Energetic Electrons Precipitating at High Latitudes: PEEL Data from HotPay-2 Mission

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Abstract: The instrument PEEL recorded low flux of precipitating energetic electrons during the flight of the HotPay-2 sounding rocket launched from Andoya Rocket Range (*Lat. 69°.18'N, Long. 16°.01'E*) on 31-JAN-2008 at 19:14:00 UT. After the brief description of the instrument, its possibilities and limitations to measure energetic electron flux in the upper atmosphere, the profile of counting rate obtained by the three detectors in four energy channels is presented. The epoch of solar activity minima and relatively low geomagnetic activity preceding the HotPay-2 mission, the detectors with given geometrical factor provided relatively low counting rate. Energetic particle precipitation contributes significantly to the energy deposition in the ionosphere and thus its measurements on rockets are important for the updating of models used in space weather forecasts. Such measurement device, can serve for space weather monitoring of energetic electrons present in the upper atmosphere. This type of in situ measurements can contribute to the completeness of the picture of electron flux (its high energy part) distribution and of its variability in the vicinity of Earth.

Keywords: Precipitating energetic electrons, rocket measurements, space weather.

1. INTRODUCTION

The energetic electrons precipitating into the atmosphere are subject of study for long time (*e.g.* [1-6] among others). The fine structure of the electron fluxes at high latitudes within the local loss cone was observed *e.g.* in papers [7, 8]. HotPay-2 provides a possibility to observe the energetic electrons at high latitudes below the altitude accessible from satellites.

The concept of the Hotel Payload rockets is described *e.g.* in [9]. The Hot Pay 2 project is described *e.g.* in [10]. The payload carried seven instrument packages, one of them was PEEL. Its position at HotPay-2 is in Fig. (**3**) of the above mentioned paper. More information about the instrument as well as on requirements, mechanical and electrical system, calibration and ground support equipment is in report [11]. Space Physics Department of IEP SAS in Košice, Slovakia, has a long track in design, construction, testing and running of measurements of energetic electrons and ions on various satellites (*e.g.* [12, 13], newer instruments at http://space.saske.sk). The ionisation of the upper atmosphere, especially at high geomagnetic latitudes, is influenced by energetic electron precipitation. While the energetic electron fluxes and its variability in space have been measured in various satellite and space probe missions, direct observations of the precipitation of electrons into the atmosphere are relatively rare. HotPay-2 provides opportunity to obtain such a piece of information.

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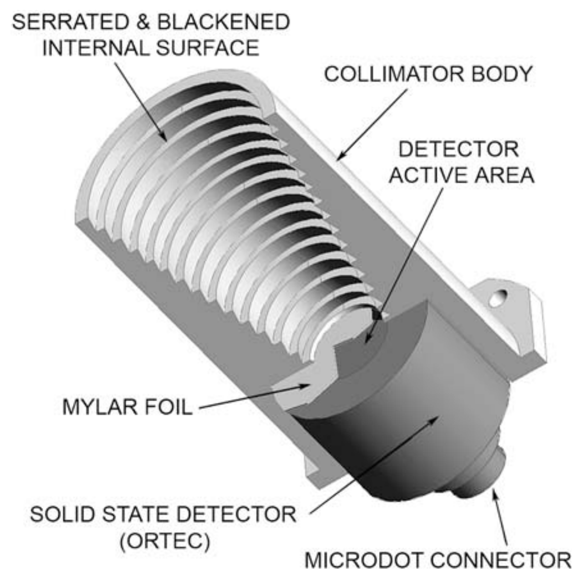

Fig. (1). Construction of the electron sensor.

After short description of the PEEL instrument, we present the first results of the measurements during that rocket mission and discuss the results obtained.

2. THE ELECTRON SENSOR

The PEEL electron sensor (Fig. **1**) is based on a solid state surface-barrier silicon detector with active area of 25 mm^2 and the depleted layer thickness of 300 μm. There is a mylar foil thickness of 3 μm installed in the detector entrance window that suppress entering of the ions to the detector. The electron flux is collimated with conical

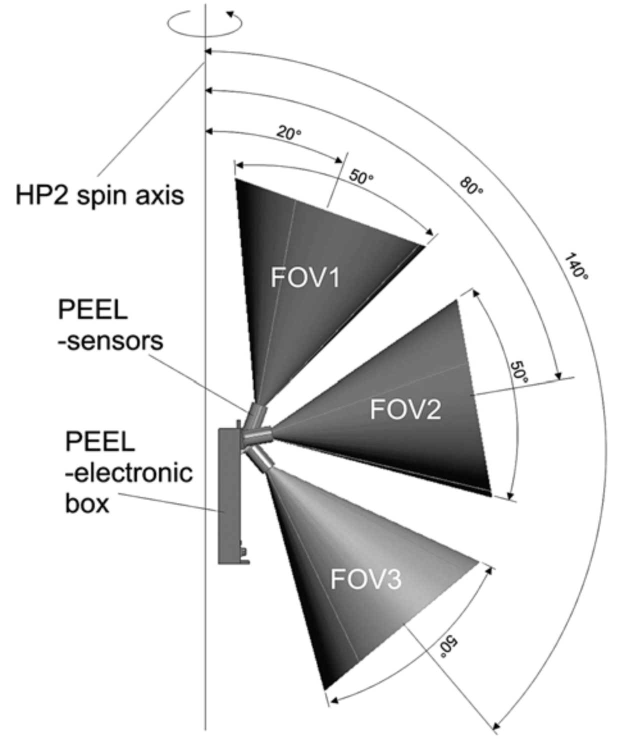

Fig. (2). Field of view of individual sensors related to the rocket spin axis.

collimator with serrated and blackened surface. The collimator provides a conical field of view 38° (fwhm), the overall sensor geometry provides the geometrical factor 0.077 cm^2.sr. The detector works in fully depleted mode under the bias voltage of 70 V. The signal of the detector is processed with charge sensitive electronics.

3. RECORDING OF THE ANGULAR DISTRIBUTION

The recording of the angular distribution of the electron flux is provided by using of 3 identical electron sensors mounted at the angles θ_1=20°, θ_2= 80° and θ_3= 140° made with the spin axis respectively (Fig. **2**). The relatively fast rocket spinning (4 s^{-1}) and fast temporal sampling of the PEEL device (62.62 samples s^{-1}) provides division of the azimuth plane to 15 sectors. Thus, the total angular coverage 160° × 360° is divided into 3 × 15 = 45 sectors.

4. RECORDING OF THE ENERGY DISTRIBUTION

Fig. (**3**) describes electrical design of the PEEL instrument. The signal from each semiconductor detector is preprocessed by a low noise charge sensitive preamplifier, by a pulse amplifier and finally by a shaping amplifier (τ = 1 μs). The stack of four discriminators provides discrimination to corresponding energy levels 30 keV, 60 keV, 120 keV and 240 keV respectively. The precise physical calibration was provided by the conversion electrons with discrete energies

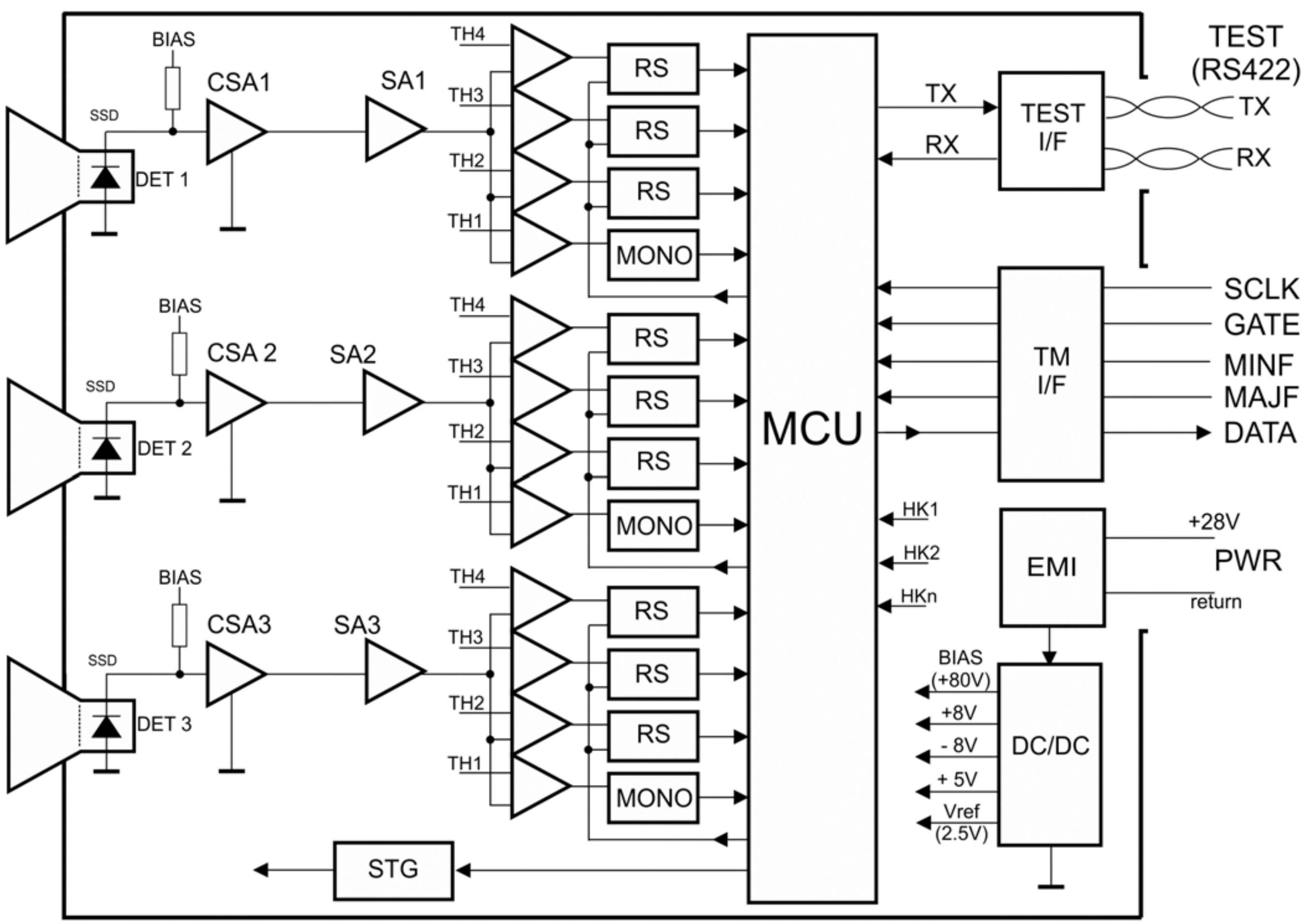

Fig. (3). Electrical design of the PEEL instrument.

62 keV and 84 keV from ^{109}Cd radioisotope. A simple hardware circuitry provides triggering and sampling of the individual events for the microcontroller. The microcontroller provides collection of the event data, formatting of the data frames and communication with the rocket telemetry. The telemetry signals are galvanically separated with fast optocouplers, the powering of the device is provided with galvanically separated DC-DC converter.

5. MECHANICAL DESIGN

The PEEL is designed as a compact unit (Fig. **4**) with all the electronic subsystems located on a single printed circuit board. The placing of the low-noise charge sensitive circuitry together with high-level digital and powering electronics required careful design and shielding policy. The unit consists of a flat metallic box with three external cylindrical sensors that are mounted to the box with wedge-shaped adapters to provide required angular orientation. The PEEL unit was installed in the nosecone part of the rocket to provide required free field of view for all three sensors. The nosecone aerodynamic shield has been jettisoned after 60 seconds of flight at the altitude of 71 km.

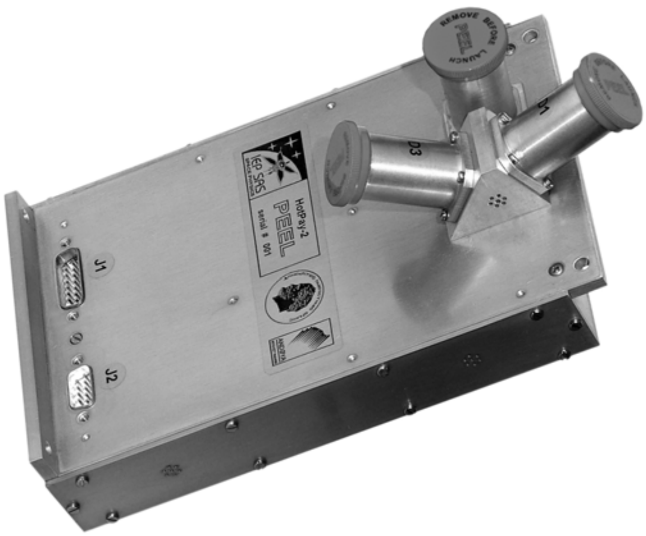

Fig. (4). Mechanical design of the PEEL instrument.

6. PEEL BASIC SPECIFICATION

Weight	0.96 kg
Dimensions	226mm × 124mm × 77mm
Power	2.1 W (75mA / 28V)
Sampling frequency	62.62 Hz
Temporal resolution	15.97 ms
Angular coverage	160° × 360° (3 × 15 sectors)
Sensor field of view	38°(fwhm) / 50° (max), conical
Geometrical factor	0.077 cm^{2}sr
SS-Detector thickness	300 μm
Mylar foil thickness	3 μm (+ 150 nm aluminium)
Energy channels	30 - 60 keV
	60 - 120 keV
	120 - 240 keV
	240 keV - ~ 350 keV
Dynamic range	2.6 × 10^6 (cm^2.s.sr)$^{-1}$
Telemetry rate	32051 bps

7. MEASUREMENT

Fig. (**5**) presents the plot of 1 sec sums of counting rate of detector 1 in the channels 1-4 during the flight. Fig. (**6**) shows plot of the flight trajectory. In addition, L parameter is added.

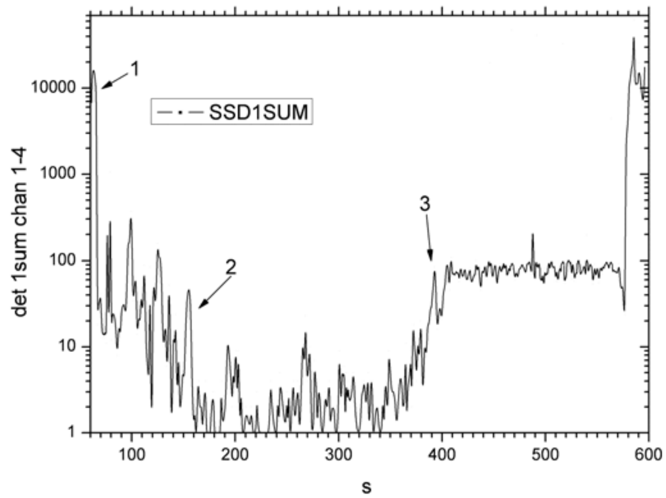

Fig. (5). The temporal profile of the sum of 4 energy channels of the detector 1 during the flight. The x-axis is in seconds after the launch at 19.14.00 UT on January 31, 2008. The 1 sec data were produced from 10 ms measurements available.

Relatively low flux of energetic electrons is observed during the flight and thus the angular distribution is not established from the existing data in the presentation here. The observations of precipitating electrons and X rays observed at the same site in a pulsating aurora indicate the isotropic flux of electrons in the energy range 10.8 - 250 keV above 10^7 (cm^2.s.sr)$^{-1}$ (figure 11 of paper 5). Using the geometrical factor 0.077 cm^2.sr of the PEEL and assuming the e-folding energy of the order of 10 keV and higher energy threshold of PEEL with respect to the detector described in [4], the highest pulse (event 1 in Fig. **5**) gives the value >10.8 keV electrons of the order of 2.10^6 which is by factor ~10 lower than what is observed during the strong geomagnetic activity [5]. The rocket campaign took place when auroral activity appeared after a long geomagnetically quiet period. There was relatively low geomagnetic activity during the mission. Dst (obtained from http://wdc.kugi.kyoto-u.ac.jp/dstdir/) was +2 nT and -2 nT for hour 19 and 20 UT respectively. The AE index (obtained from http://wdc.kugi.kyoto-u.ac.jp/aedir/) was < 190 and polar cap index pc = 1.3 (obtained from http://omniweb.gsfc.nasa.gov/). Records of magnetograms relevant for the mission are in [14]. Paper [14] reports the profiles of records of upper mesospheric and lower thermospheric electron, atomic oxygen and nitric oxide densities during the mission.

The launch of HotPay-2 was at different geomagnetic conditions, so we can just report the estimates of the fluxes of electrons during different phases of the flight in relatively quiet conditions. The values presented in Fig. (**5**) should be multiplied just by factor 13 to obtain the estimates of flux in units (cm^2.s.sr)$^{-1}$.

The maximum flux of > 30 keV electrons is observed during the event 1 (~2.10^5 $(cm^2.s.sr)^{-1}$) at about 80-100 km. Its averaged value is decreasing with the altitude to the level ~10 - 20 and it is again increasing with the decrease of altitude.

The three increases marked in Fig. (**5**) have the following energy spectra composition and downward to upward ratio at the low energies as shown in Figs. (**7-9**).

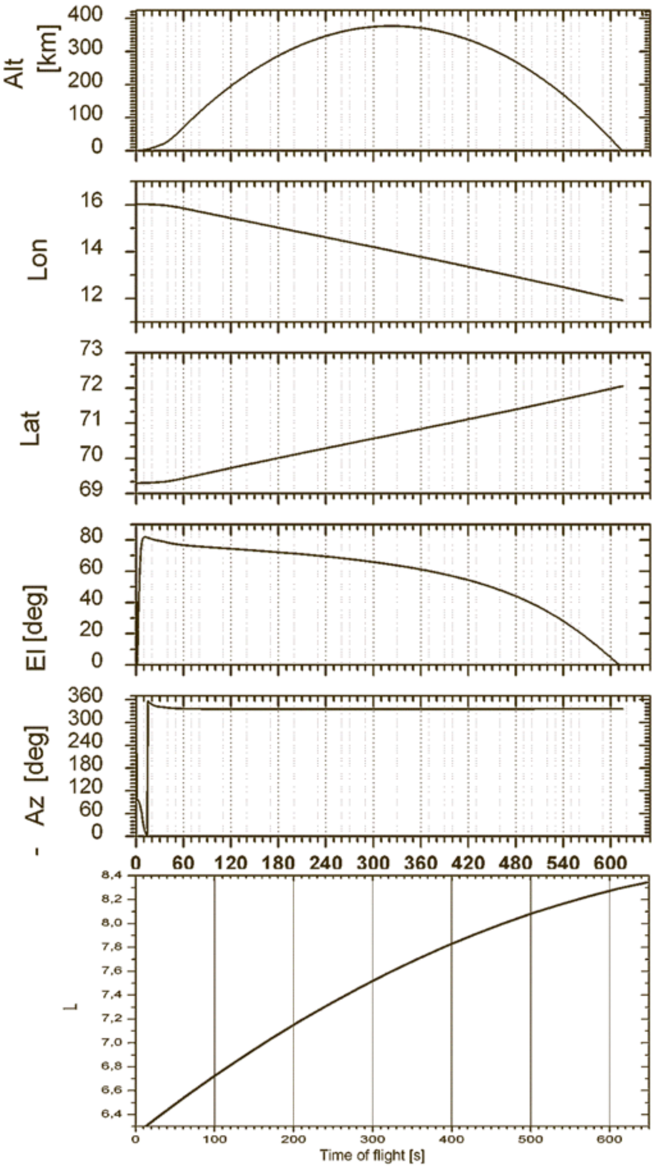

Fig. (6). The HotPay-2 flight trajectory and L - parameters.

There were several other instruments described in the Hot Pay 2 payload along with the results obtained, *e.g.*, in papers [14-18]. The observations by PEEL indicate very low flux of high energy precipitating electrons during the HotPay-2 mission. In paper [15] the authors discussing the measurements of electron, oxygen and nitric oxide density profile during the same rocket flight, it is mentioned that the precipitation (electrons, protons) is not sufficiently energetic to affect the upper mesosphere and lower thermosphere (UMLT) region. Energetic electron precipitation directly

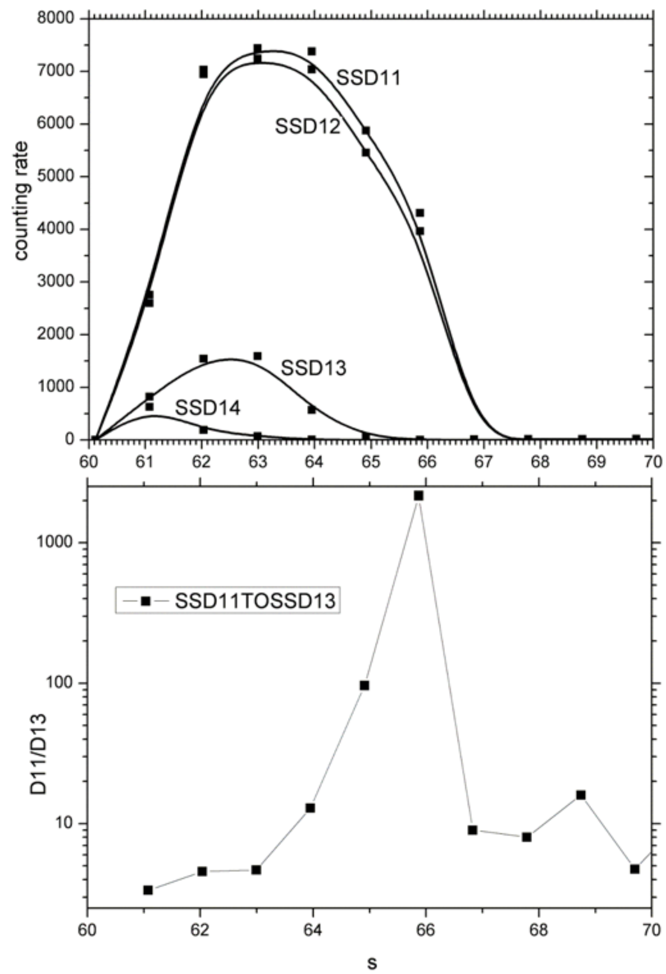

Fig. (7). The profiles of electron flux on detector 1 at 4 different energies for the event 1 marked in Fig. (**5**). The change of energy spectra shape is seen from lower panel (ratio of channel 1 to 3 is varying by more than 2 orders during the event.

affecting the UMLT altitude region do appear later during the continued Hotel Payload 2 ground-based measurement campaign in early February 2008. Thus the indication about extremely low flux of electrons measured by PEEL is qualitatively consistent with the data obtained by another measurement during the same mission.

8. CURRENT AND FUTURE DEVELOPMENTS

Rocket measurements can provide the information about the precipitating particles almost along the same field line at high latitudes (*e.g.* [19, 20] among others). Thus periodicities of precipitating electrons of purely temporal character can be observed with high time resolution (*e.g.* [21]). The energetic electron and proton precipitation observed on satellites and rockets is related to the processes like optical aurora (*e.g.* [21]), VLF emissions ([22-24]) and other phenomena. While several rocket measurements of precipitating electrons at energies below few tens of keV at various sites have been published, there are not numerous reports on higher energies. In most of the earlier publications rather sharp decrease of the energy spectra above ~10 keV is seen.

Although the energetic electron precipitation measurements have been done in the past decades, there are still questions requiring the new measurements at various positions and various times (local time, geomagnetic activity level). For example for the question of amount of NOx entering the stratosphere created by the energetic particle precipitation in the mesosphere and lower thermosphere discussed recently [25], the systematic rocket measurements of energetic electrons would be of interest. The same is probably valid for analysis of the enhancement of HOx recently done using [26]. These studies use mainly the energetic particle measurements from satellites.

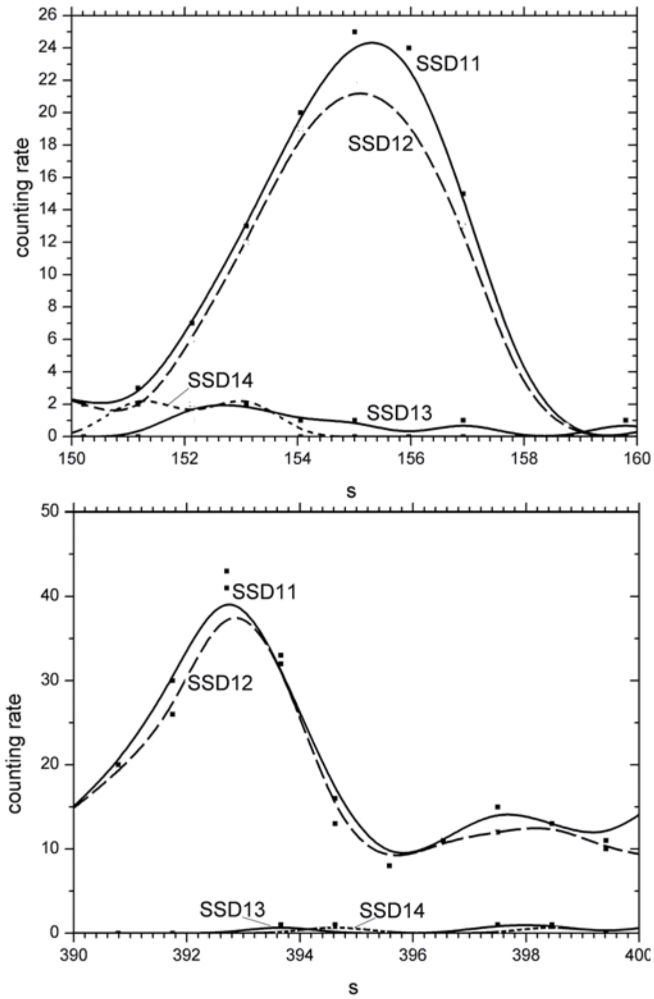

Fig. (8). The profiles of counting rate at different energies of detector 1 during the events 2 and 3.

For monitoring space weather effects in the atmosphere and ionosphere in the future rocket experiments, it may be of relevance to utilize the design of instrument PEEL described in this paper with some modifications.

9. CONCLUSION

Preliminary results obtained from PEEL measurements during the HotPay-2 campaign indicates:

1. Low level of energetic electron fluxes > 30 keV during the whole flight is observed. Authors of [15] indicate that the oxygen number density profile has a maximum at ~ 89 km and thus most probably the electron precipitation (at least at high energies measured by PEEL) was not sufficiently energetic to affect the upper mesosphere and lower thermosphere region, and that the composition was dominated by large-scale dynamics. The variability of the high energy electron flux is ranging from ~ 10 to 2. 10^5 $(cm^2.s.sr)^{-1}$ during the flight.

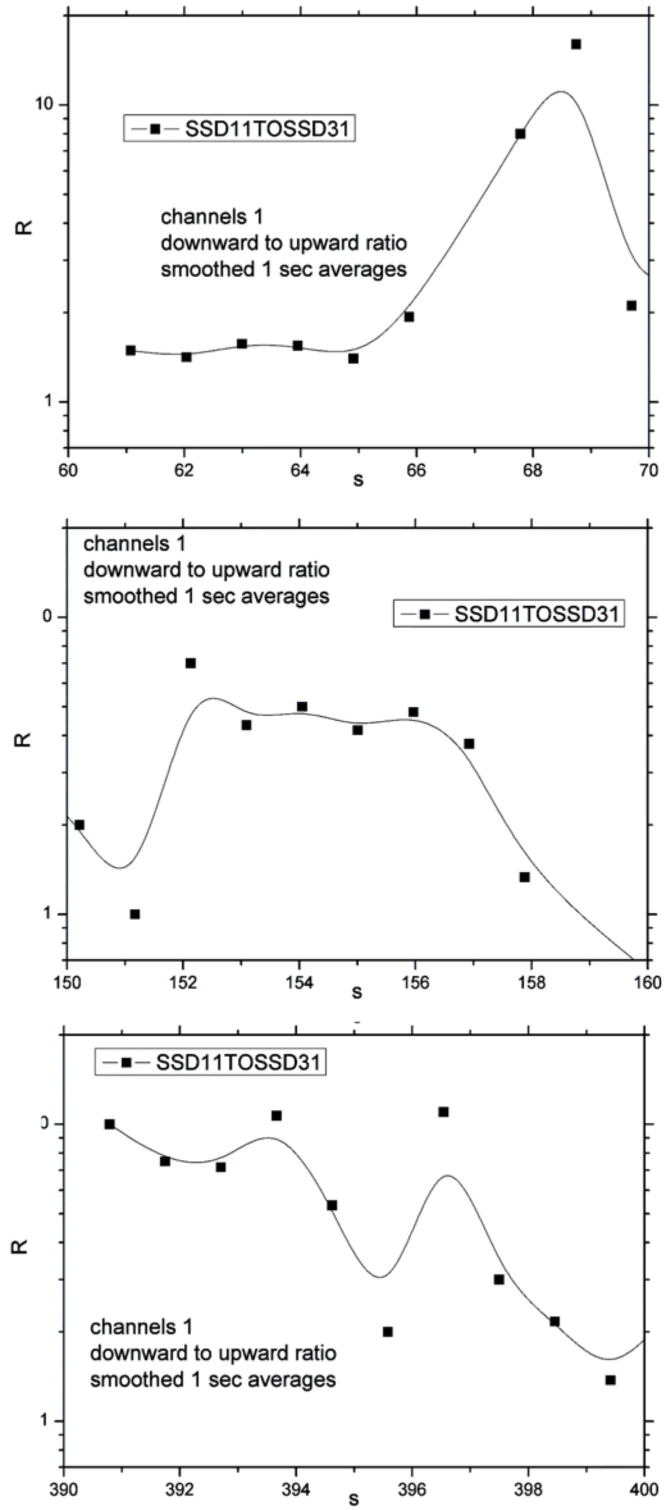

Fig. (9). The ratio of counting rates of the lowest energies in detector 1 and 3 indicating the estimate of downward to upward electron flux ratio.

2. Short spikes have rather variable energy spectra. Comparison with optical emission measurements may

be important for understanding possible relations similar to those discussed *e.g.* in paper [27]. Also data from electron density measurements profile and/or model (*e.g.* in [28]), especially for spikes of energetic electrons observed, are important in physical analysis.

3. The ratio of upward to downward flux (precipitating to backscattered particles) is generally above unity and its variability is also remarkable. It is consistent with the earlier observations [6].

4. The experimental design of PEEL can be used for other rocket sounding activities where the energetic particle measurements are of interest both from physical and application point of view.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

The authors acknowledge the grant agency VEGA projects 2/0059/13 and 2/0040/13; Democritus University of Thrace, Xanthi, Greece and ALOMAR eARI project, Andoya Rocket Range, Norway, Contract No.: RITA-CT-2003-506208. Project of bilateral cooperation SK-GR-0023-11 by APVV agency as well as discussions with Dr. Partha Chowdhury are acknowledged.

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Received: March 30, 2013 Revised: September 20, 2013 Accepted: September 21, 2013