Dust impact detections by a set of Faraday cups in the lunar environments

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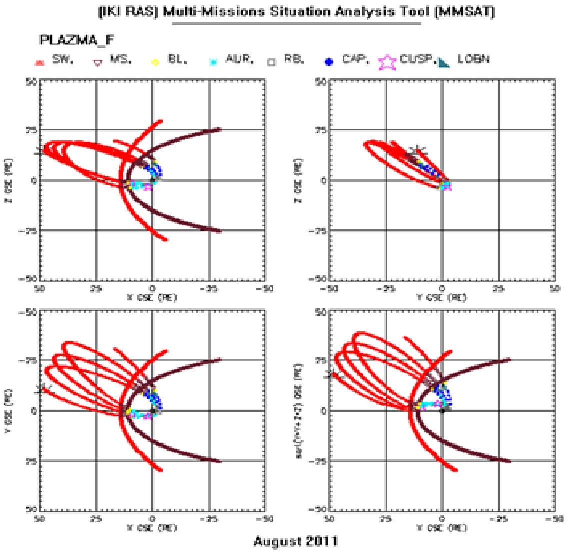
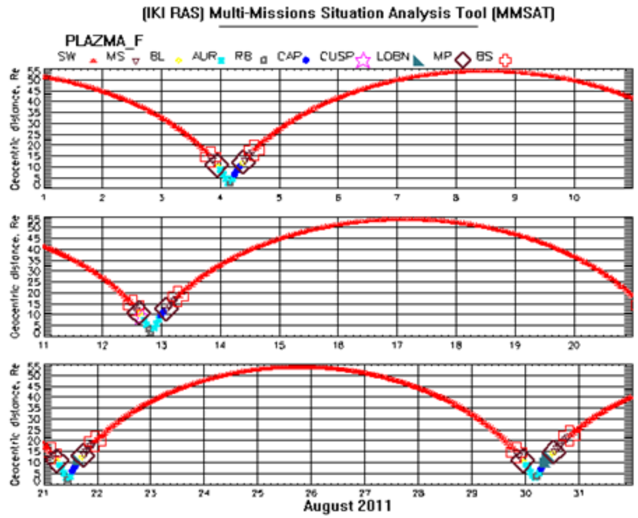
Content:

- Basic information about the Spektr-R project
- Purpose and functions BMSW
- BMSW laboratory data
- Space data analysis and simulated response
- How can we do this better (in space)

Basic information about the Spektr-R project

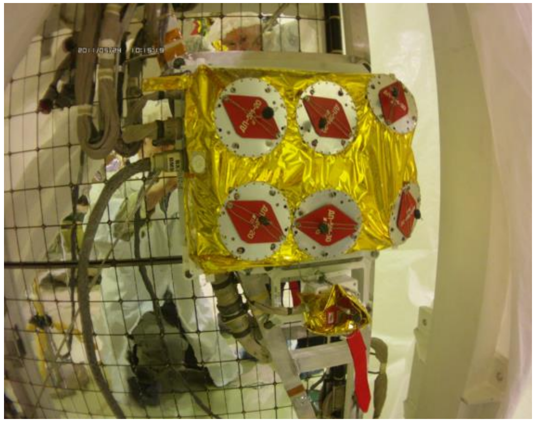
Bright Solar Wind Monitor BMSW – the instrument flown as a part of the PLASMA-F complex onboard the Russian Spektr-R radioastronomical spacecraft. The Spektr-R project was launched into Earth orbit on 18 July 2011 at 6:31 Moscow time on Zenith-3M from the Baikonur space launch facility.





SRT antenna in Lavochkin Association

Apogee ≈ 360000 km; Perigee ≈ 5000–10000 km; Orbital period ≈ 8.5 days



BMSW is mounted on the solar panel.

The primary goal of the Spektr-R mission was to study structure and dynamics of radio sources inside and outside of our Milky Way galaxy. A secondary BMSV instrument was also for installation onboard Spektr-R within the Plazma-F experiment, which aimed to measure the directions and intensity of the solar wind.

The BMSW instrument is mounted on the solar panel and consist of 6 Faraday cups (FCs), 3 of them pointing towards the Sun, 3 of them inclined by 30 degrees in complemental directions. BMSW orientation with respect to the Sun varies by 10°, but it is known with 1° precision most of the time. On 11 January 2019, the spacecraft stopped responding to ground control.

As a result of long exploitation of the Bright Monitor of the Solar Wind (BMSW) on board the Spektr-R spacecraft, studies have been conducted that confirm that this type of instrument is capable of observing dust impact on its sensors.

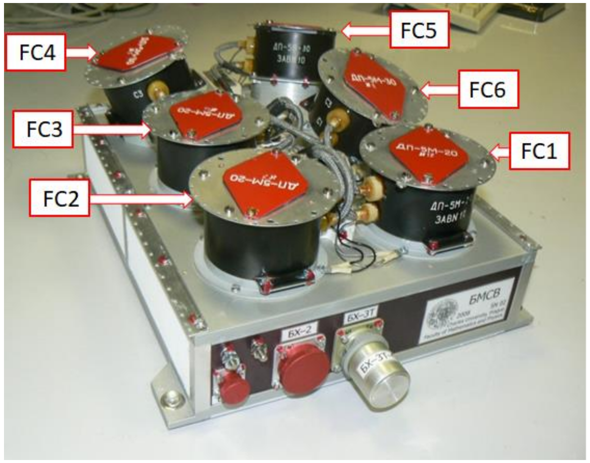
Purpose and functions BMSW

The BMSW instrument was specially designed for reaching the highest time resolution in measurements of the solar wind parameters: ion flux vector, bulk velocity, temperature and density in the energy range from 100 eV to 3.7 keV. Based on the analysis of operation of various instruments for solar wind study (in particular, different types of analyzers), it was decided that Faraday cups are the most suitable sensors for such an instrument.

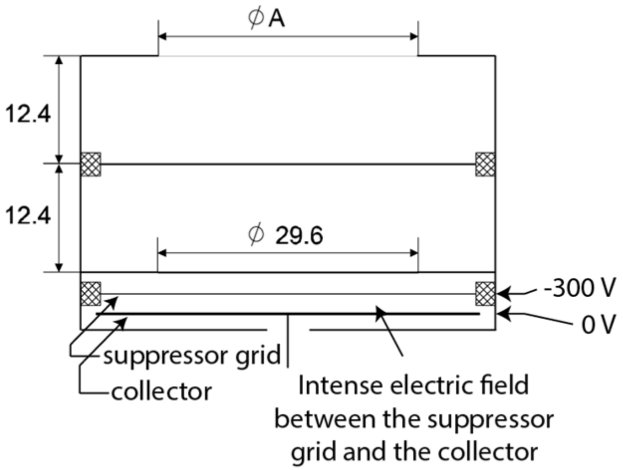
The BMSW instrument includes six sensors (Faraday cups) which are divided into two groups:

- Three Faraday cups for determination of the speed and temperature — FC1, FC2, FC3
- Three declined Faraday cups for determination of the velocity direction and density — FC4, FC5, FC6

However, once cup's collector is impacted by dust, generated plasma cloud is separated due to strong electric field (>10^5 V/m) between the collector and the suppressor grid and electrons are detected. Diaphragm diameter (A in figure below) is about 20mm for cups looking towards the Sun and about 30mm for the inclined ones respectively. Whole detection area of BMSW's cups is about $31\mathrm{cm}^2$ and the FOV is 77° and 100° respectively. Each collector's capacitance is about 20 pF, which allows detection of charges as low as 10^{-15}C.



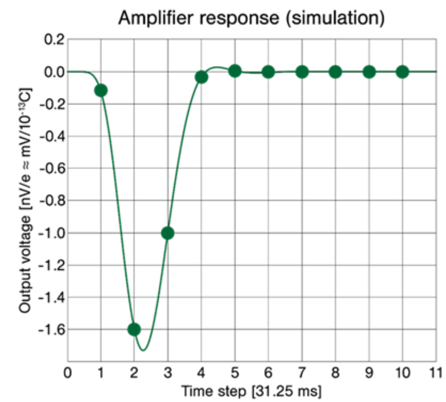
Bright Monitor of the Solar Wind (BMSW)



Schematic diagram of the Faraday cup sensor

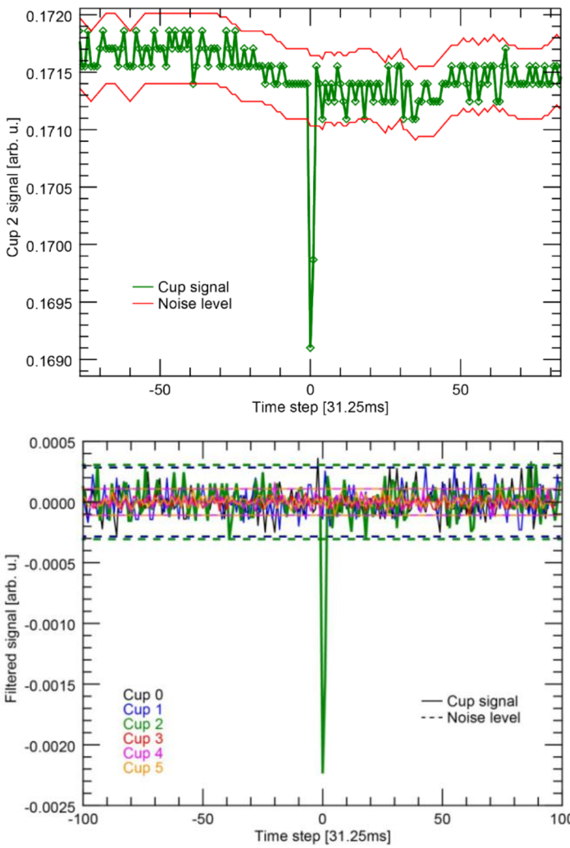
Dust Data Analysis and Simulated Response

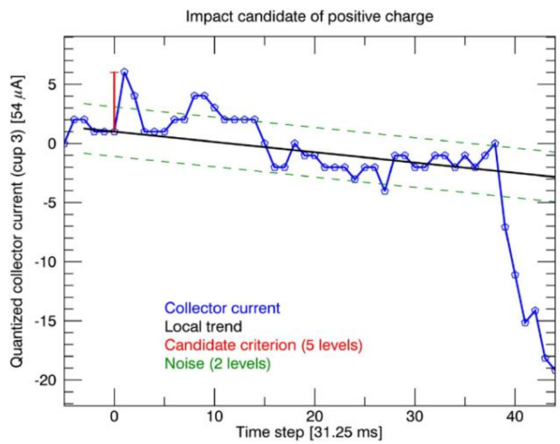
Dust of both interstellar and interplanetary origins was reported in many *in-situ* experiments devoted to dust detection during past tens of years. Most of such observations are based on impact ionization occurring when hypervelocity grains 10–100 km/s hit a surface being vaporized together with a portion of the surface material and generating transient plasma cloud. These ejected charged particles could be detected using fast and sensitive current measurement apparatus. We have searched for such events in BMSW data records. We have identified a large amount of events of expected properties.



Simulated amp. response curve

In the figure above, there is a simulated amplifier response on a unit charge. The impact ionization process itself is so fast that only amplitude of a pulse is relevant. The shape is given by the amplifier response only, impact itself happens at several orders of magnitude shorter time scales. It is important that different charge only scales amplitude of the peak, not its width (duration).





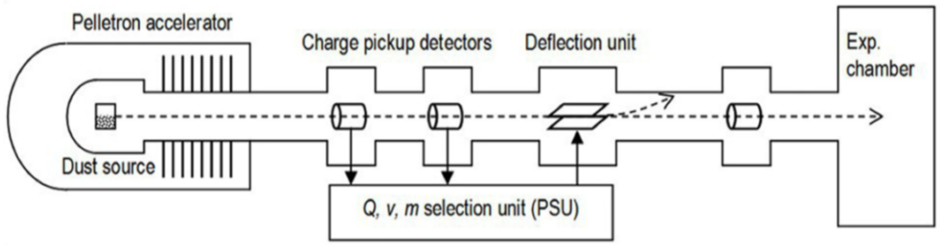
Two examples of impact candidates — the most distinctive negative (left) and a positive one (right). Top panel for negative peak shows real data while at the bottom general trend is subtracted and signals from all cups are depicted. Besides negative charge events (i.e., the cups observe negative peak first, which corresponds to impact plasma ions being repelled from the collector while the electrons return back immediately), we observed also the opposite ones. We apply following criteria to identify impact candidates:

- Peak is very narrow (2–3 time steps wide in time)
- Peak amplitude is significant (well beyond noise)
- Peak is monopolar (either positive or negative)
- Peak is detected by a single cup (other cup signals remain within noise)

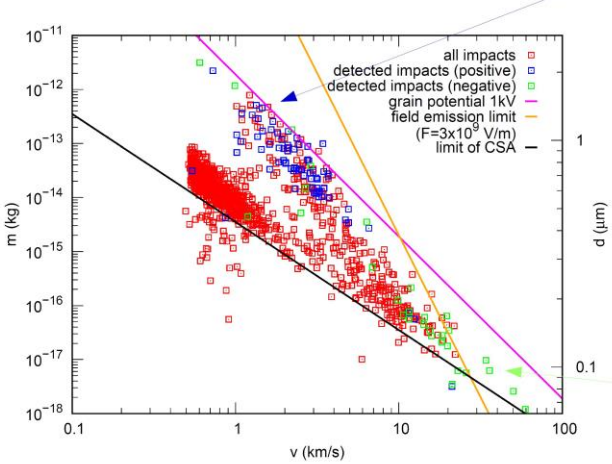
Kočiščák et al. (PSS 2018)

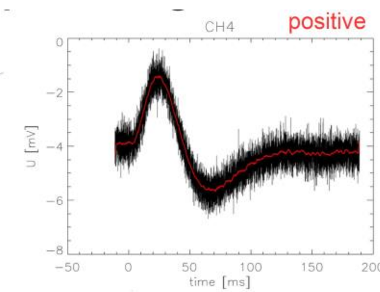
BMSW laboratory data

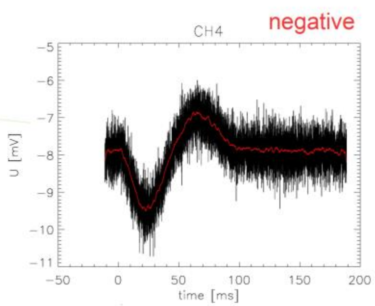
We have done tests of similar cups and amplifiers in laboratory using IMPACT linear electrostatic dust accelerator at the University of Colorado, which allowed us determining basic capabilities of our cup. However, test conditions have not been entirely the same as those in space (pressure, noise, dust material, data acquisition speed, …)



The facility, where charged micron- and submicron-sized iron grains are accelerated by 2.2 MV potential difference of dust accelerator.







All dust impacts produced during the experimental run are depicted in the accelerator plot with red squares (left). Signals produced by hypervelocity dust impacts on the collector of Faraday cup are recorded (right). They can be divided into two groups: positive end negative (with respect to the polarity of detected signal). The groups are denoted in the accelerator plot by colors; the positive group with blue color and the negative one with green. Note here that the sampling rate in this experiment is much larger than in the space experiment.

The overshoot is caused by bandwidth of electronics. The peak duration is given by amplifiers, not by physics of impacts.

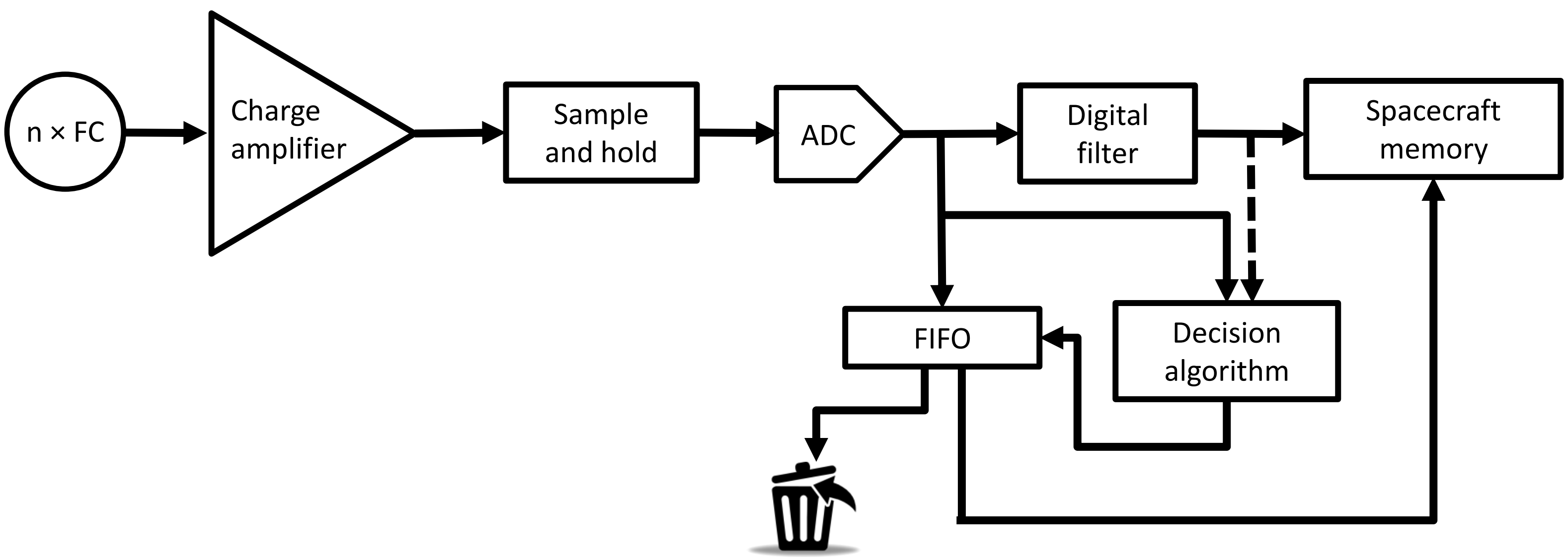
Laboratory experiments will be further used for detector calibration.

Nouzak et al. (2020)

How can we do this better (in space)

We suggest to employ digital filters for the new device and to increase the sampling rate (256 Hz) and down-sampling after filtering. Analyzing the data from BMSW, we came to the conclusion that there is no need to broadcast the entire high-rate data stream since on average10 dust particles per day are recorded in outer space . Only a fraction of a second for each event shall be stored.

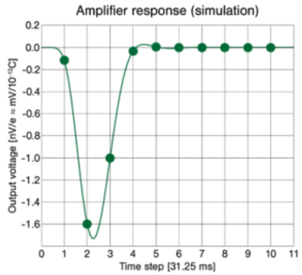
The signal source is FC, then the signal is amplified, pre-filtered and digitalized at 256 Hz. Besides applying a high-order digital filter we will side-loop data into FIFO register that gives us some time to decide, whether we want to store the raw data burst or not. We will analyze the signals from all cups, sampled at 256 Hz, while looking for the events similar to the simulated response. However, the decision can be made based on both raw data as well as filtered data (or a combination of both) — limiting factor is just time (vs register size). We can then select dust impact candidates, if only one sole cup sees the peak and others remain within noise. We expect further data processing and inter-data comparison to be performed on ground.



new device operational scheme

The decision algorithm

1) We know the expected waveform



Simulated amp. response curve

2) We have impact identification criteria.

- Peak is very narrow (approx. 100 ms)
- Peak amplitude is significant (well beyond noise)
- Peak is monopolar (either positive or negative)
- Peak is detected by a single cup (other cup signals remain within noise)

3) We can find impact candidates in static data, but can we do that in a real time conditions?

Algorithm has several limitations
- Speed: Size of shift register defines the time we can spend on impact identification
- Precision: Too many false candidates will overhaul data transmission
- Complexity: The algorithm must fit in the remaining room in detector‘s FPGA

=> that‘ll be my job in following months, stay tuned

Conclusions

The Bright Monitor of the Solar Wind (BMSW) was designed for high-frequency (30 ms) measurements of the moments of ion energy distribution by Faraday cups in the solar wind. The studies conducted using the instrument on-board the Spektr-R spacecraft demonstrated that it is possible to detect hypervelocity impacts of dust grains by such instruments. Our further analysis shows that BMSW is capable of in-situ dust detection as proved in space as well as in laboratory.

The novel design of an instrument for Luna-Resurs-1 mission will analyze plasma environment at altitudes from 65 to 150 km above lunar surface. However, the main problem of the reliable dust impact detection remains temporal resolution of a device. On the other hand, new device will process data at much higher sampling rate for the purpose of digital filtering. Our simple identification algorithm can decide which raw data shall be stored and we will receive impact waveforms in about ten times higher resolution.

In addition, we will calibrate detectors and their front electronics using a dust accelerator to find the relationship between the impact parameters and the pulse height.

Thank you for your attention!