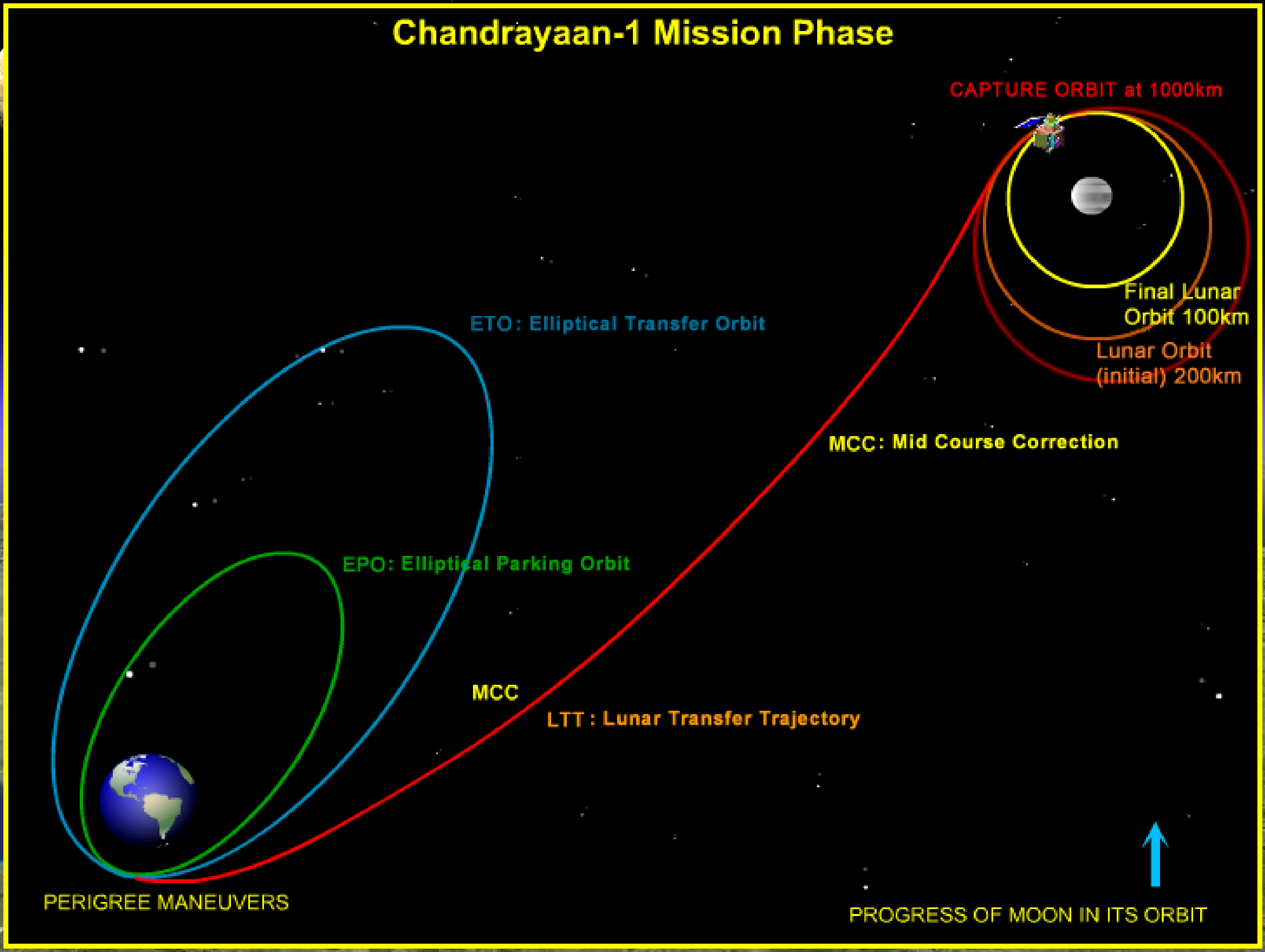
Car route as obtained by GPS receiver mounted in Liulin type spectrometer

11 Liulin type spectrometers during calibrations in CERN, October 2006

Chandrayaan-1 spacecraft was launched from the Satish Dhawan Space Centre, SHAR, Sriharikota by PSLV-XL (PSLV-C11) on 22 October 2008 at 00:52 UT

http://www.isro.org/Chandrayaan/htmls/objective_scientific.htm

Mission profile



Scientific Objectives of the Chandrayaan-1 mission

High-resolution remote sensing of the moon in visible, near infrared (NIR), low energy X-rays and high-energy X-ray regions. Specifically the objectives are:

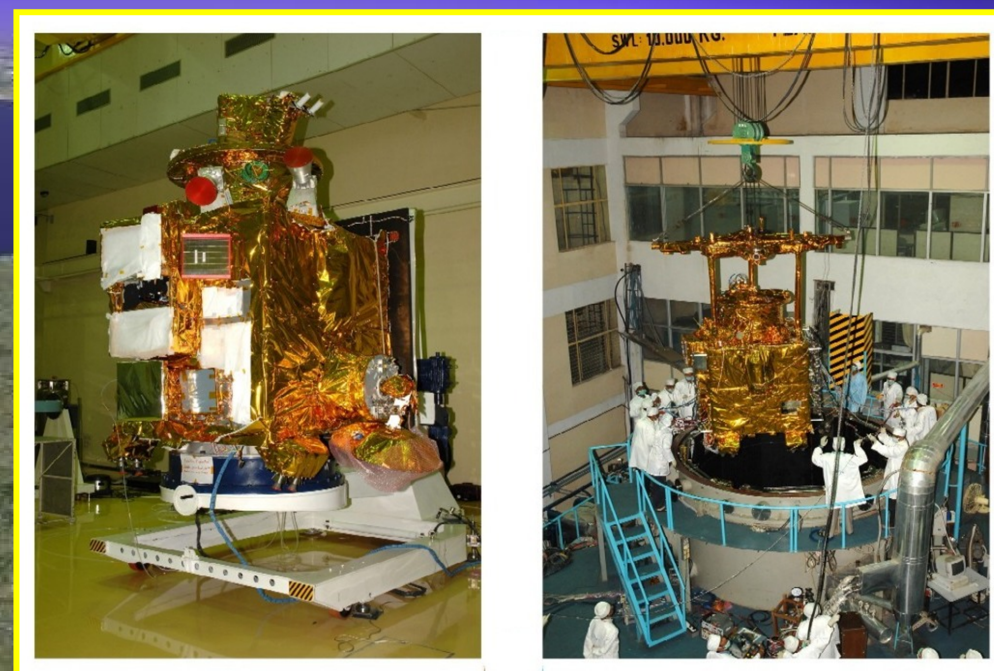
- **To prepare a three-dimensional atlas (with high spatial and altitude resolution of 5-10 m) of both near and far side of the moon;**
- **To conduct chemical and mineralogical mapping of the entire lunar surface for distribution of mineral and chemical elements;**
- **To study the Radiation environment of the Moon produced by solar radiation and solar and galactic cosmic rays.**

http://www.isro.org/Chandrayaan/htmls/objective_scientific.htm

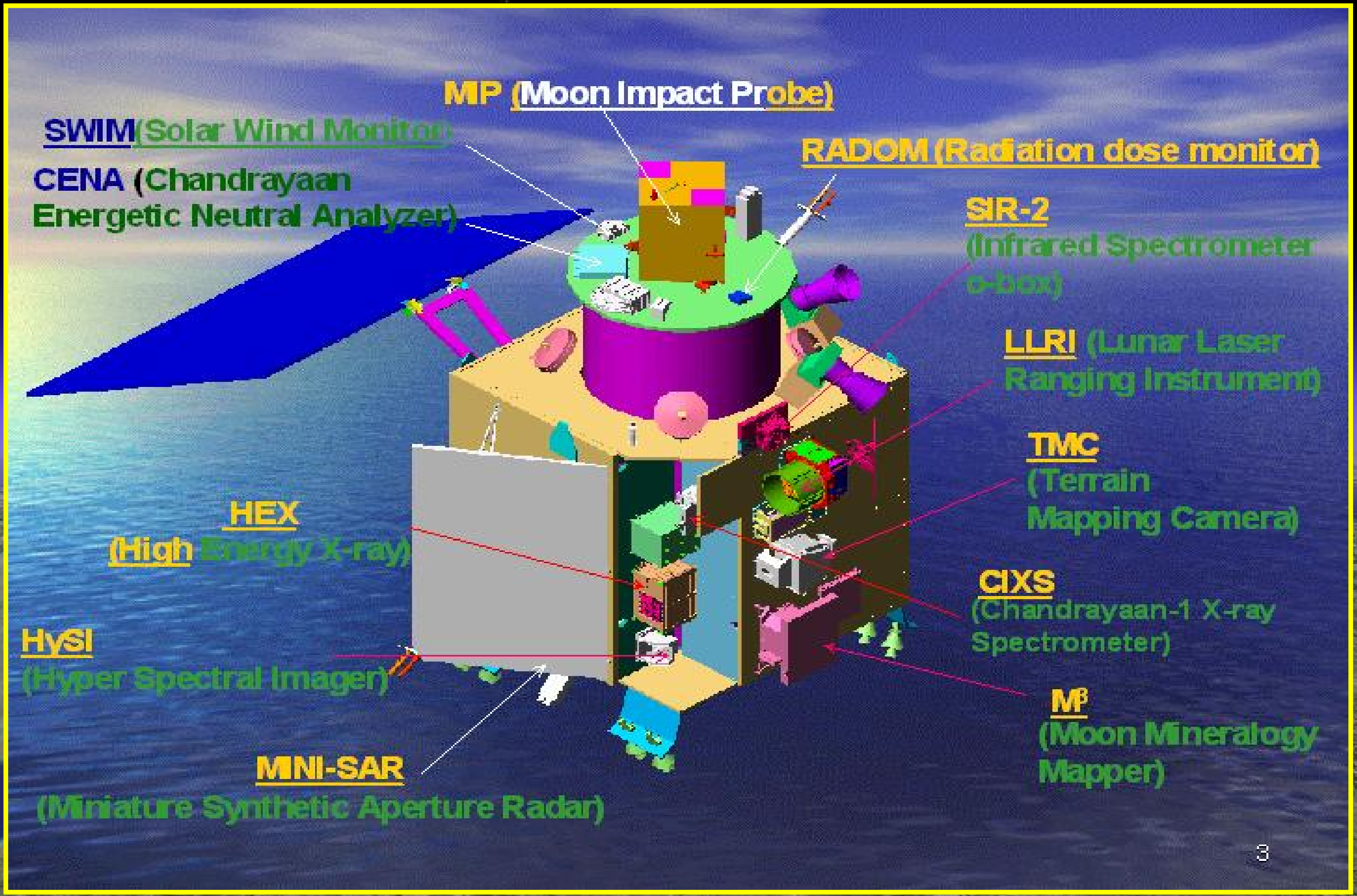
Chandrayaan-1 satellite

Spacecraft for lunar mission is:

- Cuboid in shape of approximately 1.5 m side;
- Weighing 1380 kg at launch and 675 kg at lunar orbit.
- Accommodates eleven science payloads:
  - ✓ 6 from Indian ISRO;
  - ✓ 2 from ESA;
  - ✓ 2 from NASA;
  - ✓ 1 from STIL-BAS.
- 3-axis stabilized spacecraft using two star sensors, gyros and four reaction wheels.

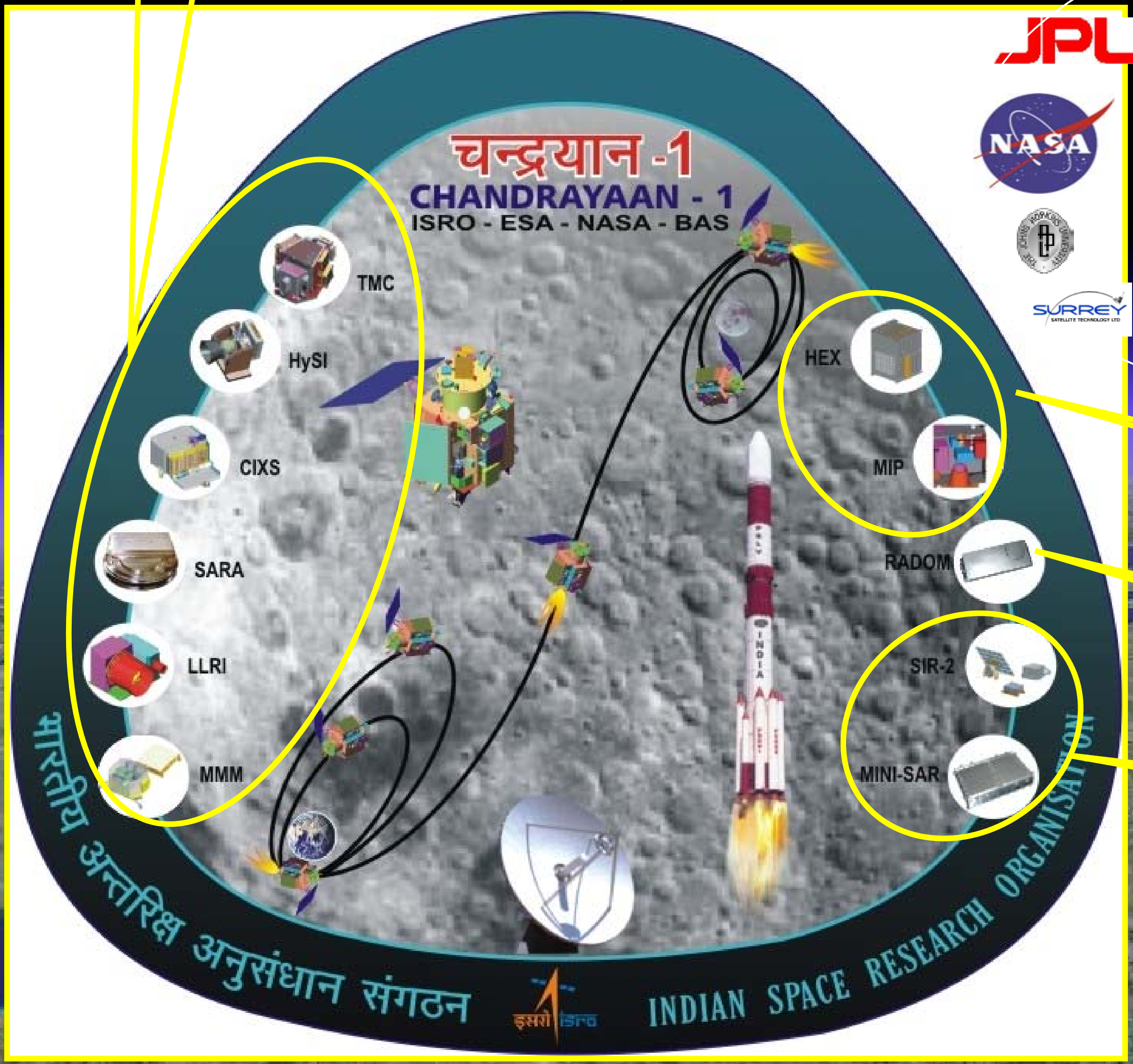


Scientific Payload



Participating agencies and institutions

ISRO



ESA

STIL-BAS

NASA

Scientific objectives of RADOM instrument

- To measure the particle flux, deposited energy spectrum, accumulated absorbed dose rates on the way to and in Lunar orbit with high time resolution, and evaluate the respective contributions of protons, neutrons, electrons, gamma rays and energetic galactic cosmic radiation nuclei;
- To provide an estimation of the flux/dose map around Moon at different altitudes;
- To evaluate the shielding characteristics (if any exists) of the Moon near environment towards galactic and solar cosmic radiation during solar particle events;
- To accumulate information for the Moon radiation environment, which further can be used for estimation of the human and electronics doses during the exploration and "colonization" of the Moon.

Instrumentation

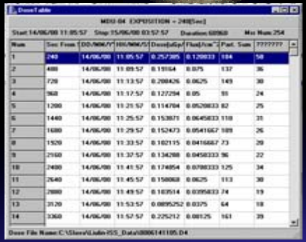
RADOM Flight model external view

Size: 110x40x20 mm; Weight: 98 g.; Consumption: 124 mW

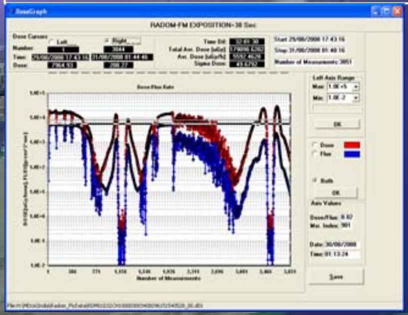
The solid state detector of RADOM instrument is behind ~ 0.45 g/cm2 shielding from front side of 2π, which allows direct hits on the detector by electrons with energies in the range 0.85-10 MeV. The protons range is 17.5-200 MeV. On the back 2π angle where the satellite is the shielding is larger but not known exactly

First screenshot of RADOM-FM.exe program for initialization and quick look of the data

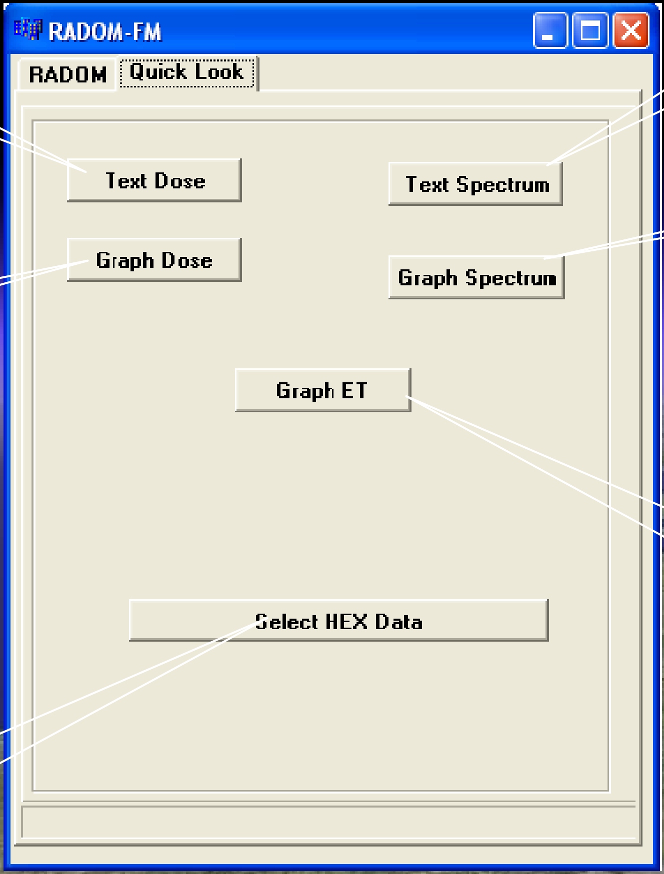
Present the data in Table form



Dose and flux graphics

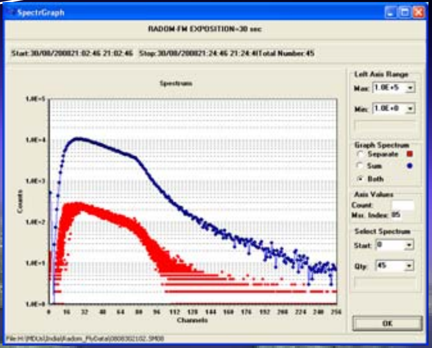


Fail selection

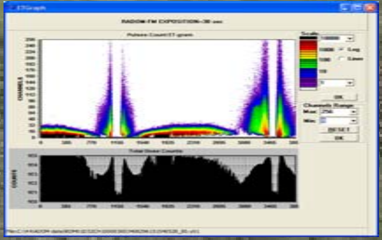


Spectra Tables

Spectra graphics



3D graphics



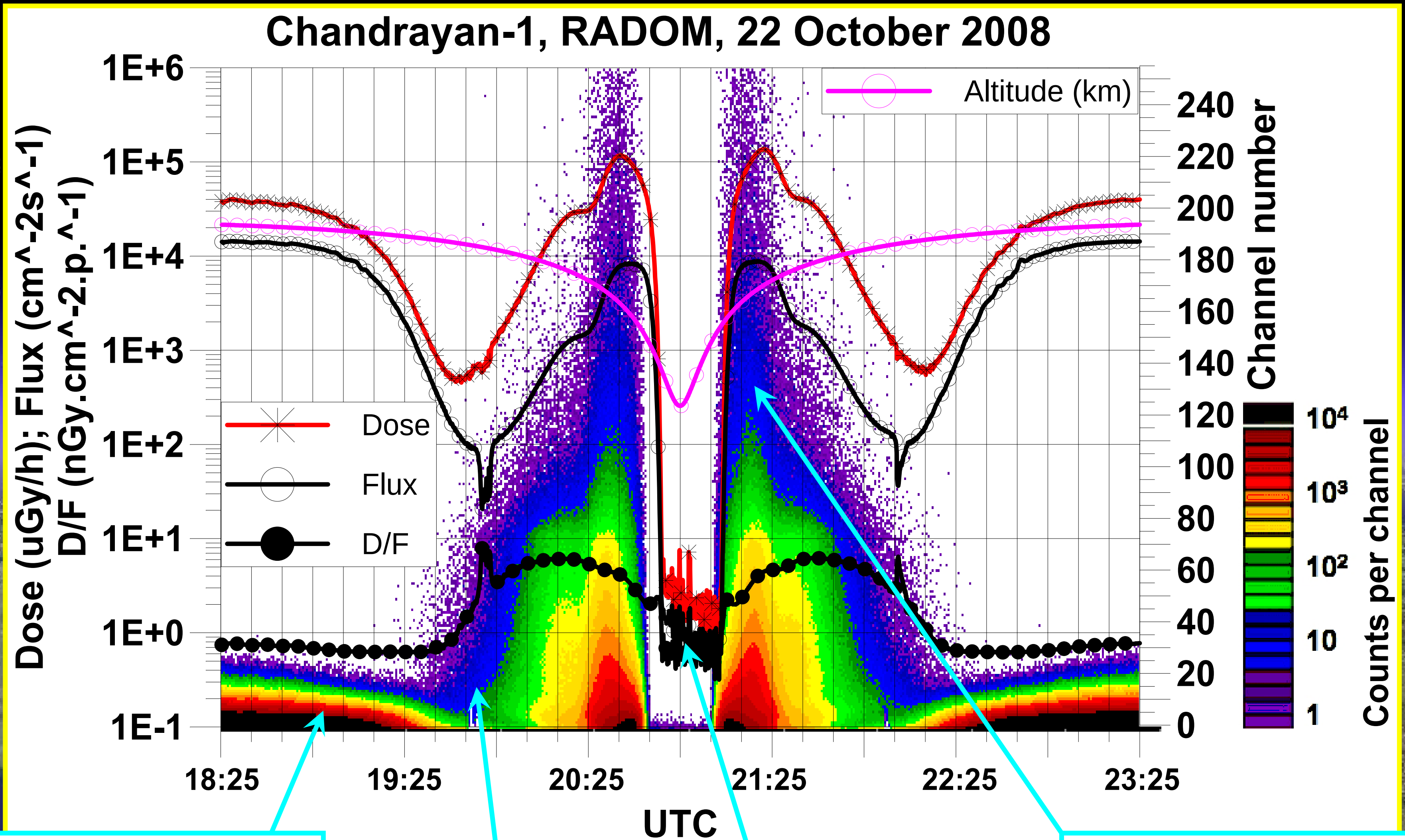
RADOM-FM.exe software is developed by STIL-BAS and was delivered together with the instrument in middle of September 2007 to ISRO

Instrument performance

- The solid state detector of RADOM instrument is behind ~ 0.45 g/cm^2 shielding from front side of 2π, which allows direct hits on the detector by electrons with energies in the range 0.85-10 MeV. The protons range is 17.5-200 MeV. On the back 2π angle where the satellite is the shielding is larger but not known exactly;
- RADOM was switched ON about 2 hours after the launch. Since this moment it works almost permanently. First the resolution was 10 sec and this was a good decision because no over scaling was observed in the Earth magnetosphere. Since December 3th it works in 30 sec resolution;
- Inside of the electron radiation belt doses reached 4.10^4 $\mu Gy.h^{-1}$, while the fluxes are $1.5.10^4$ $cm^{-2}.s^{-1}$;
- Inside of the proton radiation belt doses reached the highest values of $1.2.10^5$ $\mu Gy.h^{-1}$, while the fluxes are 9.10^3 $cm^{-2}.s^{-1}$;
- The galactic cosmic rays (GCR) doses around Earth was about 12 $\mu Gy.h^{-1}$. When the satellite was away from the Earth GCR reached 12.2 $\mu Gy.h^{-1}$. Close to the Moon the doses fall down to about 8.8 $\mu Gy.h^{-1}$;
- The total accumulated dose is about 1.3 Gy till 12th of November 2008;

Earth radiation environment

Overview of the near Earth radiation environment obtained by RADOM instrument



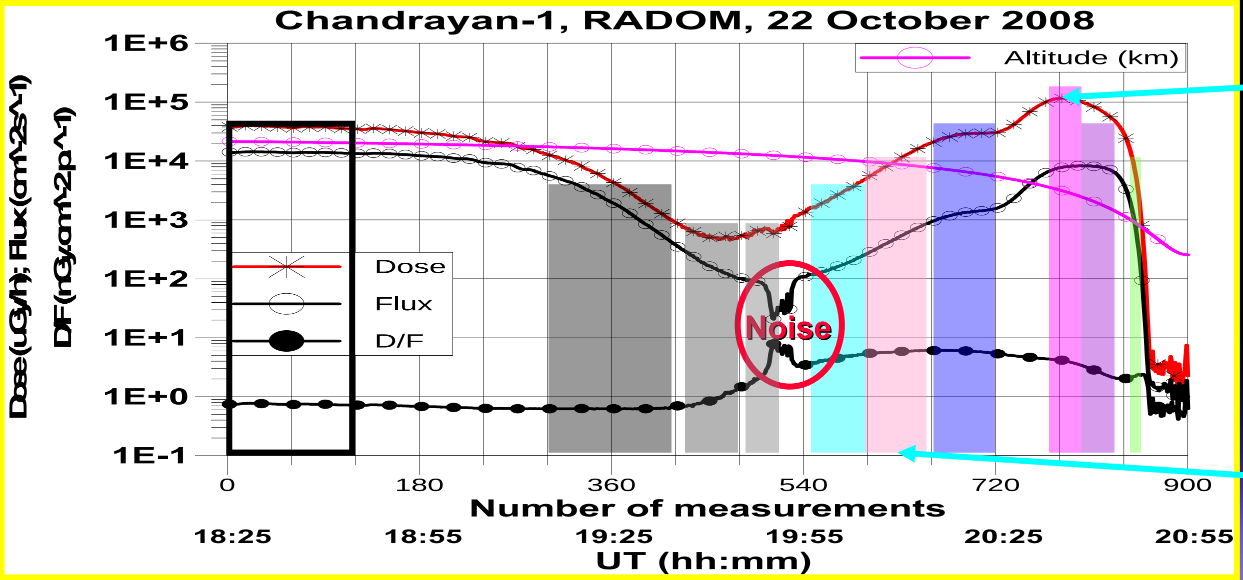
Outer (electron) Radiation belt. Dose = 40000 μGy/h

Slot region Dose = 600 μGy/h

Perigee Dose = 1.2 μGy/h

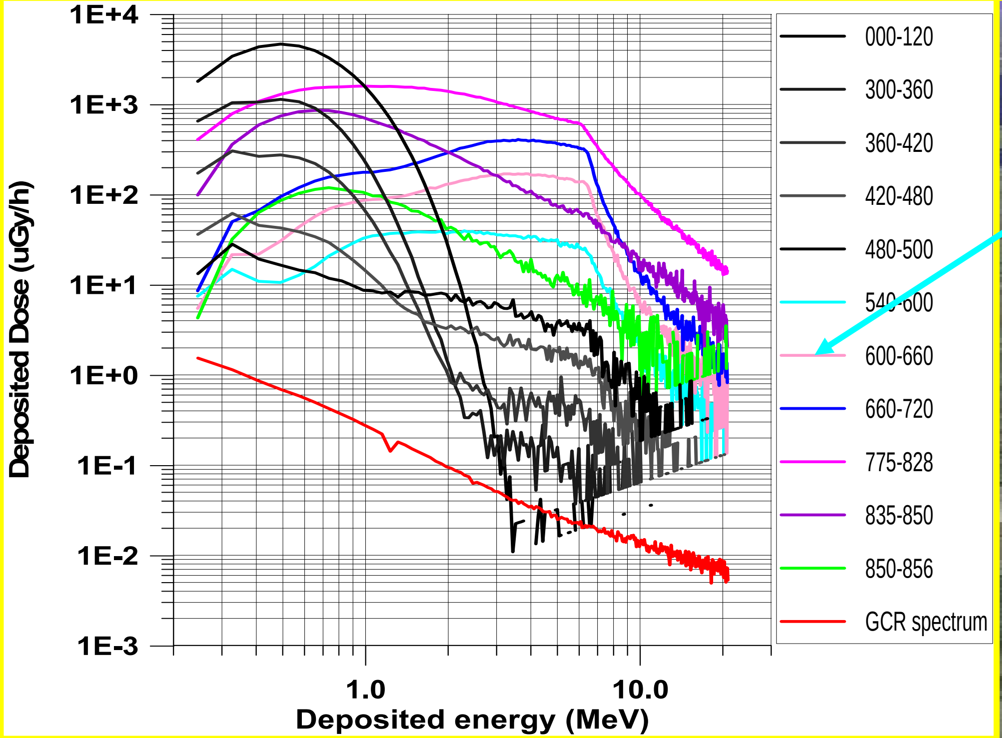
Inner (proton) radiation belt. Dose = 130000 μGy/h

Variations of the doses, fluxes and spectra shape in near Earth space



The highest doses of about 130000 μGy/h are measured inside of the proton belt, never the less that the highest fluxes are measured inside the electron belt

The different spectra colors coded different positions along the orbit

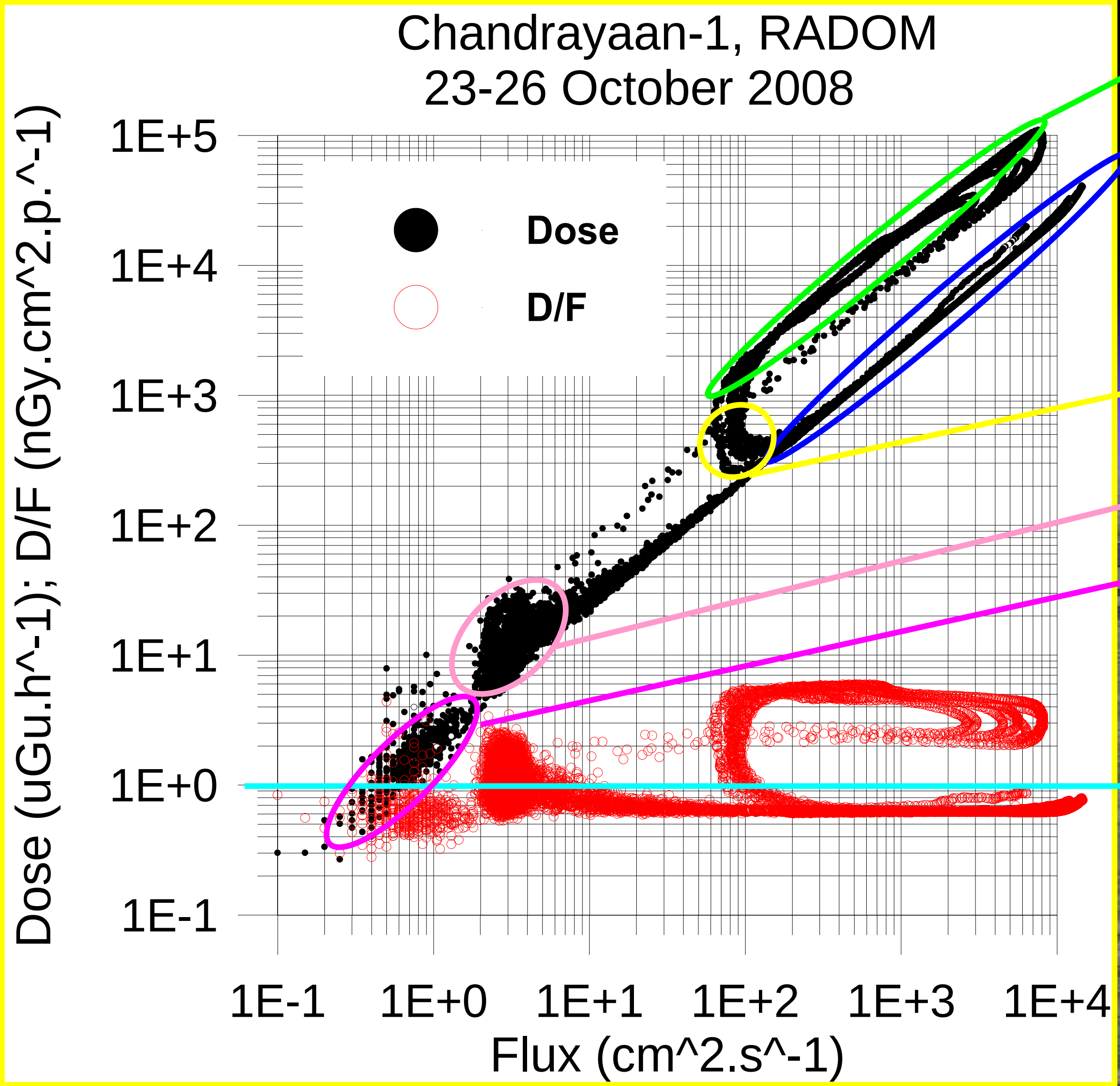


The position of the maximum along the deposited energy spectra depends by the type and energy of the measured dominating particles.

As high the area limited by the spectrum is, as high the deposited dose is!

The red spectrum in the bottom is obtained by GCR particles

The Dose to Flux ratio, (Which is in fact the specific dose per particle.) characterize the type of dominating particles



Proton belt doses

Electron belt doses

Slot region doses

Apogee GCR doses

Perigee GCR doses

If D/F ratio is above 1 nGy.cm^2/part. the dose is deposited mainly by protons

If D/F ratio is below 1 nGy.cm^2/part. the dose is deposited mainly by electrons*

*Heffner, 1971.

Dynamics of the Equivalent dose distribution (H*(10) along the Chandrayaan-1 satellite orbit

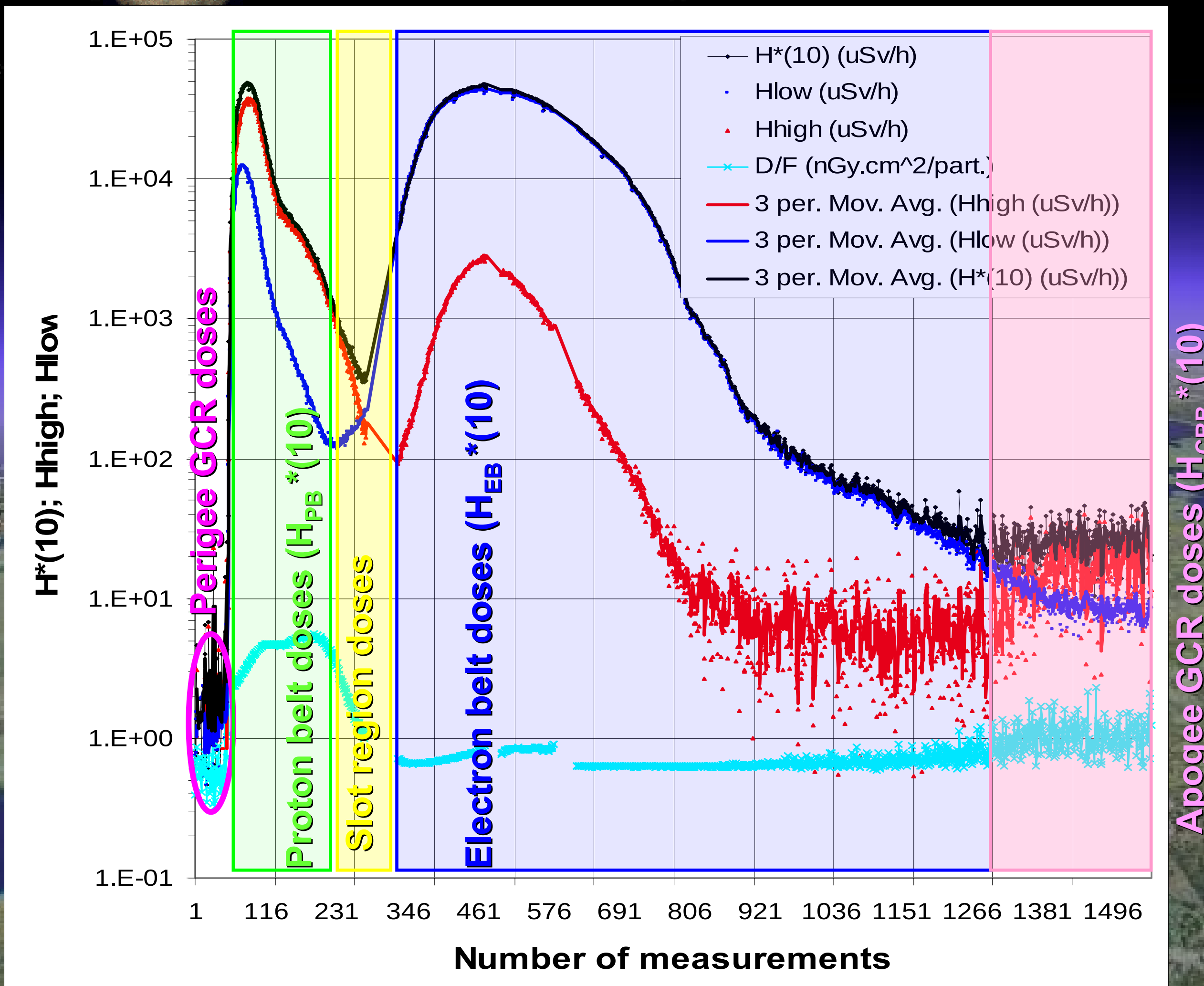
$$H_{GCR}*(10) = H_{low} + 5H_{high} = 3.357.10^{-8}\{\sum_{i=2}^{15} i.A_i + 5\sum_{i=16}^{256} i.A_i\}$$

$$H_{EB}*(10) = H_{low} + H_{high}$$

$$H_{PB}*(10) = 1.3H_{low} + 1.3H_{high}$$

Begin 26/10/09 01:44:14

End 26/10/09 06:04:14



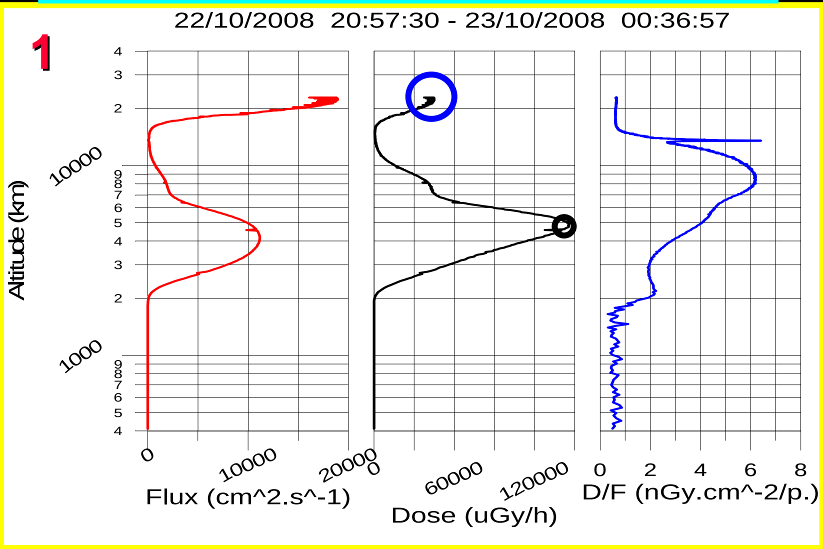
If D/F ratio is above 1 nGy.cm²/part. the dose is deposited mainly by protons and H_{high} have major contribution in the equivalent dose H*(10)

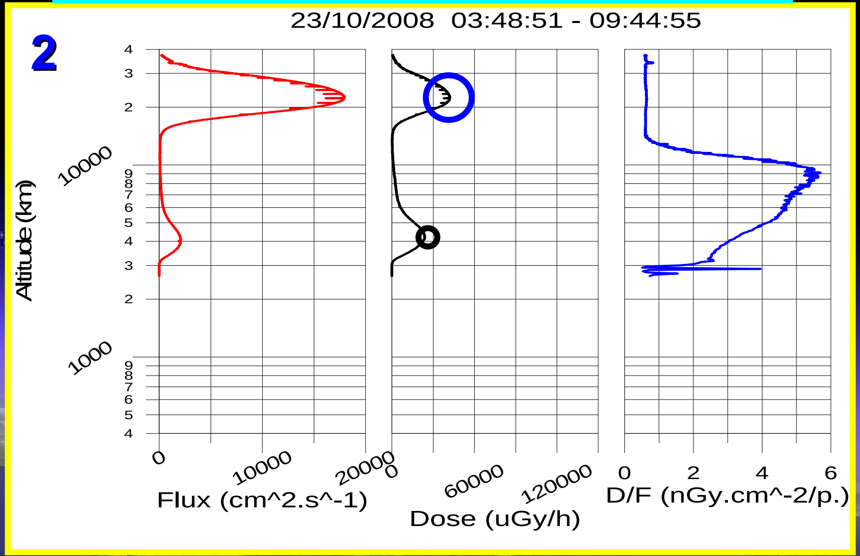
If D/F ratio is below 1 nGy.cm²/part. the dose is deposited mainly by electrons and H_{low} have major contribution in the equivalent dose H*(10)

Variations of the doses and fluxes in dependence by altitude and by the longitude /UT of the satellite

When the magnetic axes is to the right of the geographic the satellite is going trough the center of inner radiation belt

When the magnetic axes is to the left of the geographic the satellite is going trough the periphery of inner radiation belt

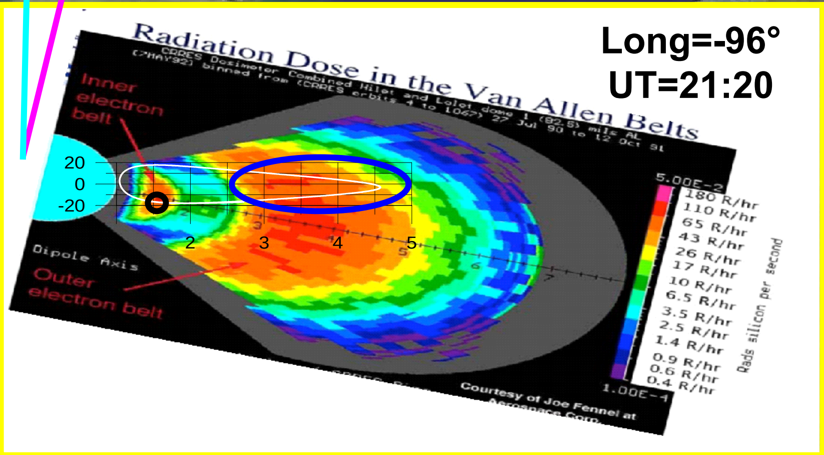


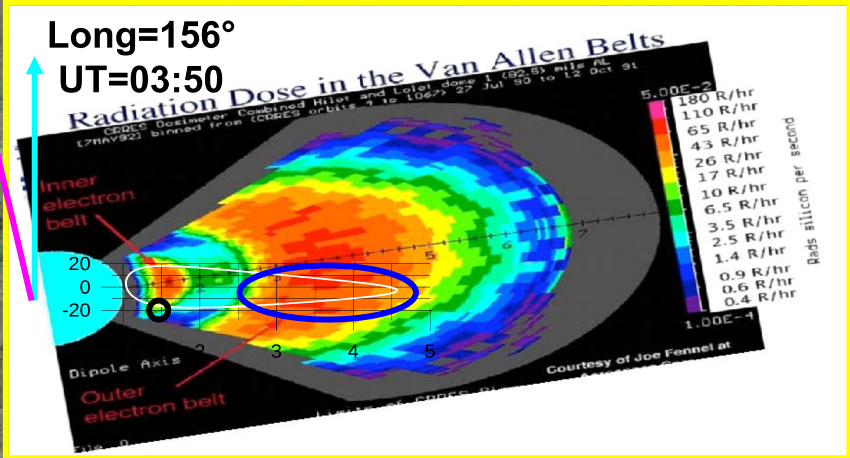


Rotational (geographic) axes

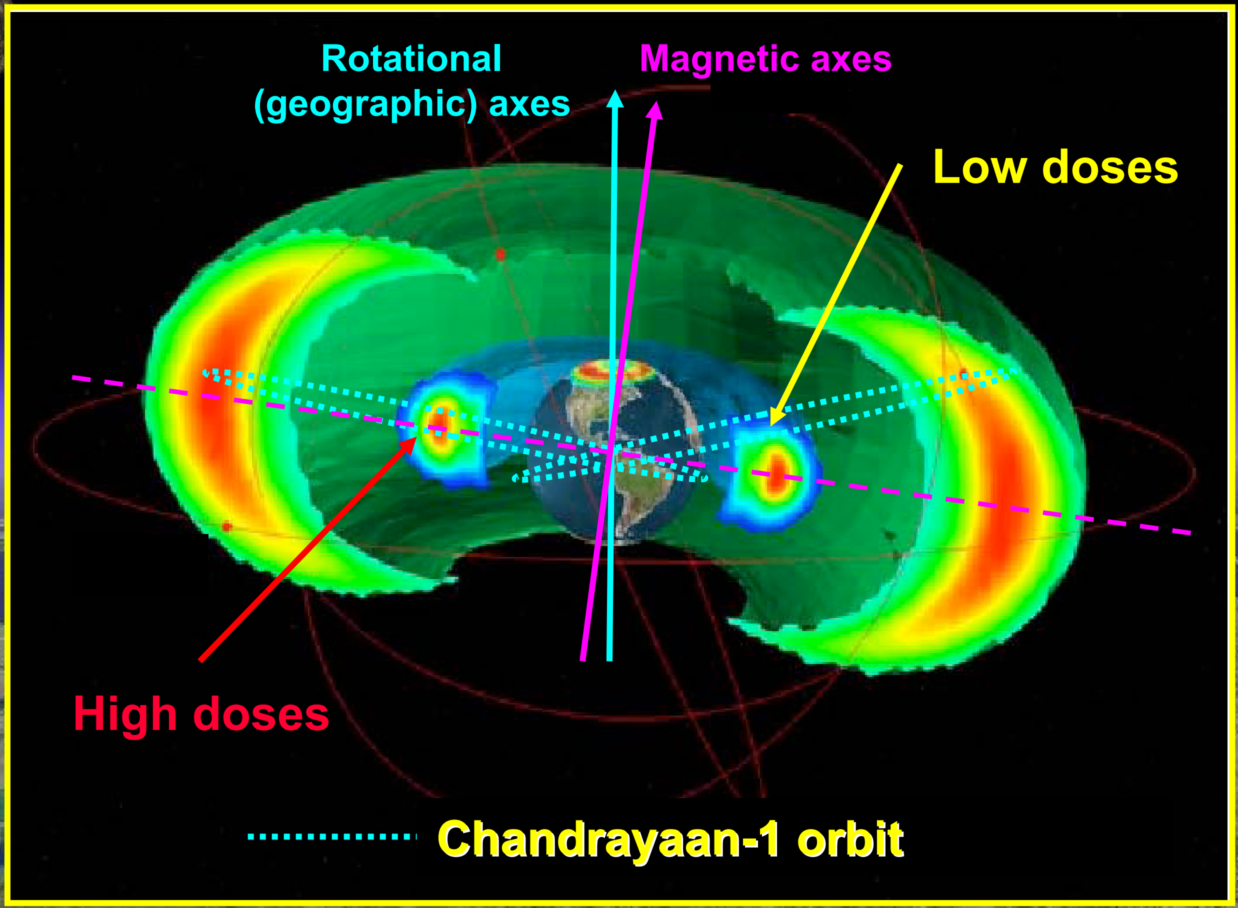
Magnetic axes

The outer belt doses are practically not affected



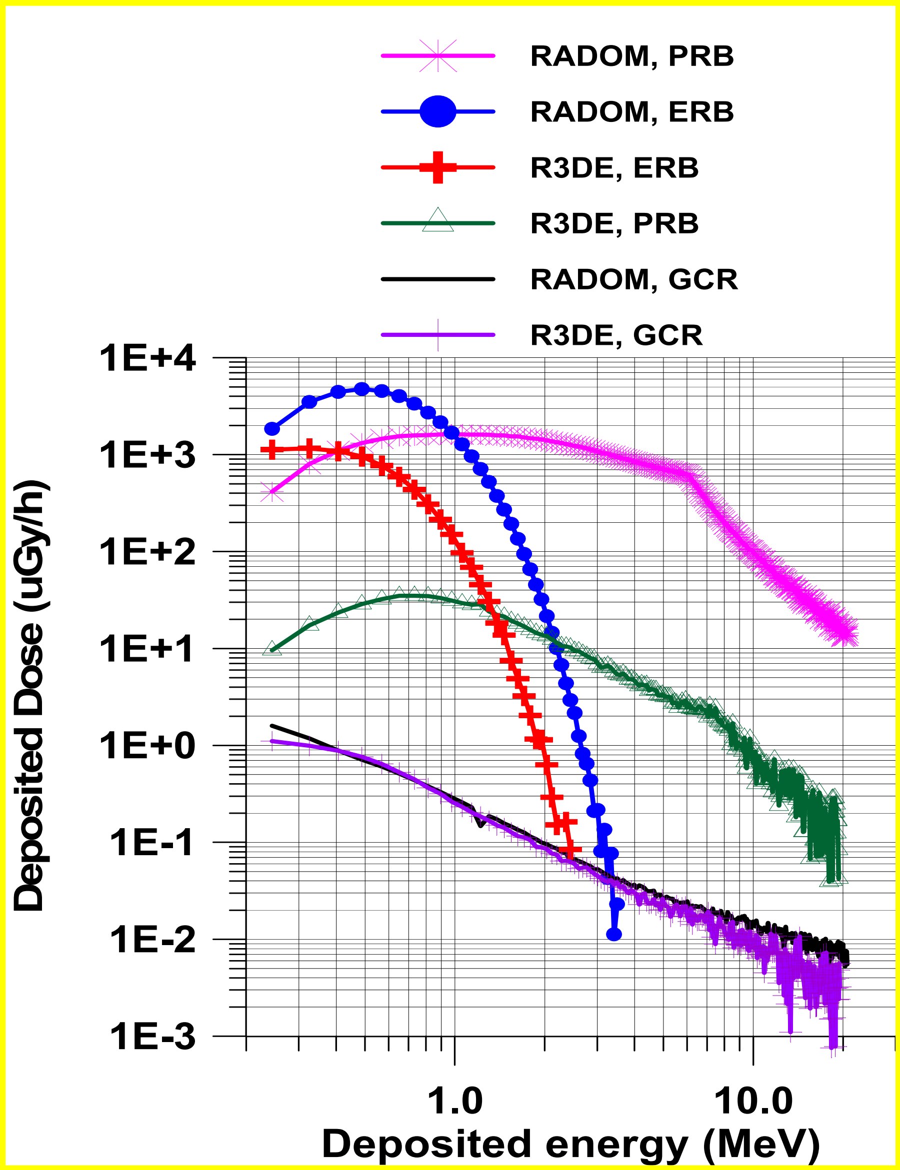


Explanation of the different doses in proton radiation belt on previous slide



3D picture of the belts is courtesy of NASA

Comparison of Chandrayaan-1 - RADOM spectra with ISS - R3DE spectra

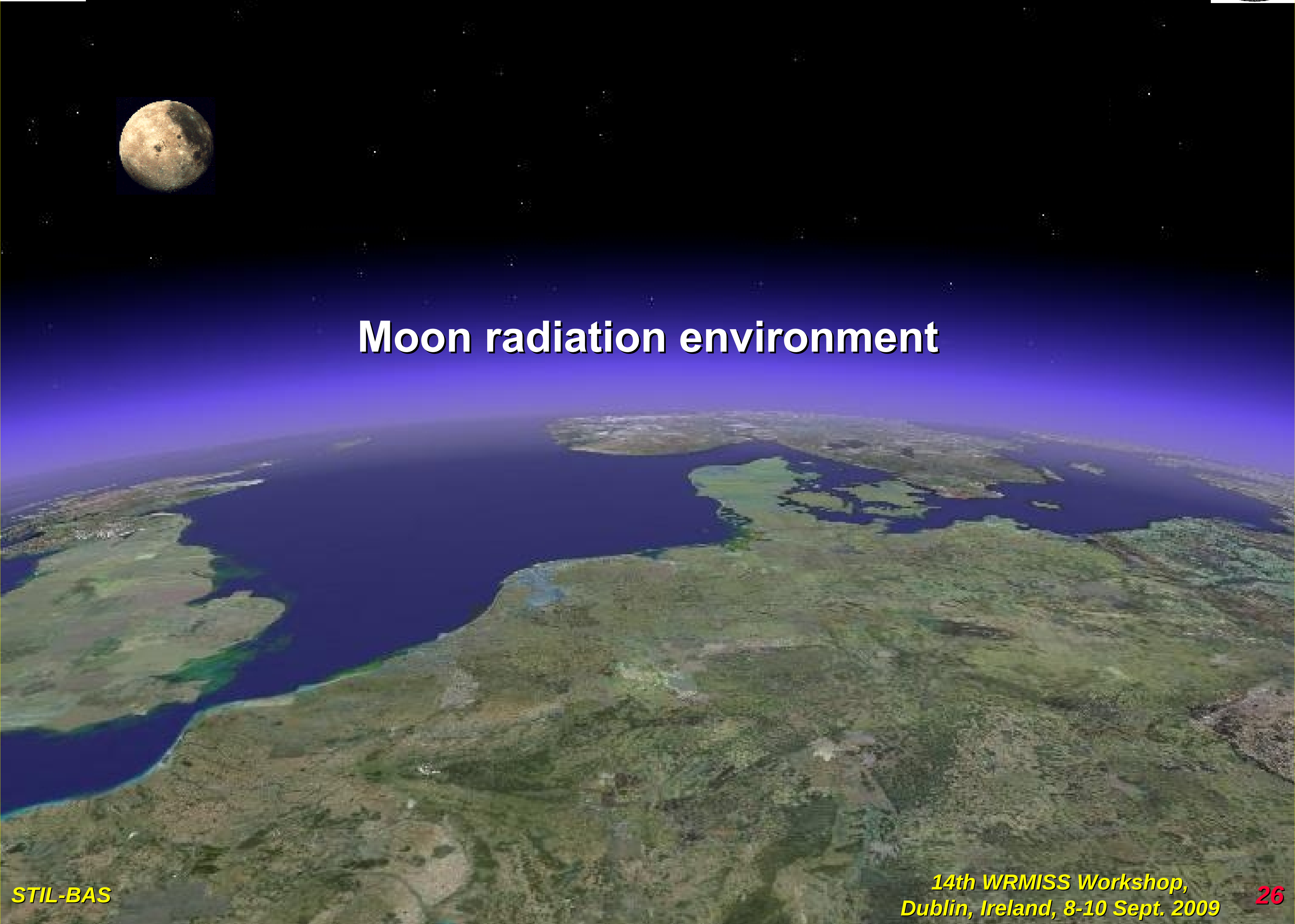


The shape of spectra obtained by RADOM are same as spectra obtained by R3DE at Int. Space Station

The RADOM proton radiation belt (PRB) spectrum is with same shape as R3DE spectrum but at about 1.5 order of magnitude higher because higher flux and respectively dose

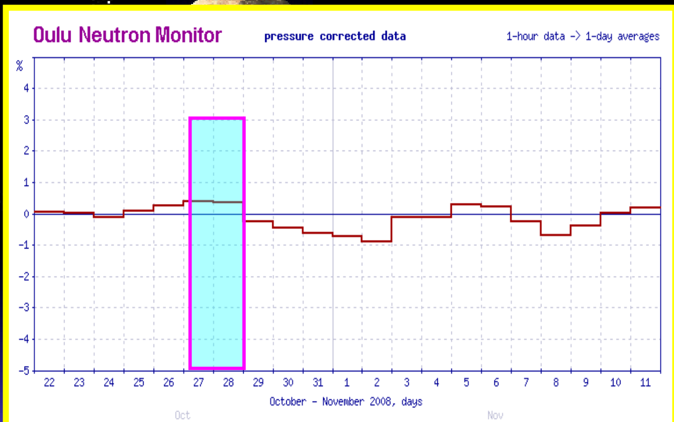
The RADOM electron radiation belt (ERB) spectrum is with same shape as R3DE spectrum but about 4 time higher level because higher dose

The RADOM galactic cosmic rays (GCR) spectrum practically overlap the REDE spectrum, because of same flux and respectively doses

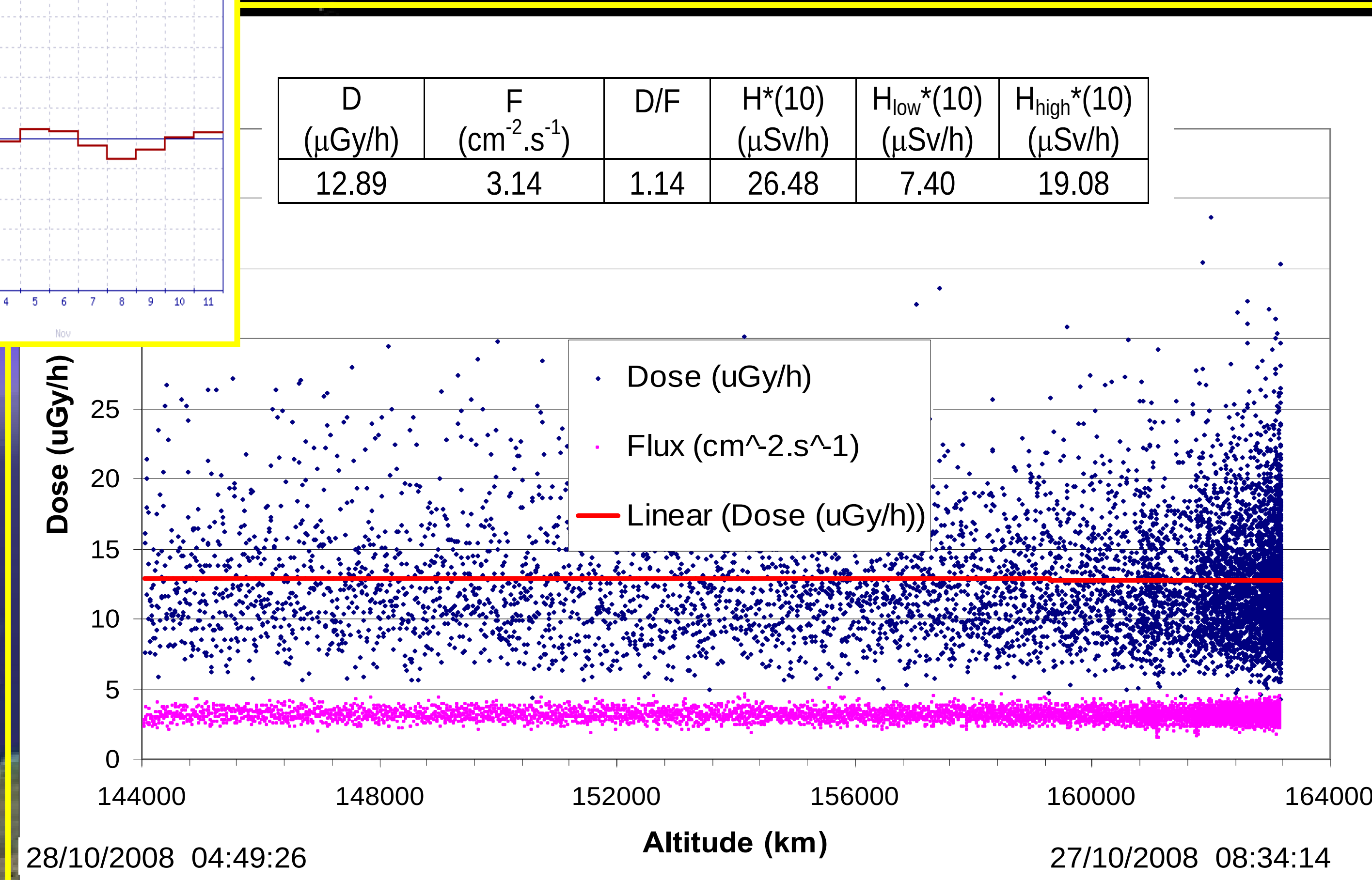


Moon radiation environment

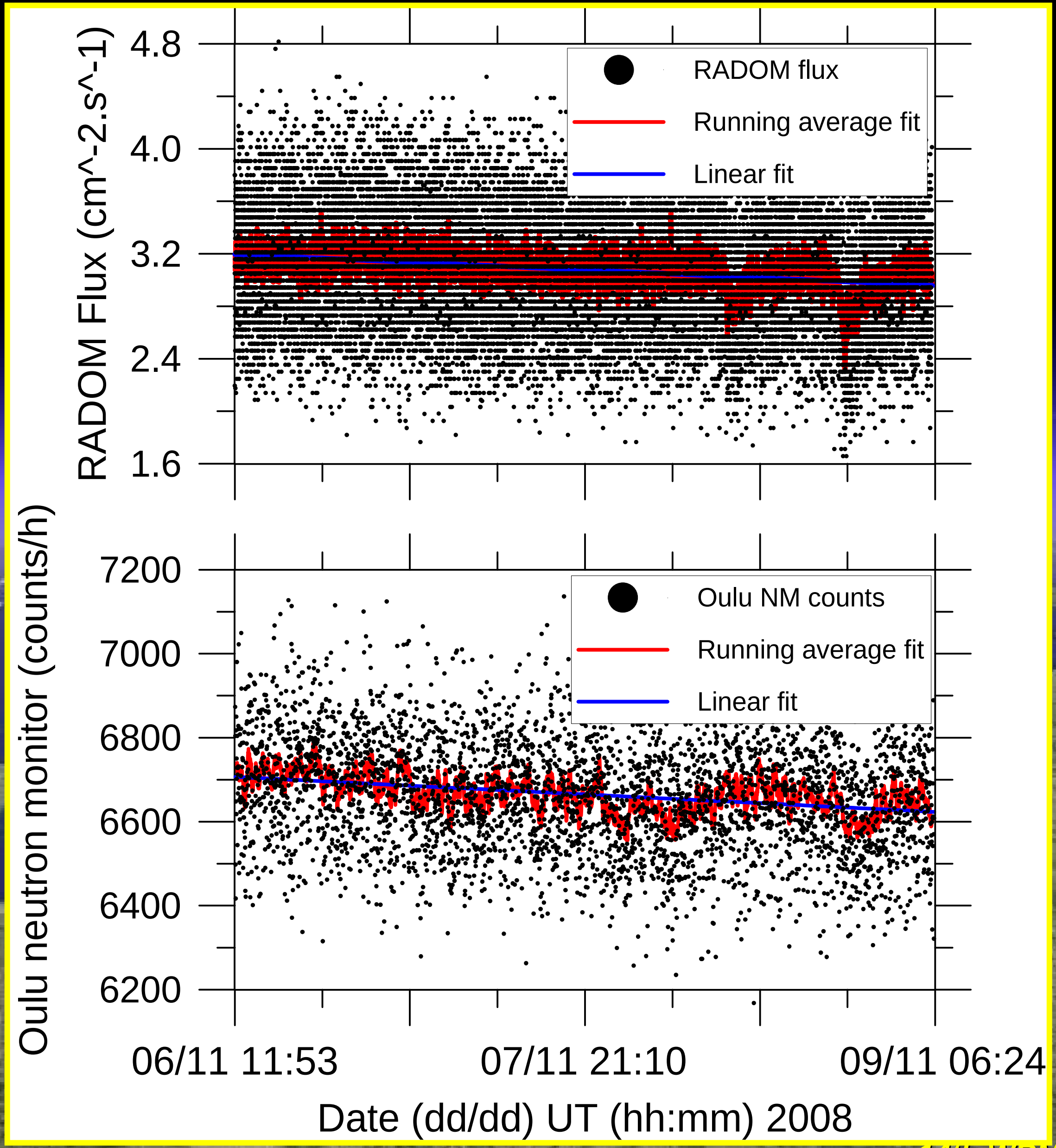
October 27-28, 2008; Perigee = 348 km
Apogee = 164600 km; Period = 73 hours
Average GCR Dose = 12.89 mGy/h



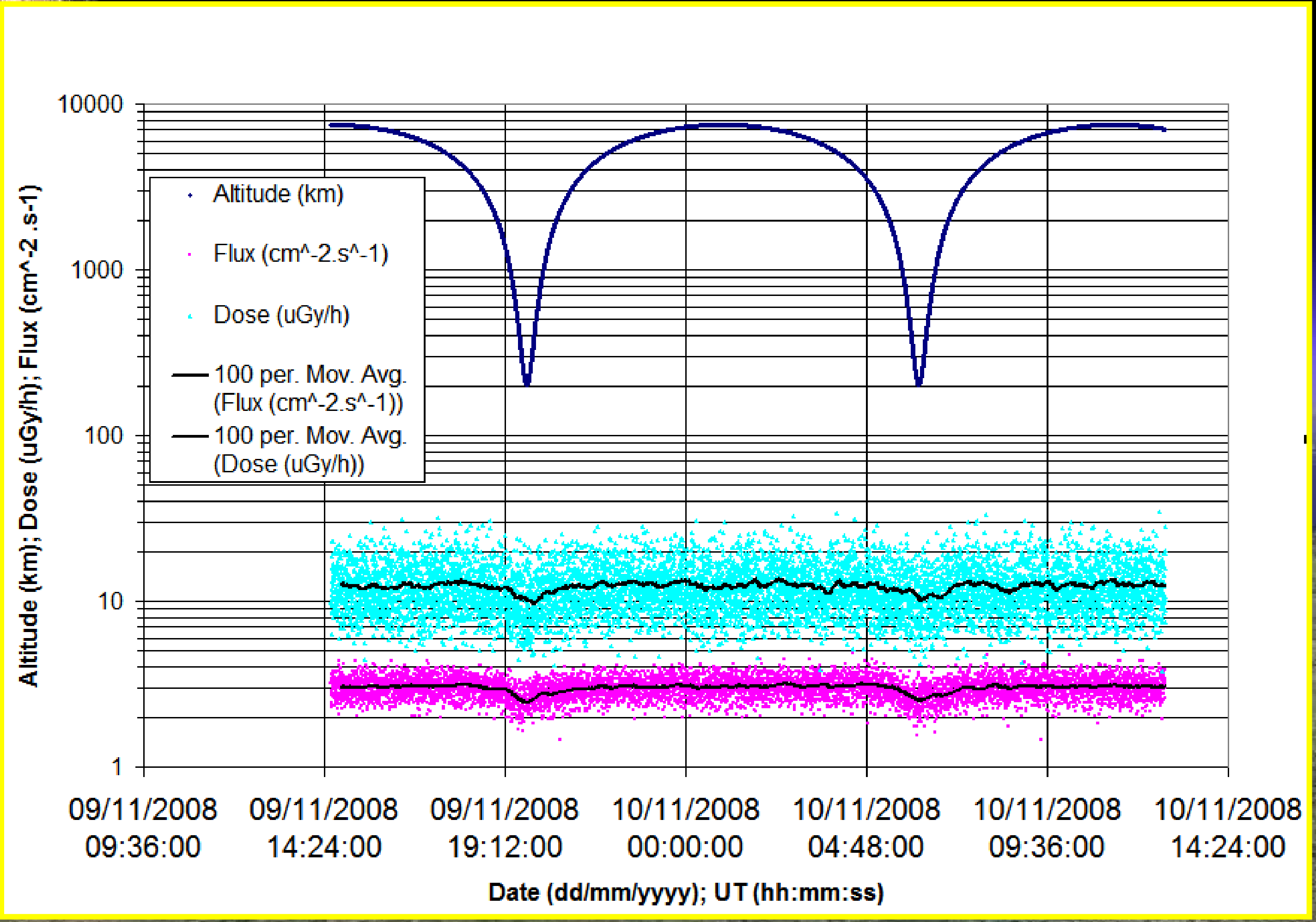
D (μGy/h)	F ($cm^{-2}.s^{-1}$)	D/F	H*(10) (μSv/h)	H_{low}*(10) (μSv/h)	H_{high}*(10) (μSv/h)
12.89	3.14	1.14	26.48	7.40	19.08



Comparison of RADOM flux data (10 s. resolution) with Oulu neutron monitor count rate data (1 min. resolution)



Because the increased shielding of the GCR by the Moon body the dose and flux levels decrease when Chandrayaan-1 satellite moves closer to the Moon on 9-10.11.2008

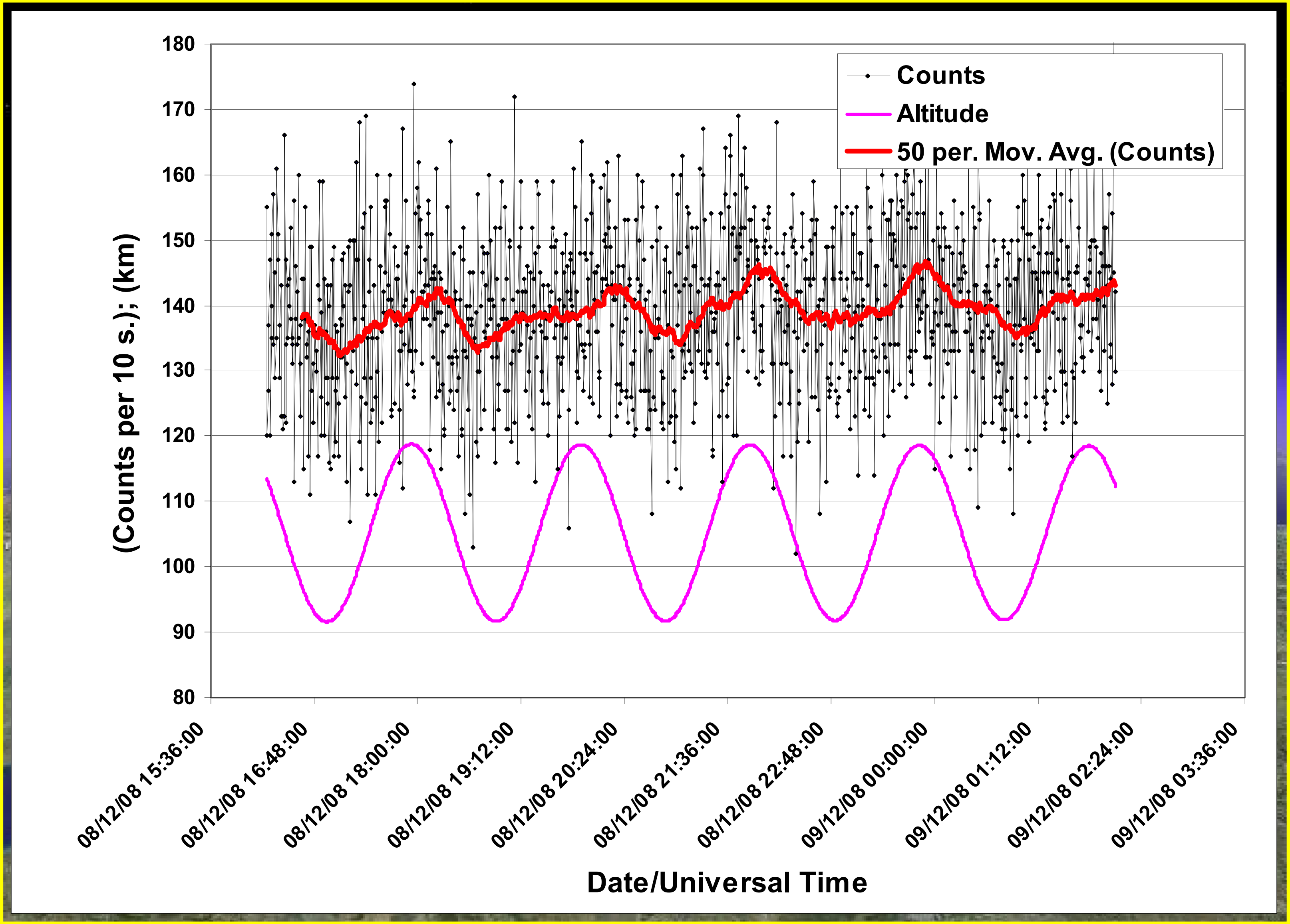


Comparisons with G. De Angelis model at 1000 km altitude

Data Particle Flux = 2.73 $cm^{-2}s^{-1}$
Average Data GCR Phys. Dose = 10.02 µGy/h
Average Data GCR H*(10) Dose = 20.94 µSv/h

Model Particle Flux = 3.05 $cm^{-2}s^{-1}$
Average Model GCR Phys. Dose = 11.16 µGy/h
Average Model GCR H*(10) Dose = 23.36 µSv/h

Variations of the RADOM count rate and respectively dose by the altitude above the Moon surface



Comparisons with G. De Angelis model at 100 km altitude

Data Particle Flux = 2.29 $cm^{-2}s^{-1}$

Average Data GCR Phys. Dose = 8.77 μGy/h

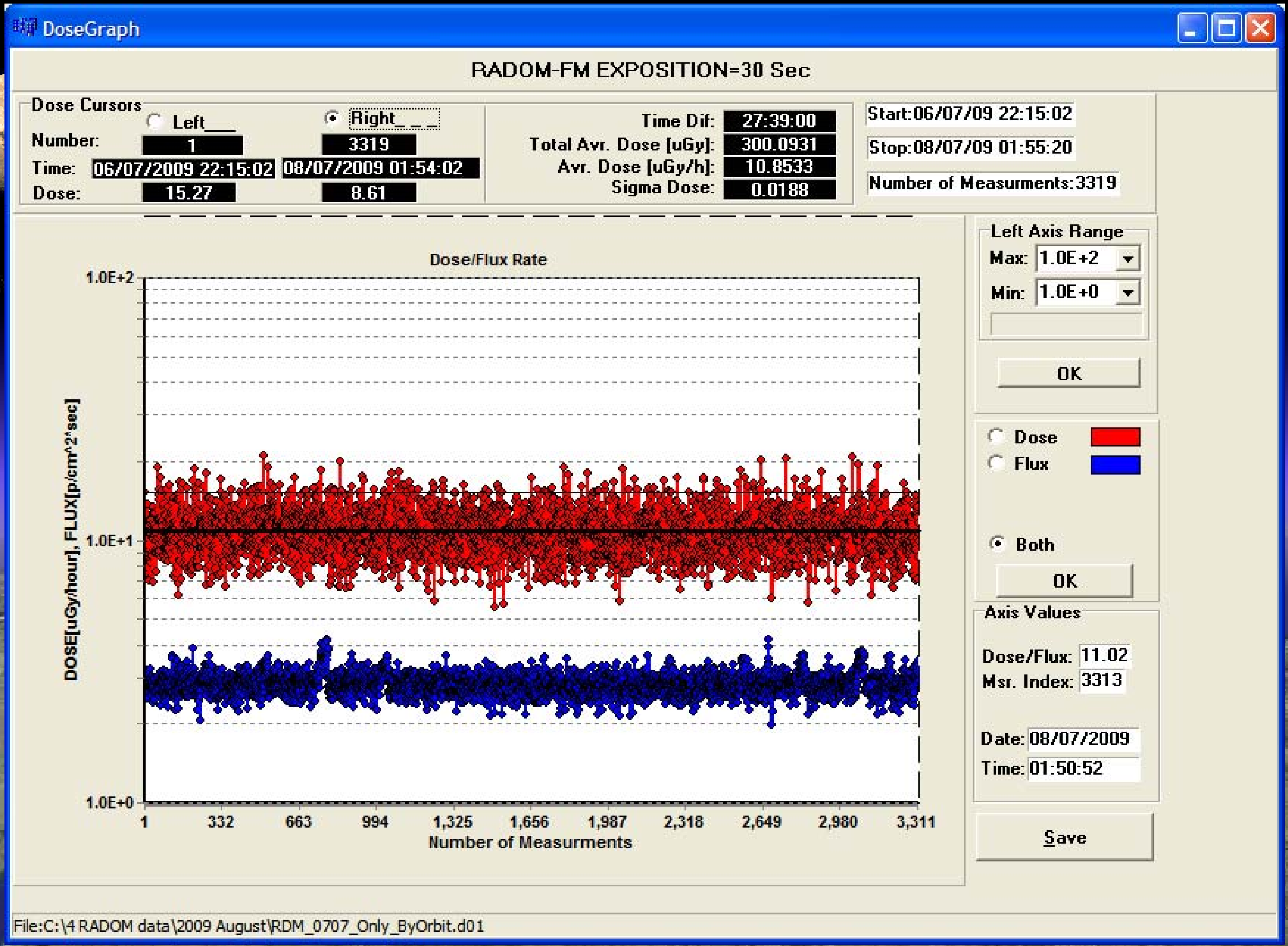
Average Data GCR H*(10) Dose = 18.54 μSv/h*

Model Particle Flux = 2.55 $cm^{-2}s^{-1}$

Average Model GCR Phys. Dose = 9.76 μGy/h

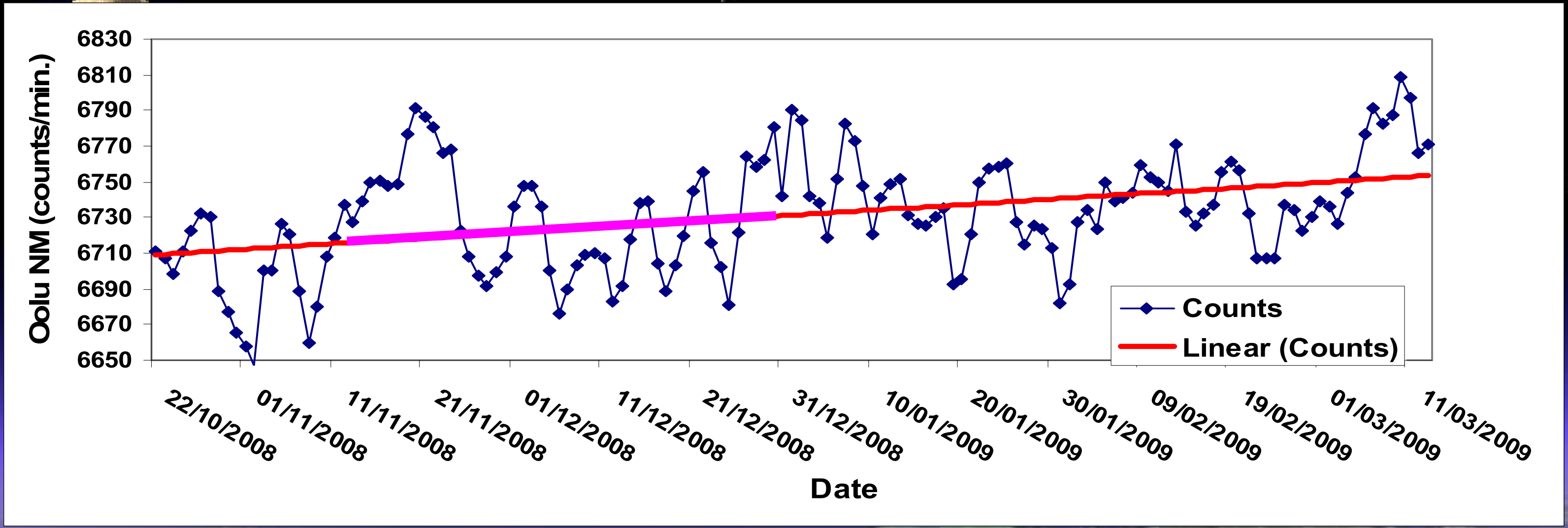
Average Model GCR H*(10) Dose = 20.06 μSv/h

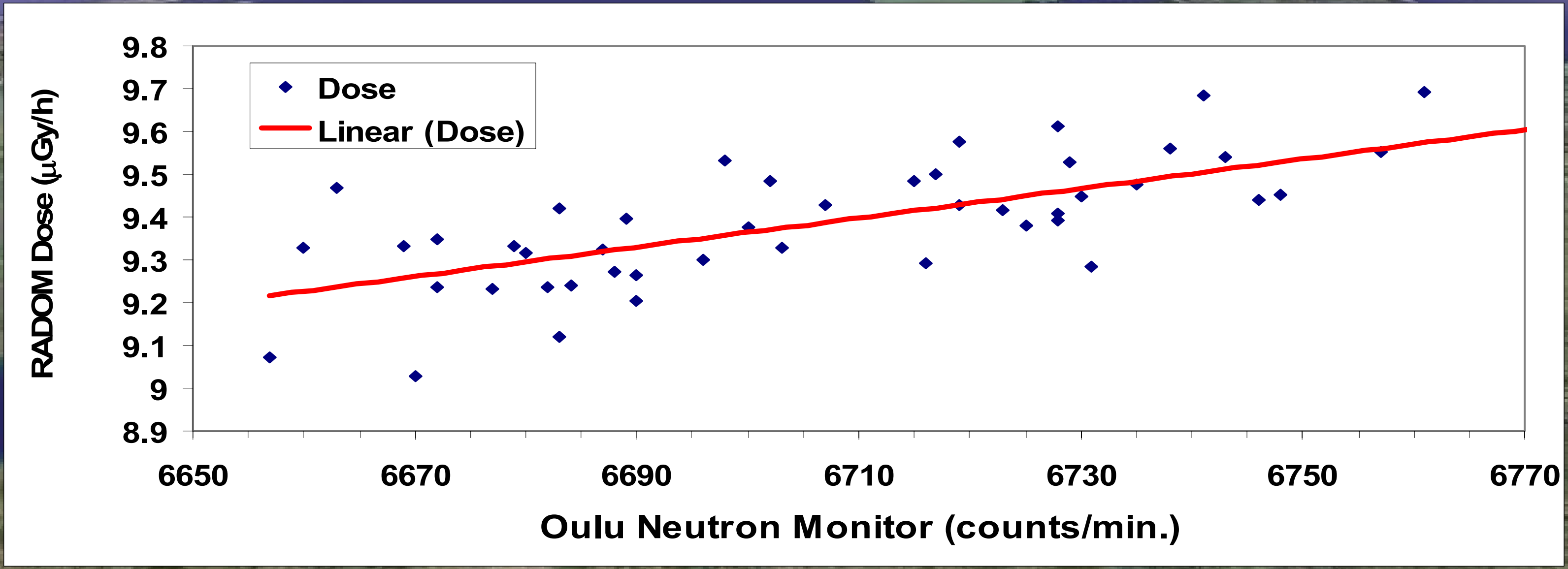
Chandrayaan-1 is at 200 km circular orbit since 19th May 2009



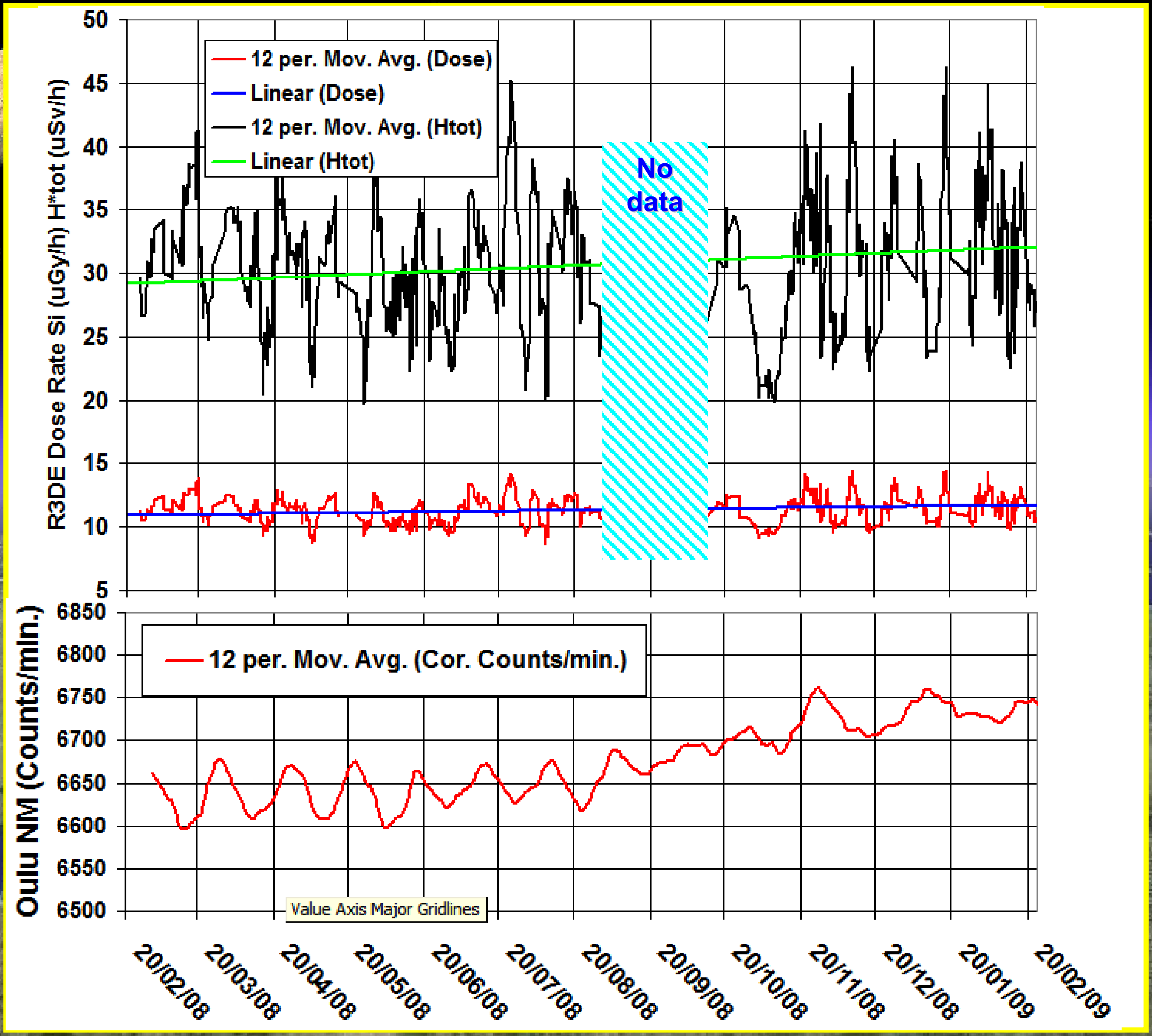
Because of smaller shielding from the body of the Moon the doses rice by more than 2 μGy/h and reach 10.85 μGy/h

The averaged per day RADOM dose around the Moon is rising in linear way in dependence by GCR

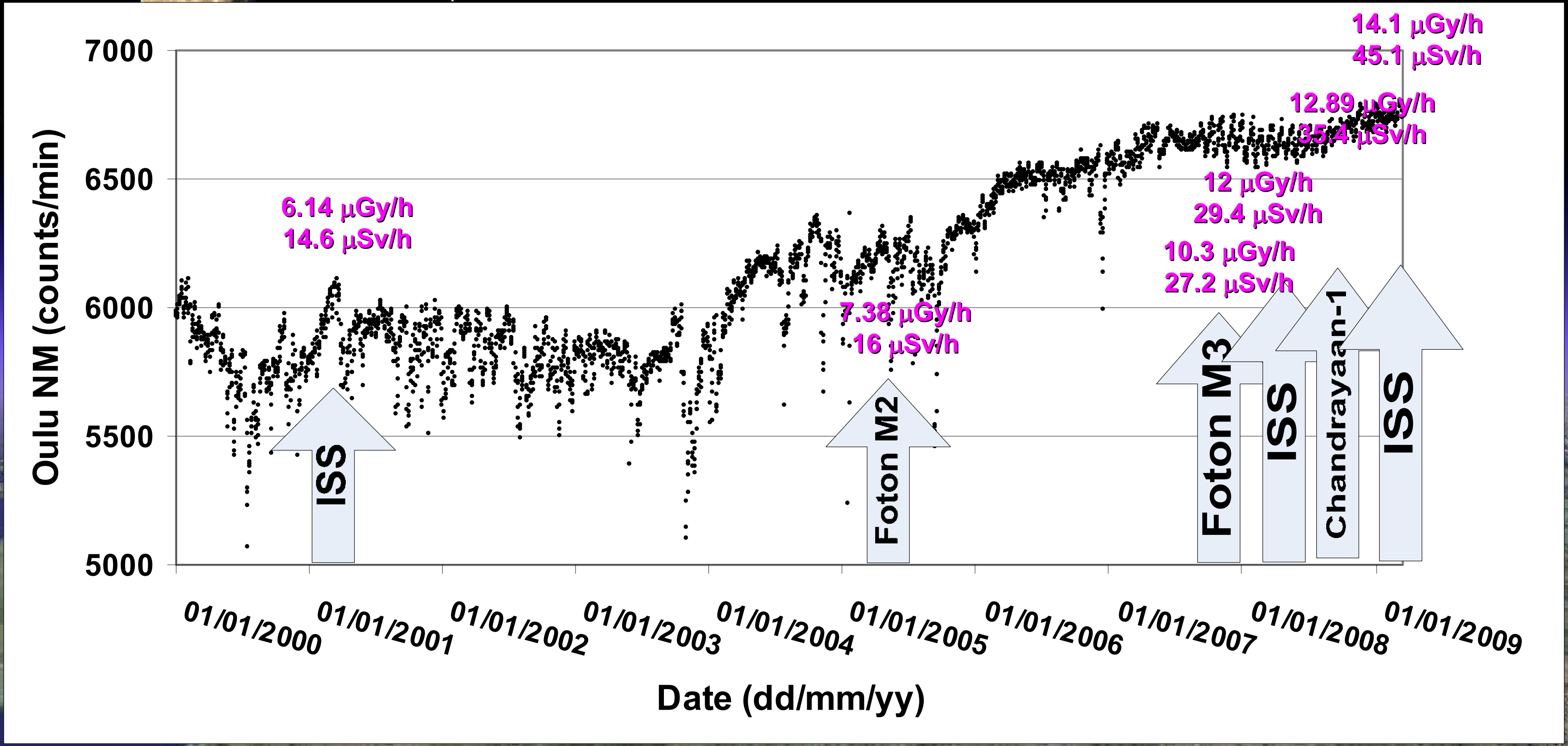




Comparison of the R3DE dose rates obtained at 5.0<L<5.05 with Oulu NM counts/min.

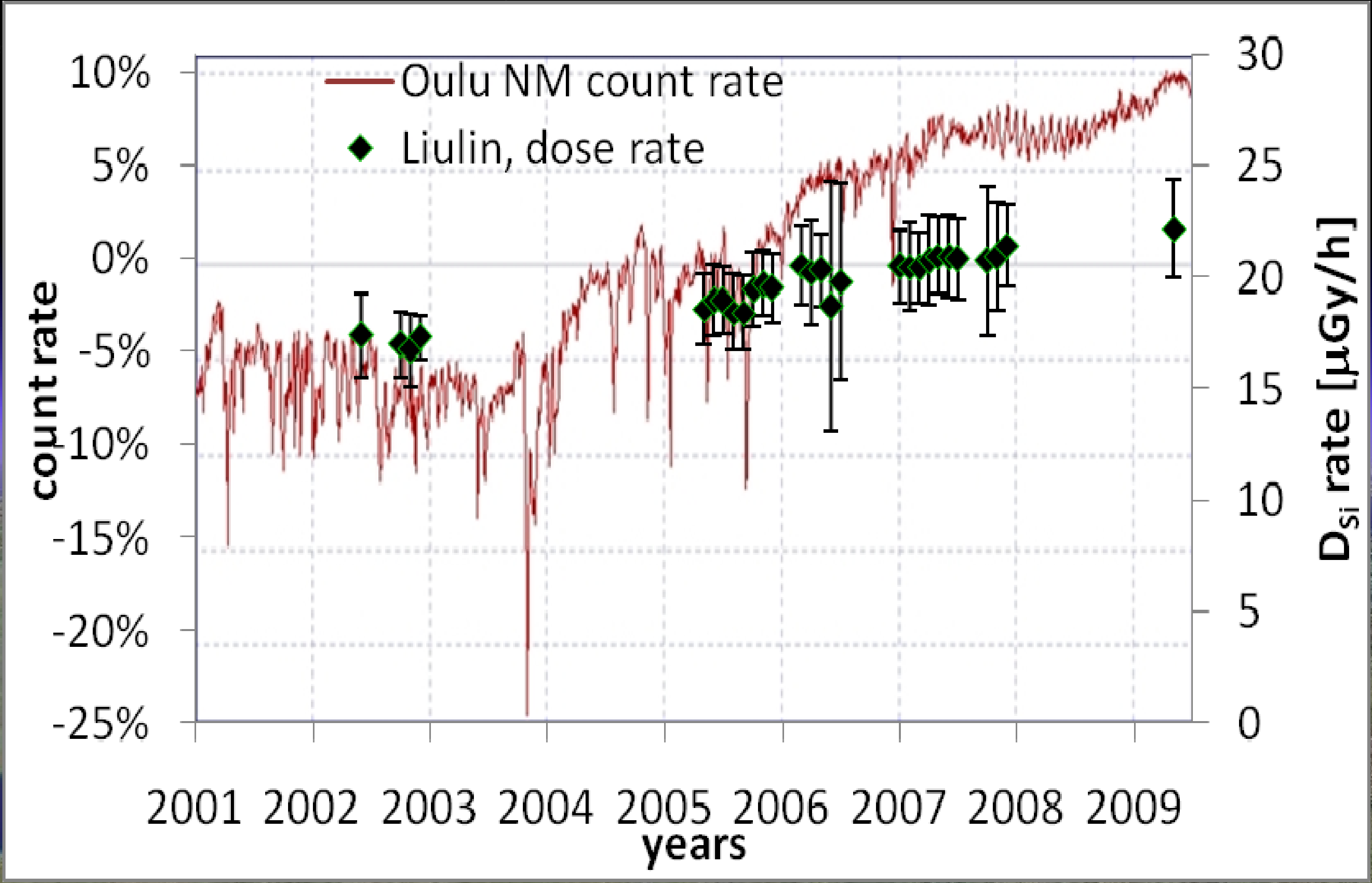


Long-term GCR doses obtained on different satellites comparison with Oulu neutron monitor data

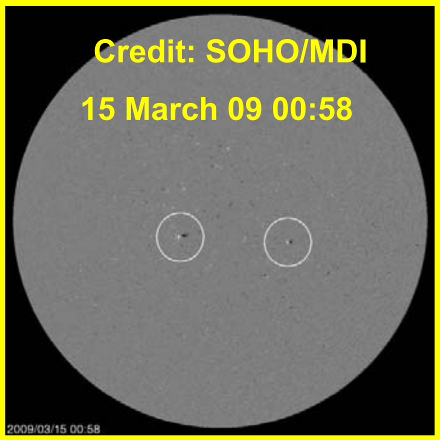


Solar minimum GCR doses measured by us in low earth orbit rise twice when the solar activity decline from 2000 to 2009

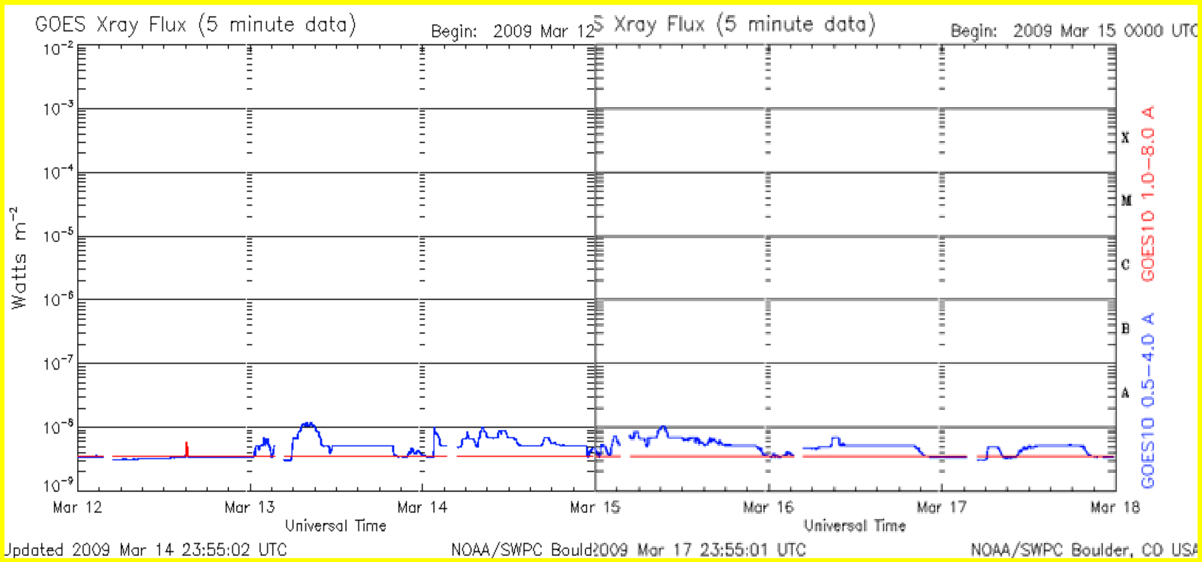
Comparison of Liulin absorbed dose rates with Oulu neutron monitor count rates



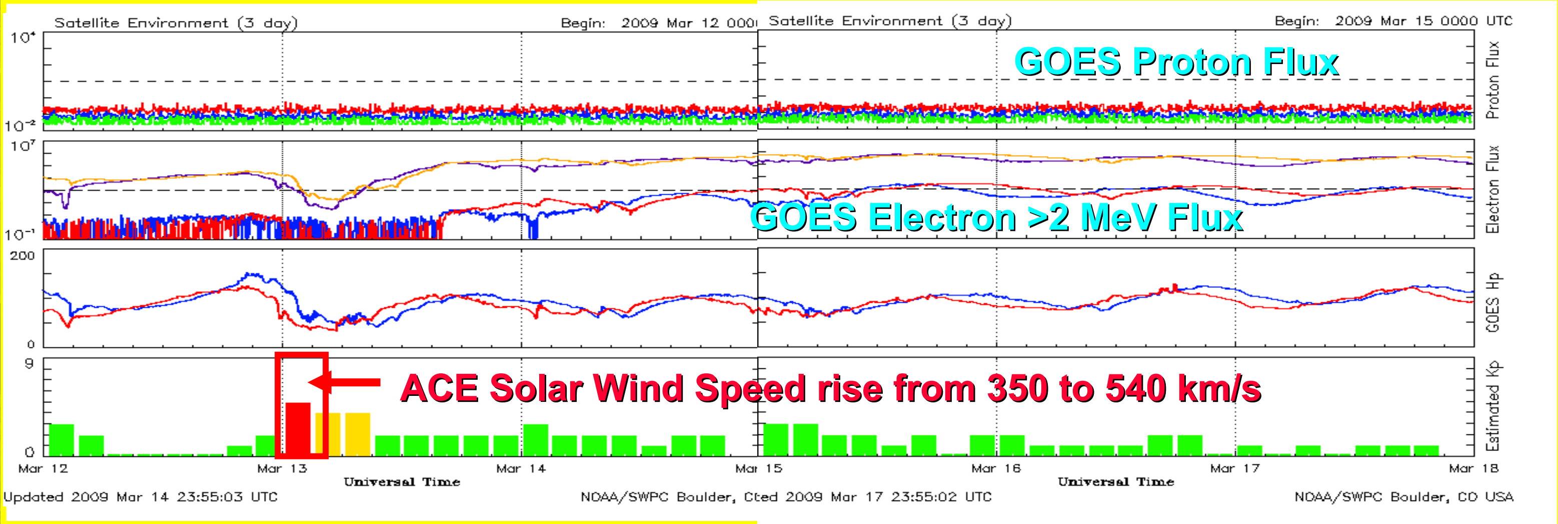
Observations during the first cycle 24 Sun flares March 12-17 2009



Daily Sun: 15 Mar 09 Two proto-sunspots are simmering near the sun's equator

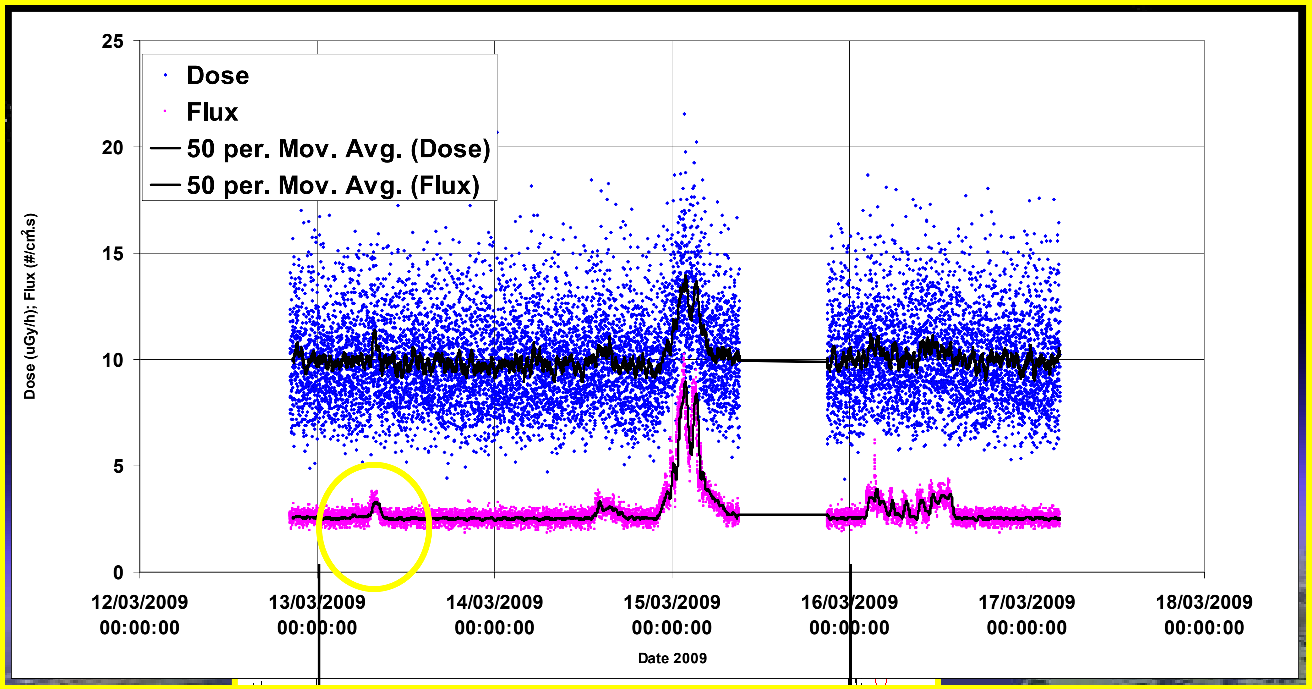


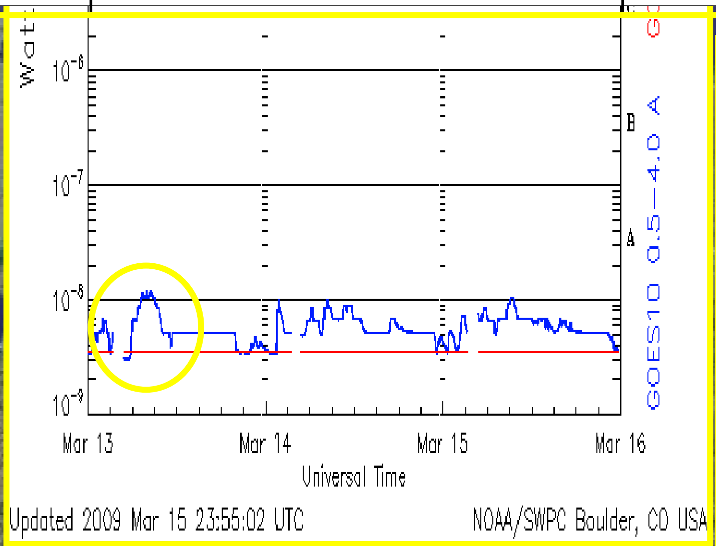
GOES X ray Flux



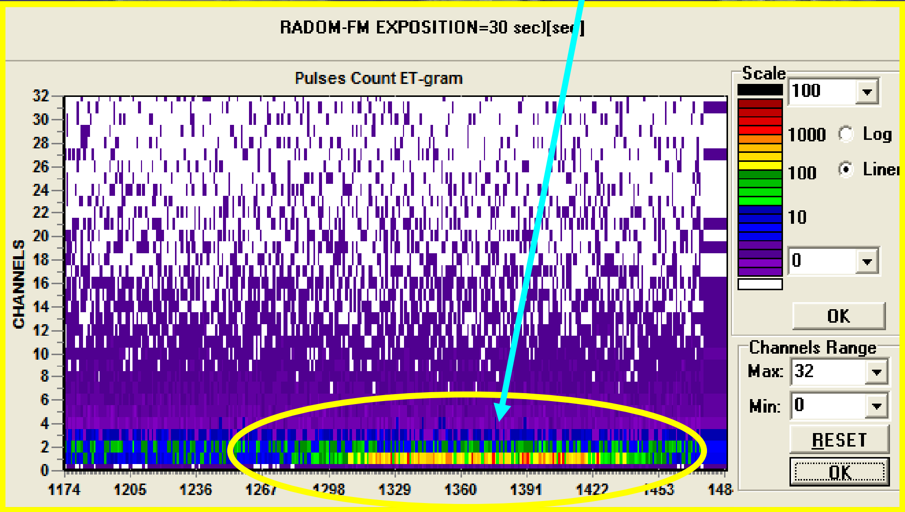
GOES Proton and Electron Flux

Comparison of the RADOM dose/flux data with the GOES10 0.5- 4.0 A Xray data

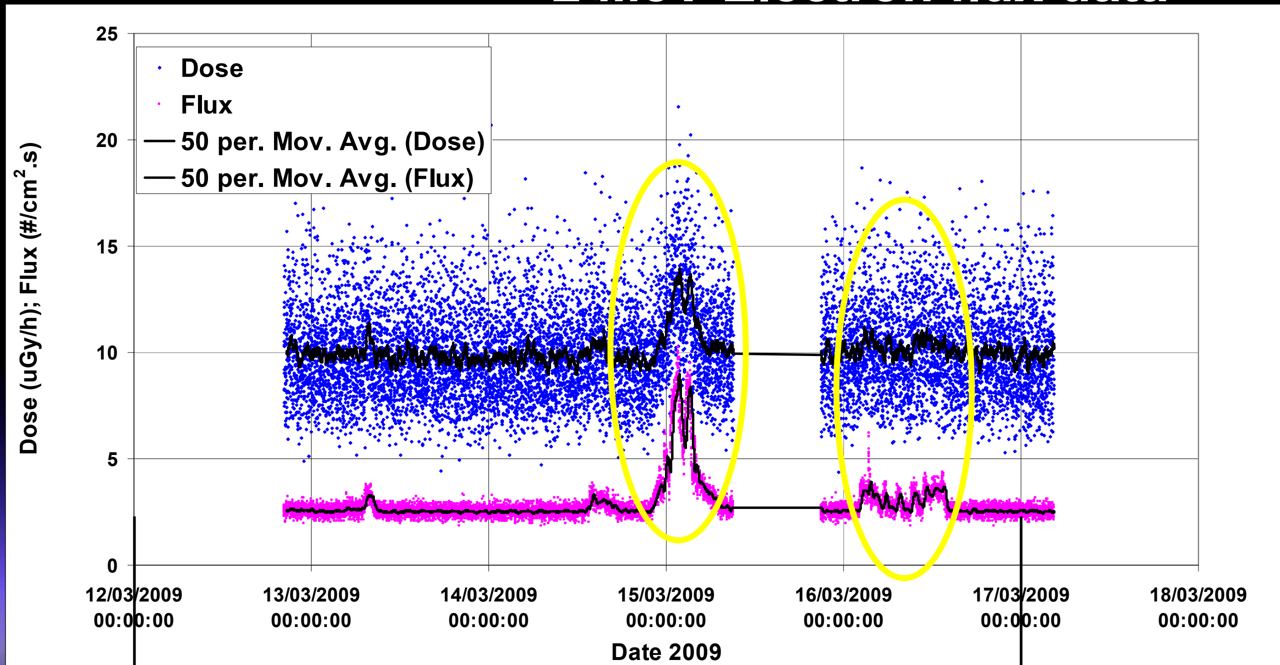




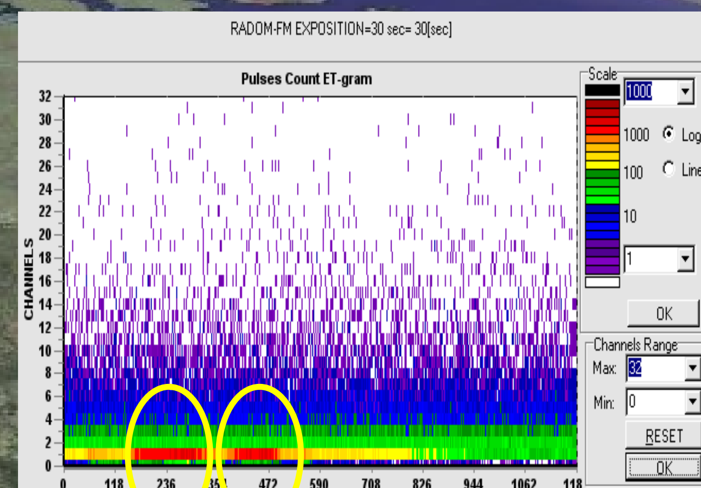
Only the first RADOM channel is enhanced, which means very low energy deposition



Comparison of the RADOM dose/flux data with the GOES11 >2 MeV Electron flux data



Only the first RADOM channel is enhanced, which means very low energy deposition



Authors thanks to V. Girish who first mention the flare data

3 new space experiments are under development

Liulin – Phobos engineering model

Liulin-Phobos

Objectives: Measurements during the cruise phase, on Mars's orbit and on the surface of Phobos. Estimation of the radiation doses received by the spacecraft electronics and assessment the radiation risk to crew of future exploratory flights to Mars.

Cooperation: STIL (Bulgaria), IMBP (Russia), NIRS (Japan), Lavochkin Space Association, Russia

Phobos - Soil sample return apparatus

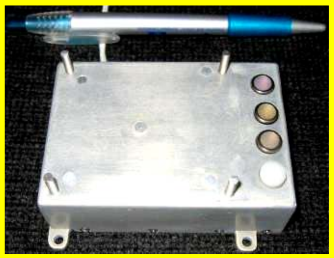
Liulin – S engineering model

Liulin-S instrument

Objectives: Measurements during the descending phase of one "Orlan" type space suit "thrown" from International Space station.

Cooperation: STIL (Bulgaria), IMBP (Russia), Lavochkin Space Association, Russia

"Orlan" space suit



R3D-B3 instrument

R3D-B3 instrument

Objectives: Measurements during the about 1 month flight of BION-M satellite around the Earth.

Cooperation: STIL (Bulgaria), IMBP (Russia), FAU, Germany, Lavochkin Space Association, Russia

BION-M satellite

Conclusions

- RADOM spectrometer proved its availability to characterize the different radiation fields in the Earth and Moon radiation environment. The proton and electron radiation belts in the Earth magnetosphere was well recognized. The electron radiation belt doses reached 4.104 μGy/h, while the fluxes are 15000 #/cm^2.s. The proton radiation belt doses reached the highest values of 1.2.105 μGy/h, while the fluxes are 9100 #/cm^2.s;
- The galactic cosmic rays (GCR) dose rates around Earth was about 12 μGy/h. Away from the Earth GCR reached 13.2 μGy.h^{-1}. At 100 km orbit the doses fall down to about 9.6 μGy/h. The rise of the orbit to 200 km increase the doses to 10.8 μGy/h;
- The total accumulated dose during the transfer from Earth to Moon is about 1.3 Gy;

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Thank you