New Results for the Earth Radiation Environment

Tsvetan DACHEV¹, Borislav TOMOV¹, Plamen DIMITROV¹
Yury MATVIICHUK¹, Frantisek SPURNY²

¹Solar-Terrestrial Influences Laboratory, Bulgarian Academy of Sciences, Bulgaria, tdachev@bas.bg

²Nuclear Physics Institute, Czech Academy of Sciences, Czech Republic, spurny@ujf.cas.cz
Outlook

- Liulin type instruments.
  Short Introduction
- Study of the Liulin MDU spectra and ambient equivalent dose distribution at different carriers and locations
- Future use of Bulgarian build spectrometers
- Conclusions
Liulin type instruments.
Short Introduction
New results...

Internal and External view of some last modifications Liulin type instruments

Internal view of Internet based device, which create own WEB page with the obtained data.

External view of rechargeable battery device with LCD display, showing current absorbed and ambient dose equivalent and the accumulated dose since the beginning of the measurements.

WRMISS-12, Stilwater, USA, 10 Sept. 2007
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; 512 MB SD/MMC card.

More than 30 days working time from accumulator.

More than 4 days working time from Li-Ion accumulator.

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

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

Walk in STIL-BAS area as obtained by GPS receiver mounted in Liulin type spectrometer. Yellow line is 20 m.

11 Liulin type spectrometers during calibrations in CERN, October 2007.

WRMISS-12, Stilwater, USA, 10 Sept. 2007
Integrated Block - diagram of the Liulin type devices

- Radiation
  - Detector 2 cm²; 0.3 mm
  - Preamplifier
  - 12 bit ADC
- Battery
  - 3.6 V DC
  - 7.2 V DC
- AC/DC Converter
  - 12 V DC
  - 220 V AC
  - 28 V DC
- Real-time clock
- Internet Module Microcontroller
- Master Microcontroller
- Satellite telemetry
  - USB Serial or Parallel port
- GPS antenna
- GPS Receiver
- GPS MCU
- Flash memory
- MMC or SD card
MDU - Liulin aircraft dose interpretation procedure

1) Dose in Si is calculated as:

\[ D = K \times \sum (E_i \times A_i) \times MD, \]

where

- \( MD \) – mass of the detector;
- \( E_i \) – energy loss in the channel \( i \);
- \( A_i \) – events number in the channel \( i \);
- \( K \) – coefficient based on \( W_e \) in Si

2) Apparent dose equivalent \( H \) (Ambient dose equivalent - \( H^{*}(10) \)) is calculated as:

- \( D(Si) \) above \( \sim 1 \) MeV \( (D_{\text{high}}) \) neutron like component
- \( D(Si) \) below \( \sim 1 \) MeV - \( (D_{\text{low}}) \) non-neutron component

\( D_{\text{low}} \) and \( D_{\text{high}} \) – multiplied by a coefficient to get \( H^{*}(10)_{\text{high}} \)

Coefficients – established in CERF fields and/or on the base of comparison with TEPC results

New results...
MDU – Liulin spacecraft dose interpretation procedure

GCR
Supposed that:
\( E_{\text{dep}} \text{ bellow} \sim 1 \text{ MeV} \) low LET component
\( E_{\text{dep}} \text{ above} \sim 1 \text{ MeV} \) high LET component composed of:
neutron component, with similar spectra as onboard aircraft, and
correction of HECP of GCR
Interpreted as:
Low LET component: \( D(\text{Si}) \rightarrow D(\text{tissue}) \rightarrow "H^*(10)" \);
High LET or Neutron component: as onboard aircraft;
GCR component: \( D(\text{Si}) \times 5 \rightarrow D(\text{tissue}) = "H^*(10)" \);
To get as good statistical reliability as possible to distinguish neutron
and GCR contribution - for energy deposition spectra above \sim 1 \text{ MeV} – all
aircraft spectra (\sim 6000 \text{ hours}; \sim 30 \text{ mSv}) summed up and regressed

SAA
Supposed that all events are due to protons of SAA
Interpretation:
\( D(\text{Si}) \rightarrow D(\text{tissue}), \) and
\( D(\text{tissue}) \times QF_{\text{average}} \) calculated from energy distribution spectra (\sim 1.3) =
"H^*(10)"
Study of the Liulin MDU spectra and ambient equivalent dose distribution at different carriers and locations
Comparison of absorbed dose data obtained by Liulin MDUs and NASA TEPC at ISS*


New results... WRMISS-12, Stilwater, USA, 10 Sept. 2007
Comparison between NASA TEPC and MDU doses. H*(10) MDU doses are calculated as shown on next slide.

Authors are thankful to Dr. E. Semones for the Phantom TORSO NASA TEPC data.
New results... New results...

**Tabulated results from previous slide**

\[
H_{GCR}^{*}(10) = K \left\{ \sum_{i=1}^{14} k_i A_i + 5 \sum_{i=15}^{256} k_i A_i \right\} / MD
\]

\[
H_{SAA}^{*}(10) = K \left\{ 1.3 \sum_{i=1}^{14} k_i A_i + 1.3 \sum_{i=15}^{256} k_i A_i \right\} / MD
\]

<table>
<thead>
<tr>
<th>Dose/Instrument Position</th>
<th>(H^*(10))low (\mu\text{Sv/h})</th>
<th>(H^*(10))high (\mu\text{Sv/h})</th>
<th>(H^*(10))tot (\mu\text{Sv/h})</th>
<th>(D \mu\text{Gy/h})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liulin MDU#4 Equator (GCR) (mean value over 81 spectra)</td>
<td>1.2</td>
<td>1.37</td>
<td>2.58</td>
<td>1.48</td>
</tr>
<tr>
<td>Liulin MDU#4 Equator (GCR) (%)</td>
<td>47</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phantom TORSO NASA TEPC (GCR) (%)</td>
<td>29</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liulin MDU#4 L~3 (GCR) (mean value over 63 spectra)</td>
<td>4.29</td>
<td>10.6</td>
<td>14.89</td>
<td>6.41</td>
</tr>
<tr>
<td>Liulin MDU#4 L~3 (GCR) (%)</td>
<td>29</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phantom TORSO NASA TEPC (GCR) (%)</td>
<td>29</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liulin MDU#4 SAA (Trapped) (mean value over 33 spectra)</td>
<td>85.1</td>
<td>53.4</td>
<td>138.5</td>
<td>106.7</td>
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<tr>
<td>Liulin MDU#4 SAA (Trapped) (%)</td>
<td>61</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phantom TORSO NASA TEPC (Trapped) (%)</td>
<td>71</td>
<td>29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Best results from the comparison are obtained for GCR component at L~3;
- The results for GCR component in equatorial region are fair;
- Trapped radiation comparison is relatively good.
Selection procedures and data positions

ISS Liulin-E094 MDU#4; 6-13 July 2001
Foton M2 R3D-B2; 1-12 June 2005

- 0.9 < L < 1.1
- L > 2.8
- Foton Outer Radiation Belt

Gmag = 0.21 Gauss (SAA)
ISS trapped
Magnetic Equator
Foton Trapped

New results...
GCR component as seen by ISS Liulin MDU#4, Foton M3
R3D-B3 and CSA MDU-5 instruments

- The Outer RB spectra, which is created mainly by electrons have very high count rate in low LET region;
- The neutron component is less than 12%;
- At energies above 1.6 MeV it coincide with the usual GCR spectra for these latitudes

►► All spectra with GCR component are with equal slope in high LET region;
►► Higher doses bring higher Y axes values;
►► The neutron component is higher than 60%

New results...
All deposited dose spectra observed at different locations at aircrafts, Foton M2 spacecraft and ISS

<table>
<thead>
<tr>
<th>Location</th>
<th>Dep. Dose magn. eq.</th>
<th>Dep. Dose at L&gt;2.8</th>
<th>Dep. Dose in SAA &gt;100</th>
<th>Dep. Dose in SAA Ch15&gt;30</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS: MDU#4; July 6-13 2001</td>
<td>1.48 uGy/h; 2.58 uSv/h; 53% neutrons</td>
<td>6.41 uGy/h; 14.6 uSv/h; 71% neutrons</td>
<td>150 uGy/h; 195 uSv/h; 41% neutrons</td>
<td>283 km, 220 uGy/h; 285 uSv/h; 59% neutrons</td>
</tr>
<tr>
<td>Foton: R3D-B2; June 1-12 2005</td>
<td>ISS: Dep. Dose at L&gt;2.8; 14.1 uGy/h; 26.3 uSv/h; 58% neutrons</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CSA; MDU#5; 6 May - 25 June 2005</td>
<td>ISS: Dep. Dose at L&gt;2.8; 1.25 uGy/h; 2.78 uSv/h; 70% neutrons</td>
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<td></td>
</tr>
<tr>
<td>CSA; MDU#5; 5 May - 28 June 2002</td>
<td>Foton: Dose at L&gt;2.8; 271 km; 128 uGy/h; 143 uSv/h; 12% neutrons</td>
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<td></td>
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<tr>
<td></td>
<td>CSA 2002 and 2005: Dose at Lat.&lt;35° Alt.&gt;10.6 km; 0.96 uGy/h</td>
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<tr>
<td></td>
<td>CSA 2002 and 2005; Dose at Lat.&gt;50° Alt.&gt;10.6 km; 1.96 uGy/h</td>
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</tr>
</tbody>
</table>

New results...
New results... WRMISS-12, Stilwater, USA, 10 Sept. 2007

<table>
<thead>
<tr>
<th>Dose/Carrier/Instrument Position</th>
<th>H*(10) mSv/h</th>
<th>Abs. Dose mGy/h</th>
<th>% Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ISS Liulin MDU#4; &gt;10 g/cm²</strong></td>
<td>2.58</td>
<td>1.48</td>
<td>53</td>
</tr>
<tr>
<td>Equator (GCR) (mean value over 2414 spectra)</td>
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<td></td>
</tr>
<tr>
<td><strong>Foton M3 R3D-B2; &lt; 2 g/cm²</strong></td>
<td>2.78</td>
<td>1.25</td>
<td>70</td>
</tr>
<tr>
<td>Equator (GCR) (mean value over 2434 spectra)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>GCR Phantom TORSO NASA TEPC (%)</strong></td>
<td></td>
<td></td>
<td>71</td>
</tr>
<tr>
<td><strong>GCR DOSTEL</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>ISS Liulin MDU#4 &gt;10 g/cm²</strong></td>
<td>14.6</td>
<td>6.41</td>
<td>71</td>
</tr>
<tr>
<td>L&gt;2.8 (GCR) (mean value over 2098 spectra)</td>
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</tr>
<tr>
<td><strong>Foton M3 R3D-B2; &lt; 2 g/cm²</strong></td>
<td>26.3</td>
<td>14.1</td>
<td>71</td>
</tr>
<tr>
<td>L&gt;2.8 (GCR) (mean value over 4454 spectra)</td>
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<tr>
<td><strong>GCR Phantom TORSO NASA TEPC (%)</strong></td>
<td></td>
<td></td>
<td>78</td>
</tr>
<tr>
<td><strong>GCR DOSTEL</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>ISS Liulin MDU#4 &gt;10 g/cm²</strong></td>
<td>195</td>
<td>150</td>
<td>41</td>
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<tr>
<td>SAA (Trapped) (mean value over 129 spectra)</td>
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<td></td>
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<tr>
<td><strong>Foton M3 R3D-B2; &lt; 2 g/cm²</strong></td>
<td>285</td>
<td>220</td>
<td>29</td>
</tr>
<tr>
<td>SAA (Trapped) (mean value over 164 spectra)</td>
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<td></td>
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</tr>
<tr>
<td><strong>GCR Phantom TORSO NASA TEPC (%)</strong></td>
<td></td>
<td></td>
<td>58</td>
</tr>
<tr>
<td><strong>GCR DOSTEL</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>Foton M3 R3D-B2; &lt; 2 g/cm²</strong></td>
<td>143</td>
<td>128</td>
<td>12</td>
</tr>
<tr>
<td>L&gt;2.8 (GCR) Outer radiation belt (mean value over 164 spectra)</td>
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</table>

► Liulin MDU H*(10) calculations in general underestimate the neutron component.
► Best results of the comparison with TEPC and DOSTEL are obtained at L>2.8.
► Worst are the comparison in SAA region, because neutrons coming from GCR are masked by bulk of protons.

New results...
SAA (trapped radiation) spectra as seen by ISS Liulin MDU#4 and Foton M3 R3D-B3 instruments

- SAA spectra are with double slope;
- The SAA maximum energy on ISS of 100-110 MeV is moved at Foton M2 to lower energy of 40-50 MeV because of lower altitude

New results...
Move of the SAA central location by altitude

The Foton M2 SAA central location moves at southeast direction at lower altitudes, because of lower proton incident energy.

New results...
ISS descending orbits SAA crossing variations

The SAA maximum energy on ISS from 100-110 MeV at L=1.25 is moved to lower energy of 40-50 MeV at L=1.85 because of lower magnetic field strength.

New results...
Movement of the SAA maximum location on ISS in dependence of the energy of protons

MDU#2 Descending June 26 - July 6 2001

Counts

MDU#2 Descending June 26 - July 6 2001

Counts
The specific doses are very similar at ISS and Foton M2 in the $1.15 < L < 1.6$.
Averaged doses and fluxes in Northern hemisphere observed on aircrafts, Foton M2 satellite and ISS

The relations between the dose and flux values do not change in the latitude range 10°-30° degree and are related as 1:2:3.

New results...
ISS was in one of two attitudes:

+XVV with the +x-axis parallel to the velocity vector

XPOP (x-axis perpendicular to plane of orbit) with +z-axis constantly pointing toward the Sun & no fixed leading edge

Node1 – zenith area of forward hatch (combined with TLD104)
In some locations the orientation do not play important role for the dose values

ISS Liulin MDU No2
SAA, Descending orbits

Deposited dose (uGy/h)

Node1 – Zenith area of forward hatch (combined with TLD 104)

Deposited energy (MeV)
Future use of Bulgarian build spectrometers

New results...
### Expected space and groundbased experiments in which we are involved

<table>
<thead>
<tr>
<th>Expected groundbased and in space experiments</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start 2007</td>
</tr>
<tr>
<td></td>
<td>2007</td>
</tr>
<tr>
<td>Liulin-ISS on RS of ISS</td>
<td>??</td>
</tr>
<tr>
<td>Liulin-R rocket experiment</td>
<td></td>
</tr>
<tr>
<td>R3D-B3 on Biopan on Foton M3</td>
<td></td>
</tr>
</tbody>
</table>
| R3D1 on ISS ESA-Columbus EuTef                 | ?? | | | | | ??
| R3D2 on Russian Segment of ISS                 | ?? | | | | | ??
| RDOM on Chandrayaan-1 satellite in 100 km Moon orbit | | | | | | ??
| Liulin-F on Phobos-Grund                       | | | | | | ??
| Liulin-R, ALOMAR, Norway                       | | | | | | |
| Liulin-M on Mousala 2925 m                     | | | | | | |
Liulin-ISS Instrument was launched in September 2005 to the Russian Segment of ISS. It is a part of Russian segment service dosimetric system and will be activated in the end of 2007.

MDU Liulin-ISS dimensions:
Weight: 229 g incl. 80 g battery
Size: 110x80x25 mm
Consumption: 84 mW
The R3D1/2 UV and space radiation spectrometers is expected to be launched inside of EXPOSE facility to Russian segment of ISS and to ESA COLUMBUS module in 2008. They are developed with the University in Erlangen, Germany.

**R3D DIMENSIONS:**
- **Weight:** 189 g
- **Size:** 76x76x36 mm
- **Consumption:** 120 mW

**New results...**

**EuTEF-FM**

**R3D/1 Flight unit mounted in the EXPOSE facility (May 2003)**

**R3D/1 Flight unit mounted in the EXPOSE facility (May 2003)**

**PAR channel**

**UV-A channel**

**UV-B channel**

**UV-C channel**

**Vibration tests in ESA May, 2003**

**EXPOSE**

**COLUMBUS**

**Russian segment**
R3D-B3 UV and space radiation spectrometer for ESA Biopan-6 facility outside of Foton M3 satellite will be launched on 14 September 2007. The spectrometer is mutually developed with the University in Erlangen, Germany.

**Block-Diagram of R3D-B3 instruments**

- **Silicon Detector**: 2 cm², 0.3 mm
- **Charge sensitive preamplifier A225**
- **Discriminator**
- **12 bit Analog to digital converter**
- **SRAM 512 b**
- **Slave Microcontroller**
- **Master Microcontroller**
- **12 bit ADC**
- **Amplifier**
- **Amplifier shaper**
- **Amplifier shaper**
- **Amplifier shaper**
- **Amplifier shaper**
- **Temperature sensor**
- **PAR Photo Diode and Filter**
- **UV-A Photo Diode and Filter**
- **UV-B Photo Diode and Filter**
- **UV-C Photo Diode and Filter**
- **+12 V DC 6 - 11 mA**
- **Biopan 5 Platform**
- **I2C Interface**
- **1 MB Flash Memory**

**Foton-M3**

- **Service Module**
- **Re-entry Module**
- **TSU Antenna**
- **Battery Module**
- **Biopan External Experiment Facility**

**Biopan-6 in ESA September 2007**
3 more experiments are under development

**Liulin-R instrument for ESA-Norwegian rocket**

Launch in October 2007

Rocket launch up to 280 km from Andoya, Norway (69.3° N)

Weight: 105 g
Size: 104x40x20 mm
Consumption: 120 mW

**Liulin-F instrument for Russian Phobos-Ground satellite**

Launch in 2010.

On the Phobos surface for 2 years

Weight: 400 g
Size: 100x100x50 mm
Consumption: 520 mW

**RADOM instrument for Indian Chandrayaan-1 satellite.** Launch in April 2008. Lifetime 2008/2010

Satellite at 100 km over the Moon surface for 2 years

Weight: 98 g
Size: 104x40x20 mm
Consumption: 120 mW
Conclusions

- Data obtained by Liulin type instruments on ISS, Foton M2 satellite and aircrafts since 2001 are analyzed to try to evaluate the contribution of neutron component in the spectra of energy deposited in Si-detector. The dose in Si, $D(Si)$, was converted to obtain an apparent dose equivalent $H_{app}$.

- The conversion coefficients used were obtained during calibrations of Liulin type instruments at the CERN (CERF) and on the base of intercomparison with TEPC during common measurements in dedicated aircraft flights.

- Liulin MDU values of $H_{app}$ obtained in general underestimate a little the neutron component obtained by TEPC.

- Best agreement with the values results of the comparison with TEPC are obtained at $L>2.8$.

- As expected the other radiation belt spectra contains very low neutron component in the spectra.

- Expected new space experiments with Liulin type spectrometers on Foton M3 satellite, ISS and Indian Moon Chandrayaan-1 satellite are shortly presented.
Thank you for your attention
All MDU all data on ISS for July 6-13 2001

All MDU; SAA+GCR data July 6-13

- MDU#1 = 2.22 uGy/h
- MDU#2 = 2.42 uGy/h
- MDU#3 = 2.34 uGy/h
- MDU#4 = 2.53 uGy/h

Flux (cm^2 s^-1)

Deposited energy (keV/u)