Study of UV atmospheric background for UHECR detection from space

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Abstract. The study of UV background radiation of the Earth's atmosphere is important for planning the measurements of emissions from Ultra High Energy Cosmic Rays (UHECR) with satellites. In this work we present the results obtained by Tatyana I and Tatyana II satellites, which are at an altitude of 800-1000 km in the atmosphere and are equipped with UV detectors among others. The results of these satellites may help to plan future space detectors to study Cosmic Rays (CR).

1. Introduction

Based on Pierre Auger Observatory results [1], the energy spectrum of the Ultra High Energy Cosmic Rays (UHECR) reveals the need of a new approach to study them. Some time ago the possibility to detect UHECR from space was suggested. Aleksandr Chudakov proposed the idea of detecting Cosmic Rays (CR) through their effects in the Earth's atmosphere [2]; John Linsley proposed to measure ultraviolet (UV) emissions and cherenkov light from space [3]. The study of Extensive Air Shower (EAS) generated by UHECR in the space, based on fluorescence observations seems to be the most effective and perspective technique to do it. The basic idea to detect UHECR is to observe the fluorescence emission of the atmospheric N_2 and the cherenkov light. However, first at all it is necessary to measure the UV light background of the Earth to evaluate this possibility. These data are important to develop the appropiate detectors and also for energy threshold determinations, detector duty cycle estimation and for choosing the triggering system and regime of operation [4]. Data obtained with Tatyana I and Tatyana II satellites with these purposes are here presented.

2. The Tatyana I Satellite

The Tatyana I satellite, with a total mass of 30 Kg, was the first one of the University Satellite Program, which was initiated by the Moscow State University with the participation of the Benemérita Universidad Autónoma de Puebla. It was launched on January 20th, 2005 into a polar orbit nearly circular, at an altitude of 950 km, an inclination of 83°, and a period of 103.8 minutes [5].

The first approach to measure the atmospheric glow is the monitoring of average UV intensity on the satellite path. This satellite began interesting experimental exploration of light transient phenomena, very fast explosions in the UV range at upper atmosphere. The nature of these phenomena is now the subject of scientific discussion.

2.1. The UV detector

The UV detector on board the Tatyana I satellite operates in the near UV range (wavelengths 300-400 nm). It worked in the January 2005 - March 2007 period. The detector consists of two Photo-Multiplier Tubes (PMT). One PMT is used for atmospheric UV radiation measurements, and the other one for estimating the background from the charged cosmic ray particles passing through the detector elements. With this last PMT tube a negligible background from charged particles was found. UV detector was monitoring the night atmospheric UV radiation every 4 seconds doing the average over 64 milliseconds (ms). The detector was able to select and measure short UV flashes with the help of two digital oscilloscopes with traces of 4 and 64 ms respectively [6] [7].

Figure 1. Tatyana I Satellite

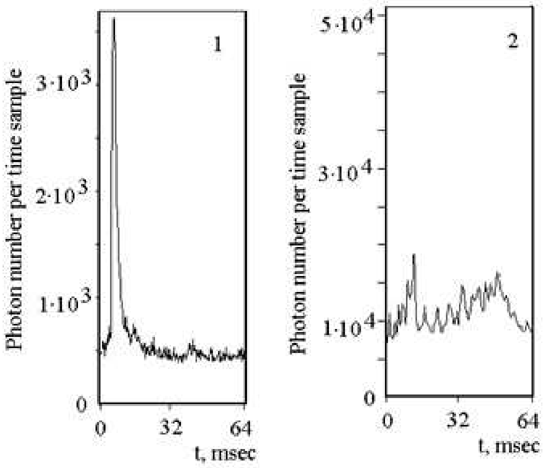


Figure 2. UV flashes measured by Tatyana I with oscilloscope trace 64 ms. The horizontal axis indicates time in ms and the vertical axis indicates photon number per time sample

3. The Tatyana II Satellite

Tatyana II satellite is the second one of the University Satellite Program. The main purpose of this experiment is to study the Earth's transient phenomena in the upper atmosphere. For this purpose, this satellite has some detectors aimed to understand the nature of these phenomena. It has ultraviolet and infrared radiation detectors and a charged particles detector. For more details see [8].

4. Tatyana I results and Tatyana II preliminary results

4.1. UV-R-IR flashes distributions

The main result by Tatyana I [6] indicates two regions of the UV intensity (I_{UV}) in Earth's atmosphere (Figure 3), which differs from one region to another by an order of magnitude:

- Polar aurora zones with $I_{UV} \sim 10^9\ ph/cm^2$s sr (photons of UV flux intensity)
- Equatorial and middle latitude zones with $I_{UV} \sim 10^8\ ph/cm^2$s sr

Some events were detected in world brightest places (Figure 4). These data should be take into account for planning the Cosmic Ray measurements by Satellites.

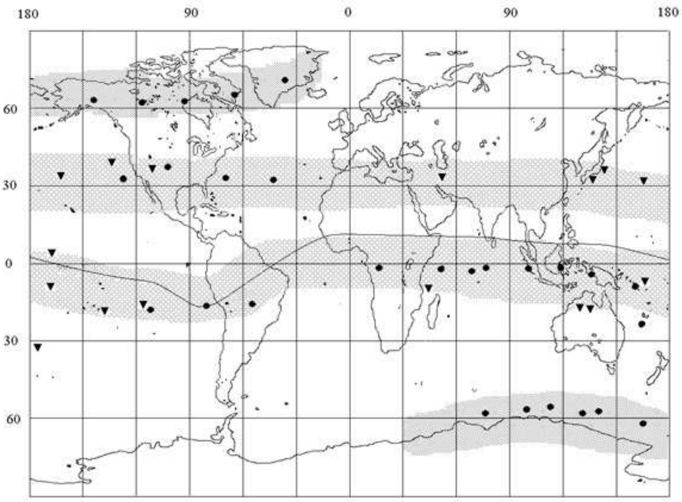


Figure 3. The above map shows the distribution of UV events obtained by Tatyana I. We can see that the UV events are mainly located in two zones, the polar one and the equatorial. Dots are for night UV intensity maxima observed in orbits when high latitudes are available. Triangles are for UV intensity maxima observed in orbits when only equatorial and middle latitudes are available. Shaded areas are for aurora ovals (latitude $\sim 60°$) and order of magnitude fainter glow ovals near equator.

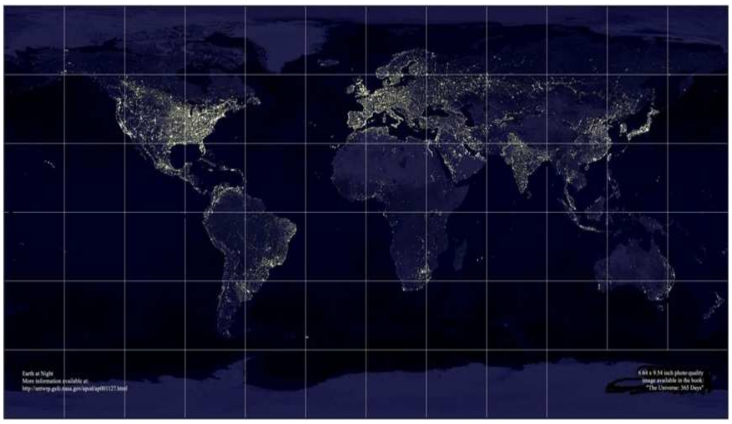


Figure 4. Map of Earth's city lights obtained by NASA. We can see that the brightest places are cities or industrial regions.

We have obtained a preliminary world maps of UV-Red-IR flashes from Tatyana II data. The flashes were recorded according the criterion under which "the brightest event over the course of one minute" was selected. The distribution on the Earth maps of these flashes (Figures 5 and 6), proved that most of the events were observed above land and equatorial regions.

We made a classification based on the temporal profile features of the flashes. The class 1 includes flashes with a short maximum in time, the class 2 is for flashes with some very short maxima, the class 3 is for extended maxima in time and the class 4 includes flashes with high amplitude and extended in time. The Figure 7 shows some examples of detected events, the

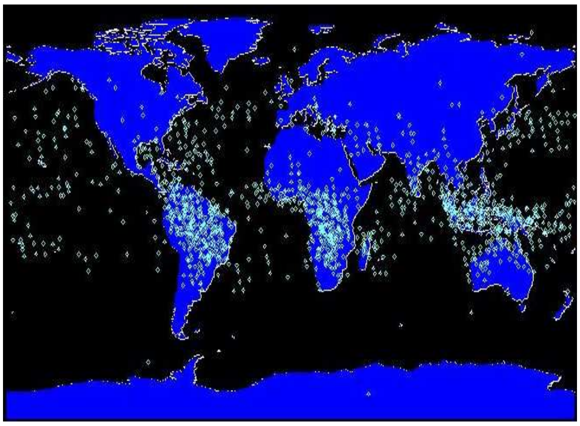


Figure 5. World map of UV flashes detected by Tatyana II.

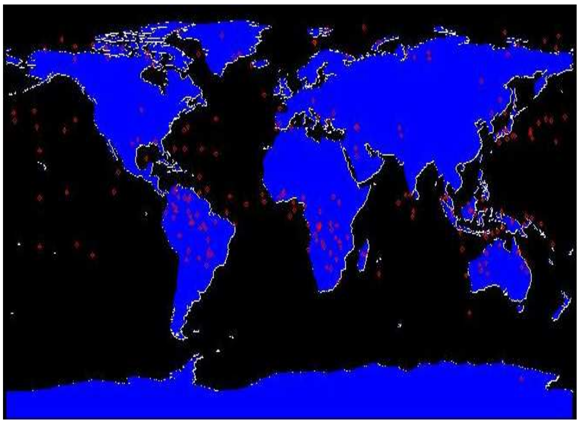


Figure 6. World map of Red - IR flashes detected by Tatyana II.

horizontal axis indicates time in milliseconds (ms) and the vertical axis indicates the amplitude which is expressed as a number proportional to the amount of photons.

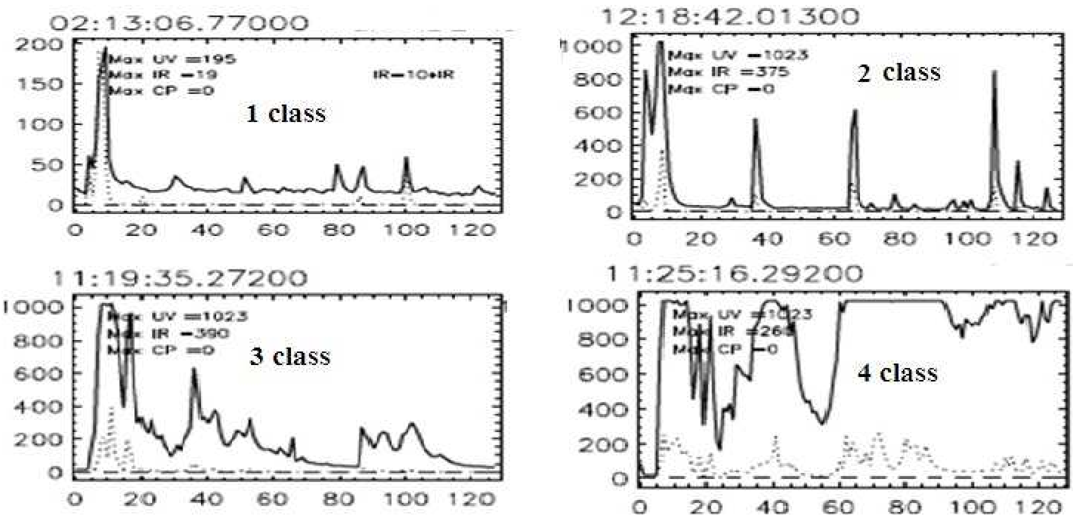


Figure 7. Time profiles of events observed by Tatyana II. They correspond to the different classes according to the behavior of the amplitude with time. The class 1 flashes are the least extended in time and the class 4 flashes are the most extended.

4.2. Transient Luminous Events

Tatyana I satellite detected several interesting phenomena in the atmosphere known as Transient Luminous Events, normally called TLE's. The TLE's are very energetic and short lived events, from few milliseconds to tens of milliseconds. There are different types of TLE's (Figure 8), Elves thought to be lightning-induced transient luminous events in the lower ionosphere with an horizontal scale of 100-300 km. Sprites are luminous discharges that occur between cloud and ionosphere. Blue Jets are cloud to stratosphere electrical discharge events (Figure 9) [10].

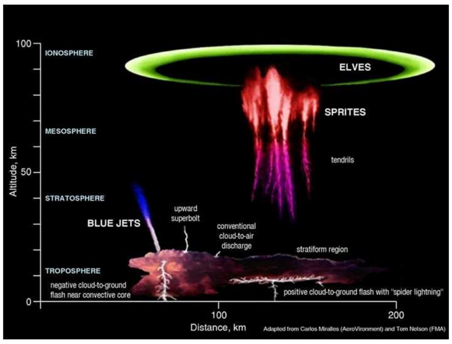


Figure 8. Types of Transient Luminous Events (TLE's).

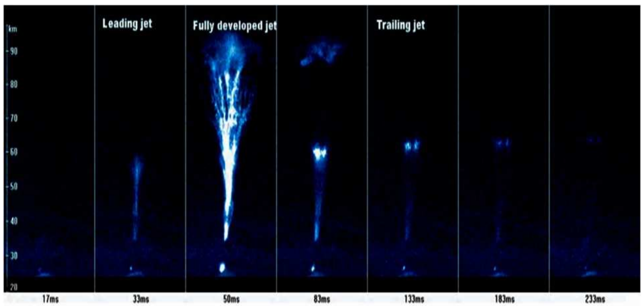


Figure 9. A Blue Jet, the images at the different frames show its development in time, an horizontal bar indicates time intervals between different phases.

The TLE's detected by Tatyana I satellite were compared with events detected by Imager of Sprites and Upper Atmospheric Lightnings (ISUAL) experiment (Figure 11). The map of the UV TLE's detected by Tatyana I is similar to the Elves events distribution detected by ISUAL, both types of events (the detected by Tatyana I and the detected by ISUAL) are concentrated in the equatorial region and occurred above oceans as well as over continents. On the other hand the distribution of lightnings are concentrated mainly above continents (Figure 10).

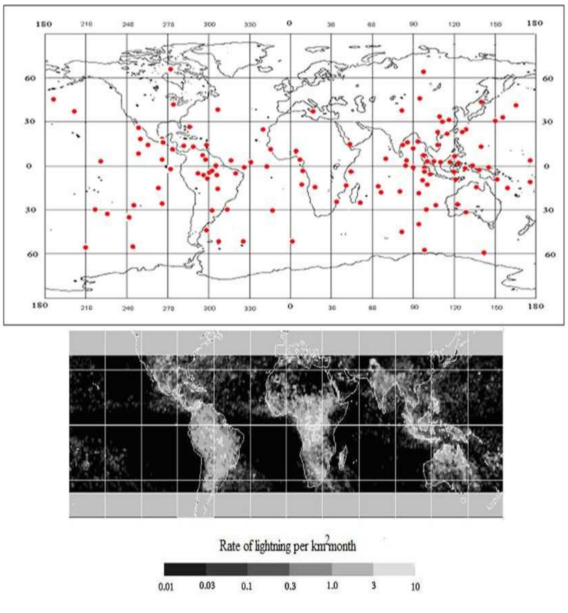


Figure 10. Upper panel: Earth map with superposed dots which indicate the locations of TLE's according to Tatyana I. The bottom image shows the distribution of thunderstorms for the same epoch.

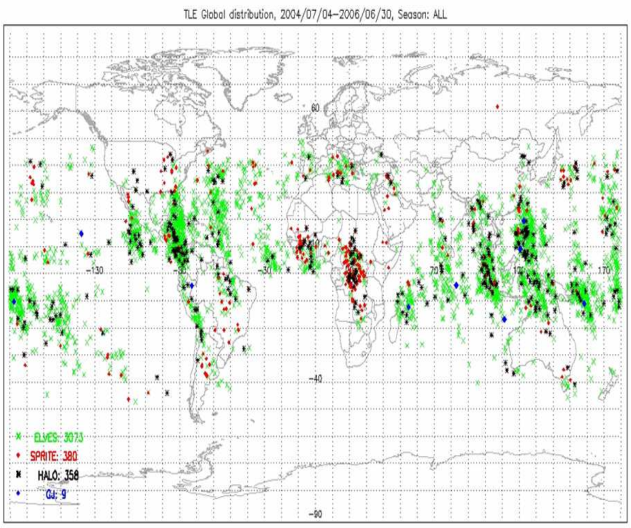


Figure 11. World map of the TLE's detected in the ISUAL experiment. Green points are Elves, red points are Sprites, black points are Halo and blue points are Blue Jets.

4.3. UV intensity and Moon influence

At moon nights the UV intensity varies mostly due to the albedo effect of clouds. A correlation of UV intensity with cloud coverage which varies in time is observed (Figure 12). At some regions the UV intensity exceeds $2 \cdot 10^9 photons/cm^2$s sr.

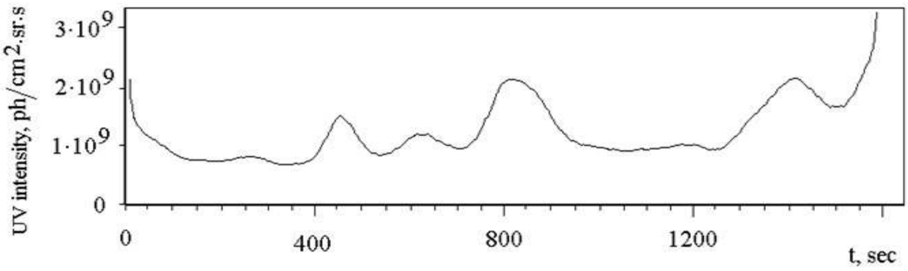


Figure 12. Variation of the UV intensity of Tatyana I data in the presence of the moon in a cloudy night. A good cloud coverage of the sky could be better for CR detection from the space because the UV emissions are better reflected.

At moonless nights the darkest places on Earth in UV light are regions of Pacific, Atlantic and Indian oceans (Figure 13). According to Tatyana I data there is a correlation between the amount of detected events and the moon phase, more events are detected at full moon nights [8].

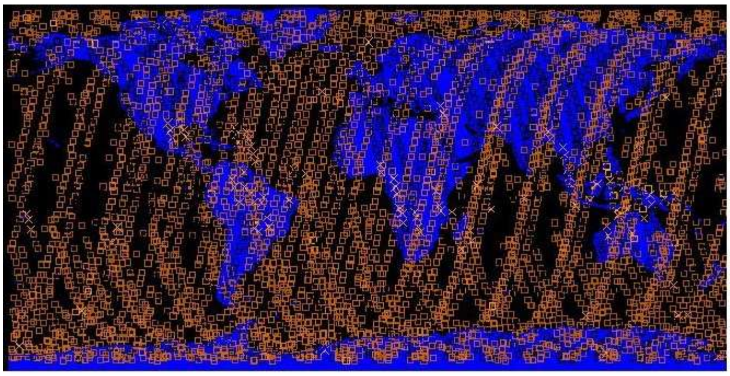


Figure 13. UV events distribution at moonless night detected by Tatyana II.

4.4. Serials of flashes

UV-R-IR detector on board of Tatyana II satellite frequently measured serials of flashes along the night orbit. In 4 months 39 serials with at least a type 4 event were recorded. Most of the serials were observed above land, also part of the serials are symmetrically located respect the geomagnetic equator (Figure 14). The origin of these serials of events is under study.

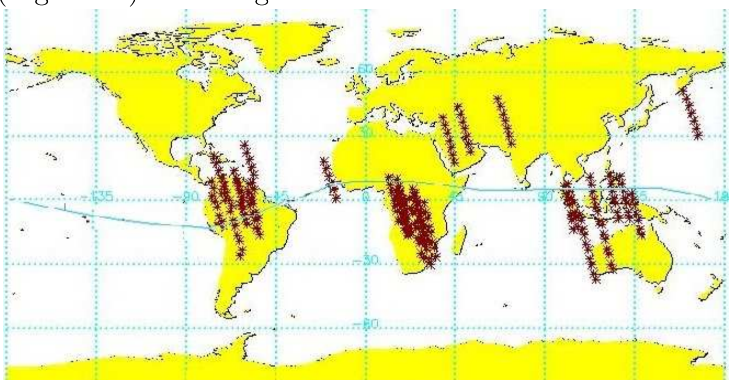
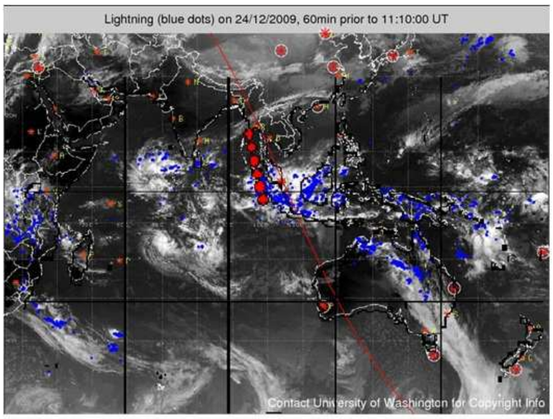


Figure 14. Serials of flashes detected by Tatyana II, the geomagnetic equator is indicated by a continuos curved line.

Many flashes occur above clouds and can be related to thunderstorms, however frequently there are no clouds under some flashes. Further statistical analysis of all events will be done.



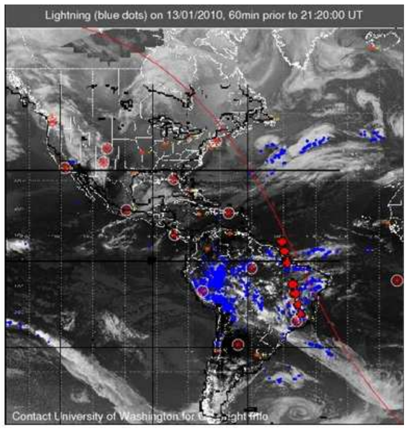


Figure 15. Ratio between UV flashes and lightnings. Red dots are serials of flashes, blue dots are lightnings

4.5. Charged Particles zones

Charged Particles (CP) detector on board Tatyana II satellite was designed for measurements of milliseconds pulses. The detector is not sensitive to low flux of charged particles. On the world map, obtained by Tatyana II satellite, only the particle flux at the South Atlantic Anomaly (SAA) is clearly seen, this result indicates that the detector works properly. In aurora regions the particle flux is near the detector sensitivity threshold. Based on UV-R-IR distributions (Figures 3, 5 and 6) obtained by Tatyana I and Tatyana II satellites and CP distribution (Figure 16) there is no clear correlation between charged particles and UV flashes.

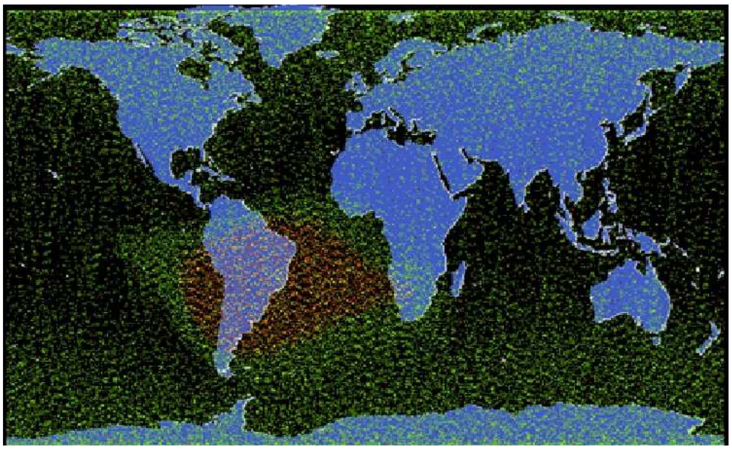


Figure 16. South Atlantic Anomaly (SAA) and auroral zones detected by the Tatyana II Satellite charged particles detector.

5. Conclusions

(i) According to Tatyana I and Tatyana II satellites, there are different sources of UV emissions in the atmosphere, this is important because they should be considered for UHECR measurements.

(ii) We have obtained maps of UV-R-IR average intensity from Tatyana I and Tatyana II data. These maps are important for planning orbital UHECR detectors.

(iii) Maps of charge particles signal were also obtained. Measurements of CP flux in SAA have shown that charged particle detector works properly. There is no clear correlation between charged particles and UV flashes.

(iv) We have measured UV flashes with various temporal profiles with short and sharp and long lasted components leading to a classification of 4 classes.

(v) Serials of flashes are measured. Serials contain flashes of various types, at least with one type 4 flash. The serials occur more frequently above land.

(vi) There are flashes not connected with lightnings (no clouds under the flash). The origin of these flashes is not clear.

DATA ANALYSIS IN PROGRESS

6. Plans for the future

- To make detailed analysis of UV/Red ratio for various classes of flashes as well as for individual flashes.
- To relate UV flashes detected by Tatyanas missions with TLE's and with other phenomena.
- To get a better classification of the TLE's according data from Lomonosov satellite (the third one of the University Satellite Program, which will be launched in about a year)

7. Acknowledgments
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