Effects of the solar wind dynamic pressure on the accelerated cometary ions in the magnetosphere of comet 67P

Aniko Timar* (1,2), Zoltan Nemeth (1), Karoly Szego (1), Melinda Dósa (1), Balazs Nagy (2)

(1) Wigner RCP, 1121 Budapest, Konkoly-Thege Miklós út 29-33.

(2) Eötvös Loránd University, Faculty of Science, 1117 Budapest, Pázmány Péter stny. 1/A

* timar.aniko@wigner.hu

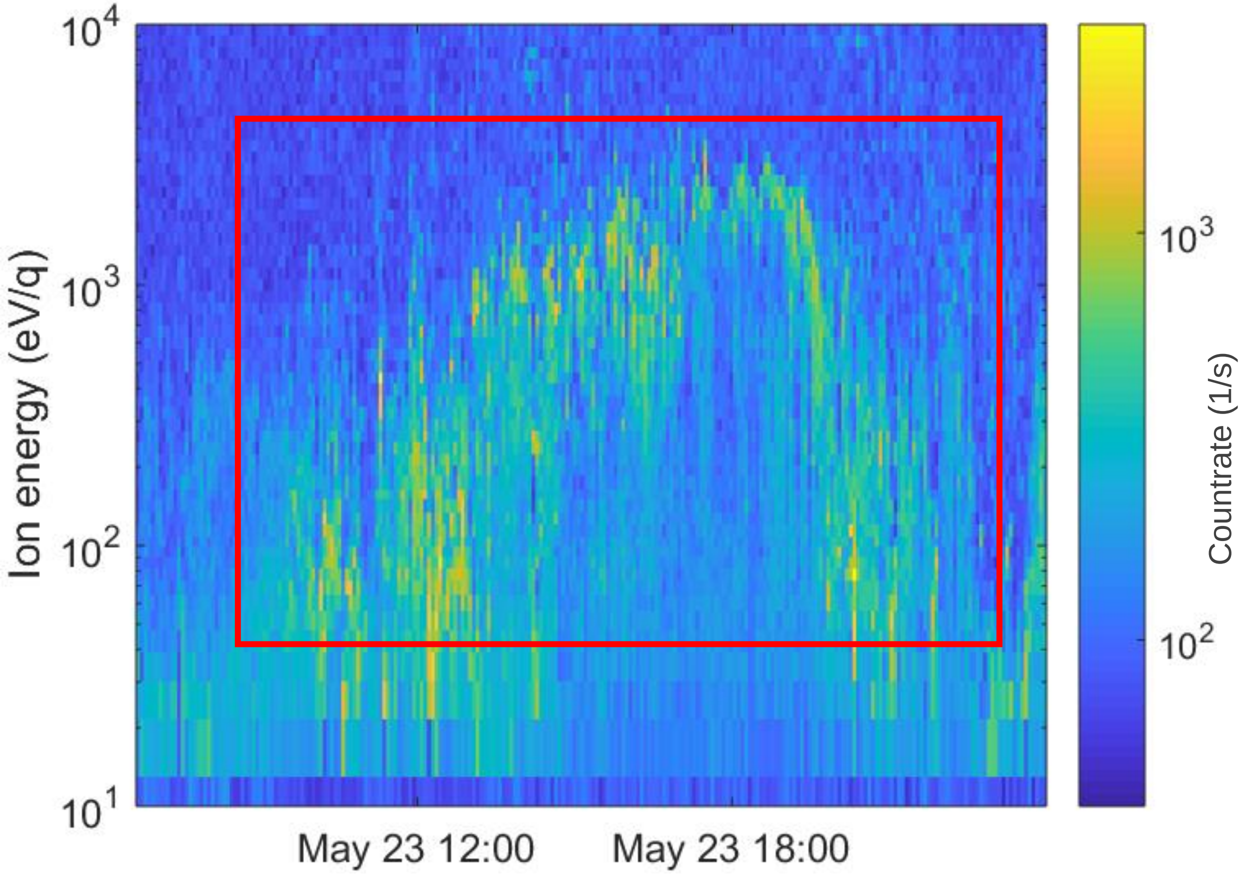
05.05.2020

Aims

- We aim to investigate the properties of the ions accelerated up to 50-1000 eV in the magnetosphere of comet 67P
- We determine the relationship between solar wind dynamic pressure and the accelerated ions
- By also taking other measurements into account we investigate the source and energy loss of the accelerated ions. We focus on questions such as:
  - How do these accelerated ions become observable for Rosetta?
  - Why are these particles absent in the inner coma?

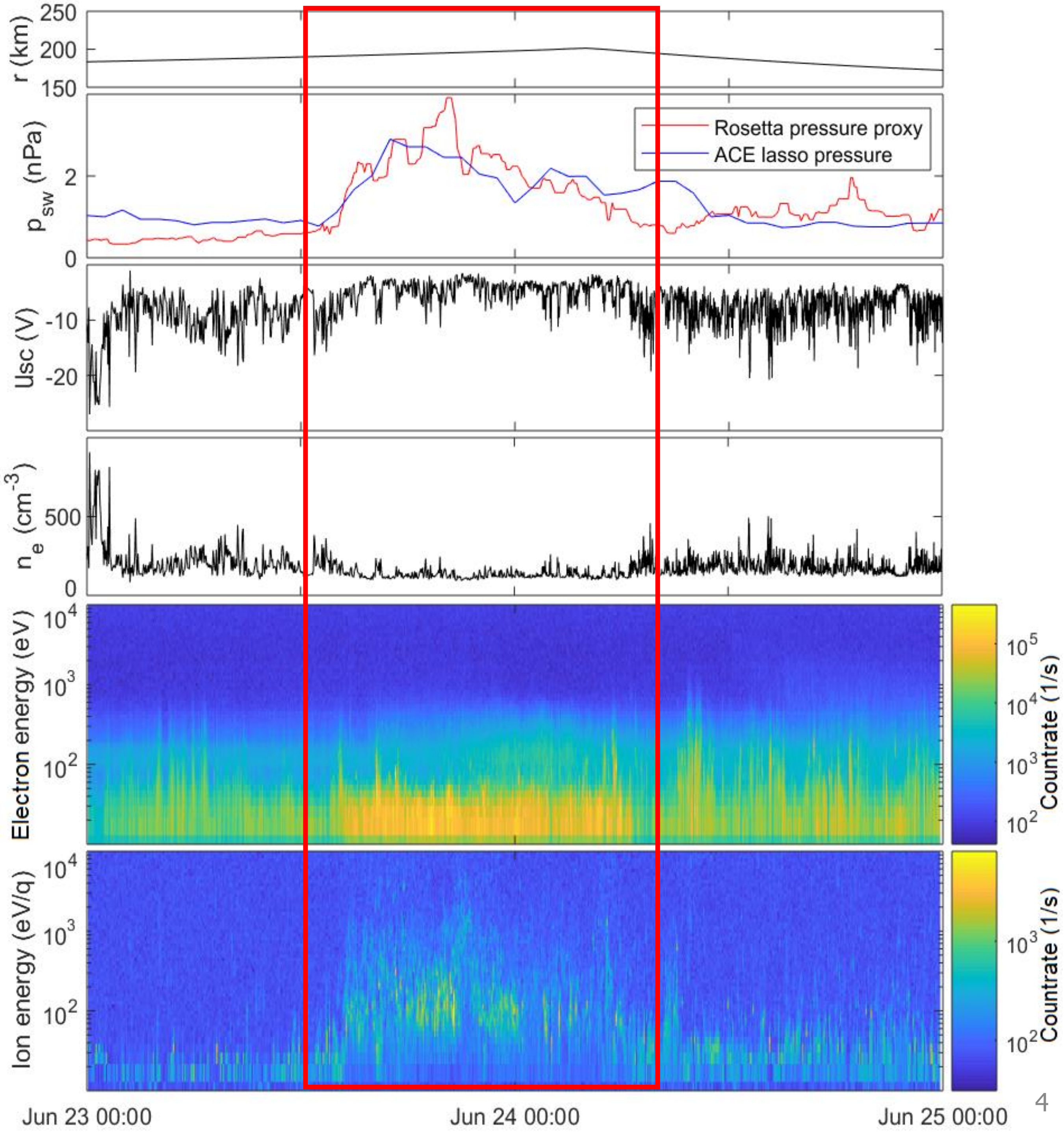
Accelerated ions

- Accelerated ions observed sporadically with energies ranging from 50 eV to about a 1000 eV in the magnetosphere of comet 67P
  - They can be seen **from late 2014 to early 2016**
  - They seem to appear on the measurements **during enhanced solar activity** (CIRs or CMEs)
- They are probably **ions picked up by the solar wind** far upstream (Goldstein et al. 2017; Berčič et al. 2018)
- They are **absent from the innermost magnetosphere**



Particle signatures

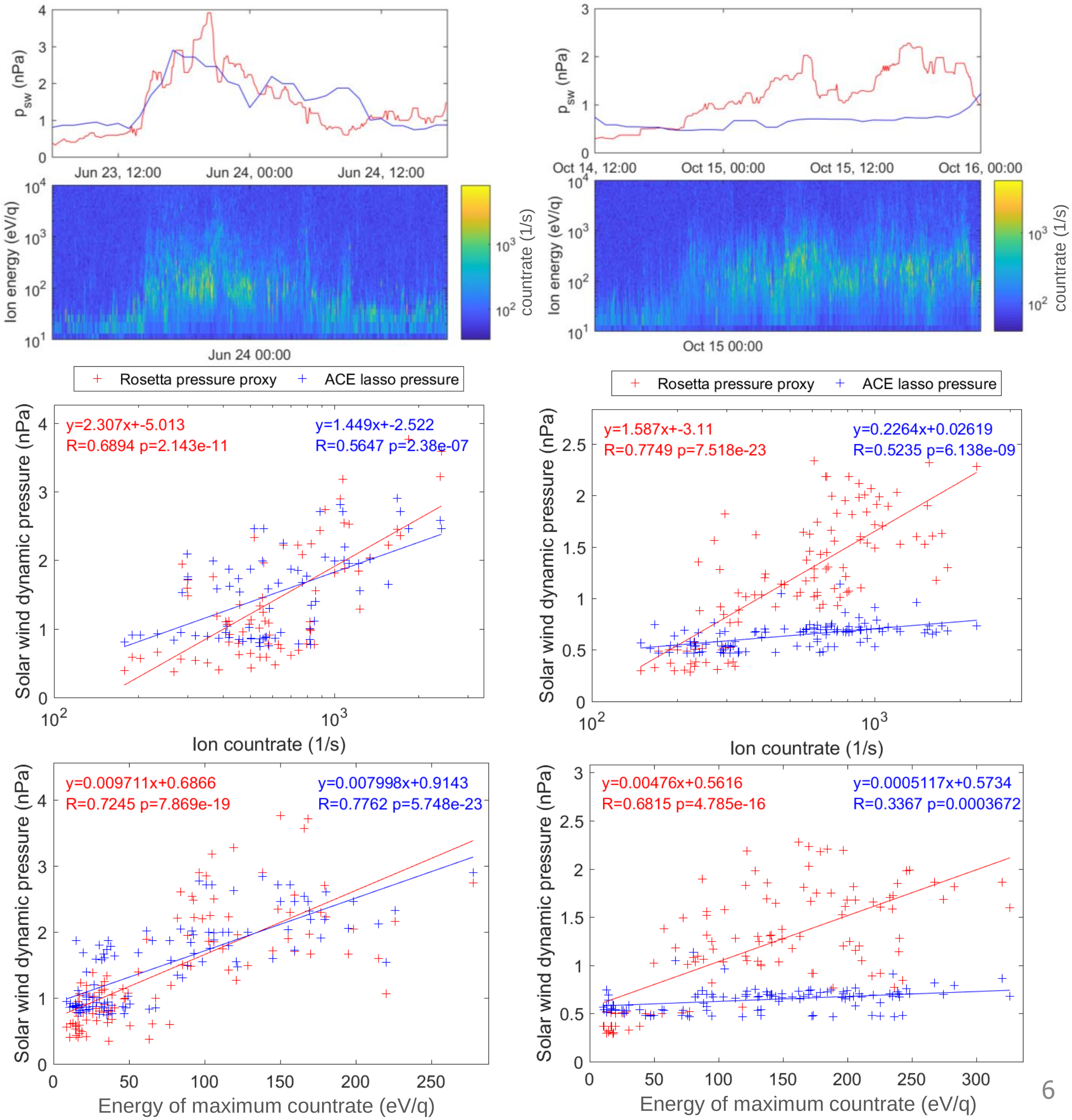
- The cometary magnetic field increases together with the increase of solar wind dynamic pressure (p_{sw})
- **Decrease of the cold** (< 10 eV) **ionospheric electron density** (n_e) is observed during the events
  - Meanwhile the **spacecraft potential** (U_{sc}) **increases** from about -20 V to near zero
- **Energetic** (10-100 eV) **electron count rates increase** suddenly and significantly
- **Lower ion energies** (< 50 eV) **are depleted** during the events; probably **due to the variation of the spacecraft potential** – the low energy ions are not accelerated into the sensor



Solar wind pressure

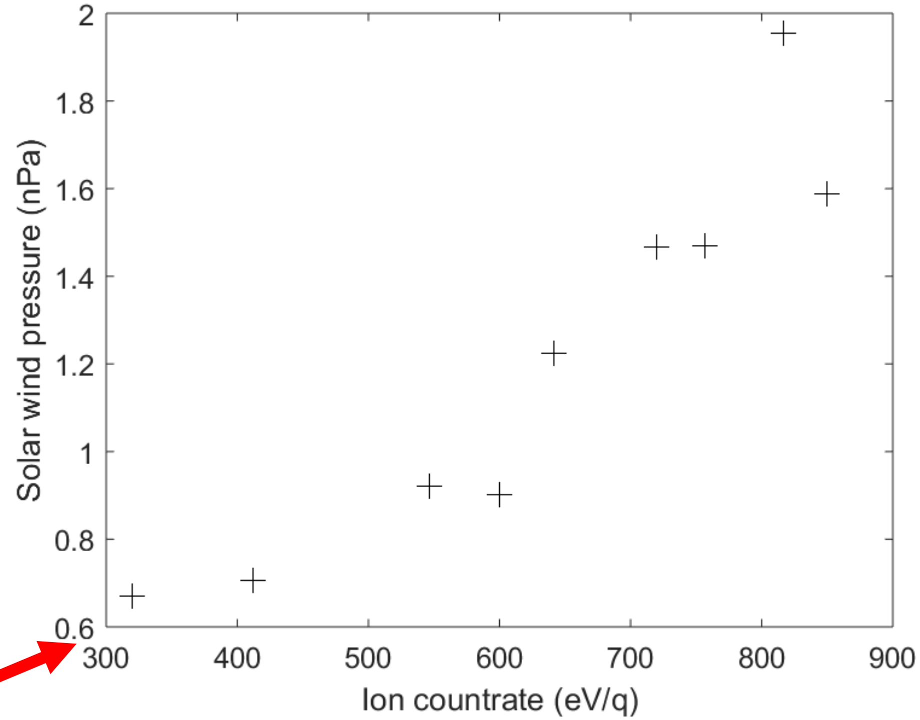
- We investigate the relationship between the solar wind around the comet and the accelerated ion events
  - **Between June and November 2015**; the Rosetta spacecraft was located inside the solar wind cavity – no solar wind was observed by the spacecraft during this time
  - We used the **OMNI lasso solar wind pressure** (Dósa et al. 2018) propagated from near-Earth to 67P and the **Rosetta pressure proxy** (Timar et al. 2019) calculated at the location of 67P from RPC MAG magnetic field measurements to characterize the solar wind
  - We studied the dependence of the value of the **maximum ion count rate** and the **energy of the maximum count rate** on the solar wind dynamic pressure

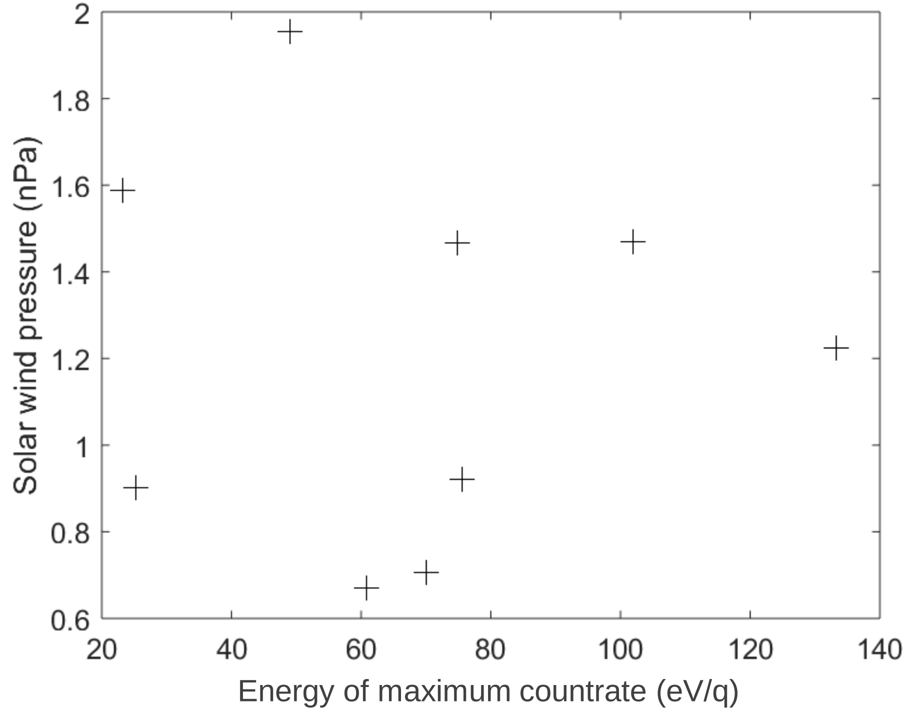
- We calculated the correlations between the ion spectrum and the solar wind pressure for 9 different ion events
  - Two examples:
    - (23-24)-Jun-2015
    - (14-15)-Oct-2015
  - There is indeed a good correlation between both the ion countrate and energy and the solar wind pressure
  - The energy of the maximum countrate correlates with the sw pressure (R≈0.6-0.8) fairly well in all 9 cases
  - Aside from three events the maximum count rate also correlates well with the sw pressure (R≈0.6-0.8)
- As expected, the overall correlation is better with the Rosetta pressure proxy
  - The propagated data can not take into account the changes in the properties of the solar wind between Earth and 67P



The global picture

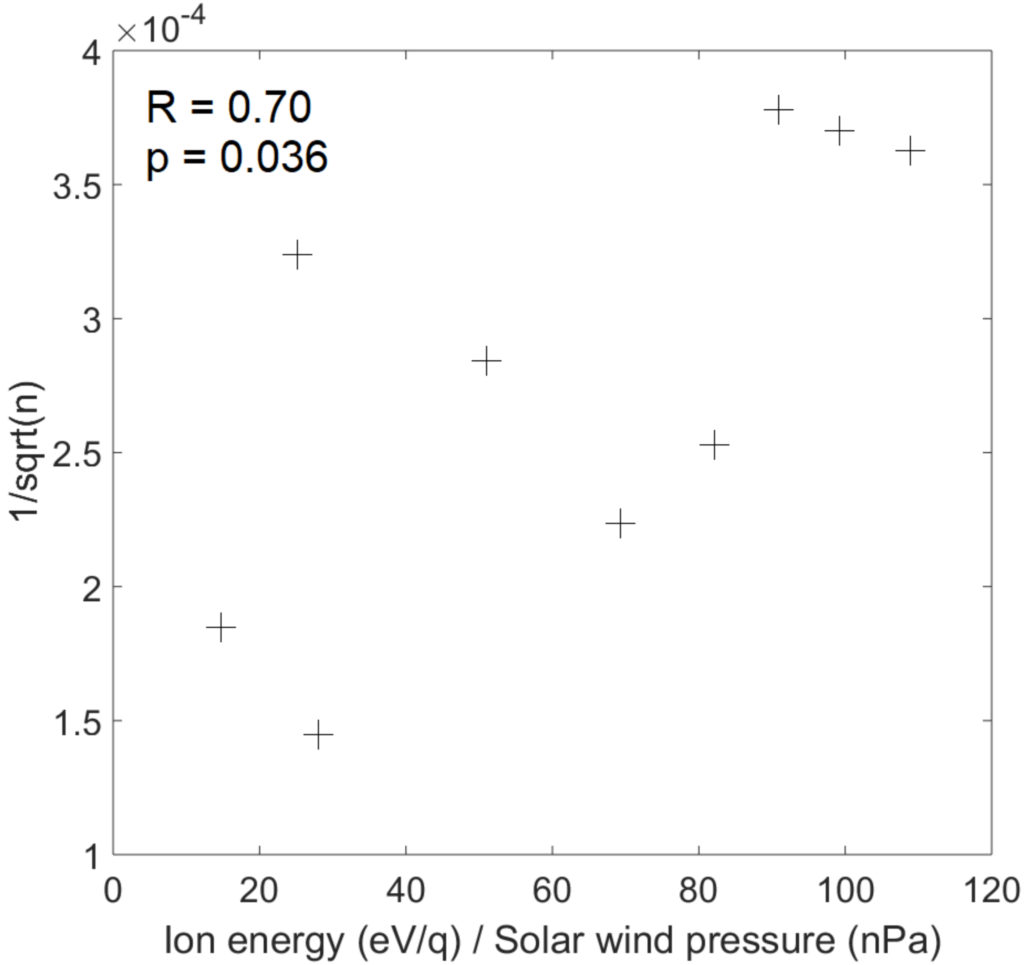
- We averaged the Rosetta measurements throughout 9 different ion enhancement events between June and November 2015
- There is a **good global correlation between the averaged ion count rate and solar wind pressure**
- There is no long-term correlation between the averaged ion energy and solar wind pressure
  - The **energy of the maximum count rate also depends on other factors**





Neutral density

- The inverse of the square root of the neutral density (n) correlates well with the ratio of the averaged energy of the maximum count rate and the solar wind dynamic pressure
  - At constant solar wind pressure ion **energies are lower in case of higher neutral density**



Energy loss

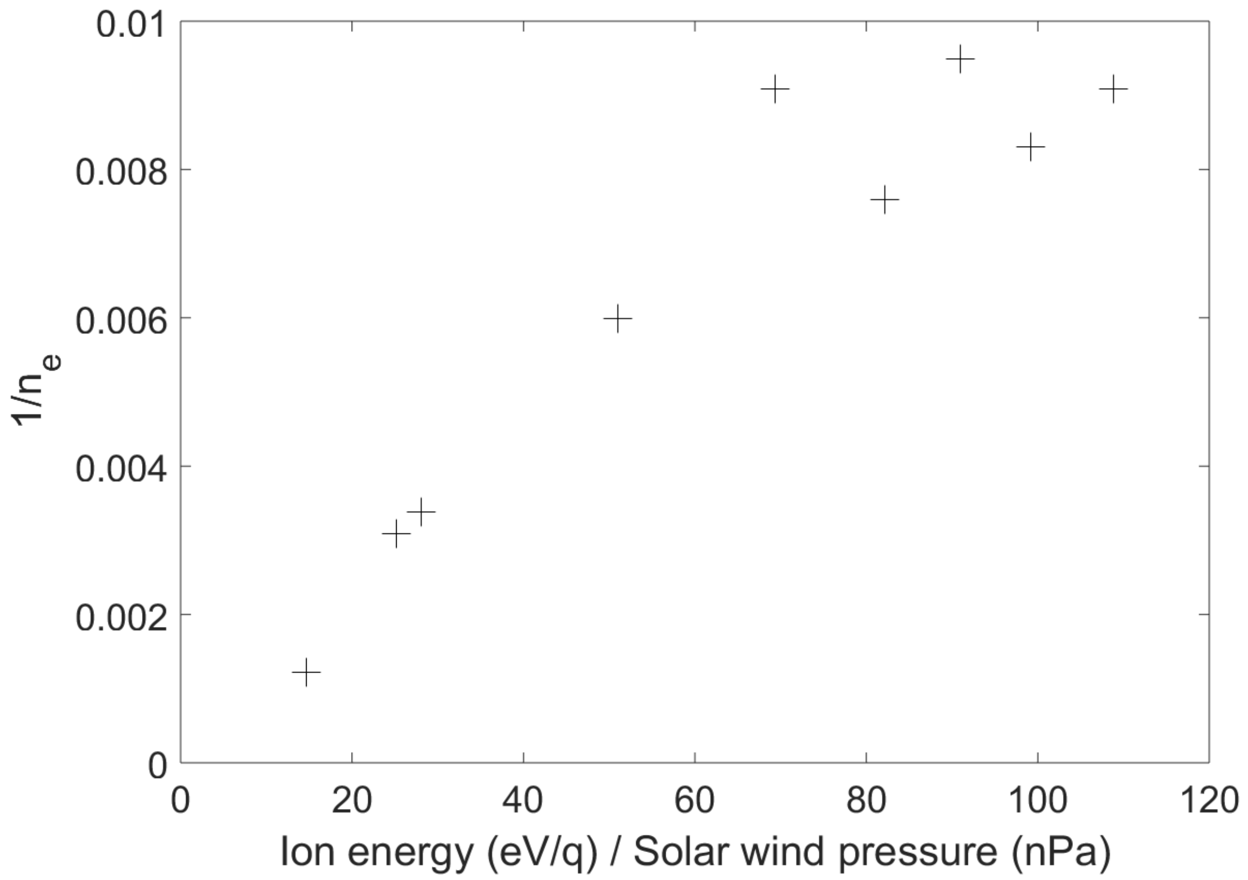
- The ions enter the dense cometary neutral atmosphere and interact with its molecules
  - They lose their energy as they collide with neutral particles (Mandt et al. 2019) and will eventually be absent from the measurements
  - At high ion energies (> few hundred eV) the differential energy loss per distance of an ion can be described by the Bethe-formula
- Goldstein et al. 2017 also reported anticorrelation between the neutral density and ion energy on a smaller time scale in June 2015
  - As the neutral densities increased from approximately 1e7 cm^{-3} to 2e7 cm^{-3} the maximum ion energy decreased from ~1 keV to <0.2 keV
- The ionization of the neutrals by the decelerating ions can be responsible for the associated electron burst in the 10-100 eV range observed on the electron spectrum

Ion source

- Changes in the ion energy observed at the position of Rosetta can be influenced by two different effects:
  a) **Moving plasma boundaries**: the increased solar wind pressure pushes the source region towards the spacecraft; the column density the particles have to travel through is reduced
  b) The **ion energy increases** in the source region: the ions would require a longer distance to slow down due to the collisions
- In each case the rate of the energy decrease can be approximated by the Bethe formula
  - The changes in the location of the source and/or in the energy of the source could be approximated

Electron density

- Inversely proportional to the ion energy maximum
  - Globally, at large timescales $p_{sw} \sim n_e$
  - This is probably **due to the correlation between the electron and neutral density**
- While **solar wind pressure variations** have no measurable effect on the neutral coma, they **influence the cometary ionosphere**
  - The magnetosphere compresses and expands depending on the sw pressure, and the region of maximum plasma density moves away from or towards the spacecraft
- Thus the electron density decreases (and U_{SC} increases) during these compression events
  - **At short timescales $p_{sw} \sim 1/n_e$**
  - This is the opposite of what was seen during CIRs at low activity (Edberg et al. 2016, Hajra et al. 2018)



Electron density

- The electron density anticorrelates with the solar wind pressure contrary to observations during CIRs during low activity
  - *…shouldn't the electron density increase as the magnetosphere is compressed…?*
- We investigated events at **high activity**, during which time the diamagnetic cavity was also present
  - At the diamagnetic cavity boundary an electron density maximum can be observed (Nemeth 2016; Henri et al. 2017)
    - Nemeth (2020) has shown that this density peak moves inward as the solar wind pressure increases
    - Thus increased solar wind pressure causes decreased plasma density at the location of the spacecraft

Conclusions

- There are good correlations between the solar wind pressure and the maximum ion count rate and the energy corresponding to the maximum ion count rate on local and global timescales as well
- The solar wind pressure together with the neutral density dictate the energy of the accelerated ions
  - Ions interact with the neutral coma and lose energy
  - At a constant solar wind pressure the energy loss is stronger in denser atmosphere
  - During the ion events the location of the source and/or the energy of the source ions changes, making the accelerated ions observable for the spacecraft located in the dense coma
- The measured electron densities decrease during the ion events near perihelion
  - Probably due to the increase in the solar wind pressure pushing the electron density maximum at the cavity boundary towards the comet

Next steps:

- Determine the ion energy loss rate using the Bethe formula and approximate the changes in the location of the source and/or in the energy of the ion source
- The dependence of the electron density on the solar wind pressure can be calculated near perihelion

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