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Ion cloud expansion after hypervelocity dust impacts detected by the MMS spacecraft

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PS2.1 session "Small Bodies Open (Asteroids, Comets, Meteoroids, and Dust)

Introduction

Dust grains impacting with high velocities the spacecraft body can be partly or totally evaporated and create clouds of charged particles. Presence of electrons and ions generated by such hypervelocity impacts can consequently influence the spacecraft potential and/or measurements of on-board scientific instruments. Electric field instruments are able to register signals generated by dust impacts as short pulses in the measured electric field. These signals can be used for detection of dust grains by spacecraft without dedicated dust detectors.

We present a study of events related to dust impacts on the spacecraft body detected by electric field probes operating simultaneously in the monopole (probe-to-spacecraft potential measurement) and dipole (probe-to-probe potential measurement) configurations by the Earth-orbiting MMS spacecraft. The presented study is focused on events when expanding ions affect not only the potential of the spacecraft body but also one or more electric sensors at the end of antenna booms. Expanding ions can influence electric probes located far from the spacecraft body only when the spacecraft is located in tenuous ambient plasma as inside of the Earth's magnetosphere.

Dust impacts on the spacecraft body

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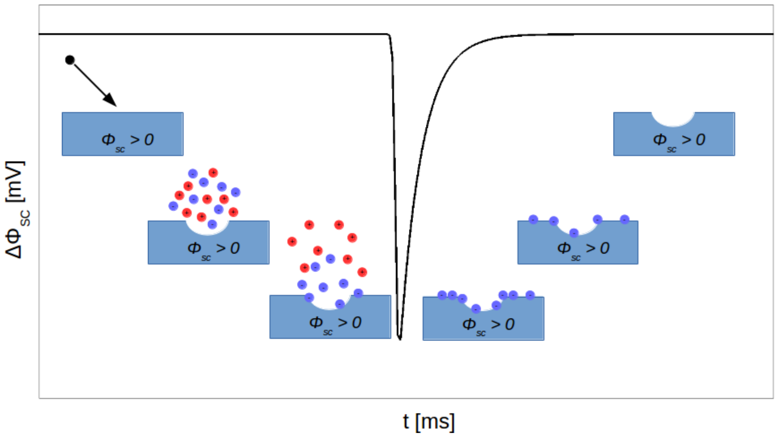
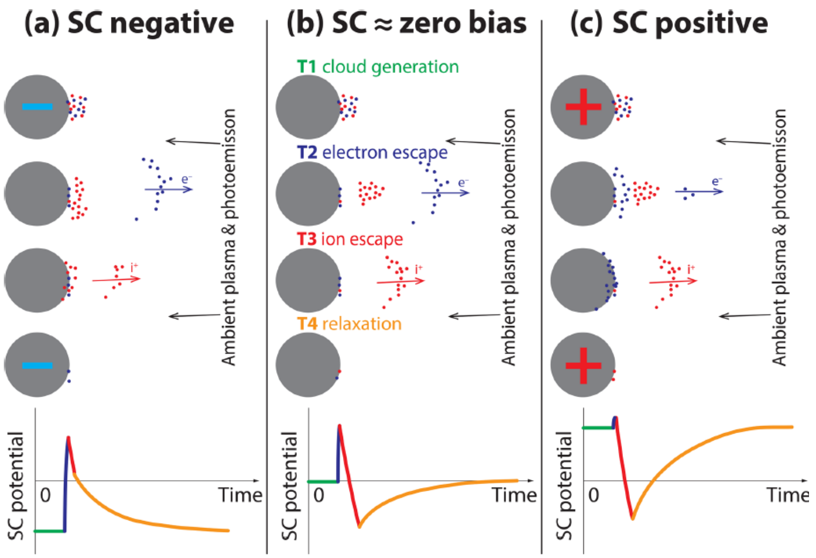


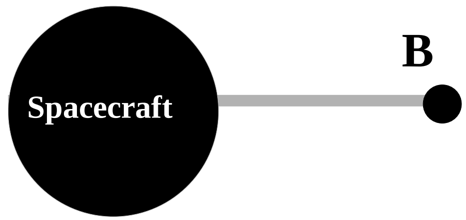
[Vaverka et al., 2017]



[Mann et al., 2019]

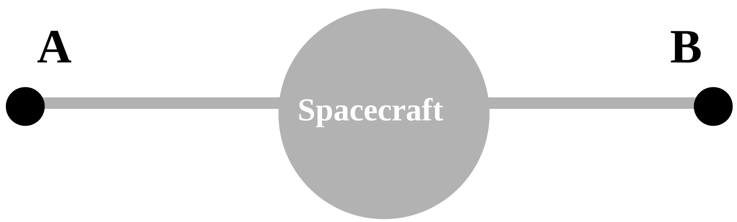
The electric field measurement

The monopole configuration (probe-to-spacecraft potential measurement)



$$E = U/d = (\varphi_B - \varphi_{SC})/d$$

The dipole configuration (probe-to-probe potential measurement)



$$E = U/d = (\varphi_B - \varphi_A)/d$$

The monopole configuration is sensitive to changes in the spacecraft potential, on the other hand, the dipole configuration is sensitive only to changes at the potential probes at the end of each antenna boom.

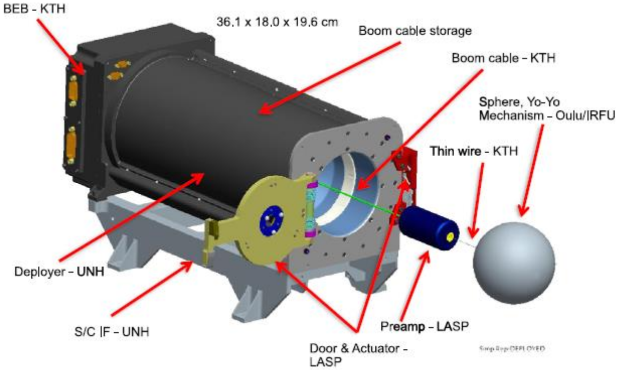
** black parts are sensitive*

MMS spacecraft

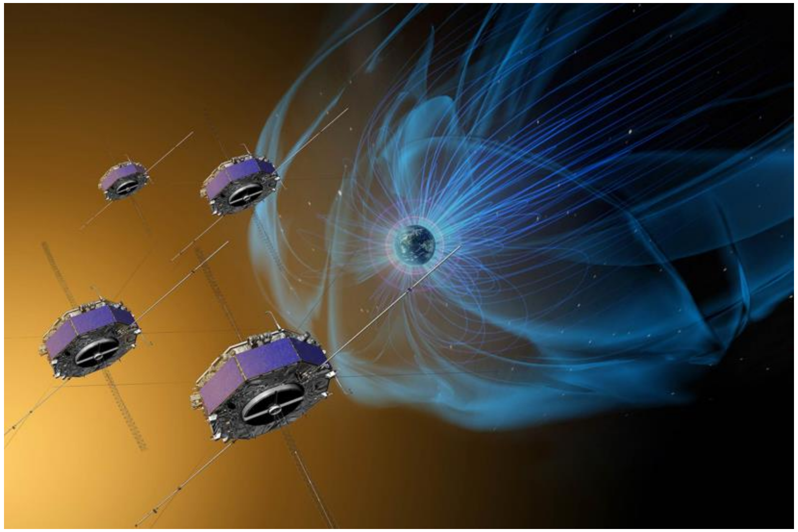
- four identical spacecraft flying in a close formation
- launched in 2015
- the highly elliptical orbits
- 6 electric probes

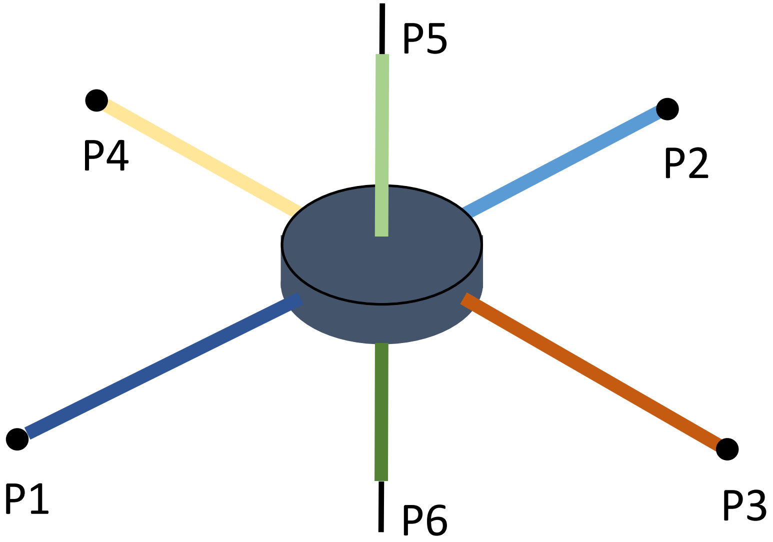
    4x 60 m

    2x 12.5 m

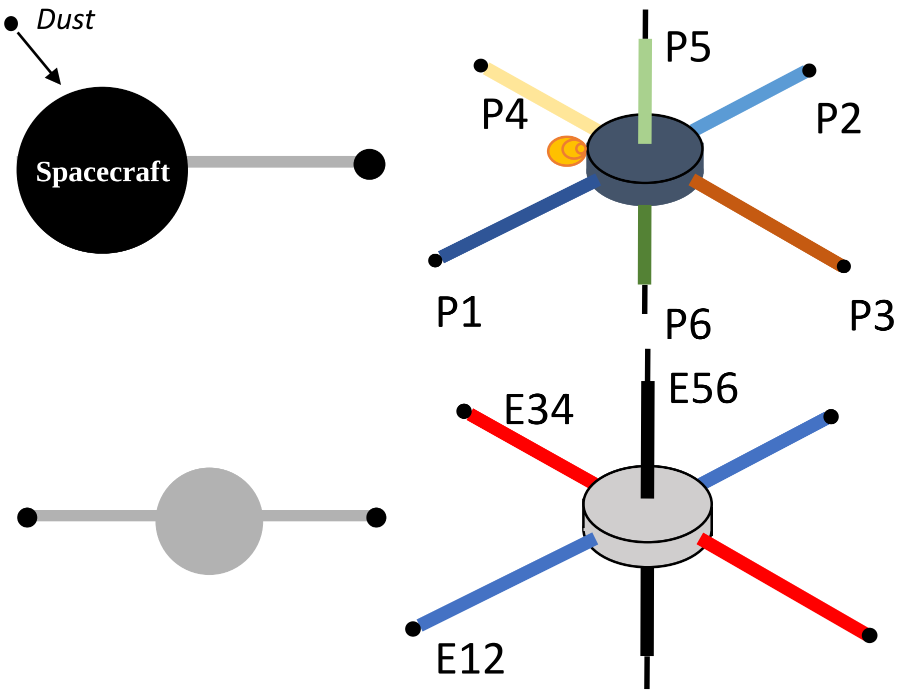


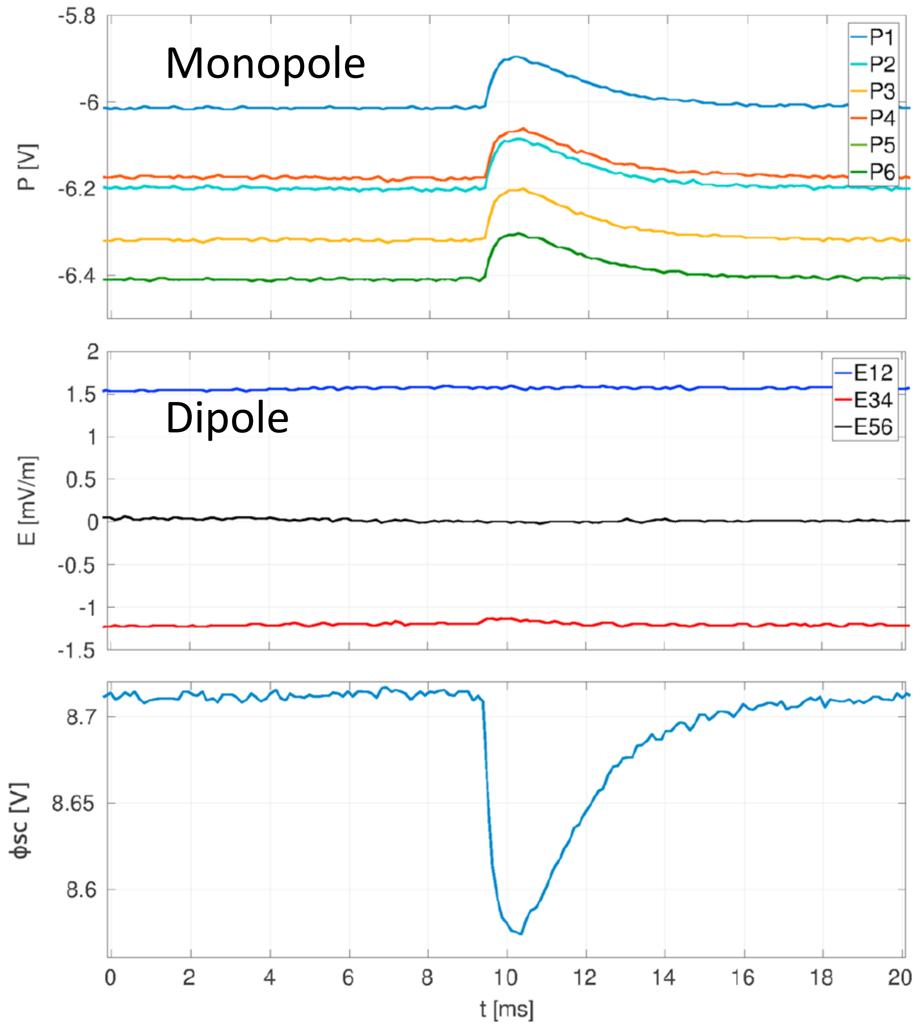
- **‘simultaneous’ probe-to-spacecraft measurement (monopole) and E-field measurements (dipole)**





Example of detected impact



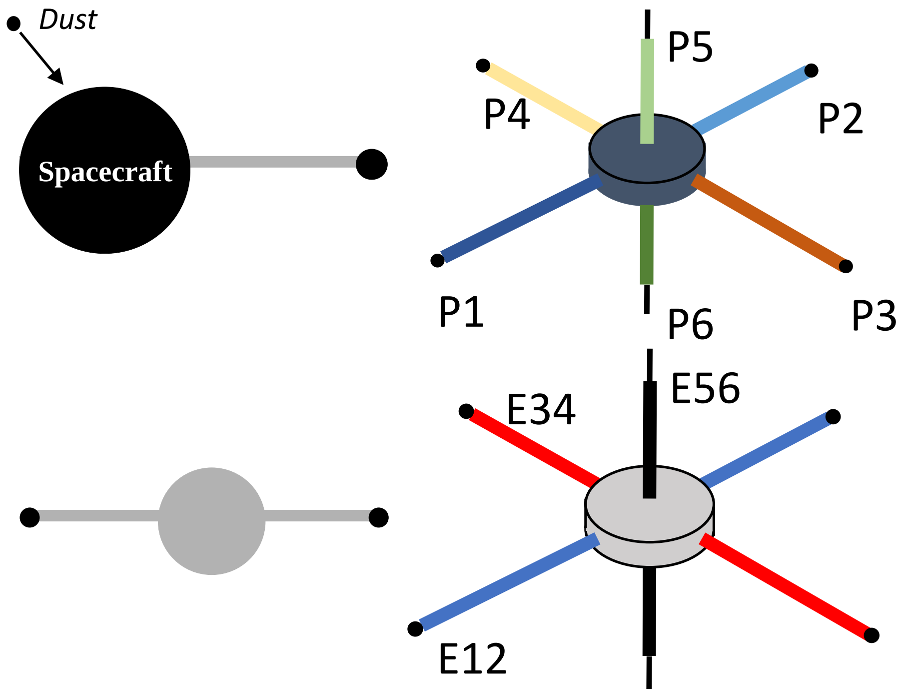


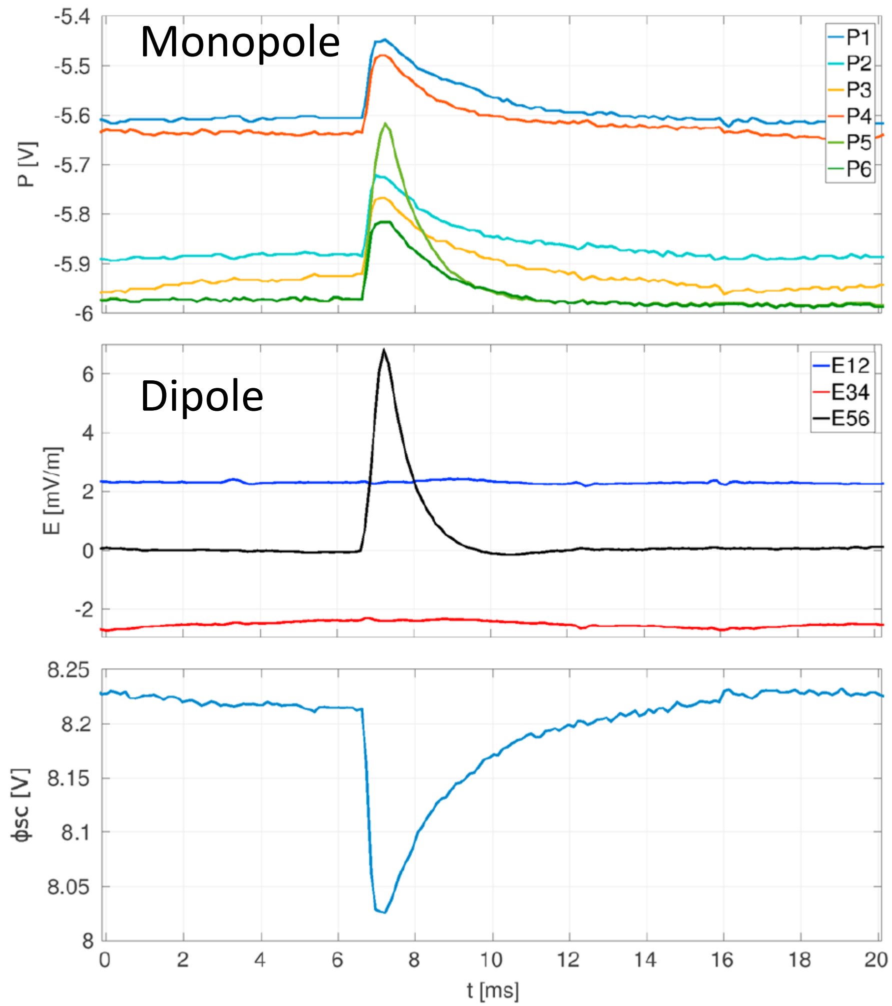
No signal in measured electric field (dipole configuration) and all monopole probes detect identical signal
=> change in the spacecraft potential

[Vaverka et al., 2018]

A change in the spacecraft potential—28 March 2016 at 16:31:05.37 UTC. Probe-to-spacecraft potential, *P* (top), the electric field, *E* (middle), and the spacecraft potential, Φ_{SC} (bottom).

Example of detected impact – with expanding ions





A change in the spacecraft potential—8 April 2016 at 20:58:13.00 UTC. Probe-to-spacecraft potential, *P* (top), the electric field, *E* (middle), and the spacecraft potential, Φ_{SC} (bottom).

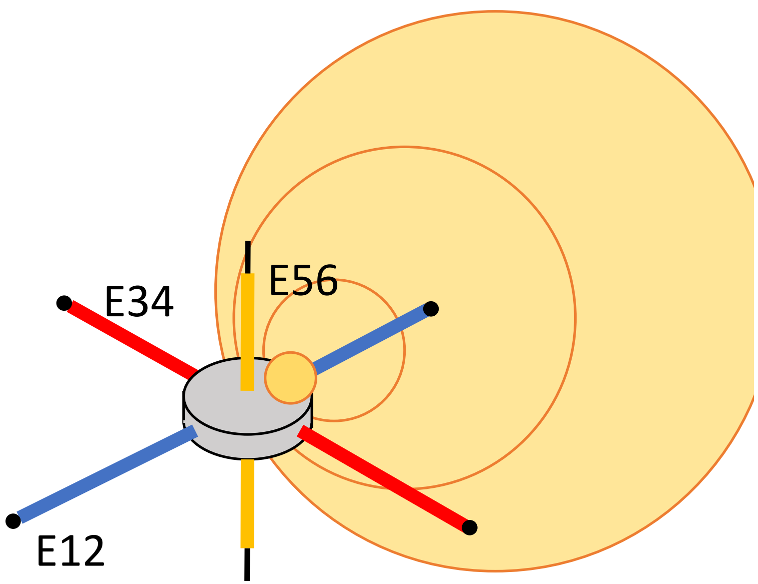
Some signal detected also in one dipole (E56) and one monopole (P5) detected enhanced signal
=> combination of the change in the spacecraft potential and signal from one monopole probe (P5)

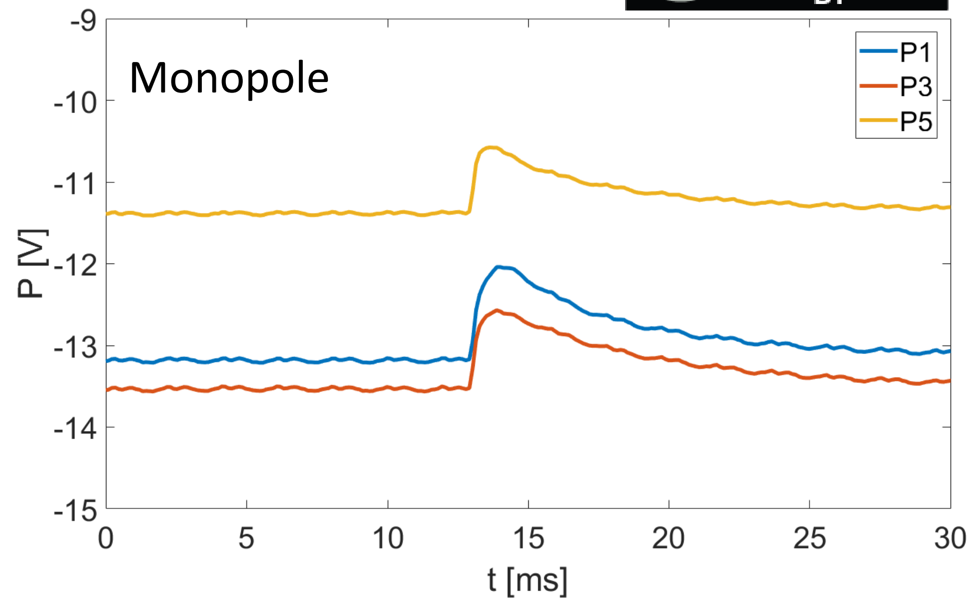
[Vaverka et al., 2018]

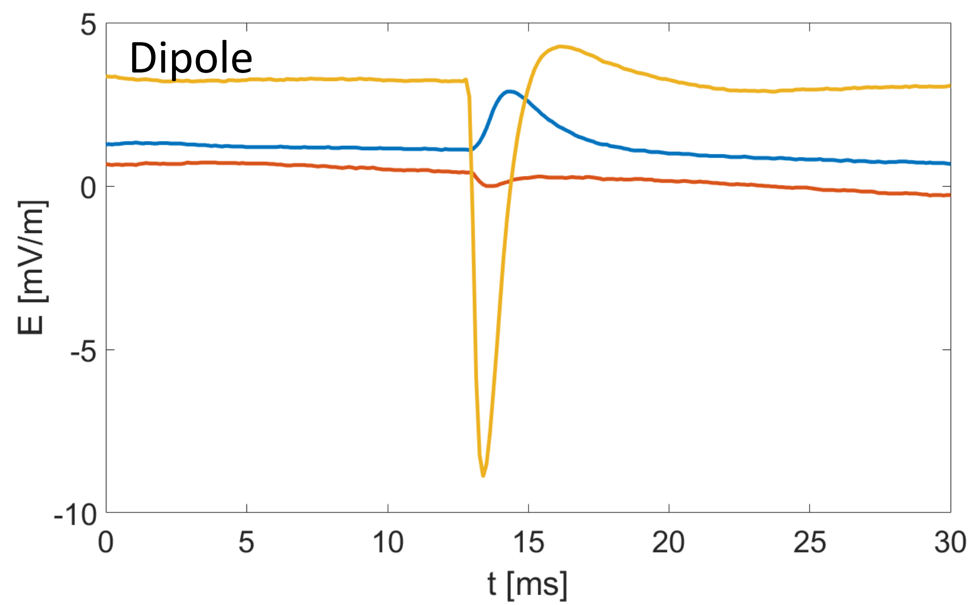
Example: ion expansion

Ion cloud expanding from the positively charged S/C body can influence potential of the potential sensor

In some rear cases even all three dipole probes detected signal at the same time







Expansion velocity

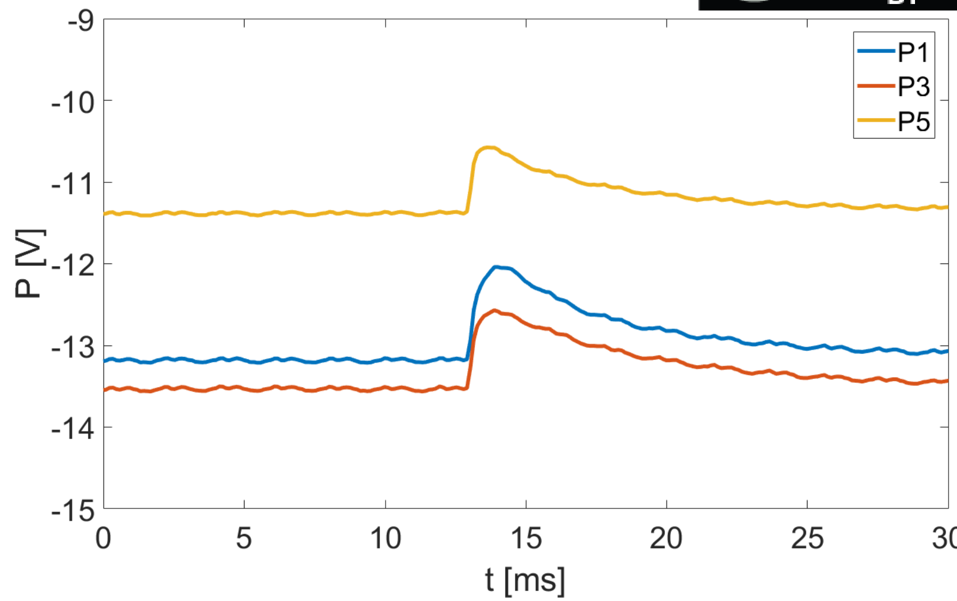
363 changes in the S/C potential

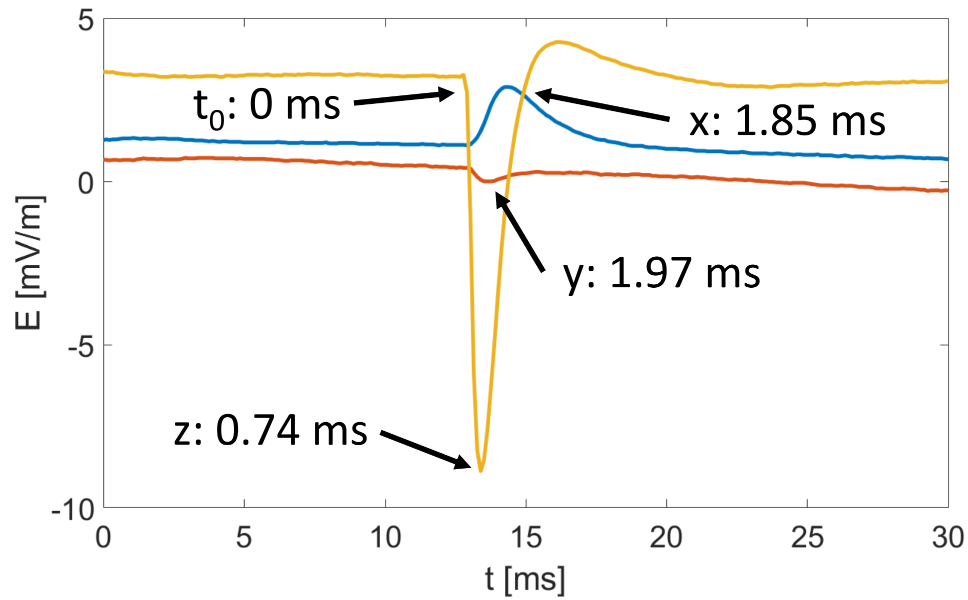
155 (43 %) of these events contain signal in short dipole (E56)

74 (20 %) cases contain signal in one or both longer dipoles (E12/E34)

The signal is registered first by a shorter dipole antenna (z) in all cases

z: 0.74 ± 0.03 ms
x: 1.85 ± 0.15 ms
y: 1.97 ± 0.17 ms





Expansion velocity

Expansion velocity derived from the length of the antenna and time of maximum of the pulse:

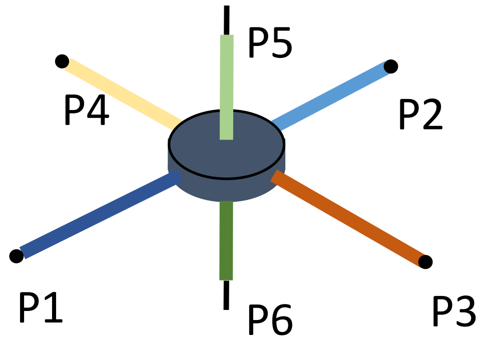
z: 16.2 ± 0.7 km/s (12 m)
x: 32 ± 3 km/s (60 m)
y: 30 ± 3 km/s (60 m)

Acceleration can be caused by the ambient electric field (s/c potential)

"Using two analyzers at different distances from the target, the expansion speed of the impact plasma was measured to be between 10 km/s and 30 km/s."

[Lee et al., 2012]

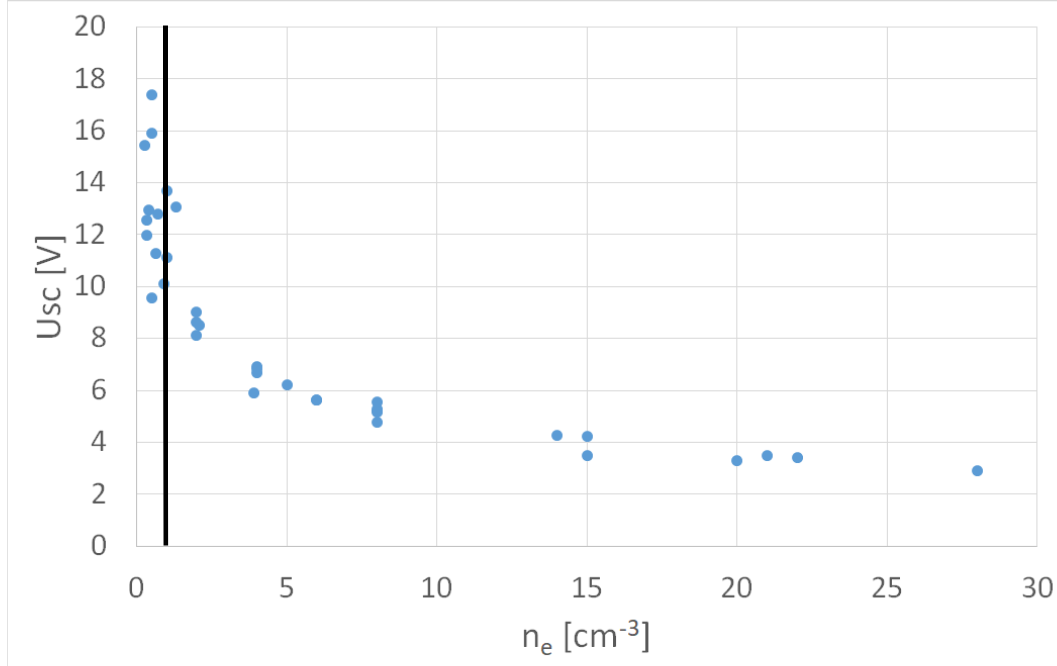
No polarity preference (P1 vs. P2)
(same number of positive and negative pulses detected by all antennas)
   -spacecraft rotation

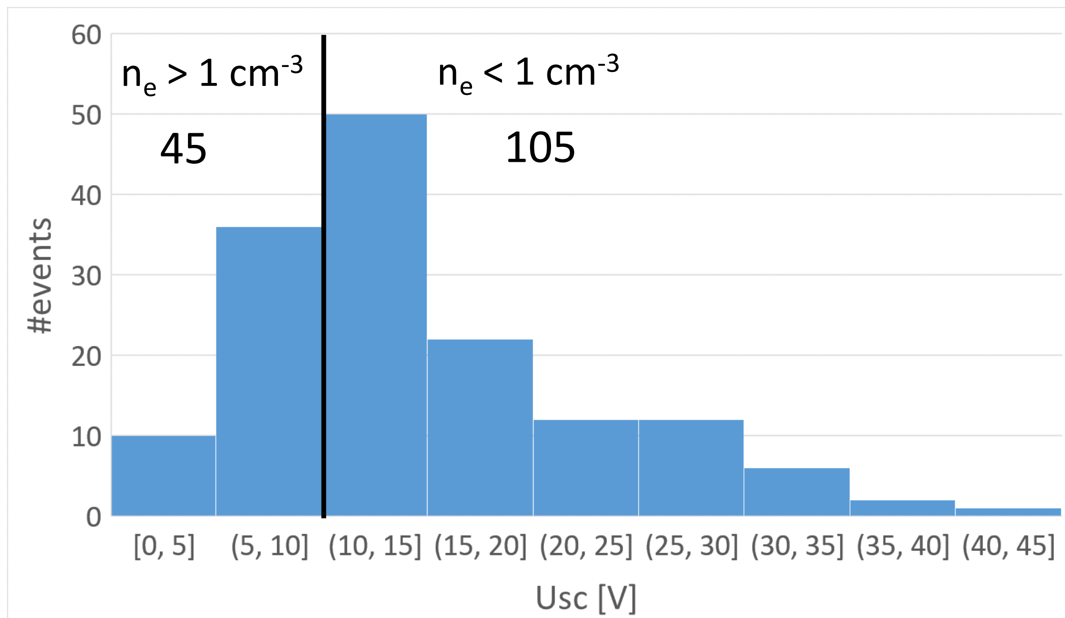


Ambient plasma

The equilibrium spacecraft potential is given by the ambient plasma density

The expansion of ion clouds is detected mainly when spacecraft is located in the tenuous ambient plasma ($n_e < 1$ cm^{-3})

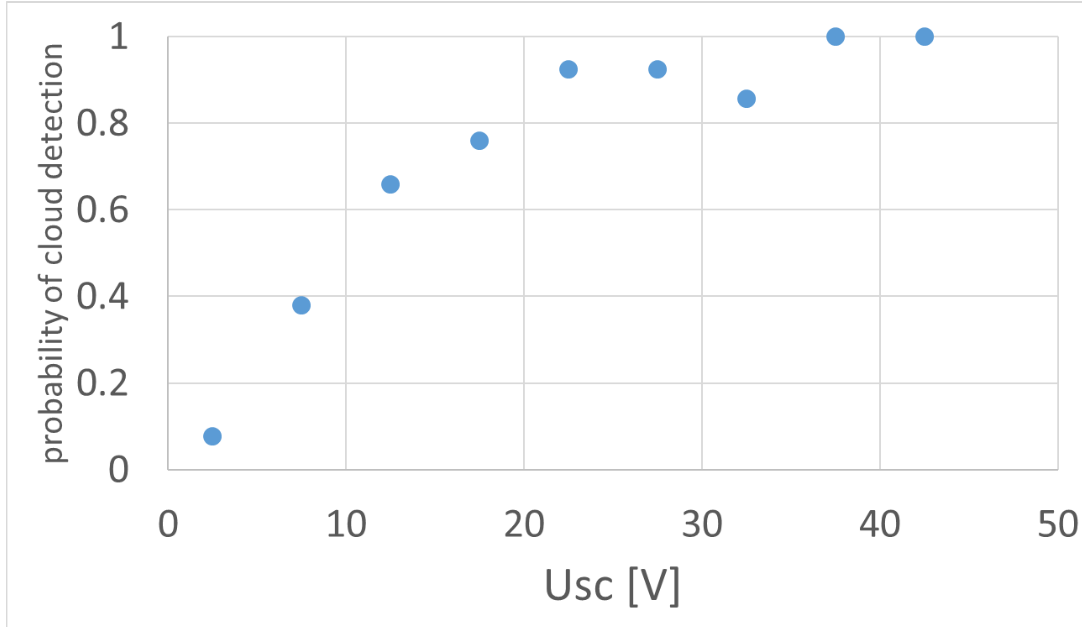


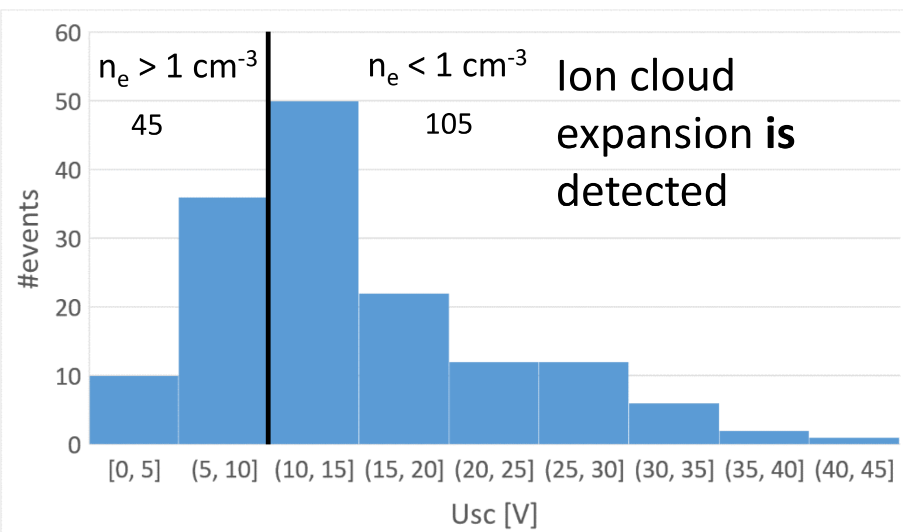


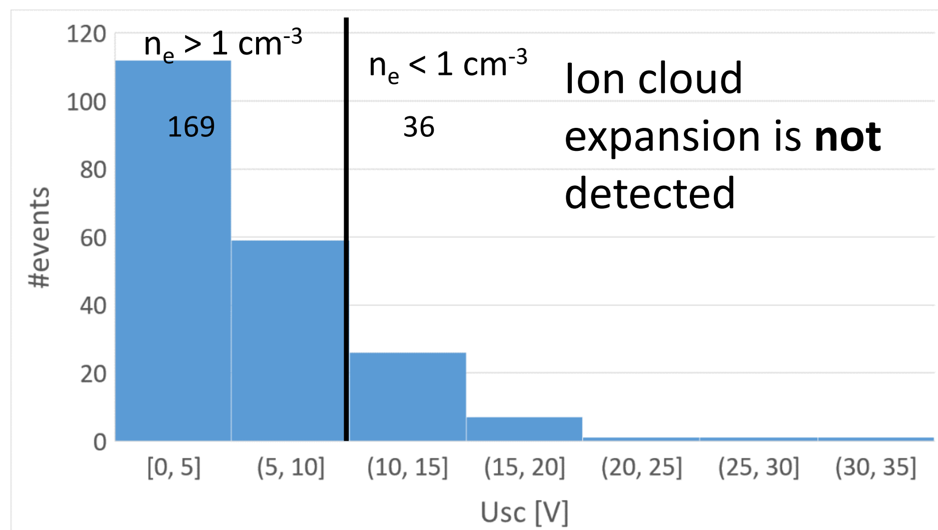
Ambient plasma

Probability of ion cloud detection depends on the ambient plasma density

This support our hypothesis that this signal is connected to expansion of the ion cloud







Conclusion

We have analyzed pulses connected to changes in the spacecraft potential caused by dust impacts onto spacecraft body [Vaverka et al., 2019].

155 (43 %) of these events contain signal not only in monopoles but also in short dipole (E56) and **74** (20 %) cases contain signal even in one or both longer dipoles (E12/E34)

There are several indications that these events are related to expansion of ions from the spacecraft body

- detection of ion cloud expansion depends on the ambient plasma density
  higher probability is in the tenuous plasma, $n_e < 1\ cm^{-3}$

- derived expansion velocity (15 – 30 km/s) corresponds to previously published values

- there is no polarity preference of the detected signal – rotation of the S/C

Please write your questions or comments under this presentation or during **PS2.1 session "Small Bodies Open** (Asteroids, Comets, Meteoroids, and Dust) on **Wednesday 6 May, 8.30-10.15 and 10.45-12.30**