Solar wind interaction with 67P

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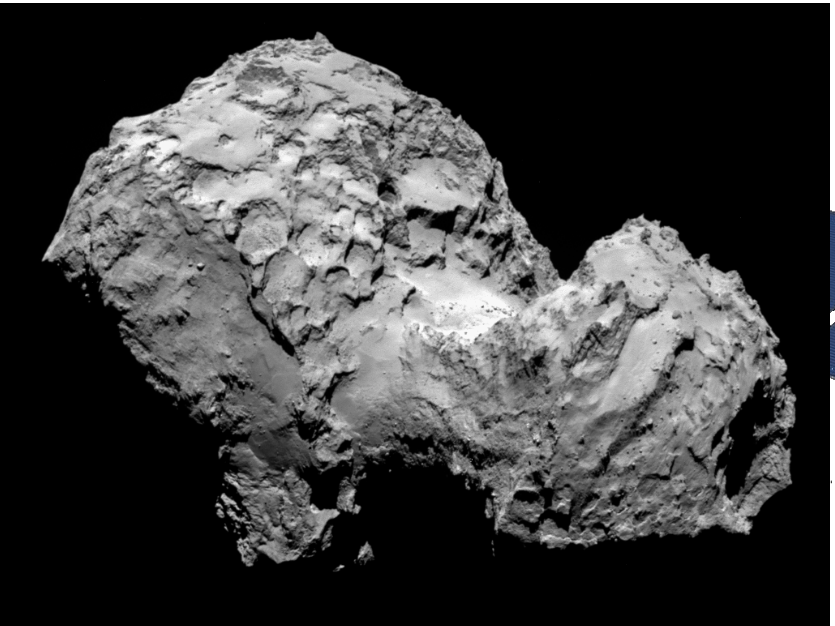
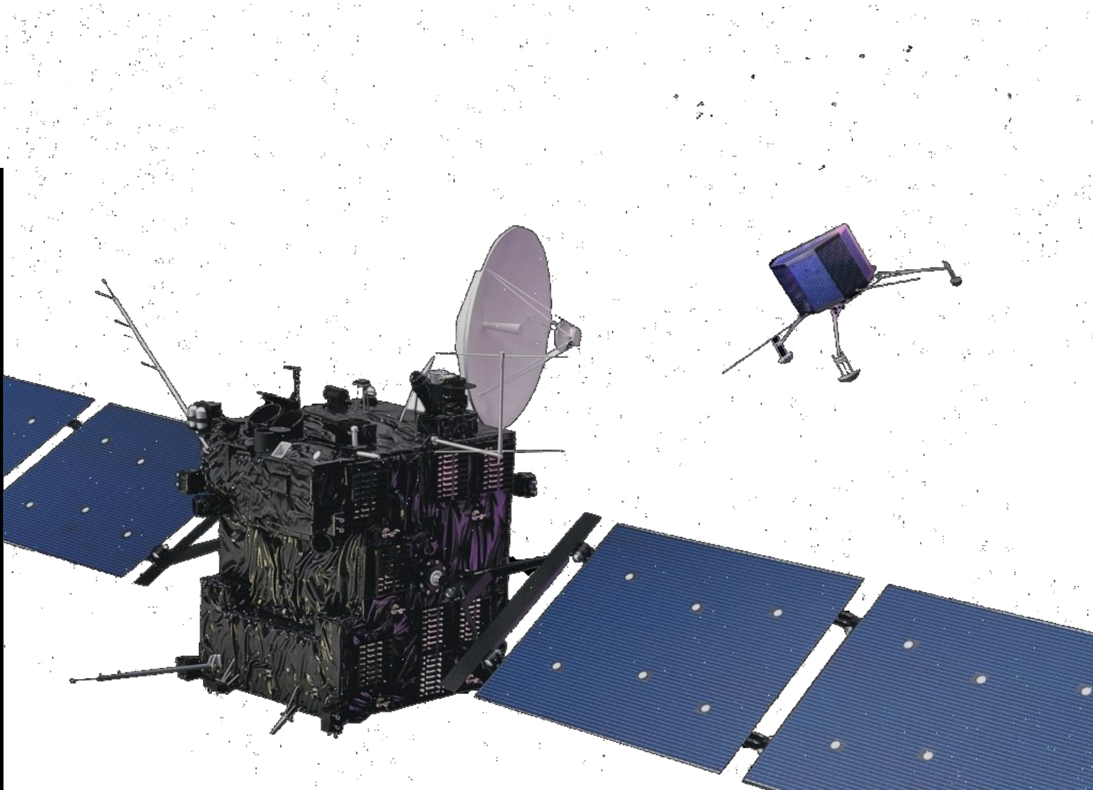
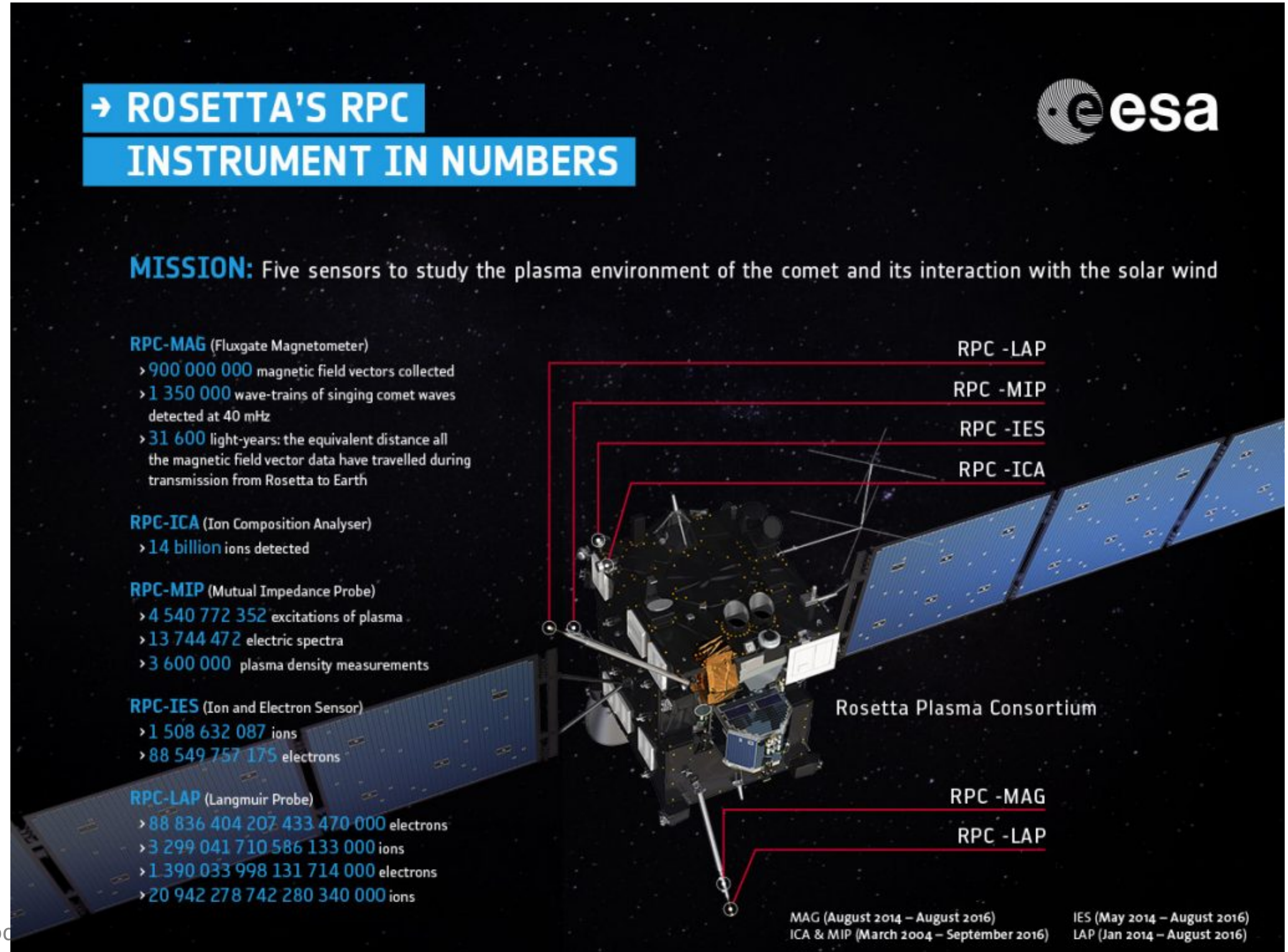
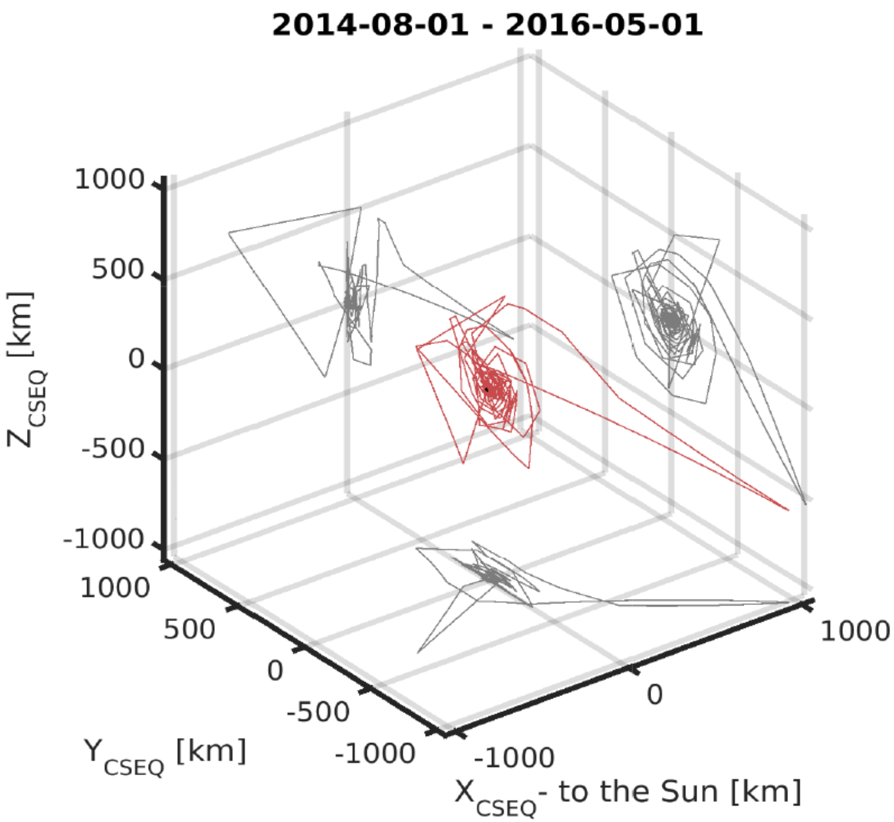


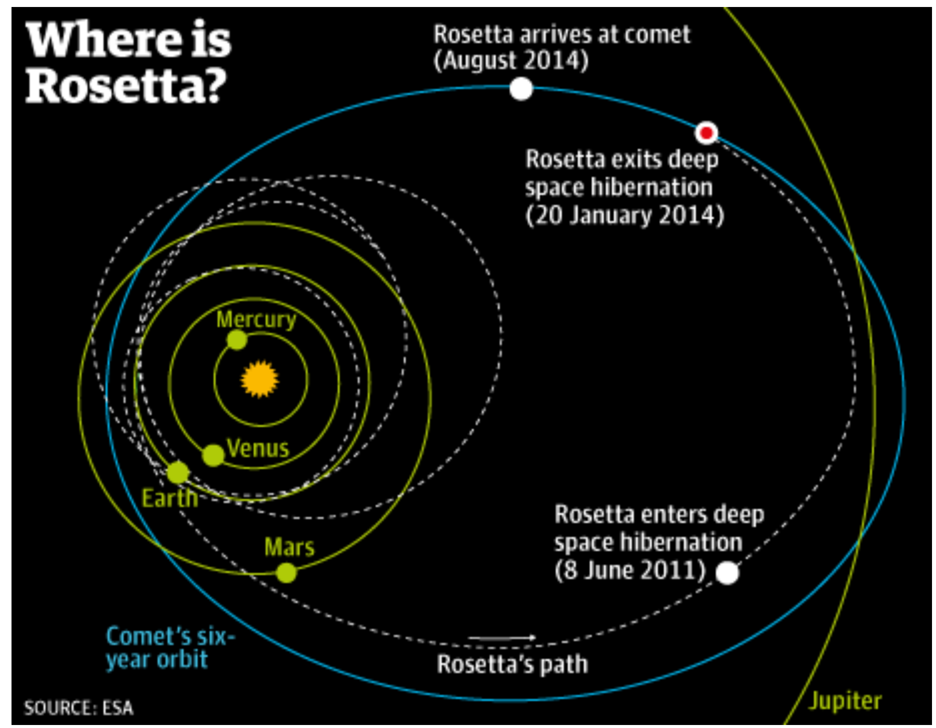


Rosetta Plasma Consortium



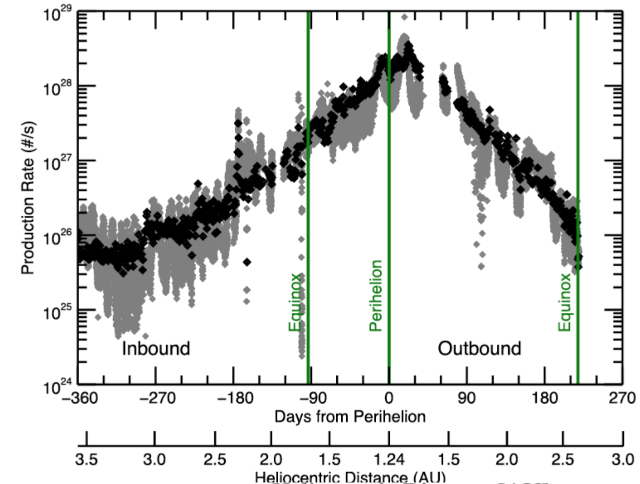
Rosetta mission

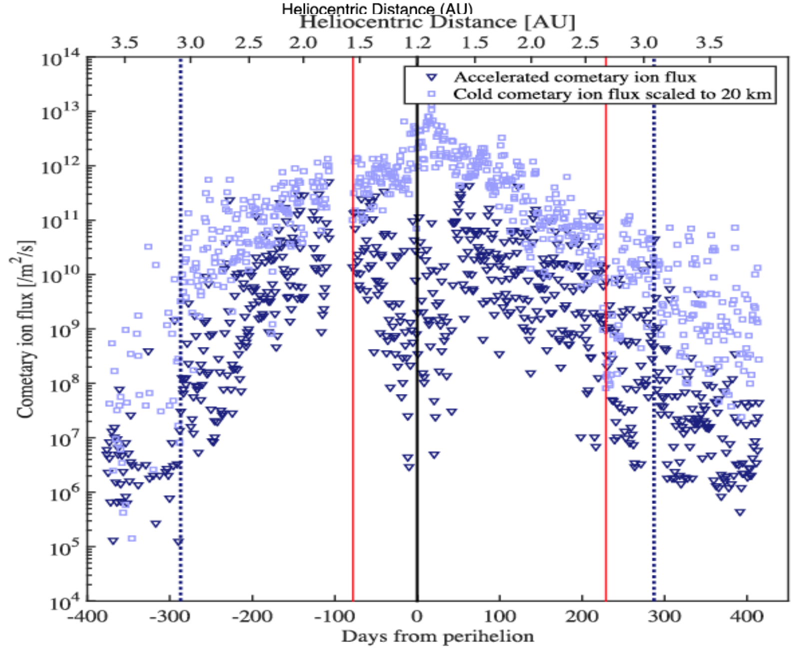


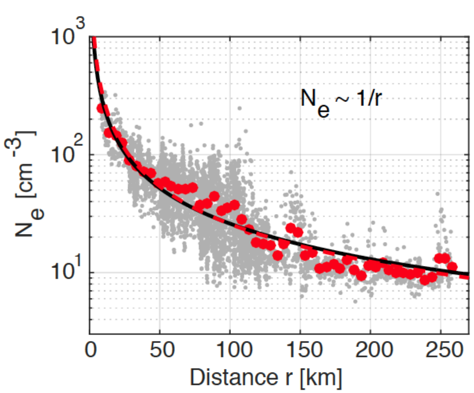


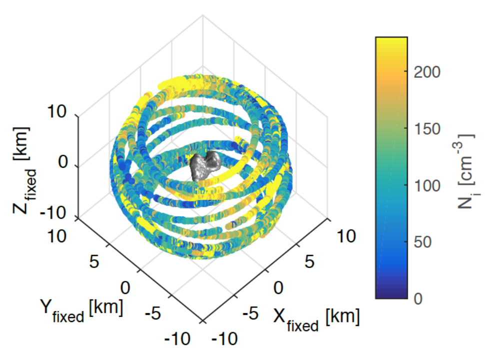
Plasma environment of 67P

- 67P is a weakly outgassing comet with $Q = \sim 10^{28}\ s^{-1}$ at perihelion, mainly water
- Comet heats up by sun and sublimate
- ionised by EUV, particle impacts, charge exchange
- neutrals flow radially outward at ~550 m/s, no gravity.
- ionised by EUV and particle impacts
- Neutrals falls off as $1/r^2$, plasma as $1/r$
- Plasma of hot and cold electrons, cold and accelerated ions, heated to 100s eV (possibly waves), cooled by collision
- Highly dynamic plasma environment



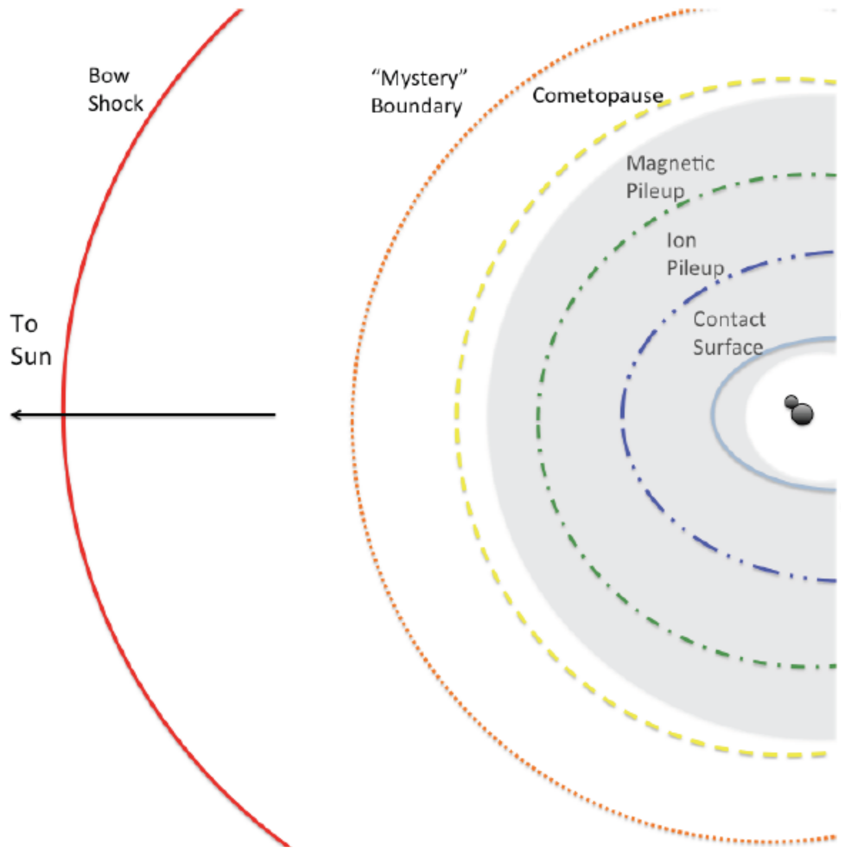


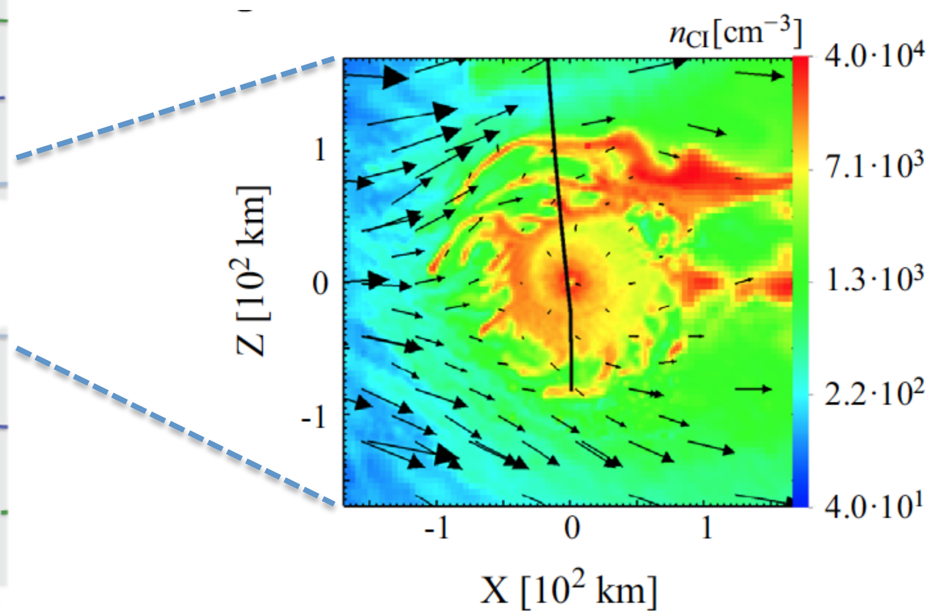




Cometary plasma environment

- 6 different "boundaries" observed at comets
- 4 permanent boundaries
- Rosetta has observed 2 of these: contact surface (diamagnetic cavity) and collisionopause

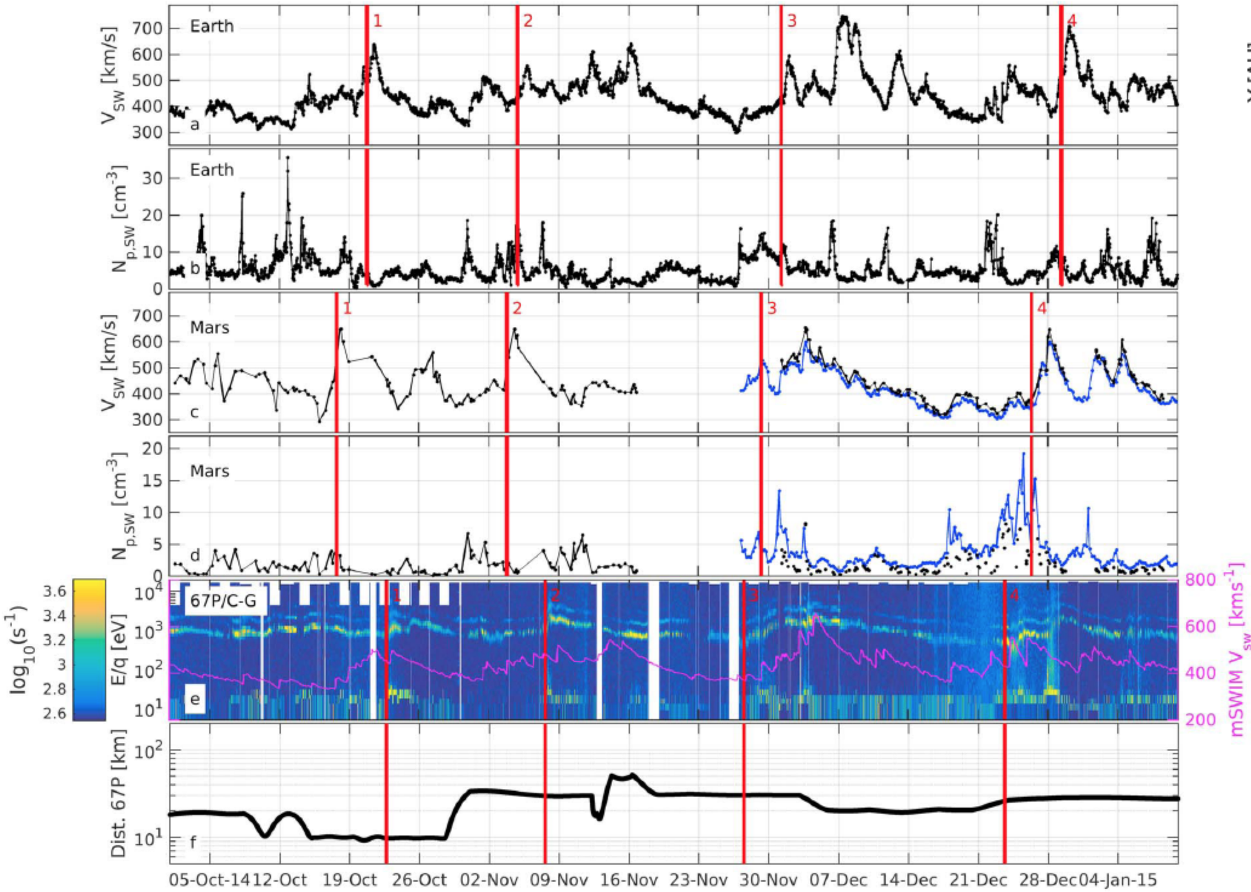


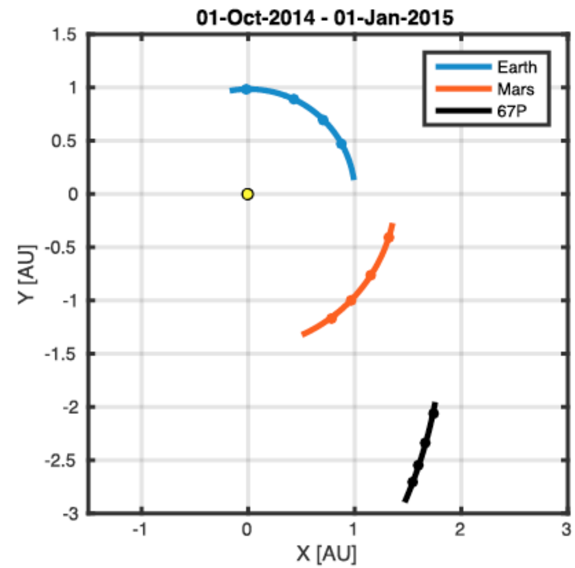


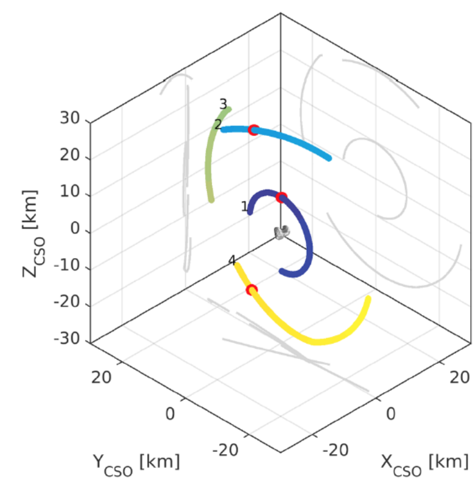
Koenders et al., 2015

Mandt et al., 2016

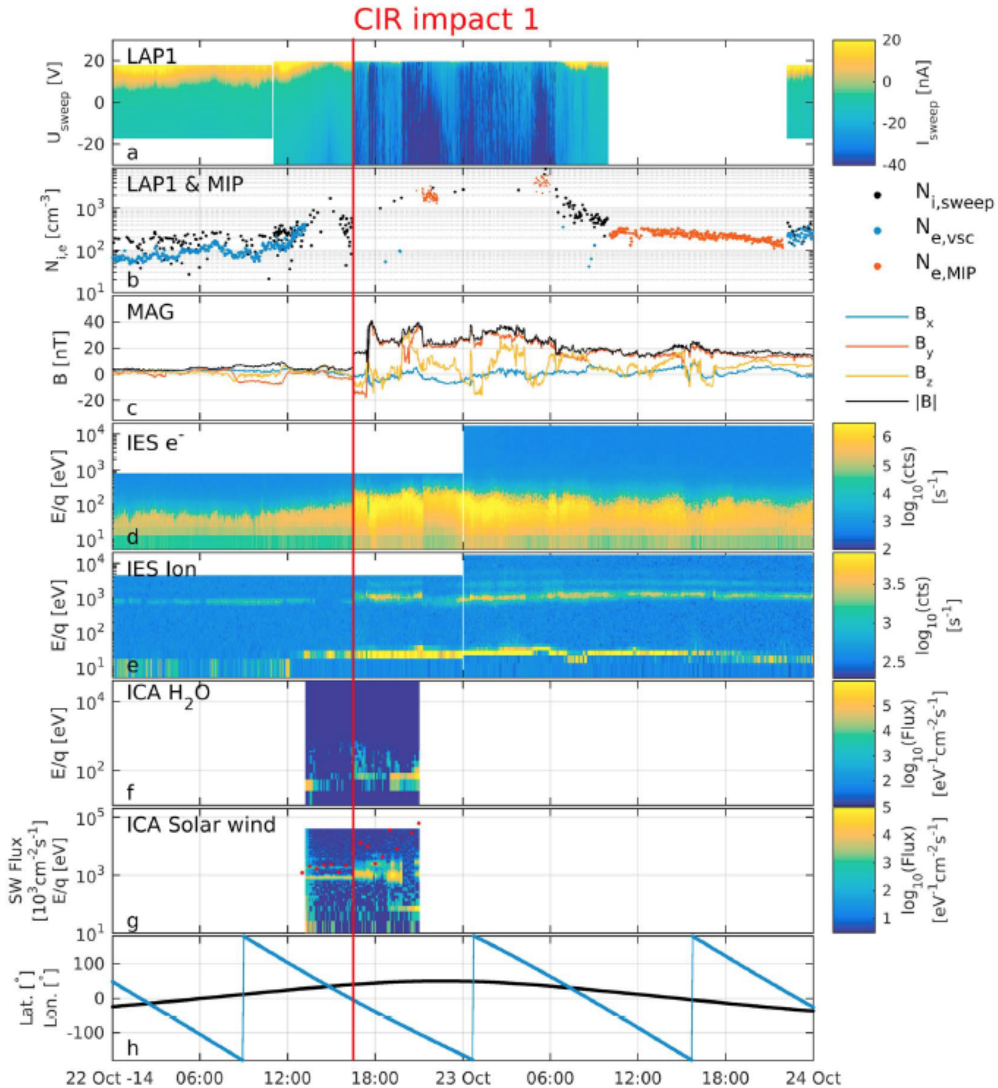
CIR impacts during low cometary activity







Comet's response to a CIR impact 1

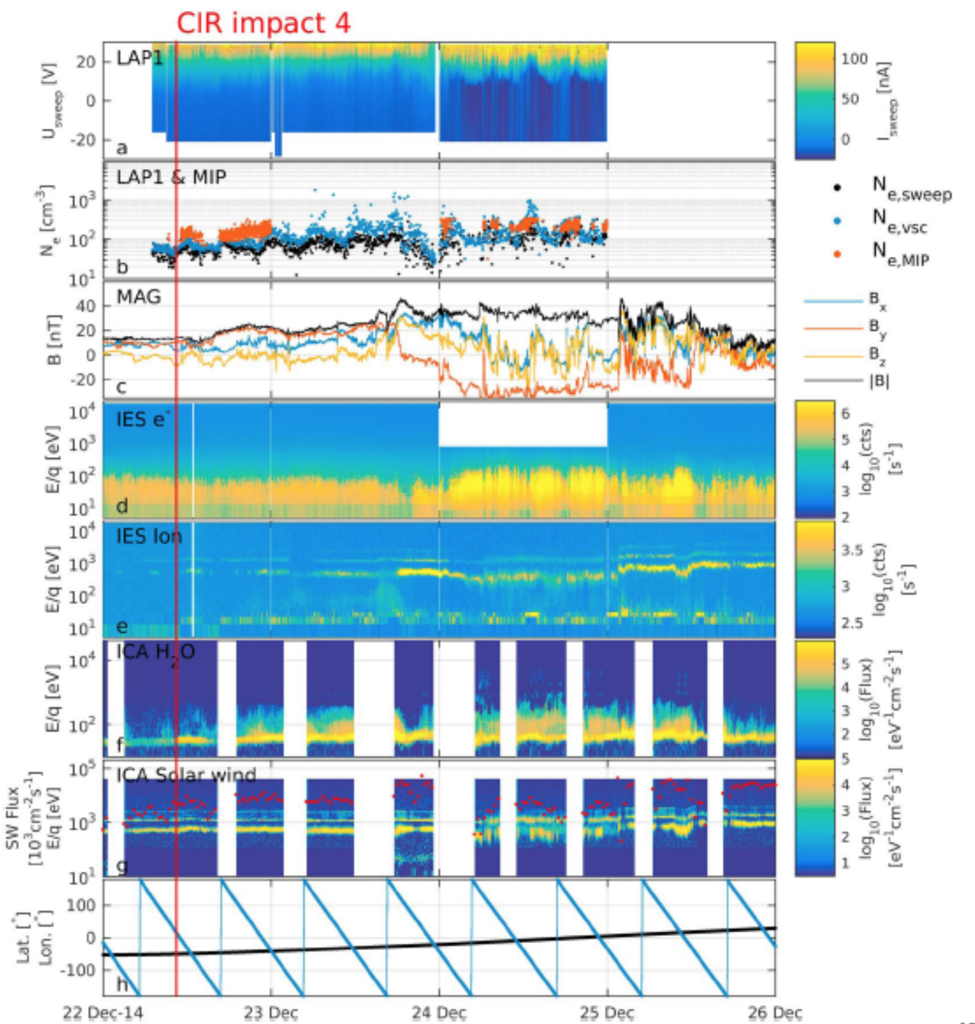


Impact observed in all RPC instruments:

- Plasma density increases by one order of magnitude (LAP,MIP)
- Neutral density varies by about a factor of 5.
- B-field strength increase to 40 nT, direction varies (MAG)
- Electron fluxes around 100 eV increase (IES)
- Solar wind ion flux and accelerated water ion flux increase at impact (ICA)
- 6 hour periodicity discernable in the interaction

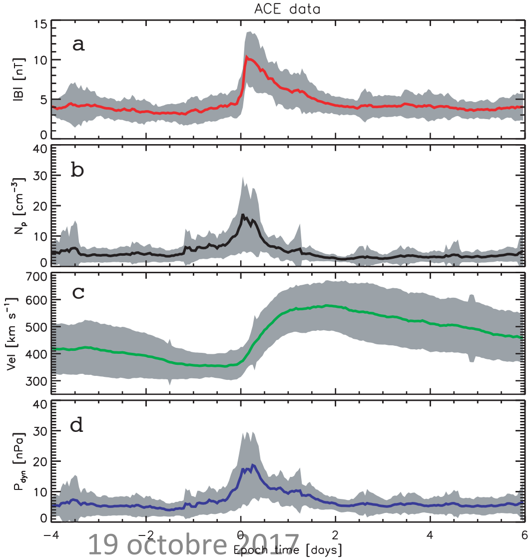
Increased ionization by particle impact and charge exchange could cause the increased plasma density? Sweeping up of upstream plasma?

Comet's response to a CIR impact 4



- Small(?) plasma density increase – follows latitude change
- Gradual magnetic field strength increase, gradual orientation change, abrupt increase on 25 Dec
- ICA accelerated water ion flux increased over several days, but starting before
- IES 100 eV ion flux increase at impact

Time varying solar wind conditions



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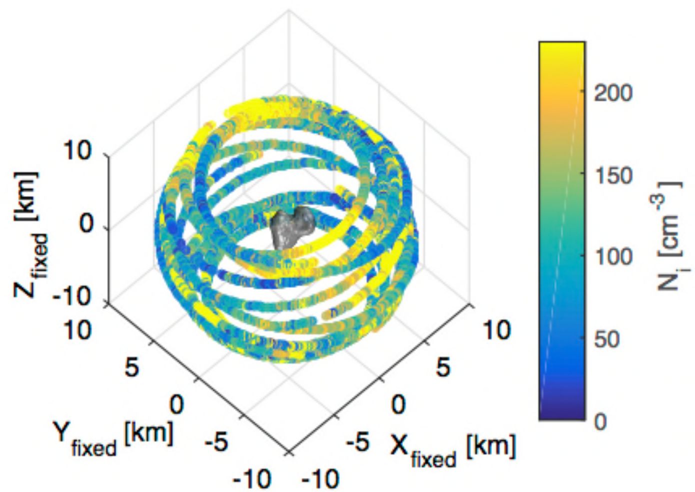
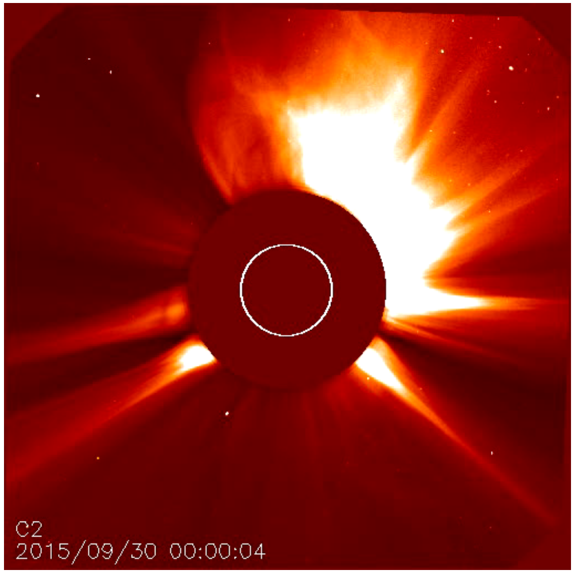
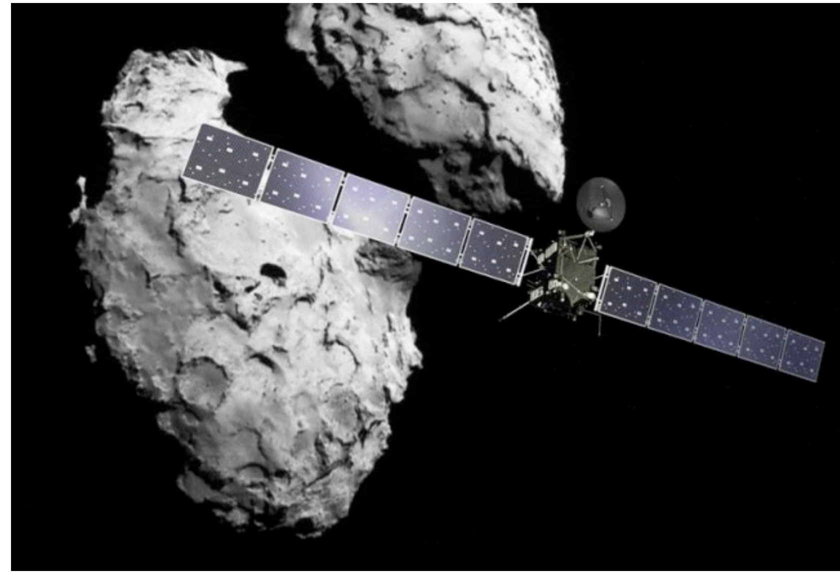
Highly structured, rotating, expanding, and evolving cometary ionosphere

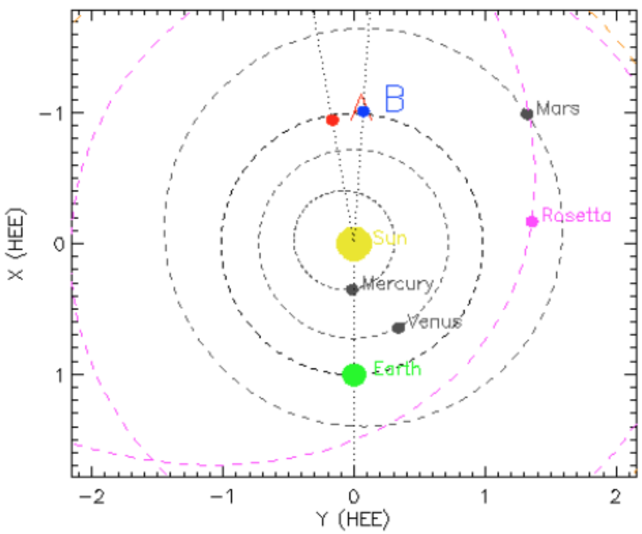


= Complex interaction

Impact of CME on comet 67P







- Propagate radially outward in solar system
- Arrival date at comet:

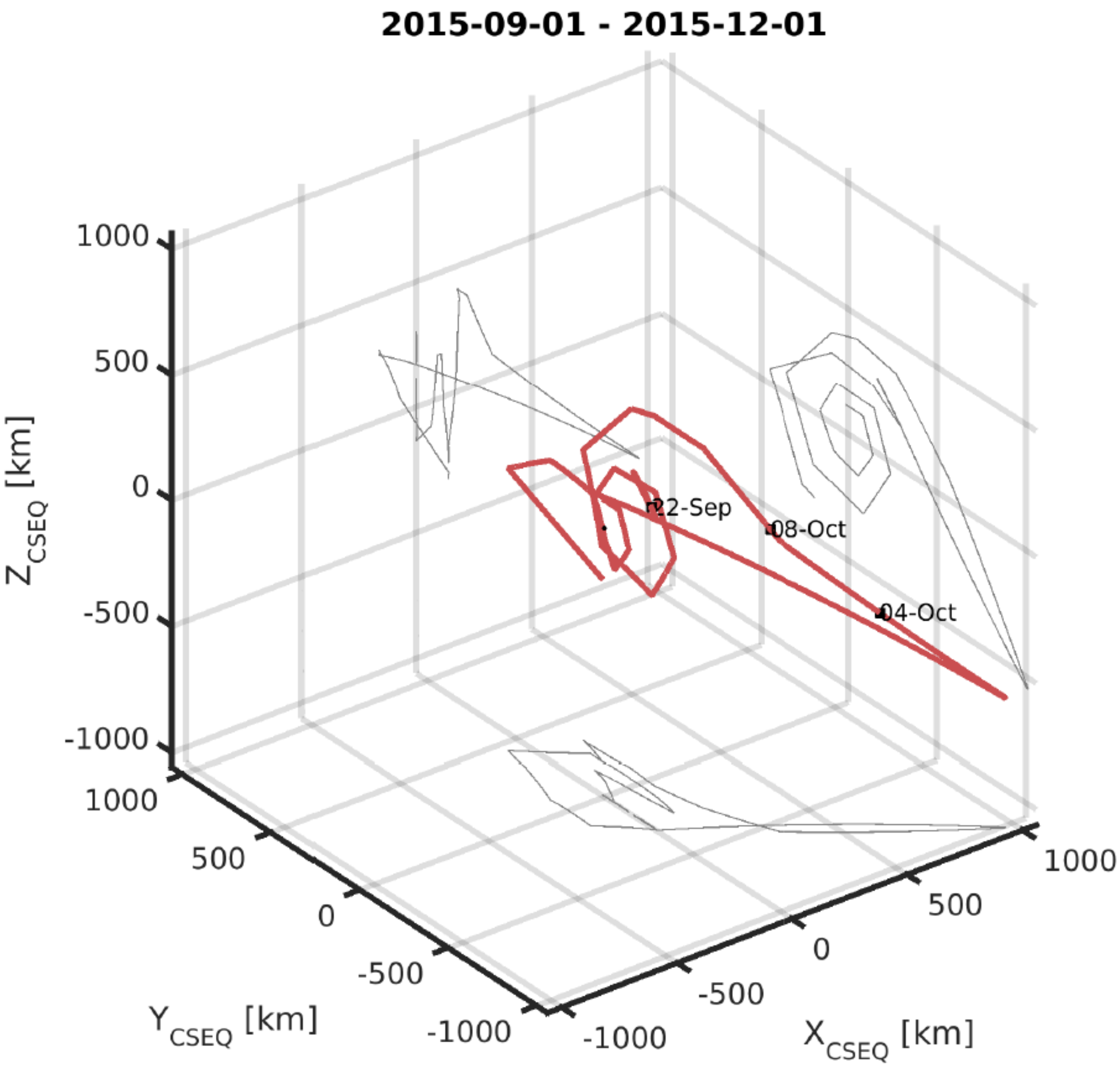
v = ~500 km/s

d = 1.4 AU

-> t = ~5 days travel time to 67P

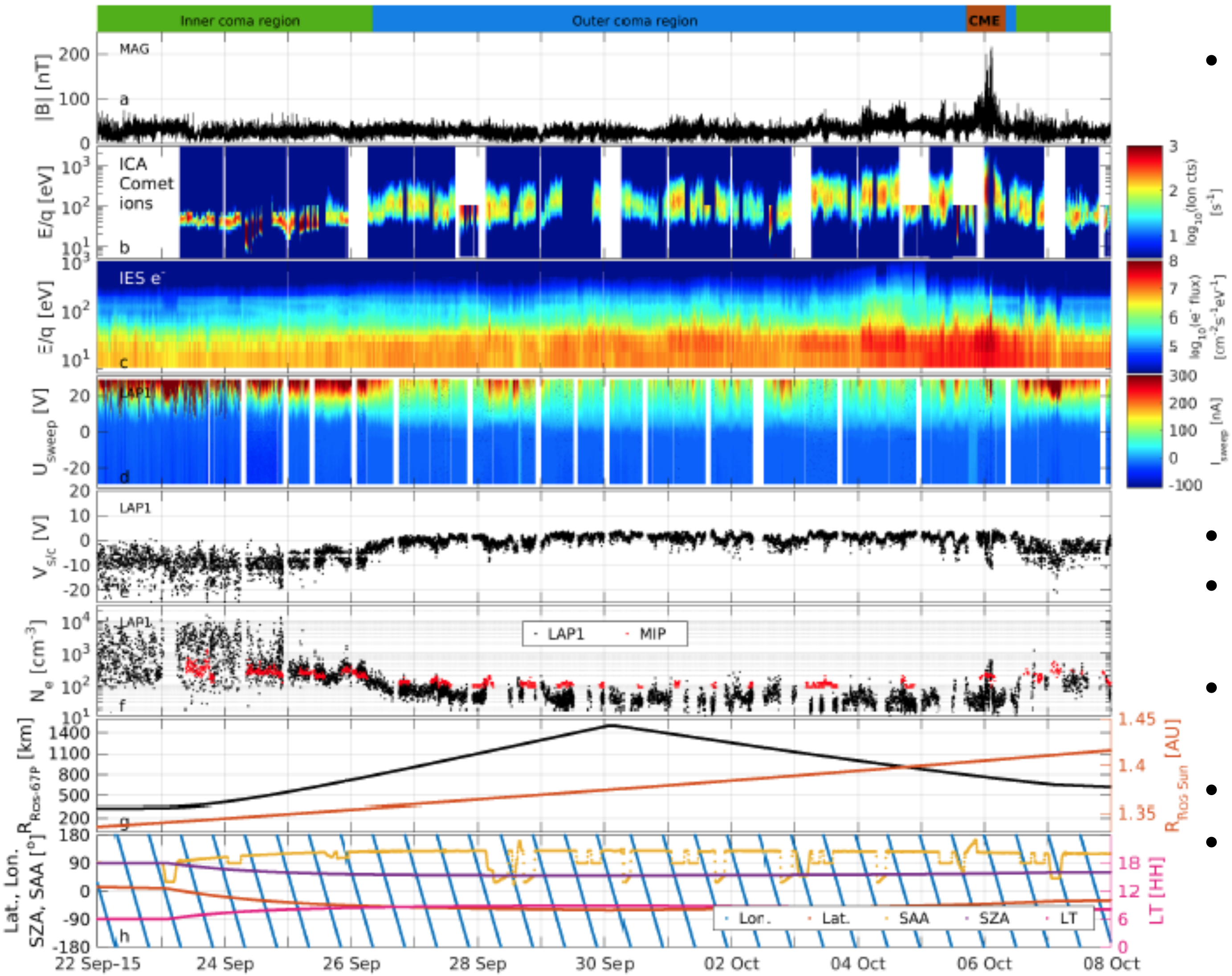
Arrival around 5 Oct 2015

Trajectory during dayside excursion



- Started at 300 km from nucleus on 23 Sep 2015
- Close to perihelion
- ~45° off the Sun-comet line
- Reached 1500 km on 30 Sep
- Back again around mid-October

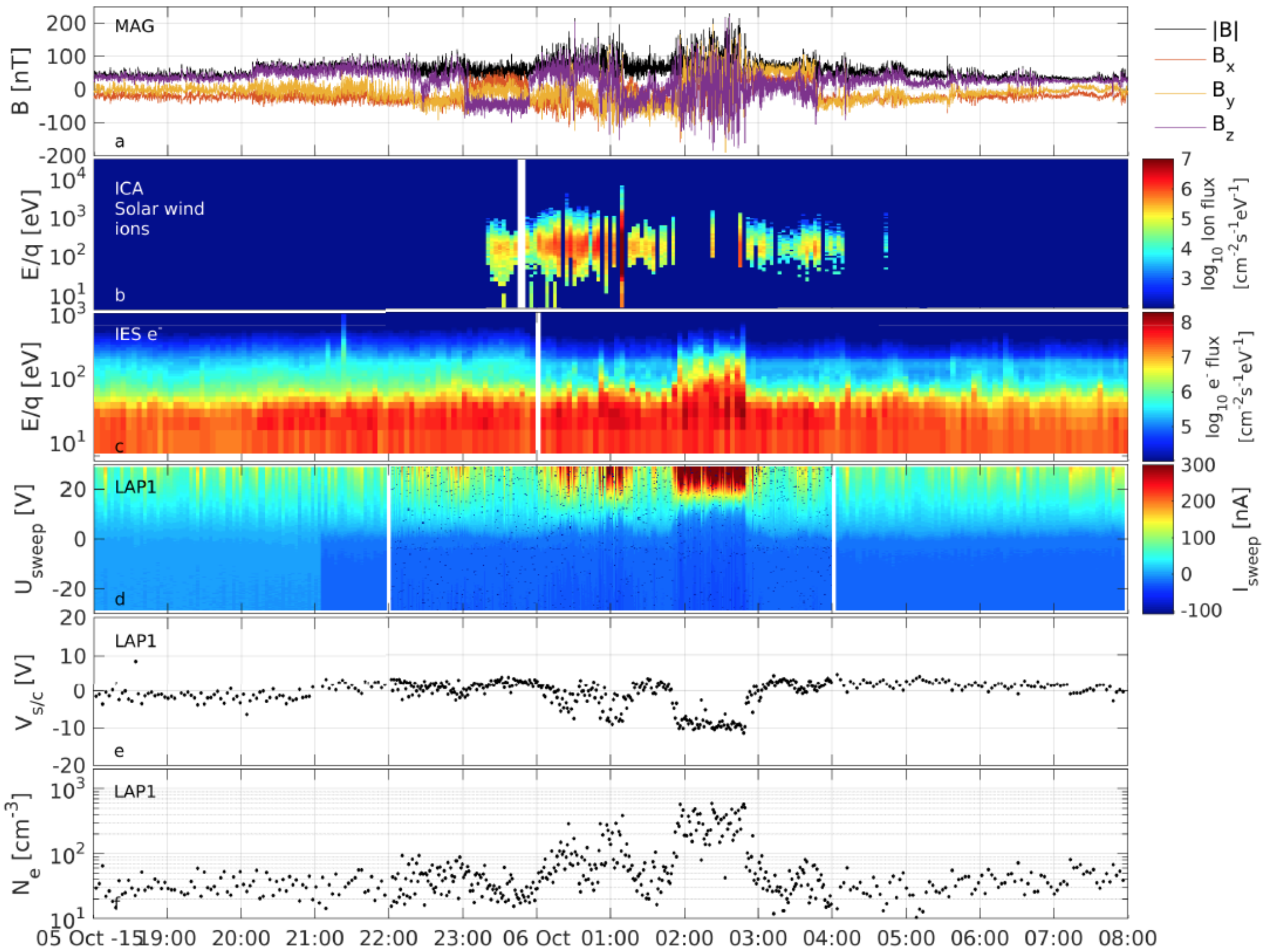
Overview of RPC excursion data



- Combined RPC data set
  - MAG (B magnitude)
  - ICA (heavy ions)
  - IES (electron flux)
  - LAP S/C potential
  - LAP e^- density
  - MIP e^- density

- 22 Sep - 08 Oct
- A scan through the plasma environment
- Some variations due to S/C attitude changes
- No bow shock observed
- One boundary observed, interpreted as a collisionpause (Mandt et al., 2016)

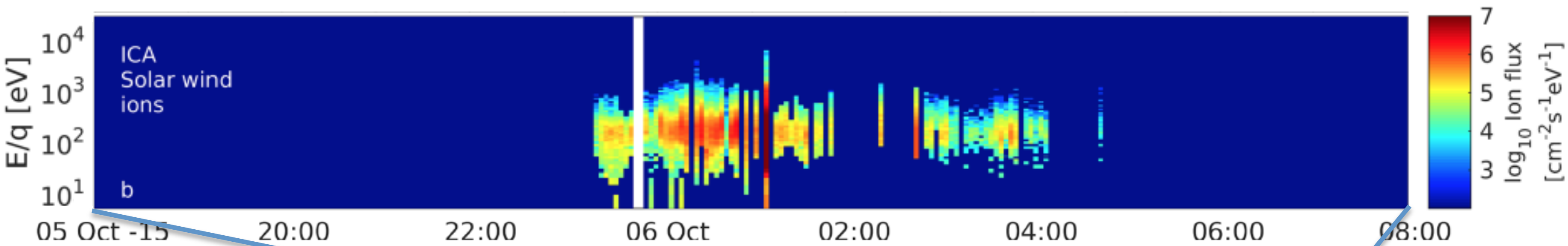
Zoom in during CME impact



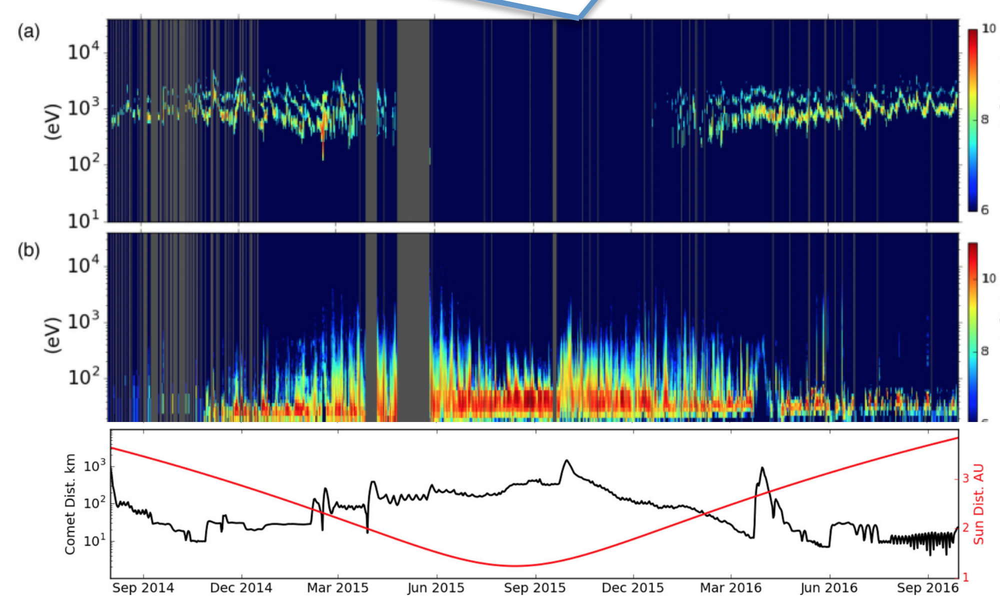
Three specific observations:

1. **Return of the solar wind**
2. **Increased density**
3. **Magnetic flux ropes**

1. Return of the solar wind

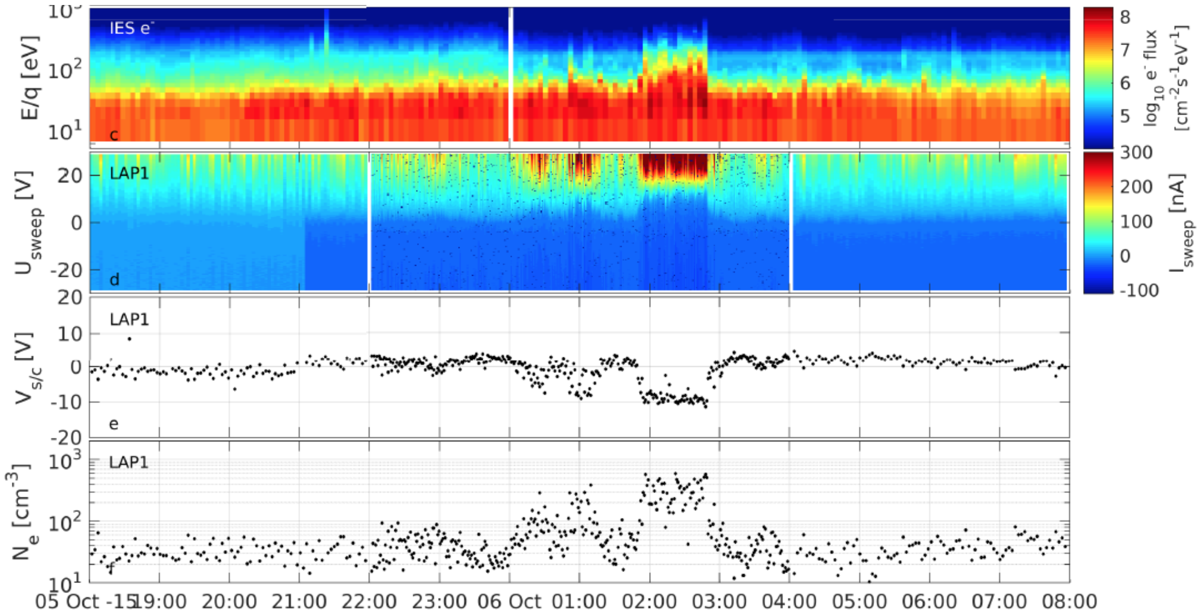


- Solar wind observed at 800 km
- Relatively low fluxes still
- Cometary ions scattered some 10s deg from preferred anti sunward direction
- A few days earlier when at 1500 km the solar wind was not seen.
  -> Indication that the CME really impacts and compresses the plasma environment a factor of ~2 or more
- Solar wind deflected some 30-50 deg of sun-comet line



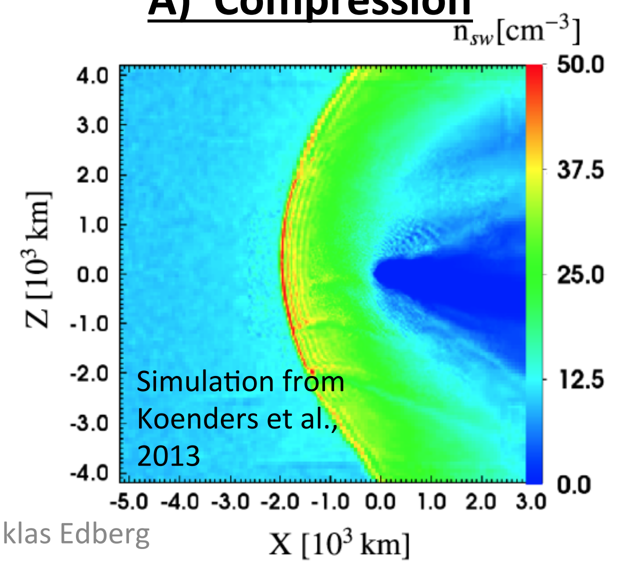
Nilsson et al., 2017

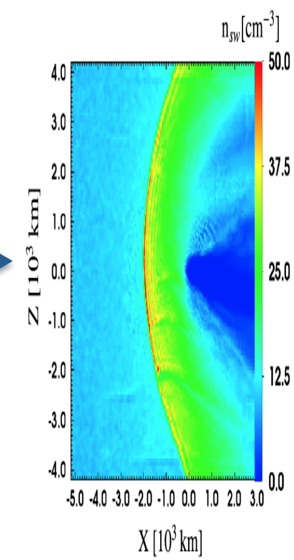
2. Increased plasma density



- Density increases by a factor of ~10
- Spacecraft potential drops from +1V to -10V
- Three causes of this increase

A) Compression



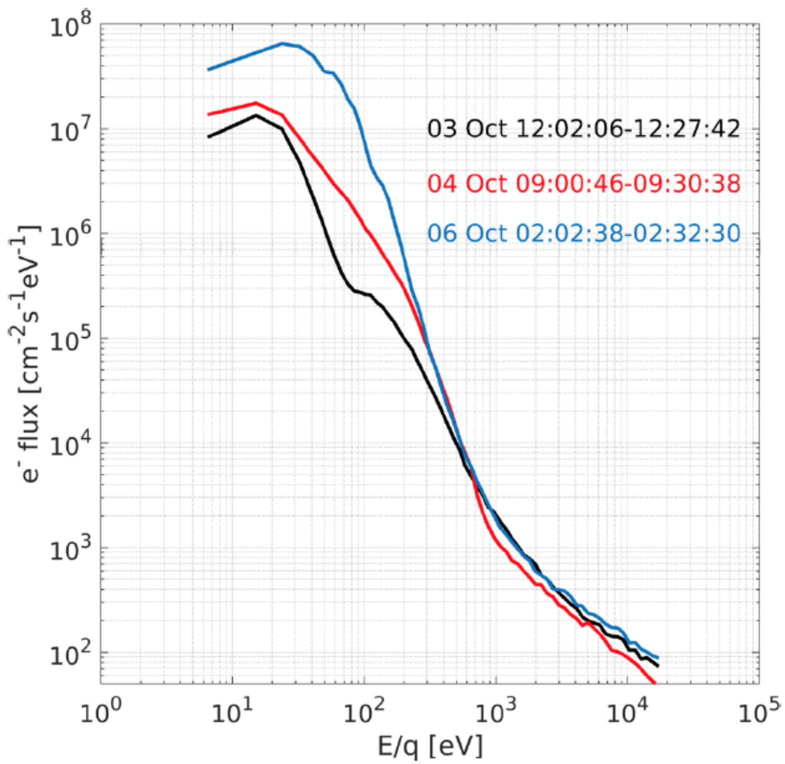


Background magnetic field increases a factor of ~3, solar wind located a factor of two(?) closer to the nucleus -> ***Density increase by a factor of 2-3***

2. Increased density (cont)

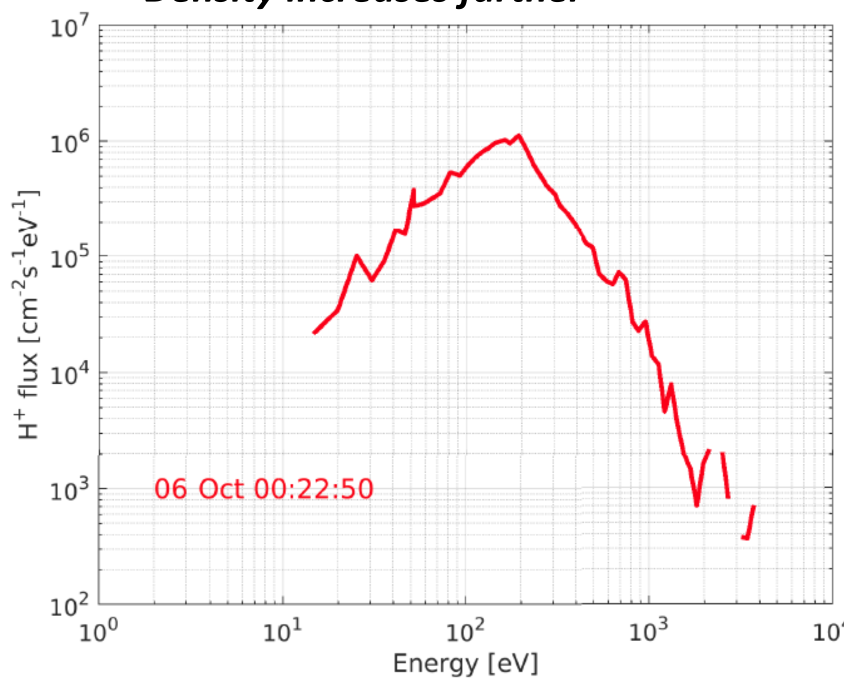
B) electron impact ionisation

- e^- flux increase a factor of ~10 at most:
- Ionisation frequency f_E go from $2.6 \cdot 10^{-8}\ s^{-1}$ to $6.8 \cdot 10^{-7}\ s^{-1}$ ->
- ***Density increases by factor of ~2.5***

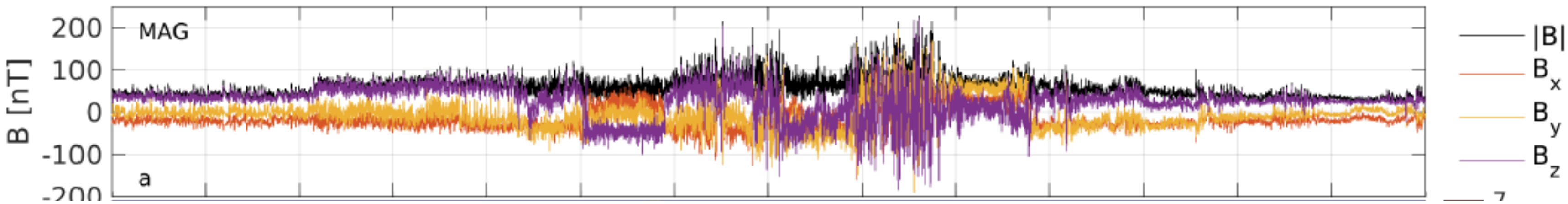


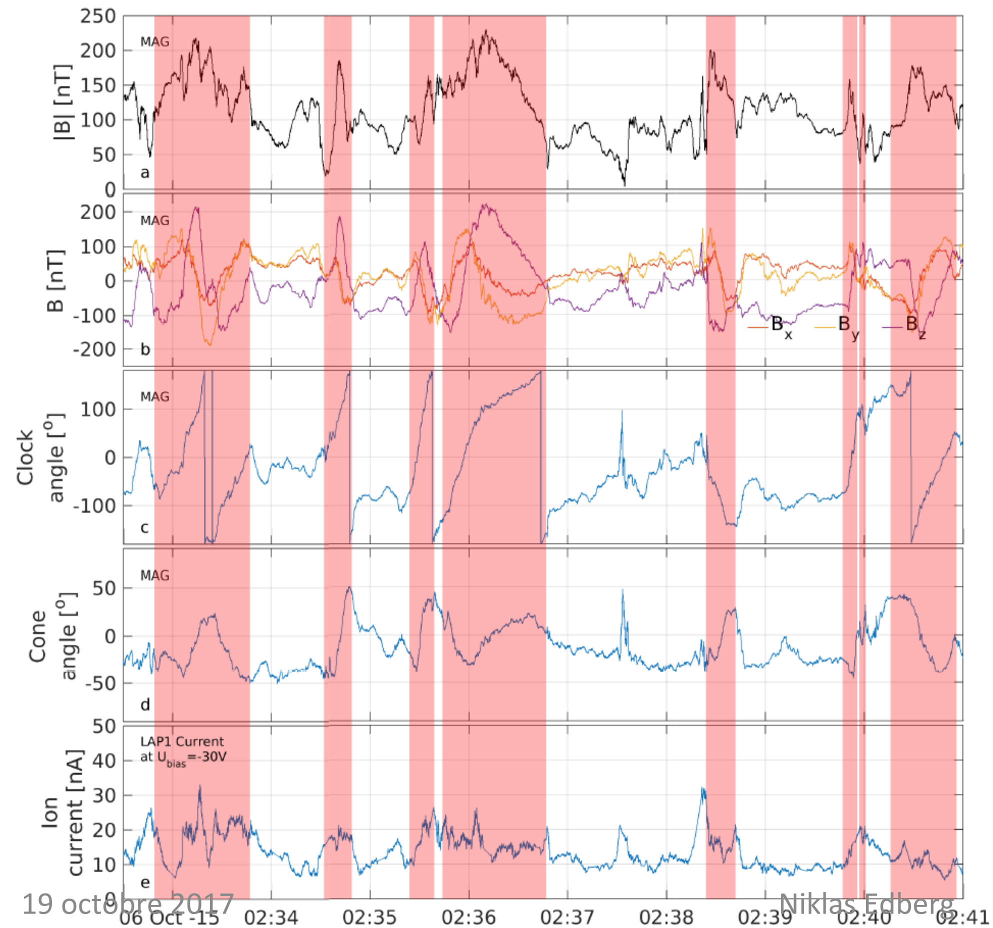
C) charge exchange

- $H^+ + H_2O \rightarrow H + H_2O^+$
- Spectra below, from CME impact, gives production rate comparable to photo-ionisation
- Increases the mass of the ion population, and slows it down ->
- ***Density increases further***

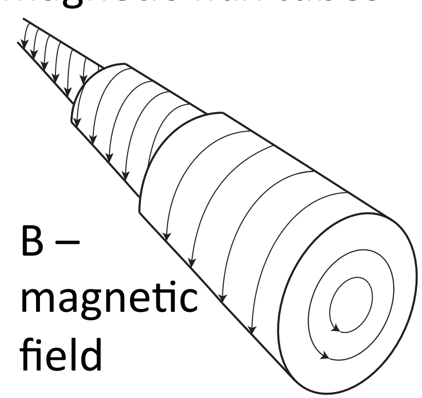


3. Observations of magnetic flux ropes





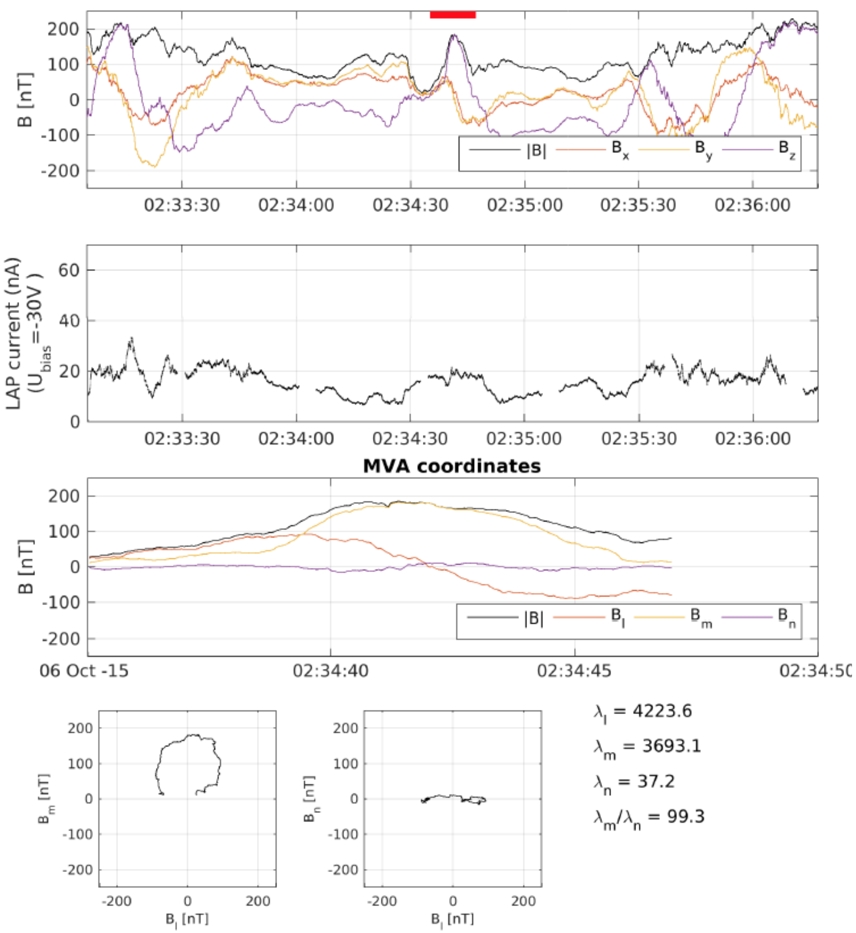
- Lots of magnetic field spikes, some reach above 200 nT
- Zoom in on some of the largest spikes
- 8 magnetic field signatures in this interval shaded red
- We believe these are so called magnetic flux ropes, i.e. twisted magnetic flux tubes



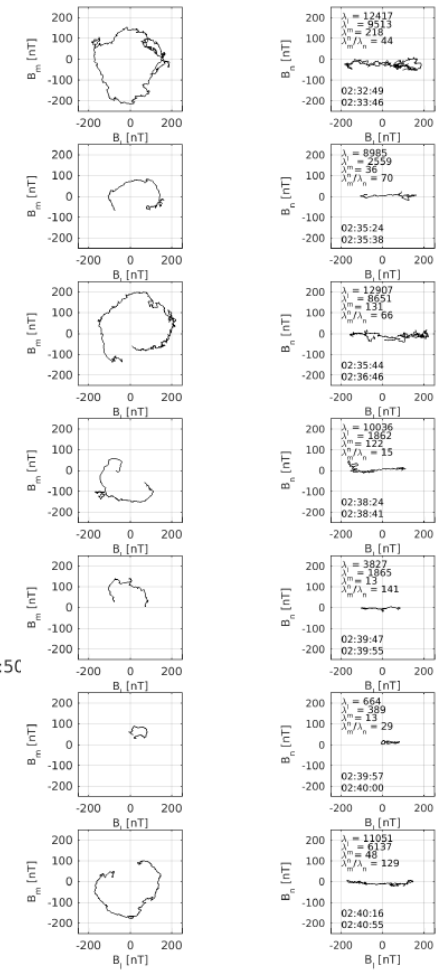
B – magnetic field

3. Observations of magnetic flux ropes

1 event…

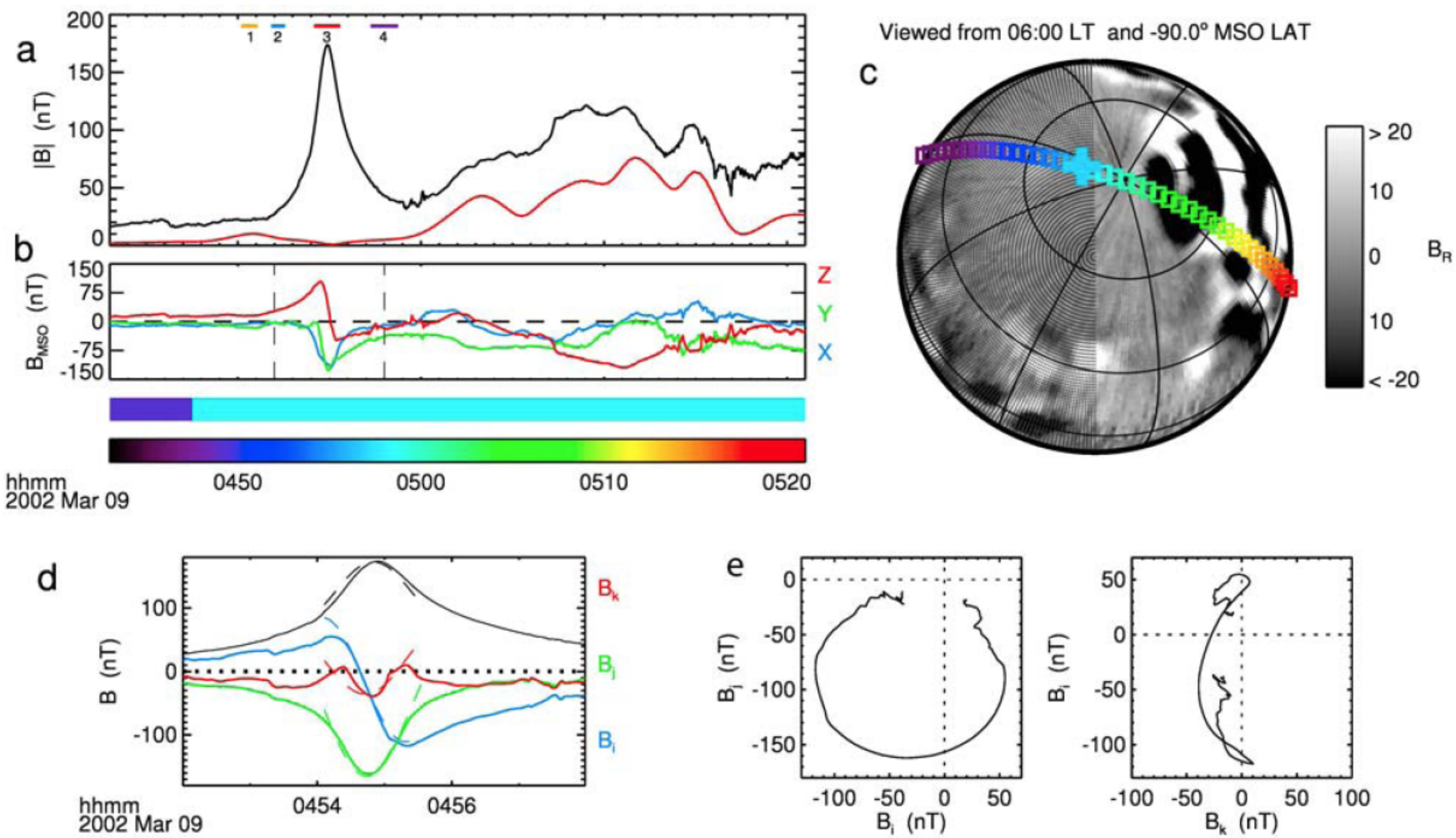


…7 more events

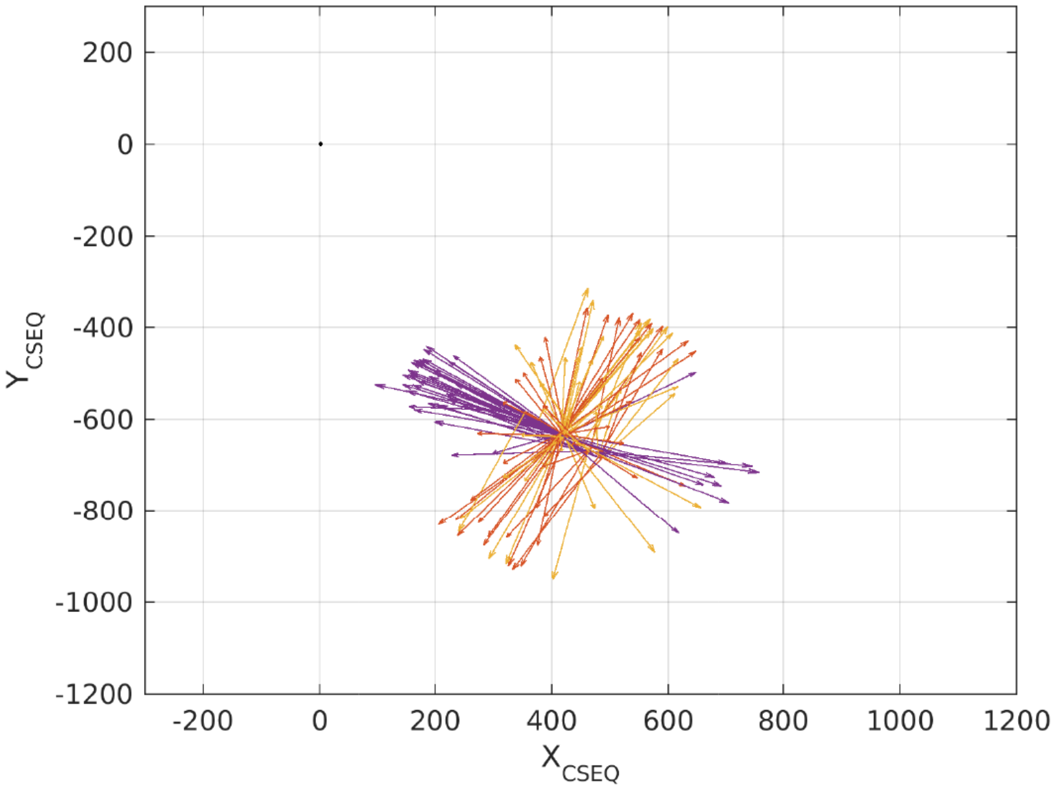


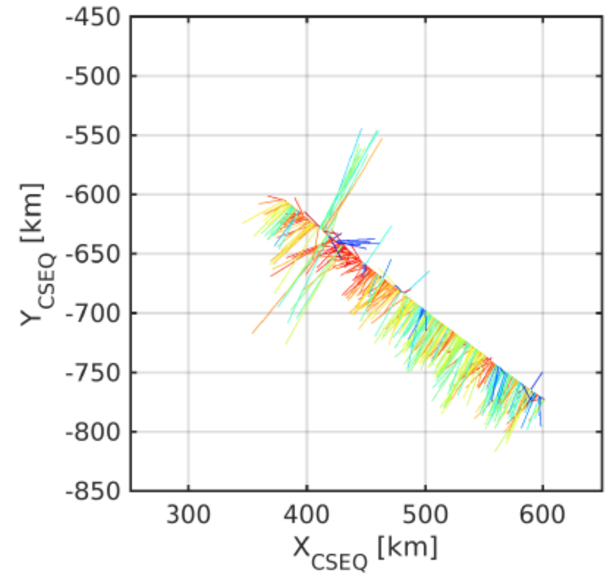
- Minimum variance analysis gives the normal of a current sheet from 1-spacecraft measurements, or the orientation of a flux ropes
- MVA results suggests that the signatures are indeed flux ropes (the shape of the hodograms and ratios of eigenvalues)

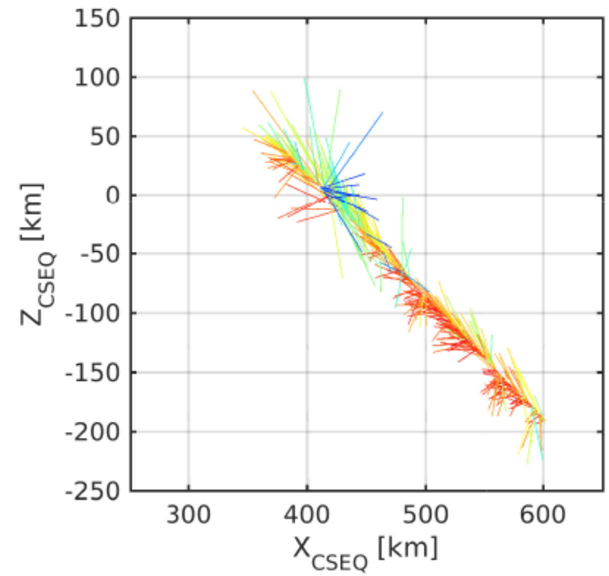
Comparing to Mars (Brain et al., GRL, 2010)



3. Observations of magnetic flux ropes

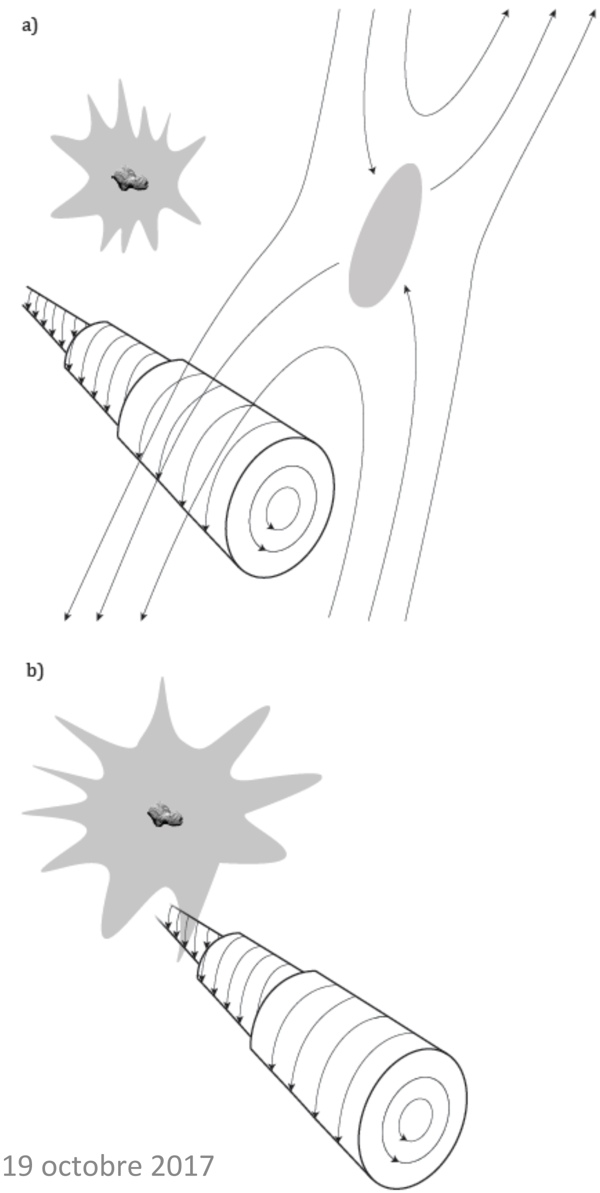






- Purple arrows give rope axes of some 40 events in a 2 day interval around the CME impact
- Ropes axes directed in general direction of between comet and tail
- Axes perpendicular to the large scale magnetic field direction before the CME impacts

3. Observations of magnetic flux ropes



Discussion:

- Flux ropes (or plasmoids/magnetic islands/FTE) can be formed due to magnetic reconnection, either as oppositely directed field lines pile up and meet, or due to the dynamics in the inner coma
- Flux ropes can also form due to large shears in the plasma flow, associated with Kelvin-Helmholtz instabilities, as suggested to exist adjacent to the magnetic cavity (Goetz et al., 2016).
- Typically 100 km large (observed for 10s assuming 10 km/s).
- 100 km radius and 600 km long with density of 600 cm^{-3} gives 10^{20} particles
- Do they move radially (with ion/neutral nominal direction) or toward the tail (with solar wind flow)?
- Do they flap back and forth past Rosetta?

Tail disconnection?

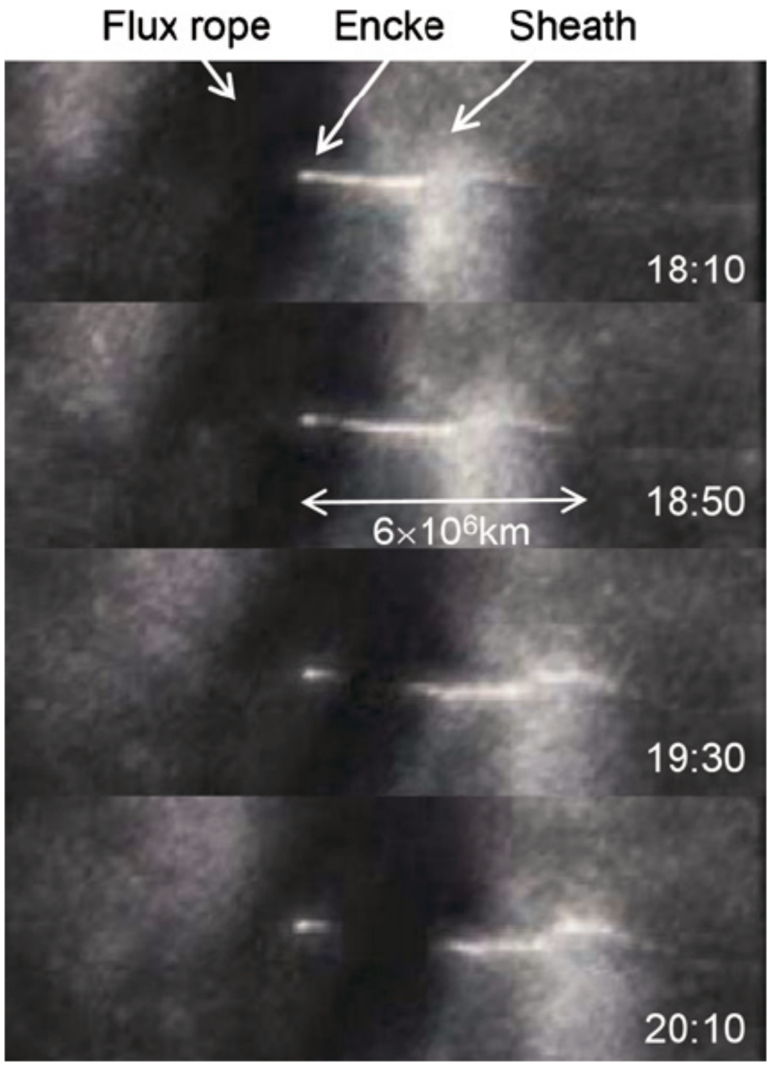


Figure from Jia et al., (2009) Ap. J.

Vourlidas et al., 2007 observed a CME impacting on comet 2P/Encke, leading to a tail disconnection event.

Tail disconnection events are rather common and have been observed remotely for a long time, see e.g. Niedner & Brandt, 1978. Magnetic reconnection is usually included as part of the explanation, and that disconnection events occur during passings of heliospheric current sheets or interplanetary shocks, or CMEs.

Are we seeing the near-nucleus signatures of cometary tail disconnection?

Summary

- Several observations of CIR events and their influence on the coma
- Fortunate observation of a CME impact
- Solar wind returns for a brief time
  - factor of 2 compression of plasma environment
- Factor of 10 increase in plasma density
  - compression, impact ionisation, charge exchange
- Flux rope structures form
  - Large magnetic field amplitude, ~100 km large