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Comet Siding-Spring interaction with Mars' atmosphere and interplanetary space weather

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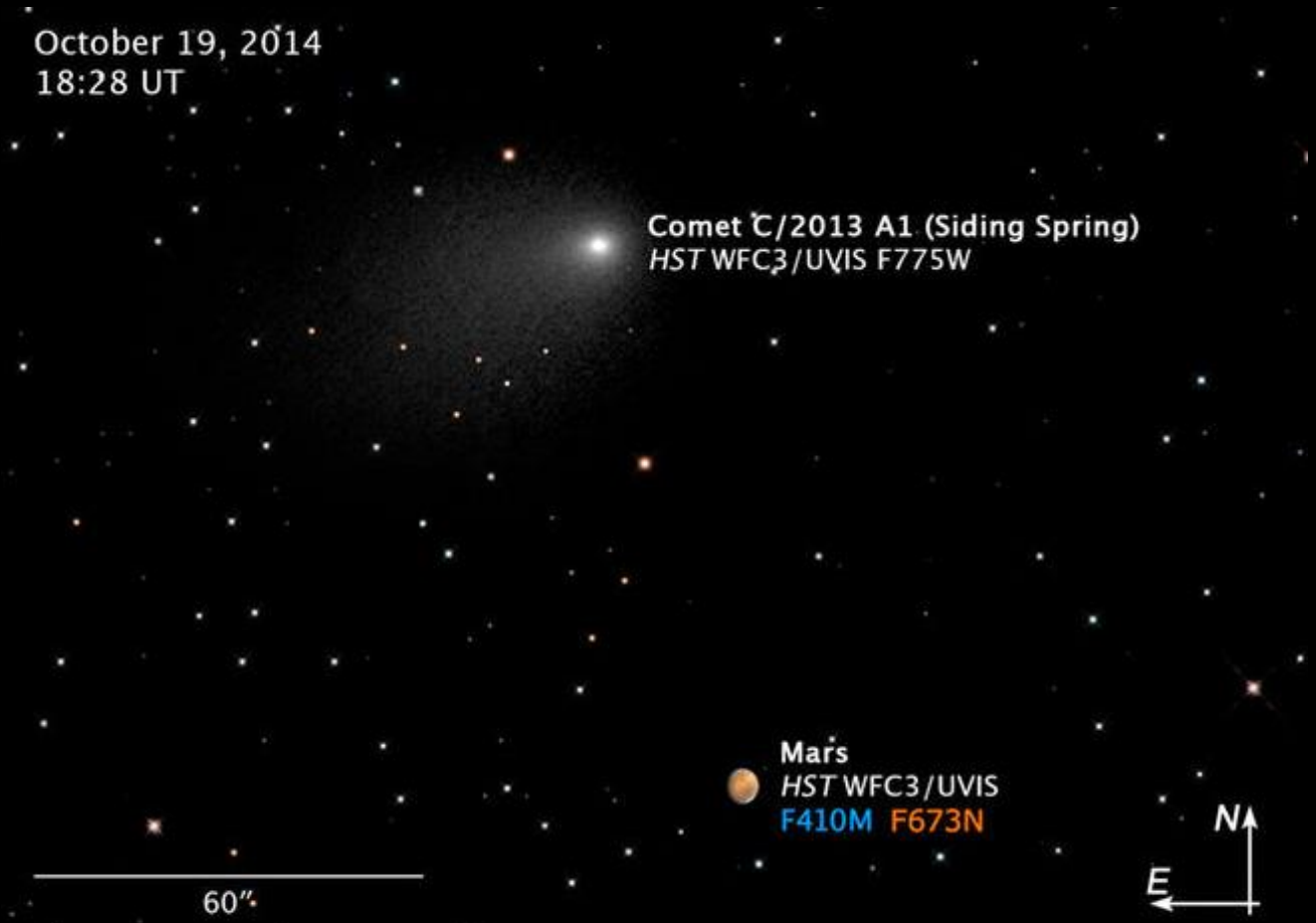
+ many other colleagues

Seminar at ESAC, 16 December 2019

Context

Comet Siding Spring (C/2013 A1) is an Oort-cloud comet that did a very close flyby to Mars on 19th October 2014. The Closest Approach (CA) occurred at ~140,000 km (~35 R_M).



Credits: Hubble Space Telescope

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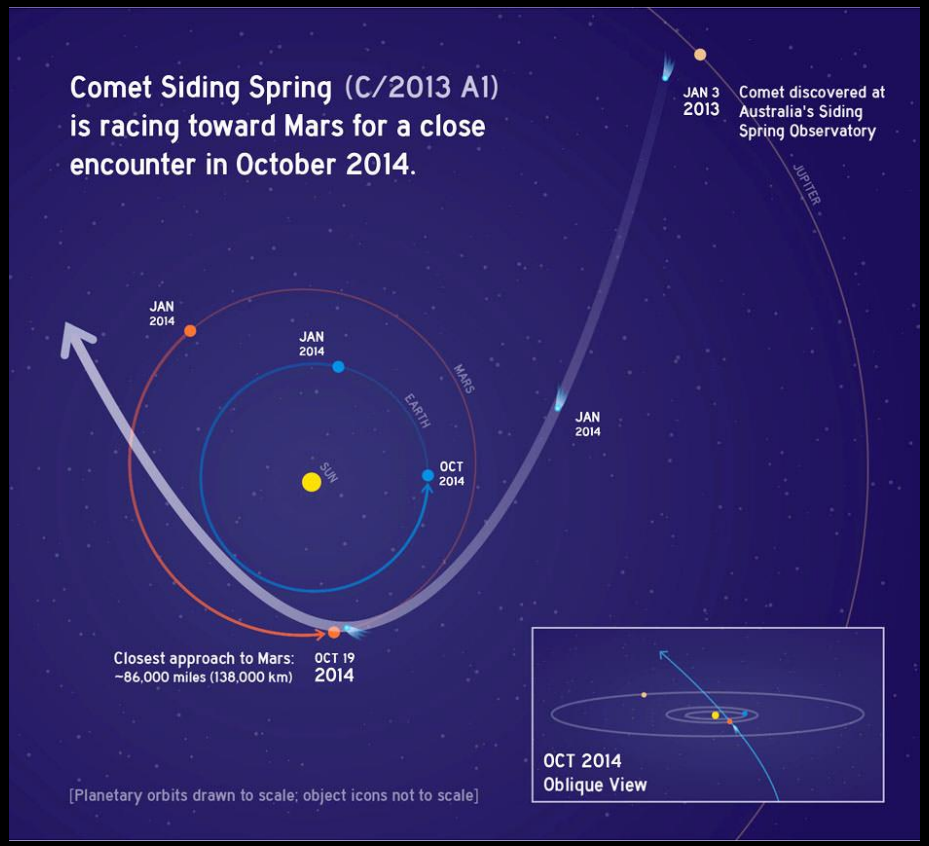
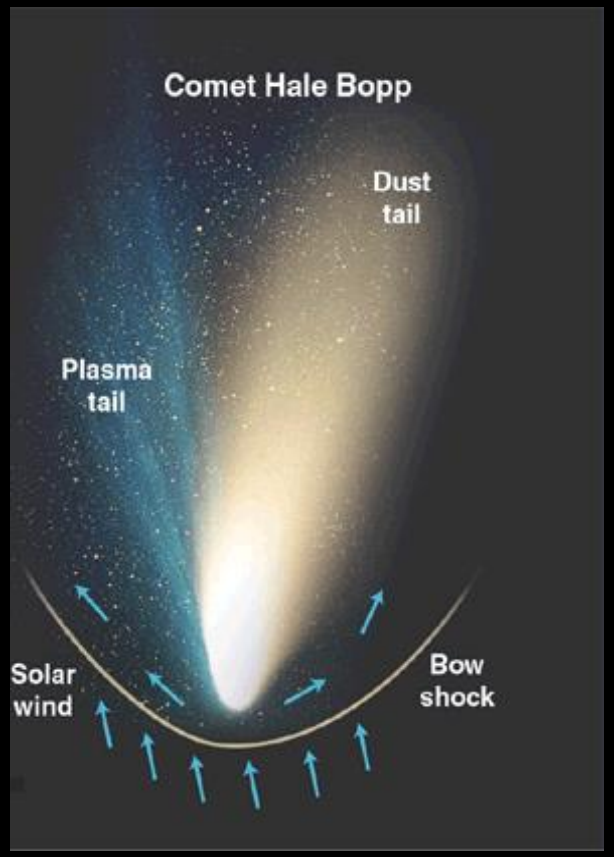
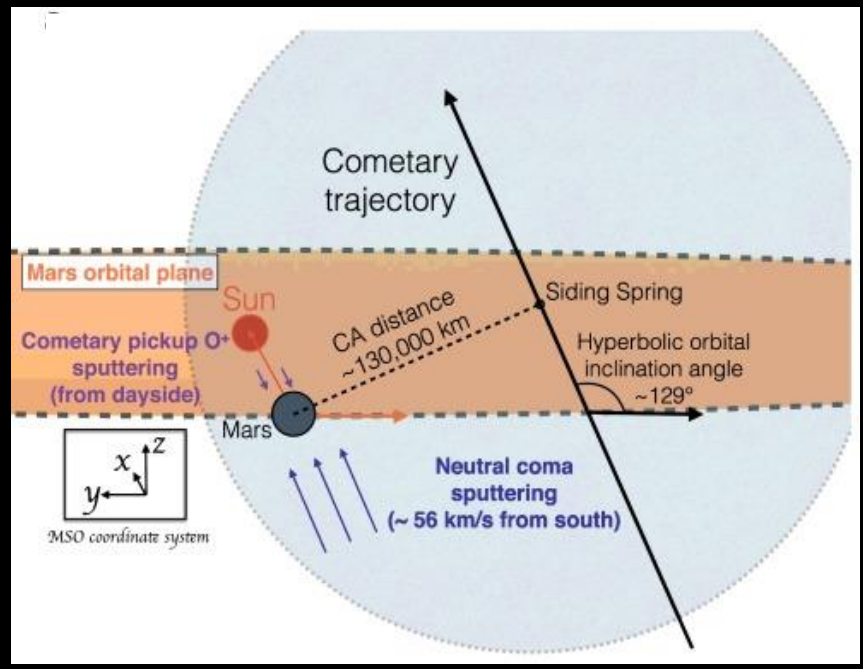
Context

Mars was embedded within the coma of the comet for about 10 hours.



Credits: NASA





Wang et al., 2016

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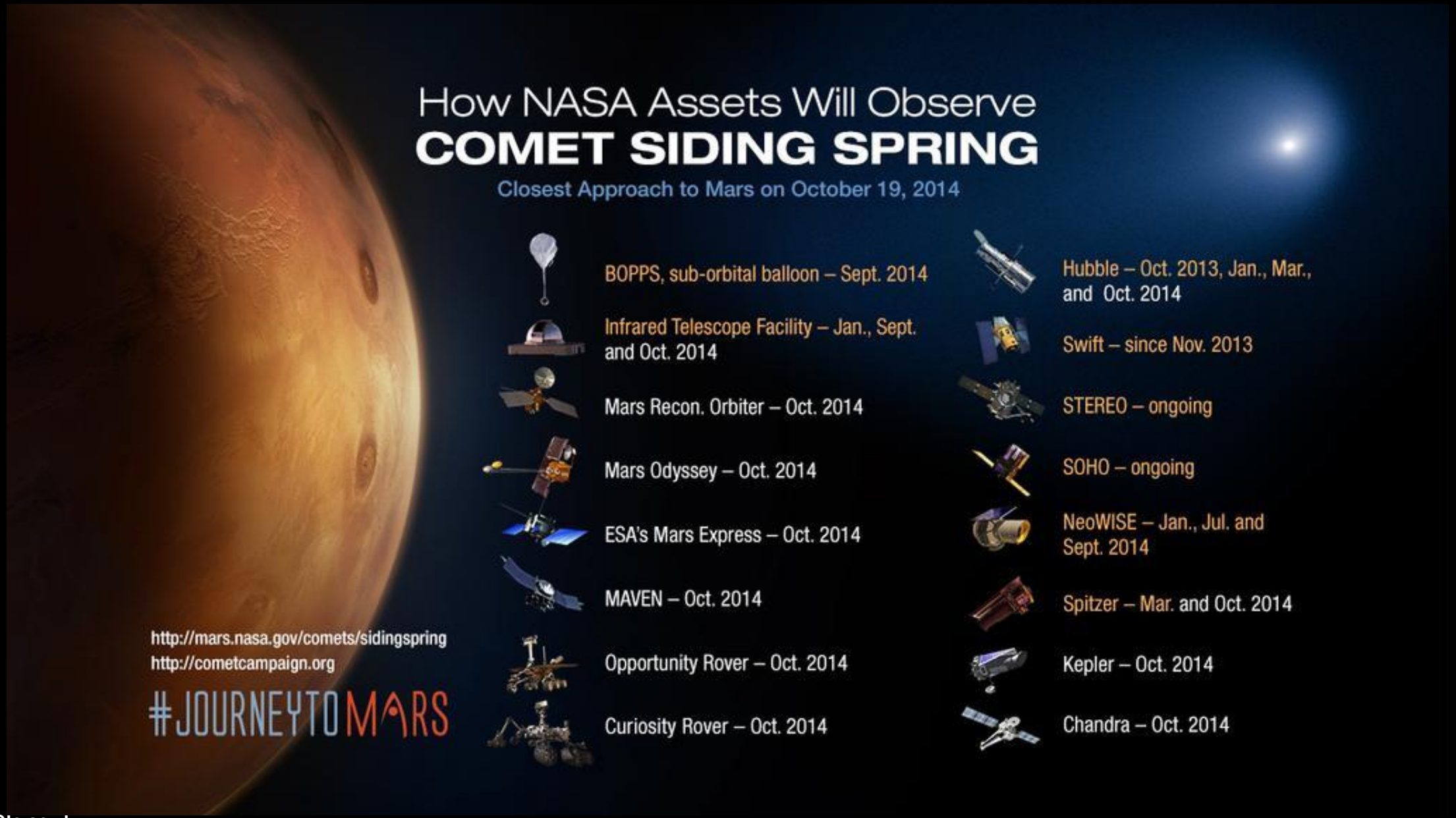
Context



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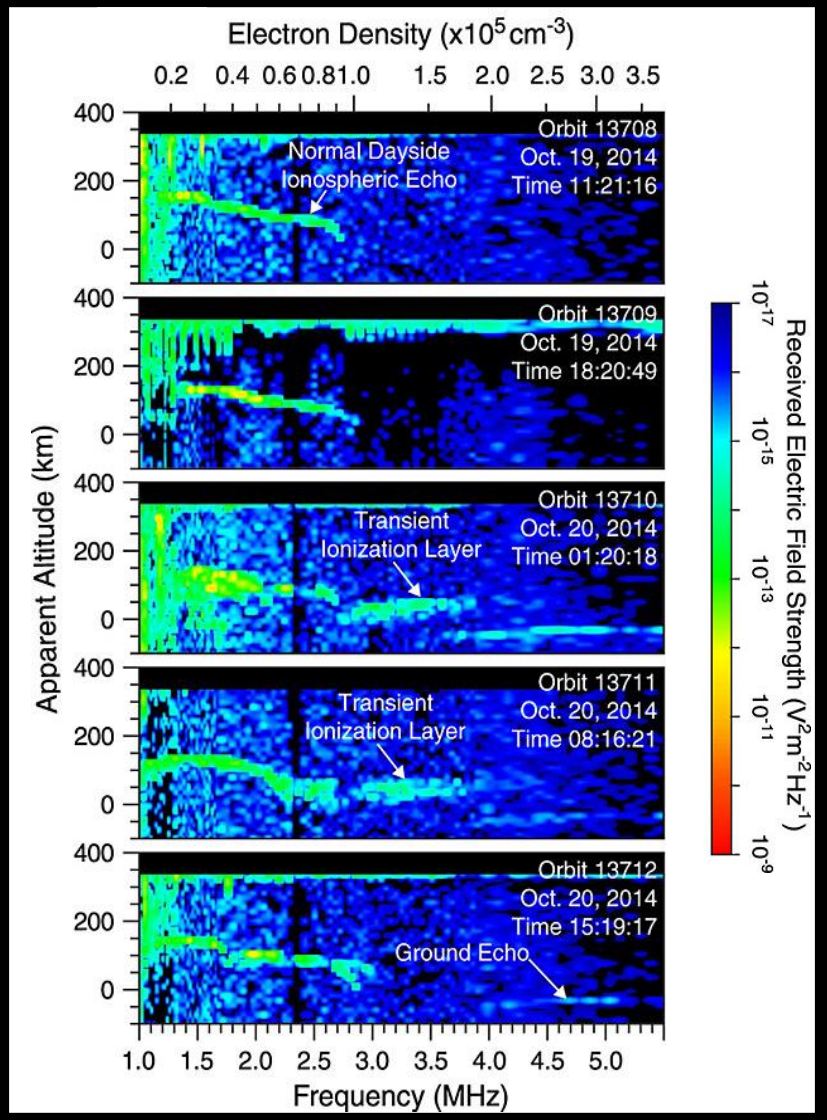
Findings post-comet flyby

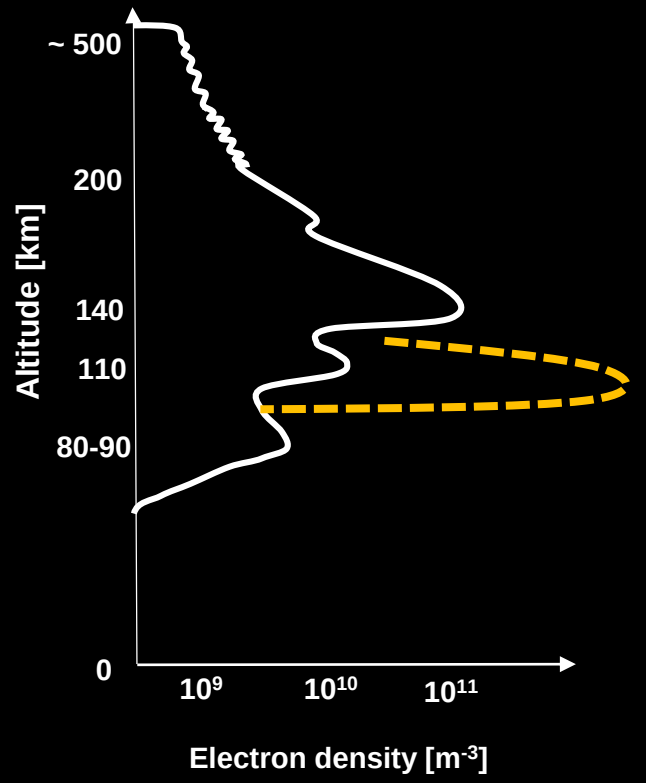
Most of the previous results come from few hours after the comet passed Mars, when dust was fully settled in the atmosphere

Important results:

- Water production: 1.1-1.5±0.5×10^{28} molecules s^{-1}
- 82±25 t of dust deposited in Mars' atmosphere
- The largest meteor layer ever observed at a planet other than Earth
- Dust re-distribution in the upper atmosphere within a couple of days
- Metal ions of Na, Mg, Al, K, Ti, Cr, Mn, Fe, Co, Ni, Cu, and Zn, and possibly of Si, and Ca, identified in the MAVEN-ion spectra collected at altitudes of ~185 km



Gurnett et al., 2015



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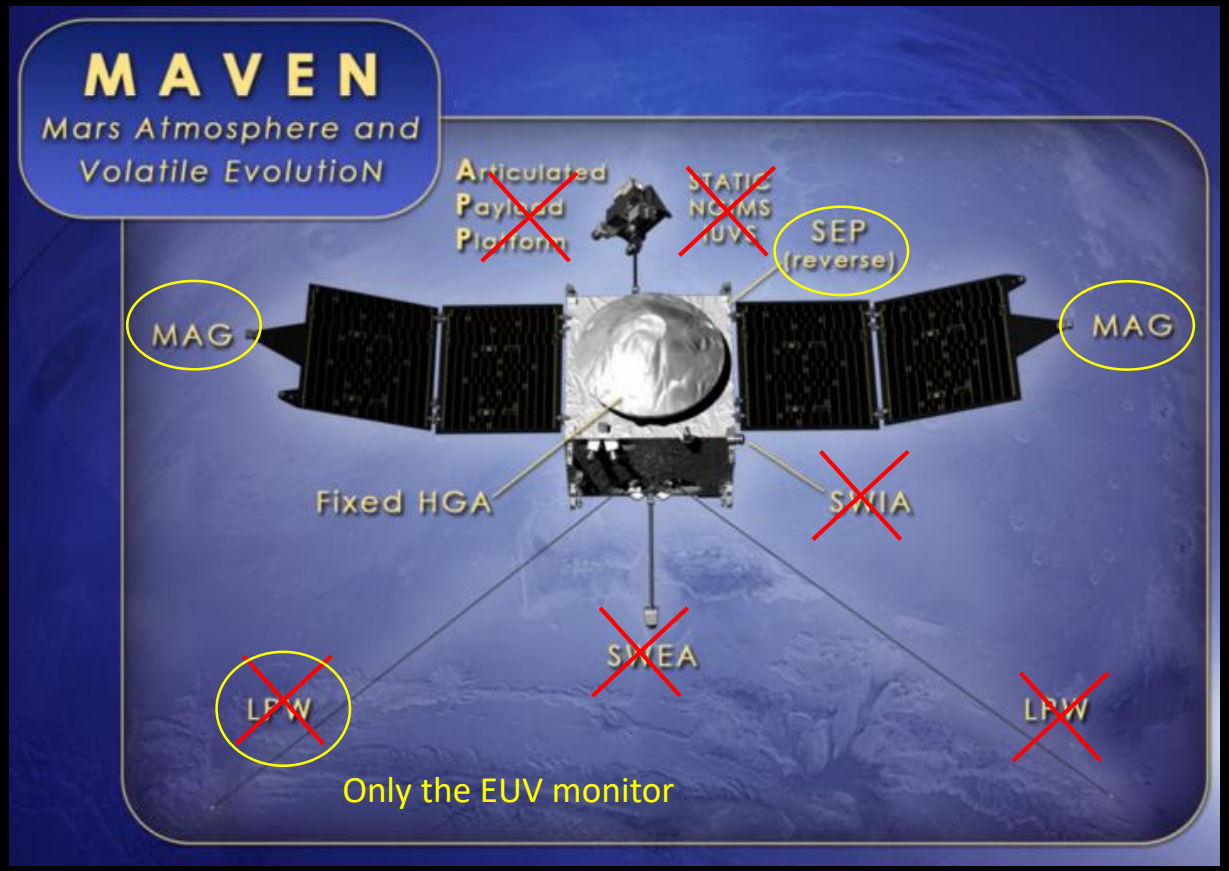
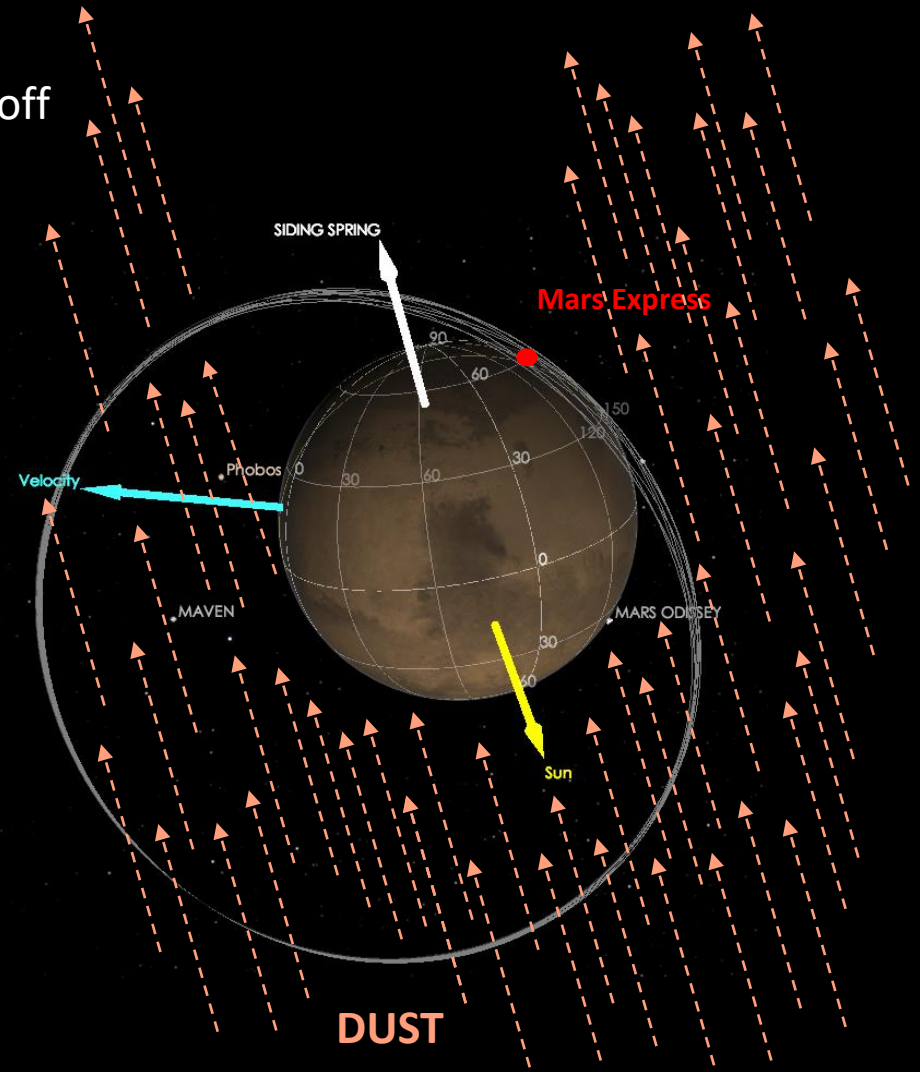
However during the flyby….

All spacecraft were placed in a safe area, and many payload was switched off





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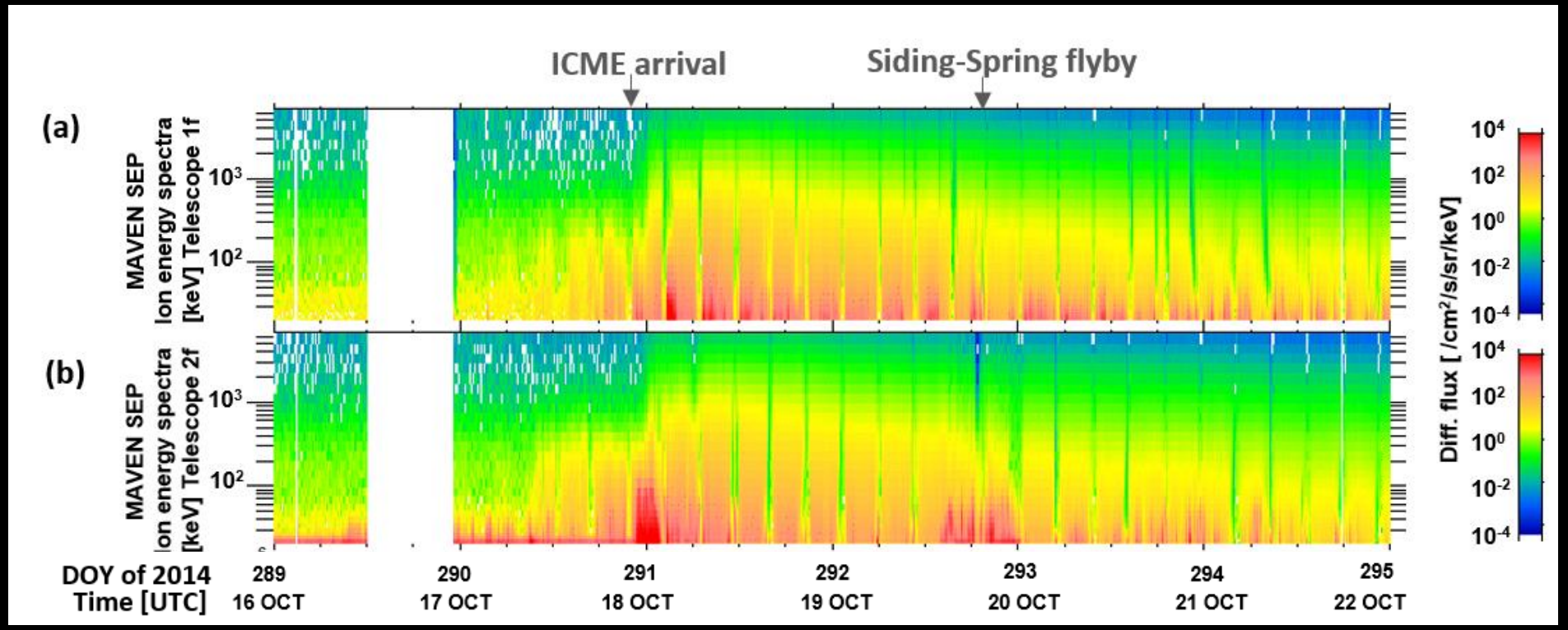
However during the flyby…. comet or space weather effects?

The event at closest approach was masked by a large solar storm that arrived at Mars ~44 h before the comet flyby. All the particle observations were extremely difficult to analyse, continuing even today.

ESAC colleagues were a key untangling this puzzle.



Sánchez-Cano et al., *JGR*, 2018b

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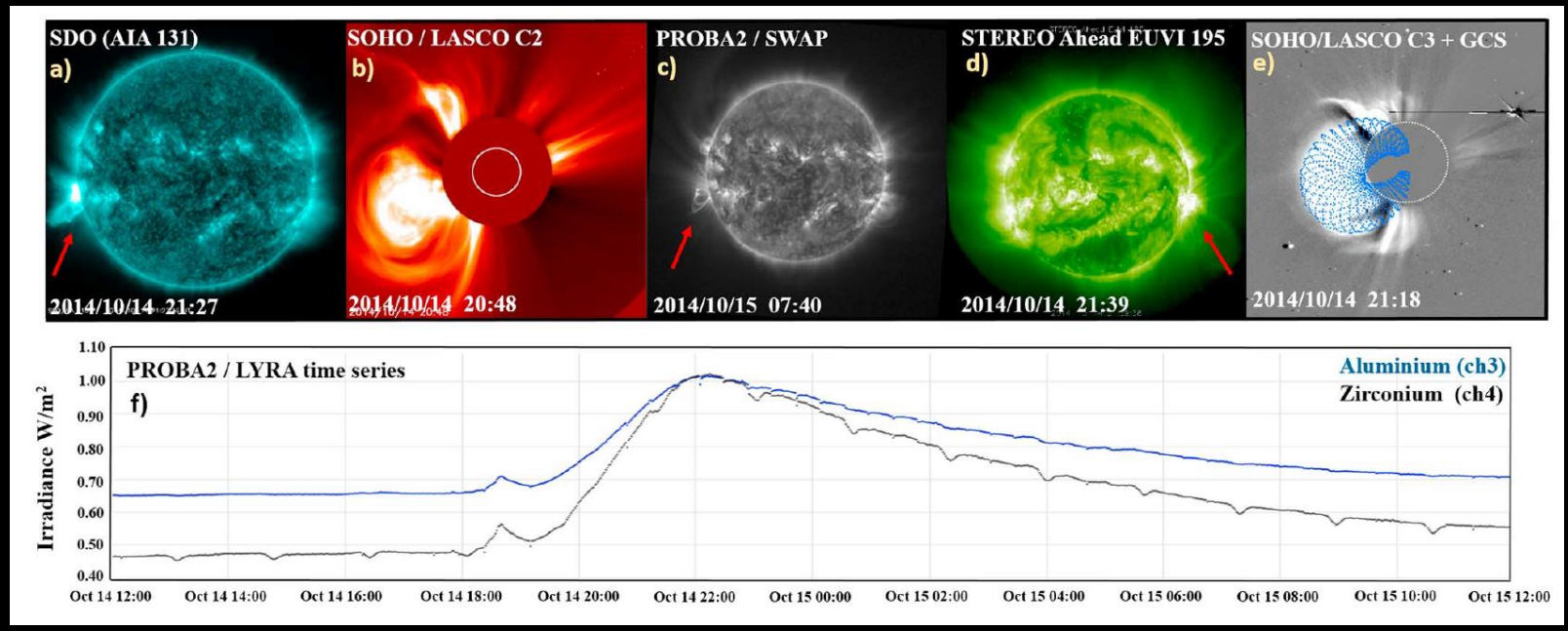
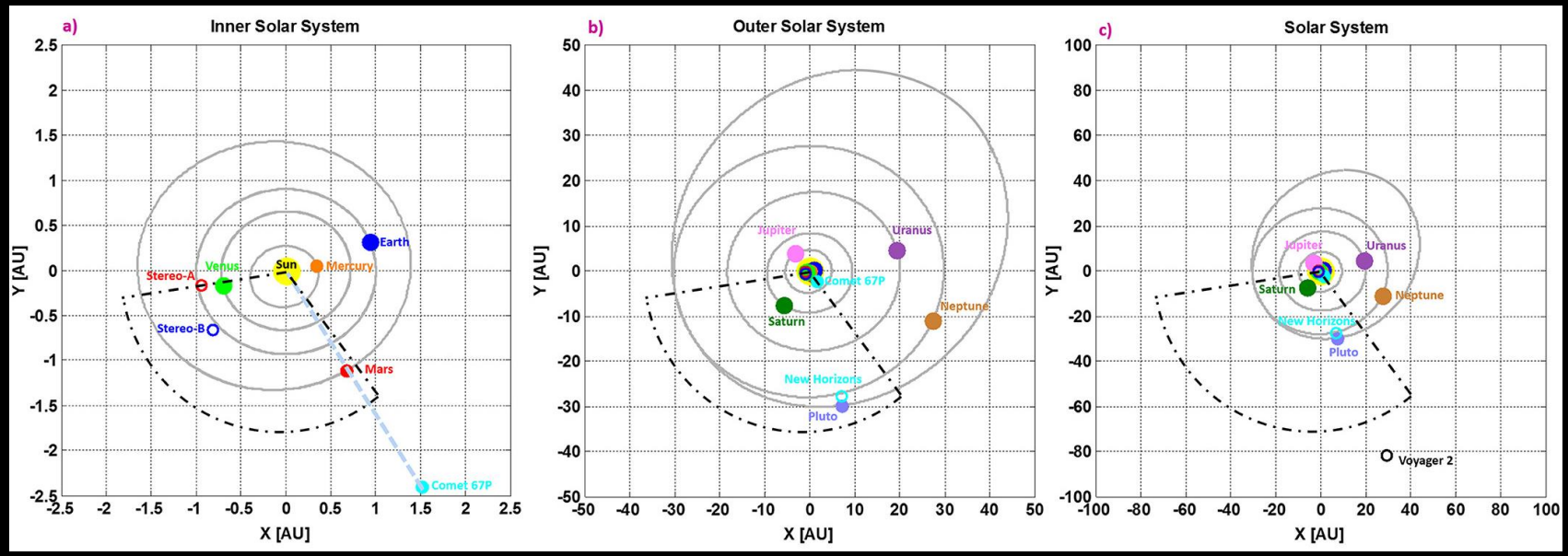
CME ejection

14 October 2014 18:30 UT (along with M1.1 and M2.2 flares)

v = 850 ± 200 km/s
lon = -120° ± 30°
lat= -11° ± 5°
full width = 106° ± 10°





Witasse, Sánchez-Cano et al., 2017

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The journey of the solar storm

Courtesy NASA Goddard Space Flight Center

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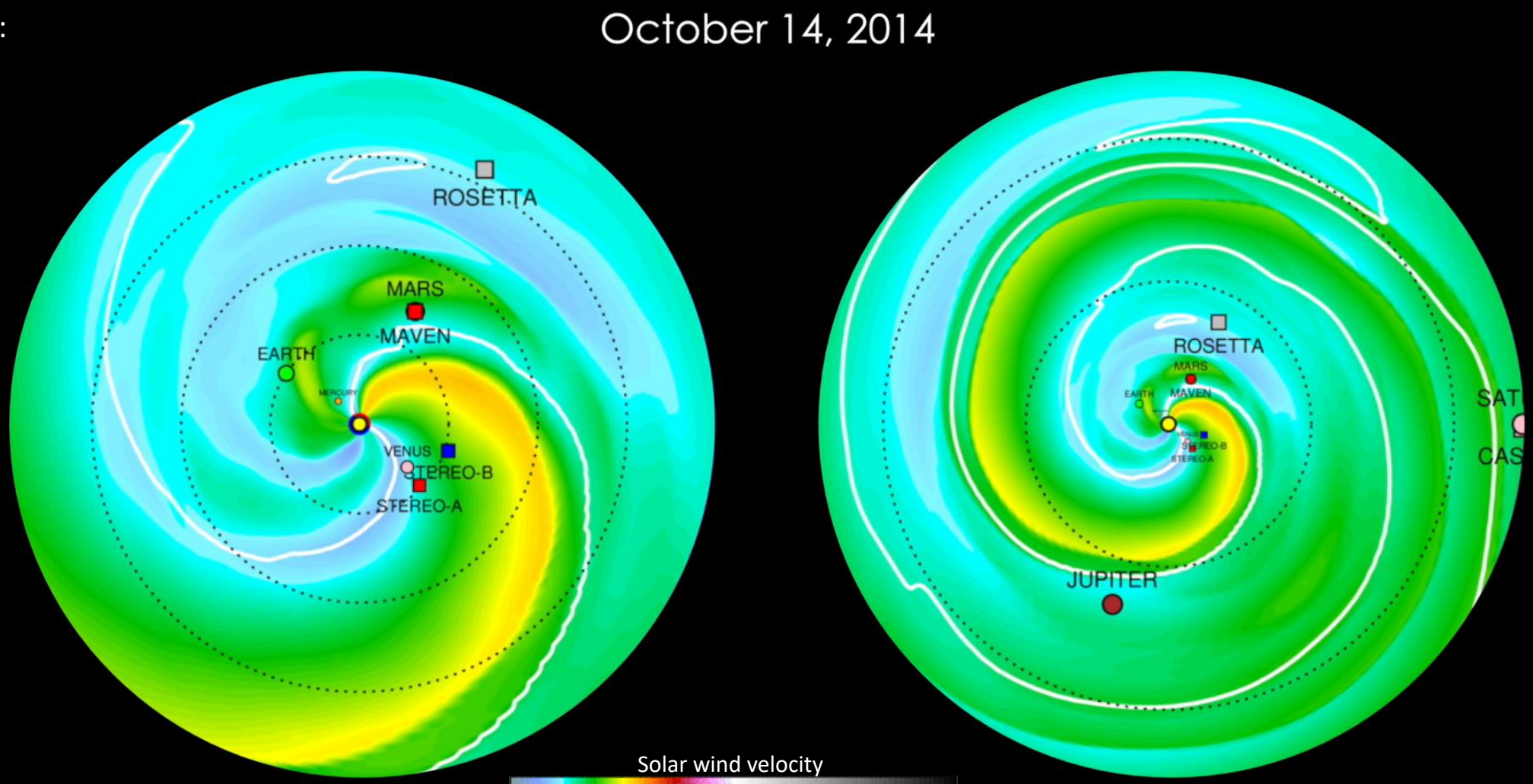
Solar wind simulation

It contains 138 DONKI CMEs with v>500 km/s

CME input parameters:
v = 1015 km/s
lon = -150°
lat= -12°
full width = 116°

Caveat: *ENLIL does not include the drag effect from pickup ions or the enhancement of the wind mass density due to photoionization of neutral hydrogen entering the heliosphere from the interstellar medium*



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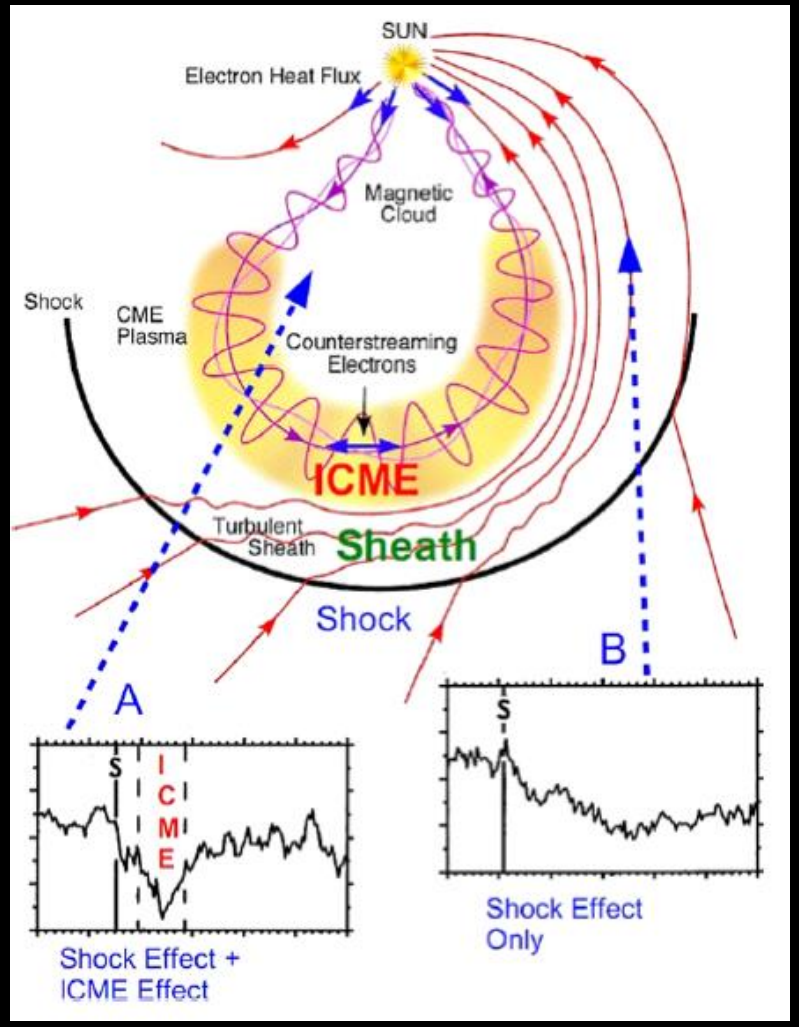
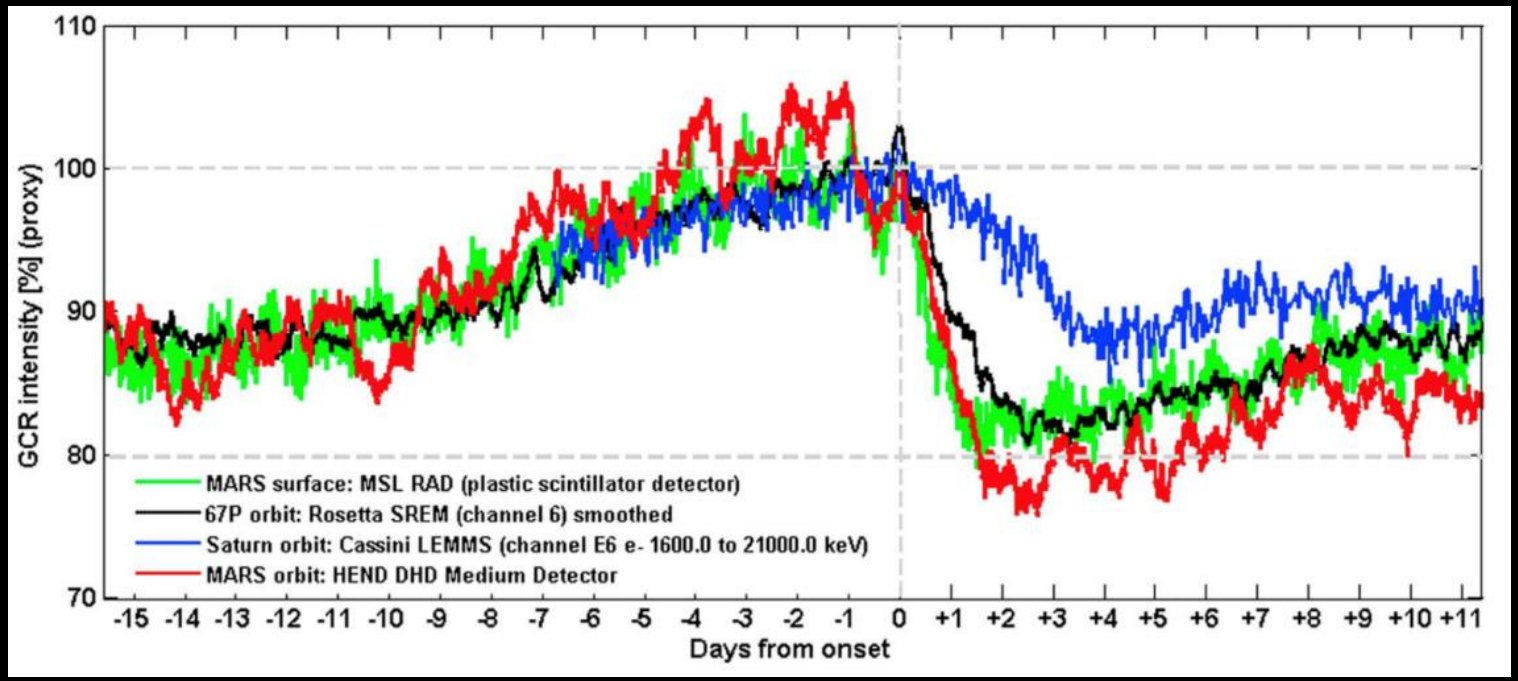
Important findings: Same Forbush decrease at 3 different locations



Richardson and Cane, 2011

Cosmic rays can be used as solar storm trackers, as the solar wind modulates their behaviour



Witasse, Sánchez-Cano et al., 2017

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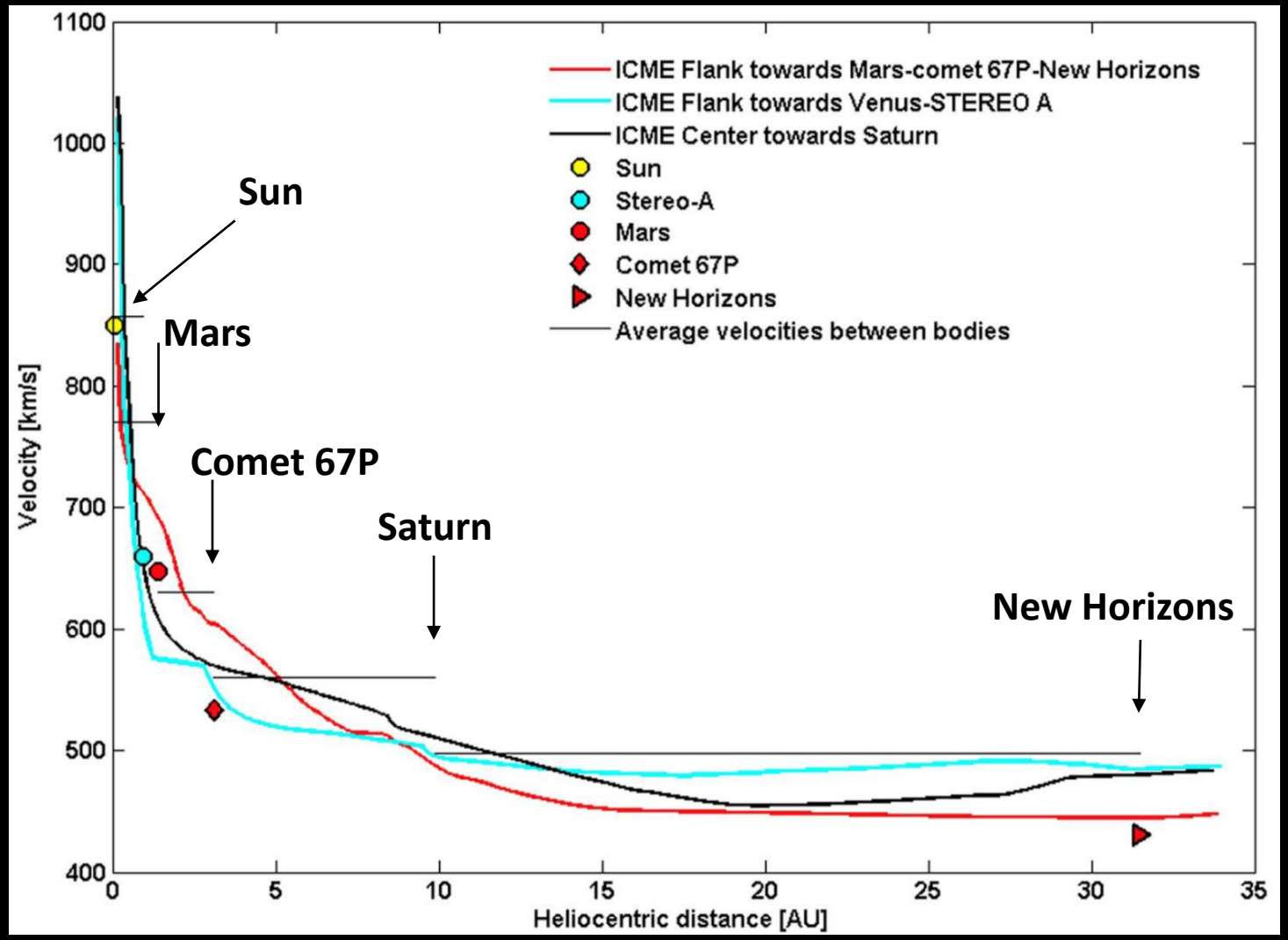
Important findings: ICME speed up to 30 AU



Witasse, Sánchez-Cano et al., 2017

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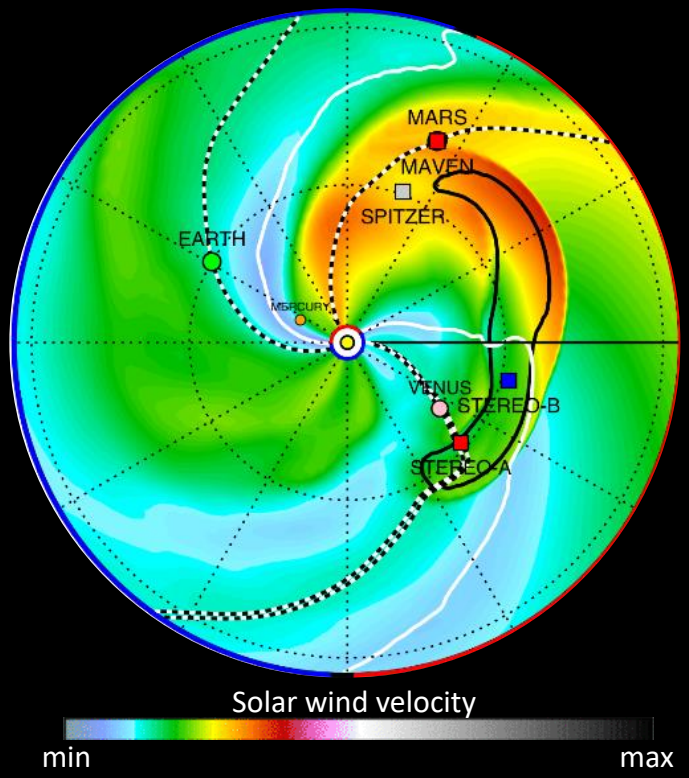
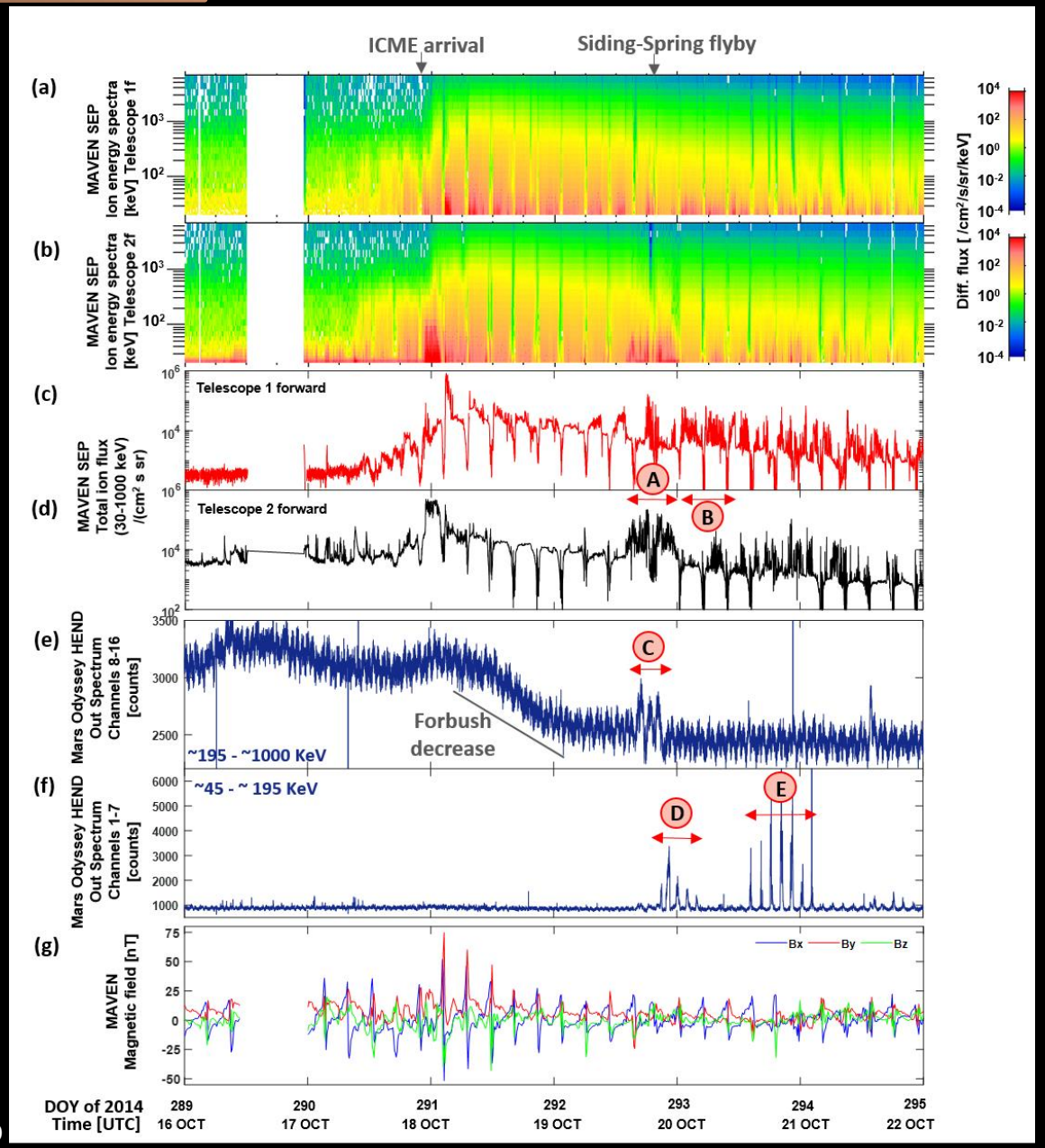
The solar storm and the comet at Mars



The comet's flyby deposited a significant amount of energetic particles into Mars' upper atmosphere, at a similar level to a large space weather event.

However, the magnetic field environment was not very affected, just a magnetic rotation was observed.



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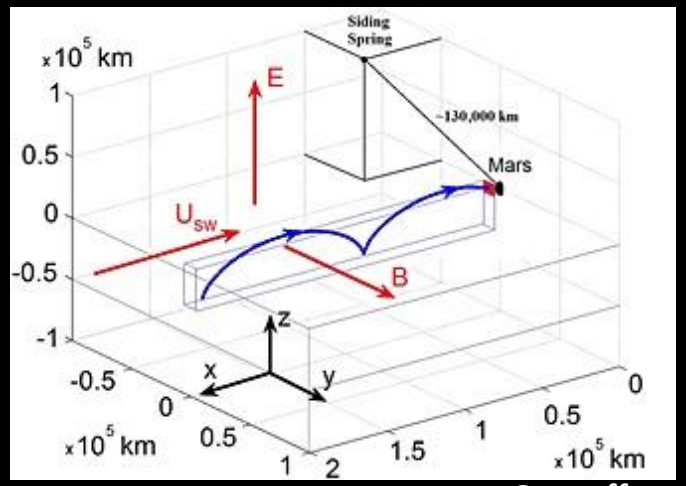
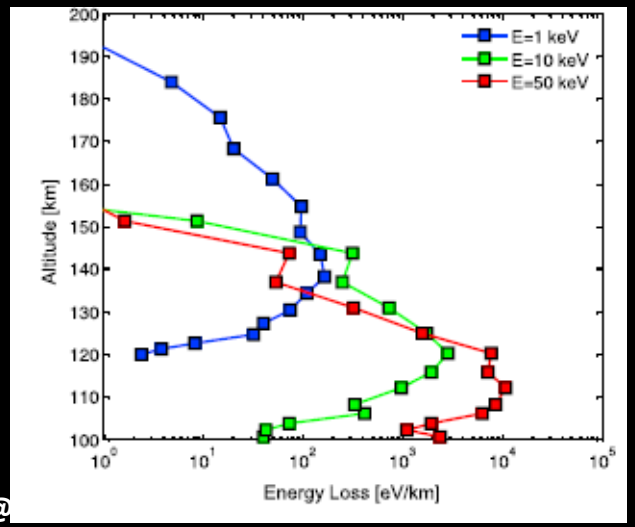
Sánchez-Cano et al., 2018b

Comet pick up ions

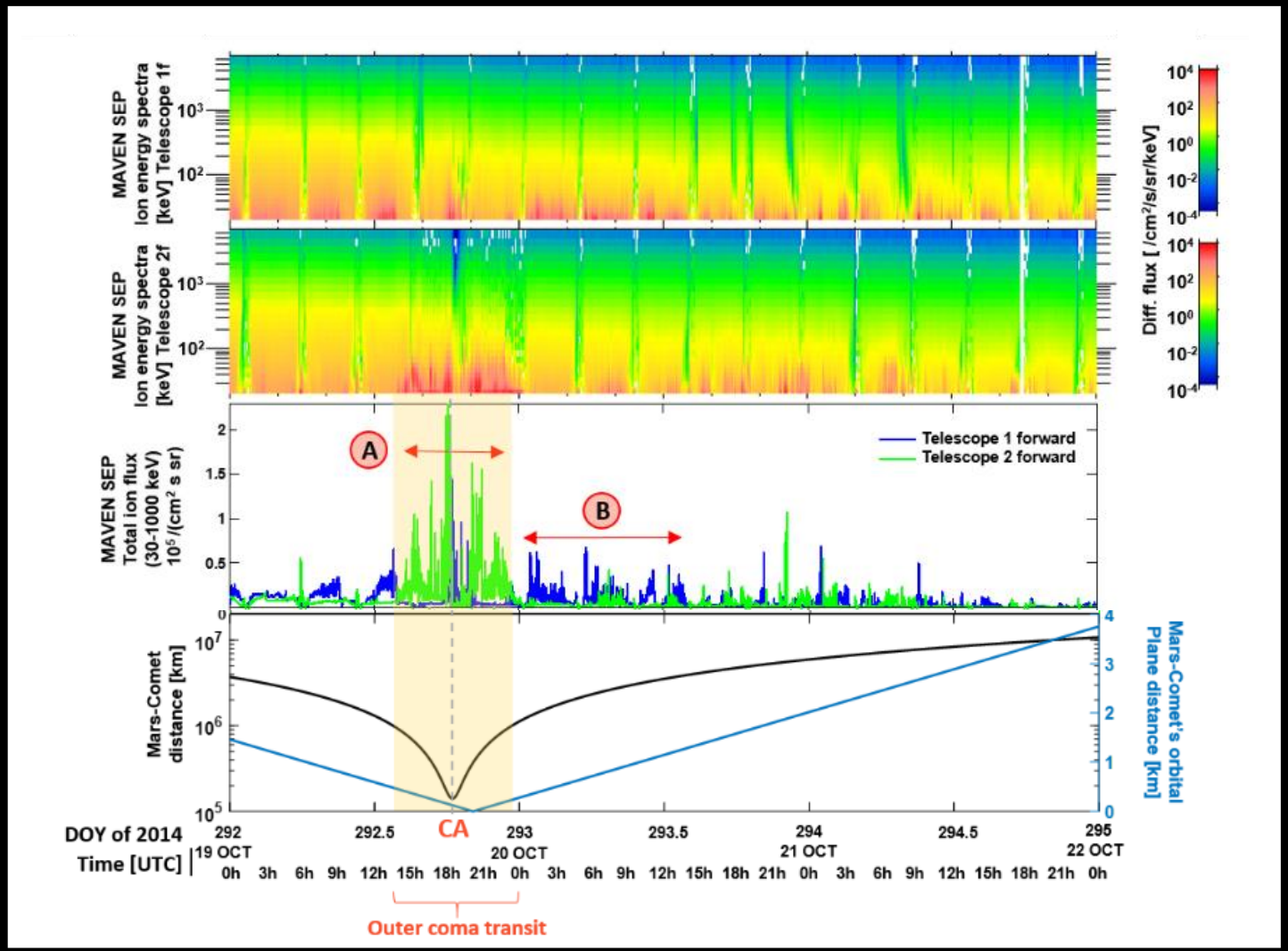
There were continuous precipitating cometary O^+ pick-up ions on Mars' dayside during the ~10h that Mars transited the comet's coma region. Also after CA for several hours, although whether their origin is from the comet or space weather cannot be firmly concluded.



Gronoff et al., 2014



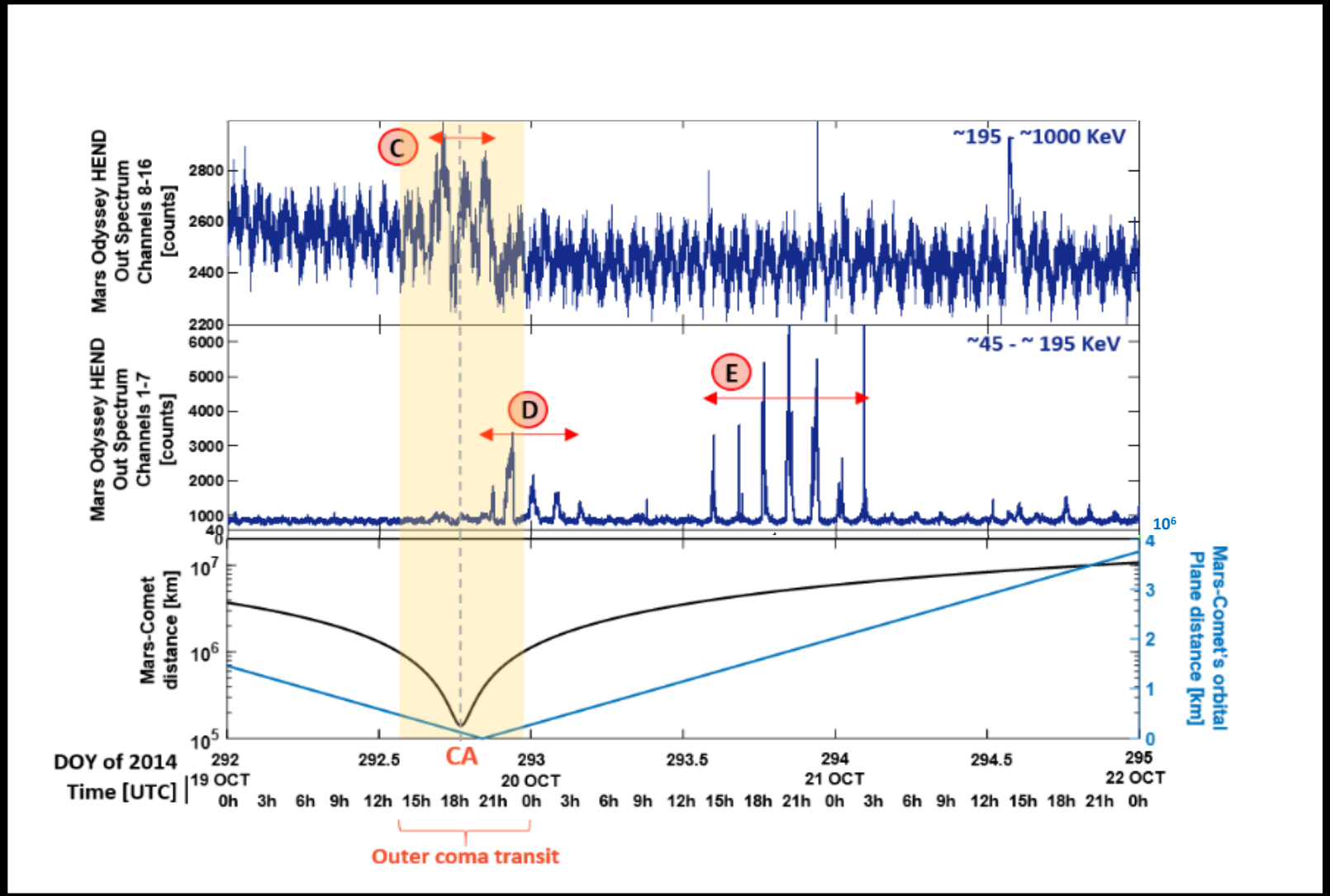
Sánchez-Cano et al., 2018b



Dust tail hit?

More energetic particles were detected at CA, and after the comet flyby (up to 1.5 days after) in the neutron monitor of Mars Odyssey.

Those detections are very genuine and seems related to dust tail particles hitting the instrument and producing X-rays and gamma-rays.



Sánchez-Cano et al., 2018b

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Or space weather?

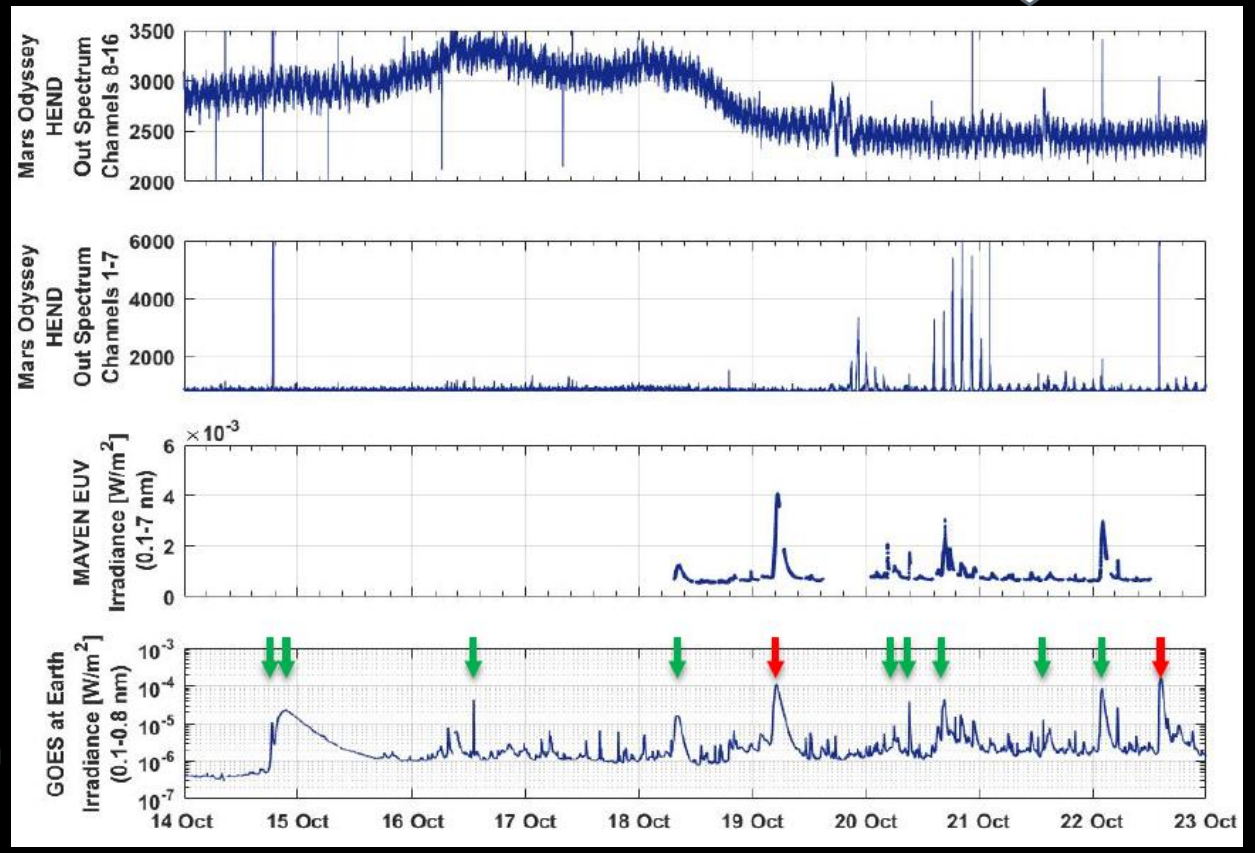
The Hinode Solar Flare Catalog has identified 66 solar flares in the 14th to 22nd October interval.

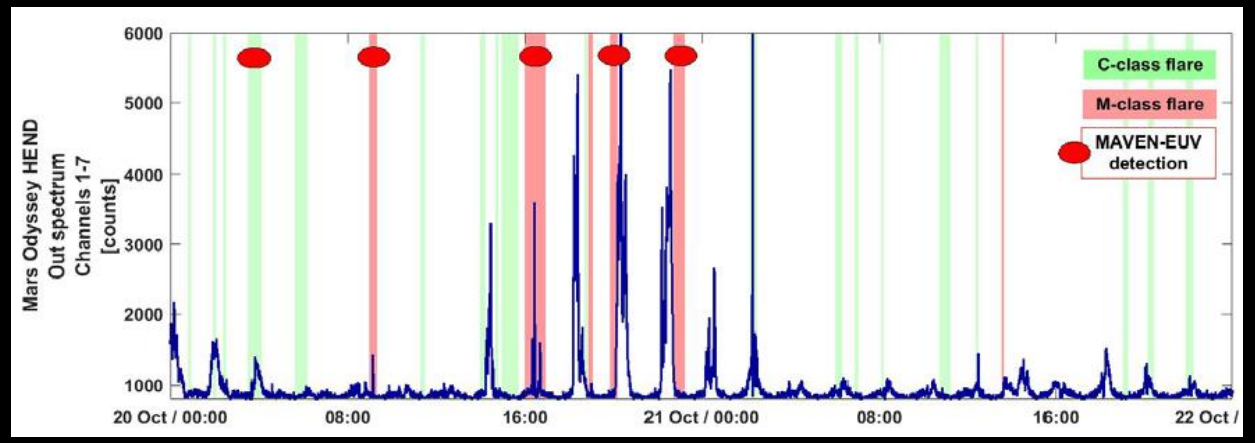
Just before the closest approach on 19th October an X1.1 flare occurred at 04:17 UT, peaked at 05:13 UT and ended at 04:48 UT.

However, the Mars Odyssey-HEND peaks do not match with the flare occurrence, meaning that they are most probably caused by the comet.

X-rays at Mars

X-rays at Earth





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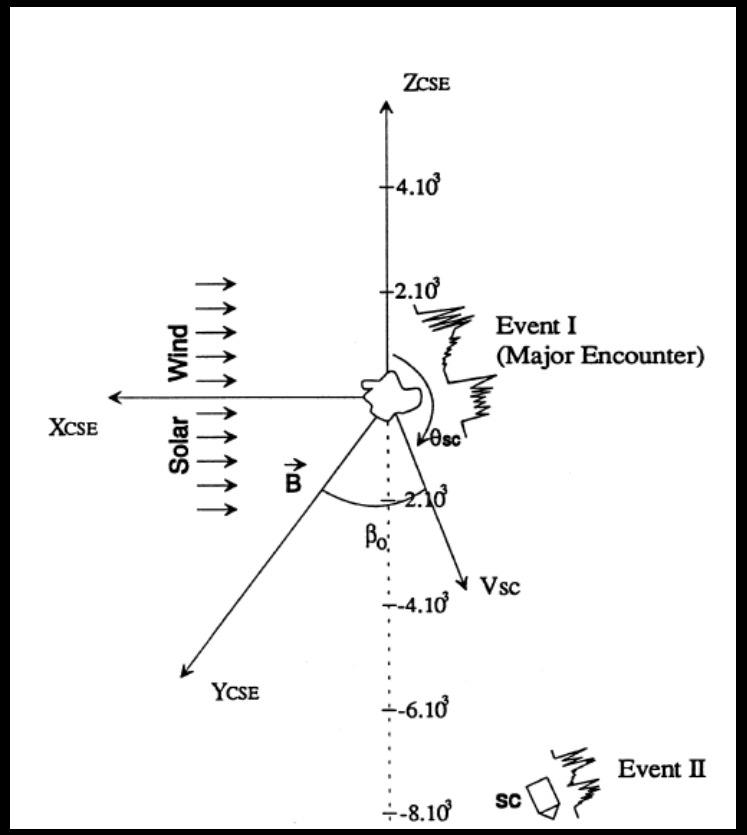
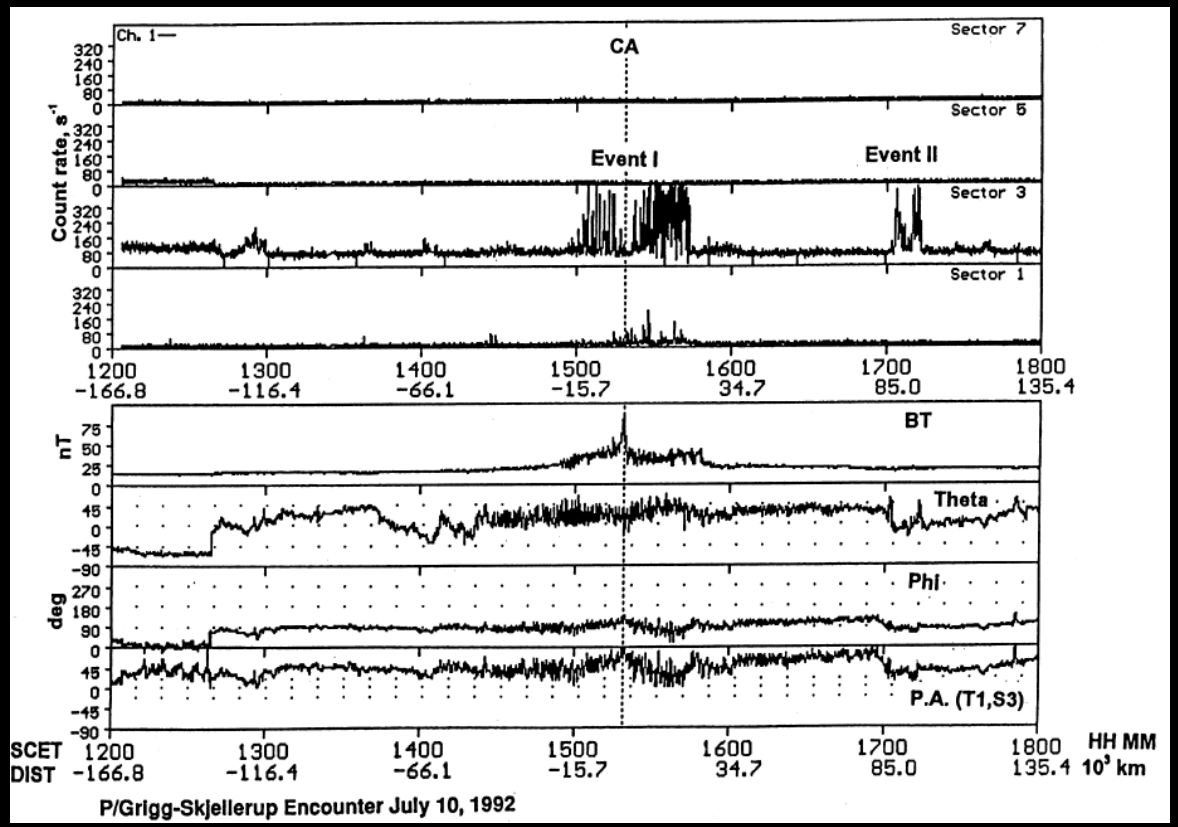
Similar observations from Giotto

The EPONA instrument onboard the Giotto mission detected very similar features after the CA to the comet 26P/Grigg-Skjellerup in 1992. The energetic ions were observed in the energy range ~60-100 keV at $9x10^4$ km from the comet.

Based on EPONA and magnetic field observations, McKenna-Lawlor and Afonin (1999) suggested that those late enhancements were caused by a fragment of the main comet within the comet's tail.





McKenna-Lawlor and Afonin (1999)

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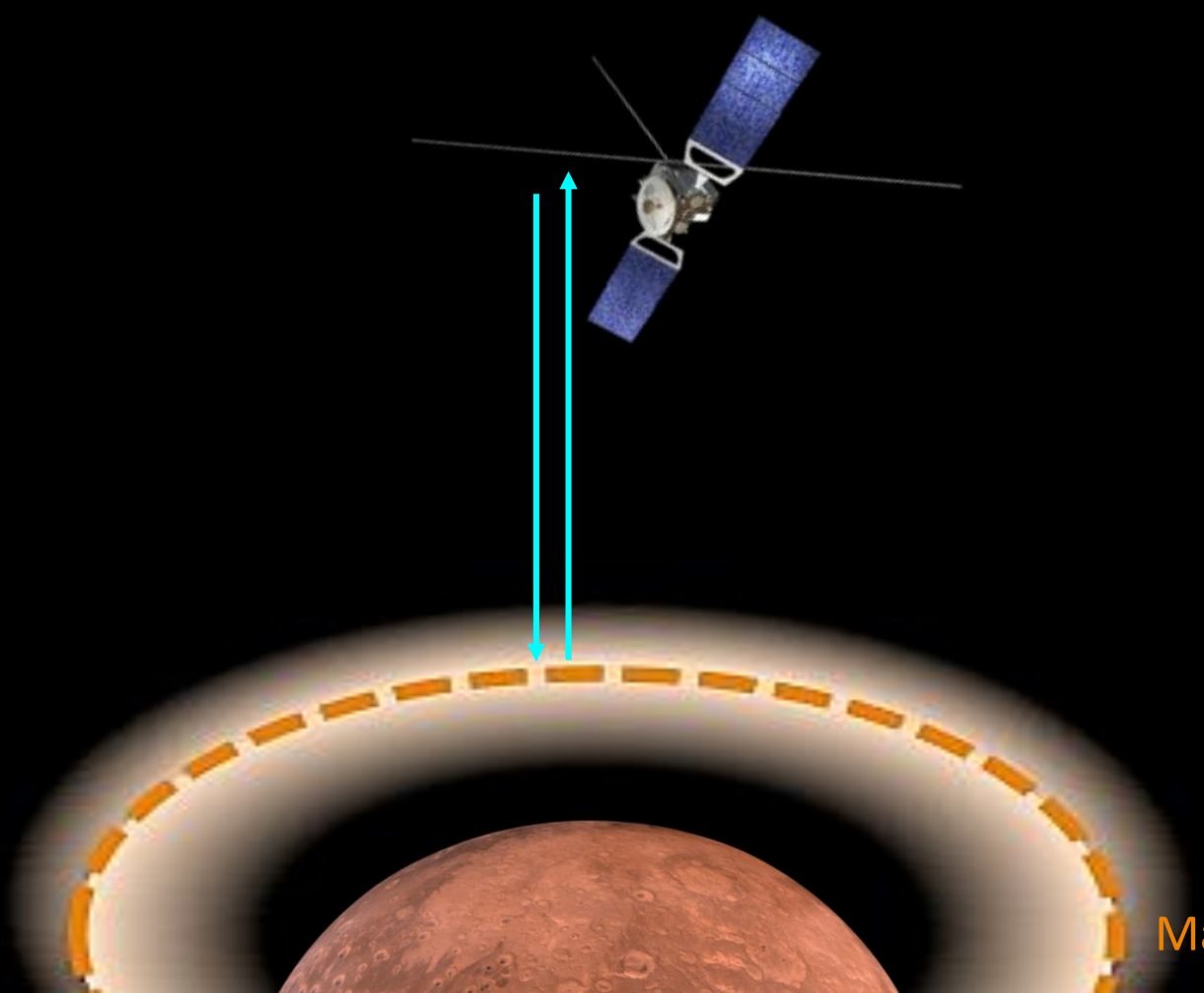
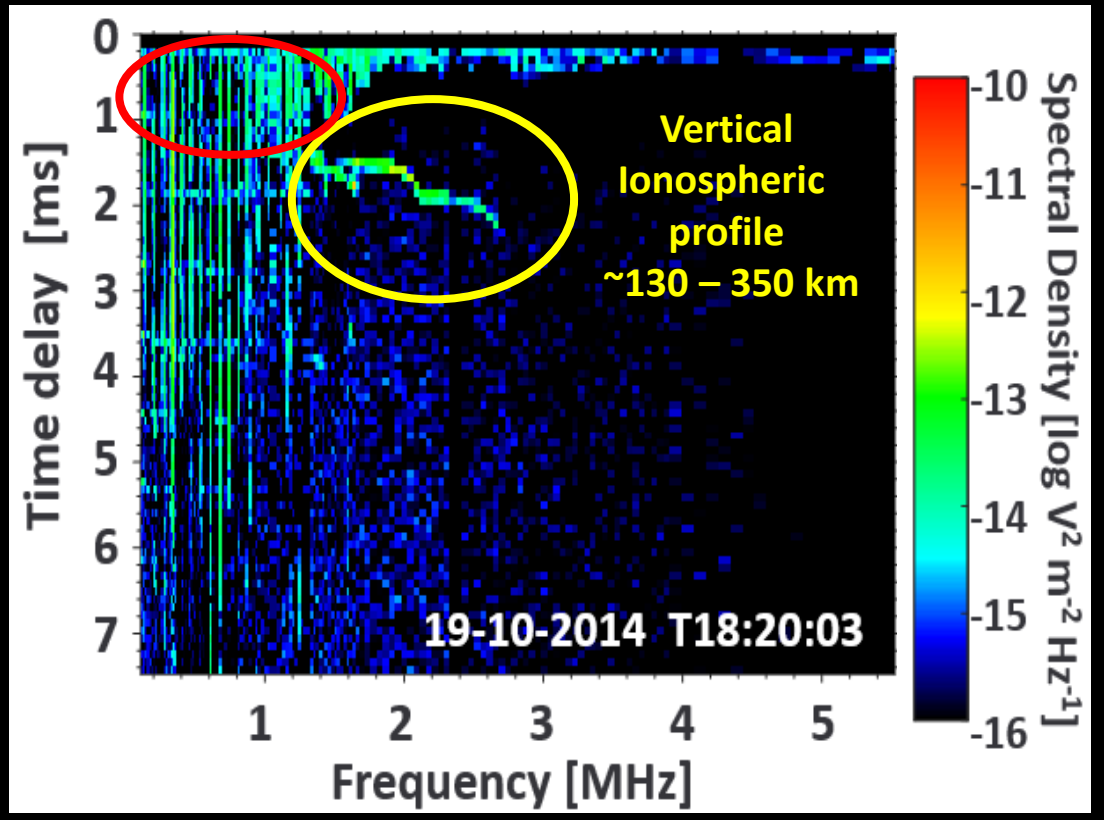
Ionosphere: MEX-MARSIS dataset



Max of ionization

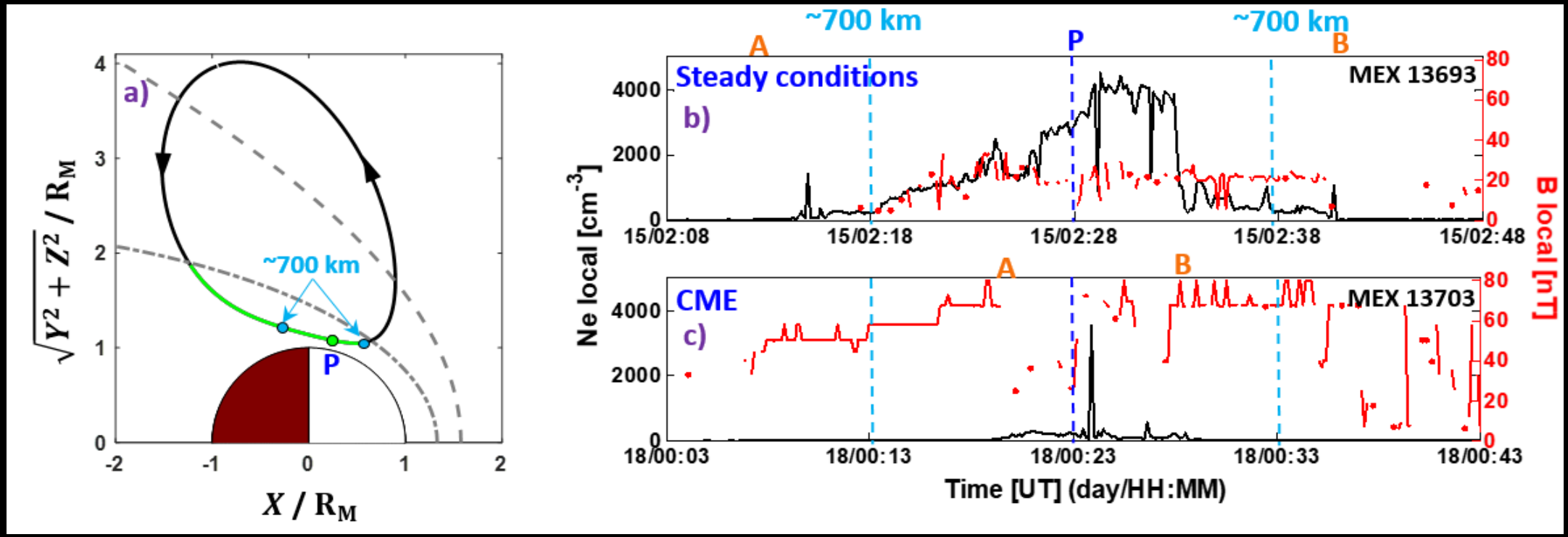
Ionospheric density at the spacecraft
from ~350 (periapsis) to ~1000 km (pileup boundary)



The ionosphere between 350 and 1000 km

Local plasma observations at the spacecraft surroundings

The orbit period is 7h, and consecutive orbits are similar



Sánchez-Cano et al., under review

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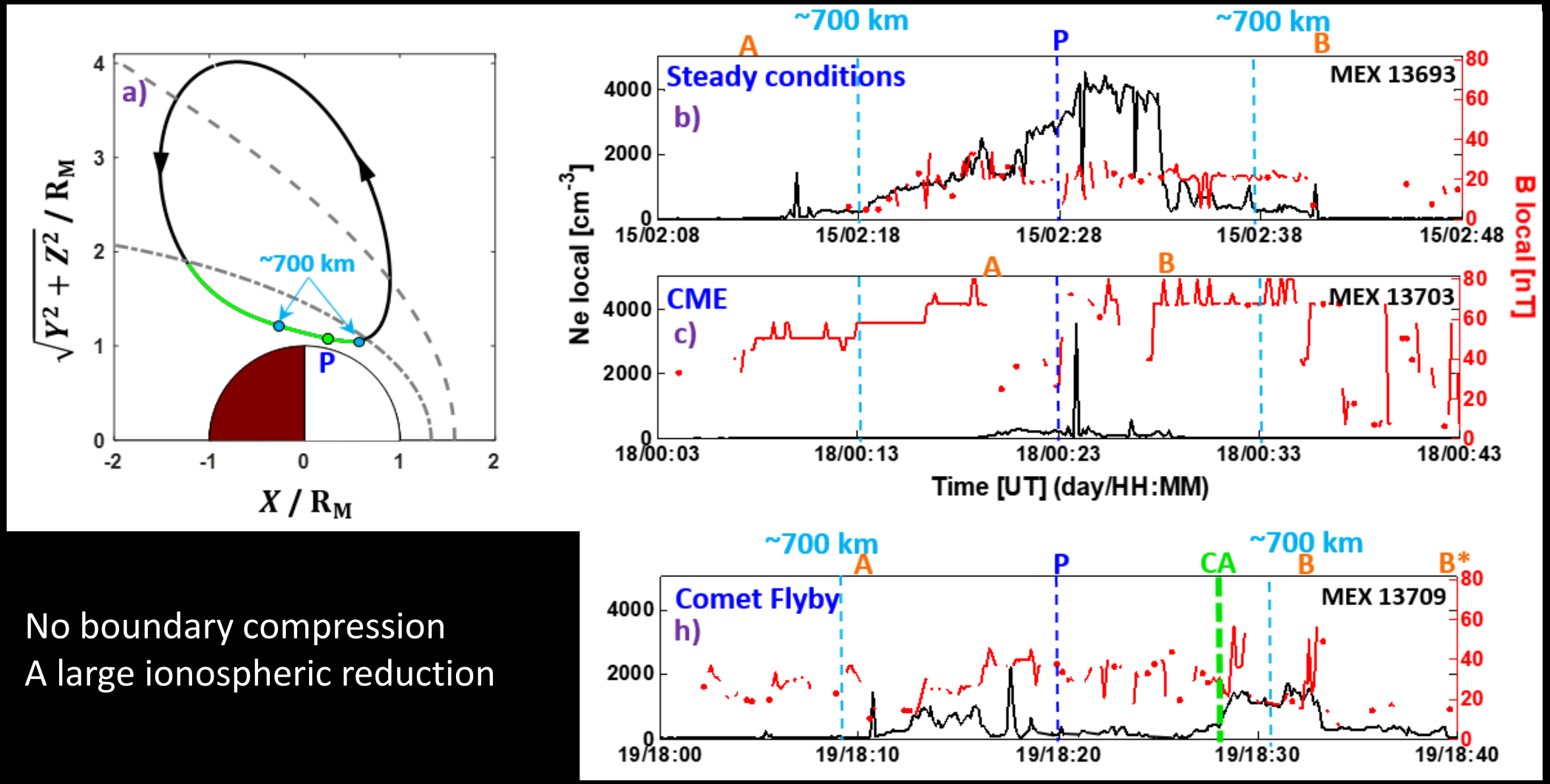
The ionosphere between 350 and 1000 km



- No boundary compression
- A large ionospheric reduction

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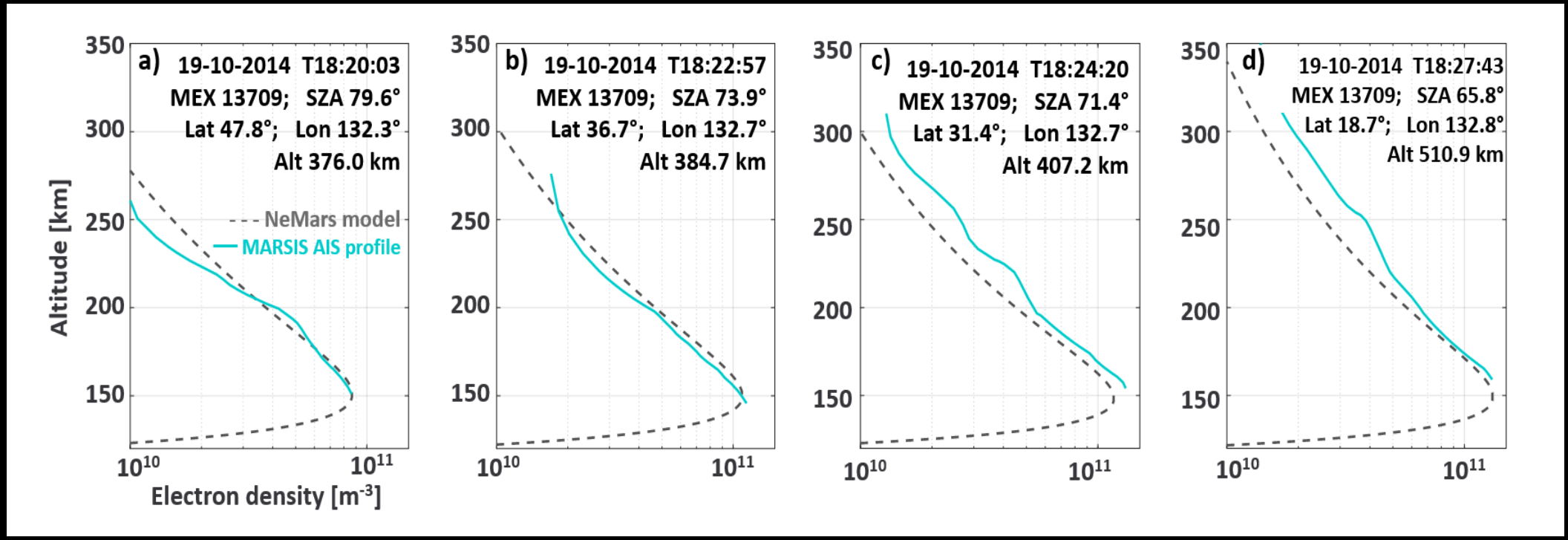
Sánchez-Cano et al., under review

The ionosphere between 130 and 350 km

We use the NeMars model to evaluate the degree of variation of the ionospheric profile with respect to steady conditions.

The ionospheric profiles show very rapid variability along the orbit.



NeMars model → Sánchez-Cano et al., *Icarus*, 2013

Sánchez-Cano et al., under review

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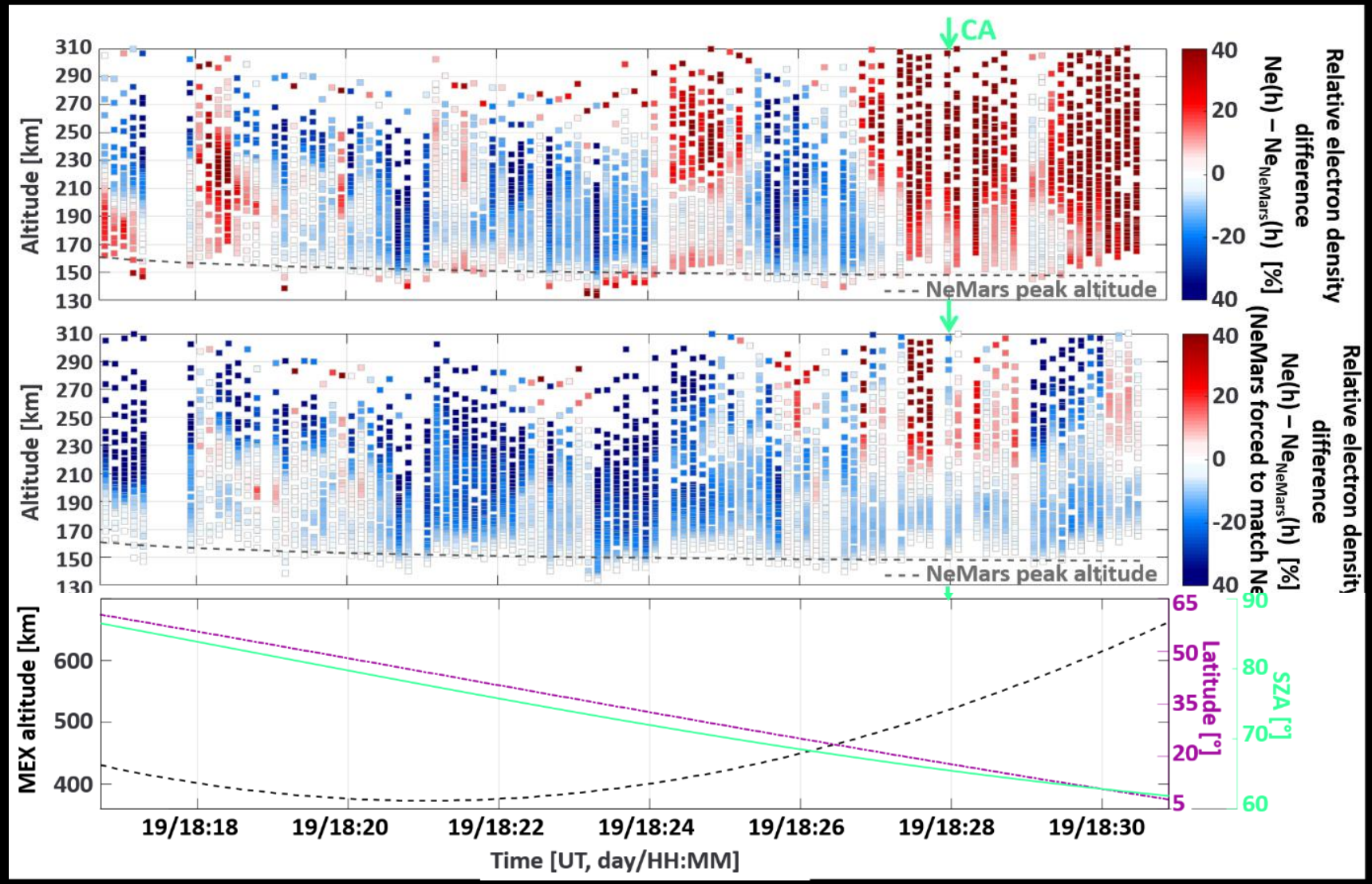
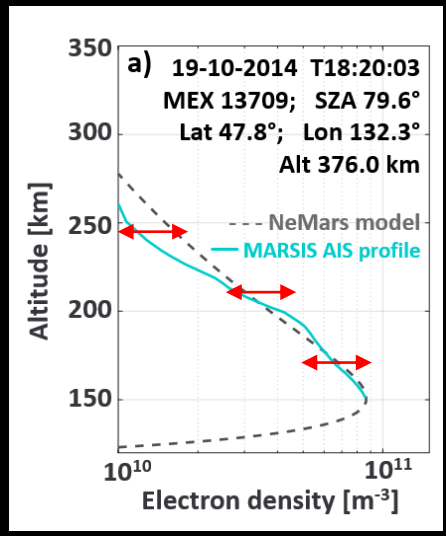
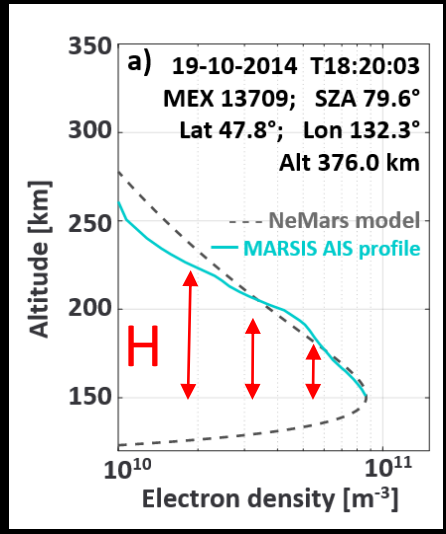
The ionosphere between 130 and 350 km







Sánchez-Cano et al., under review

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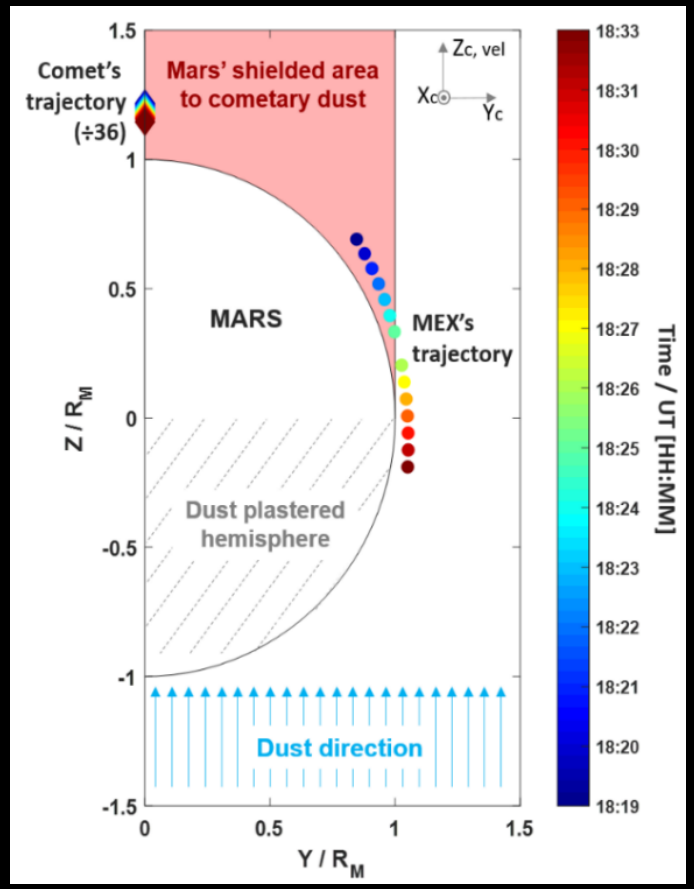
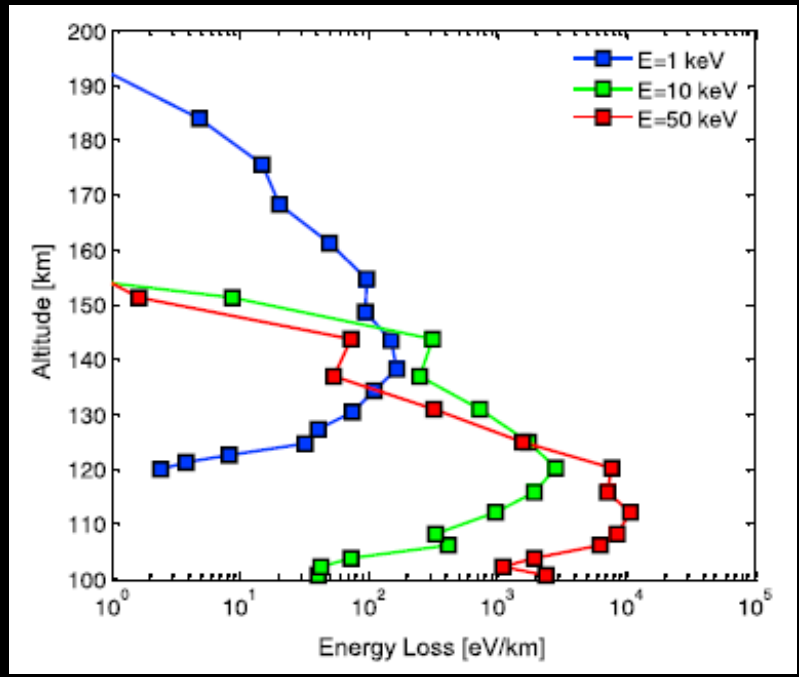
Possible causes for the **density increases** after 18:26 UT?

Was it caused by dust impacts because the spacecraft and the ionosphere were less protected?



Was it caused by O^+ pick up ions?



Sanchez-Cano et al., 2018b

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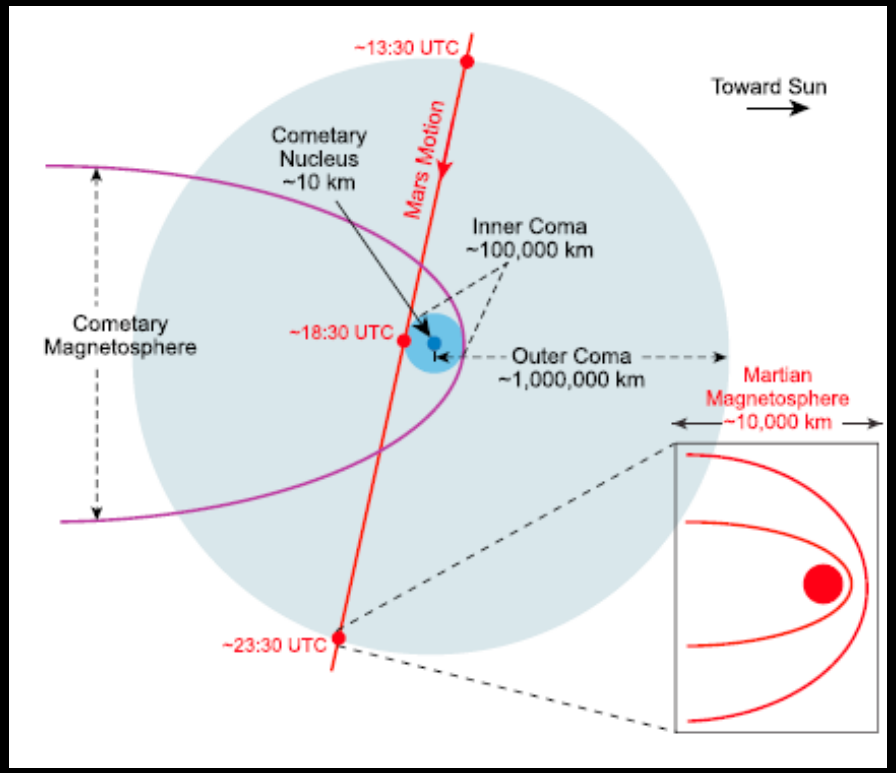
Possible causes for the **density decreases** before 18:26 UT?

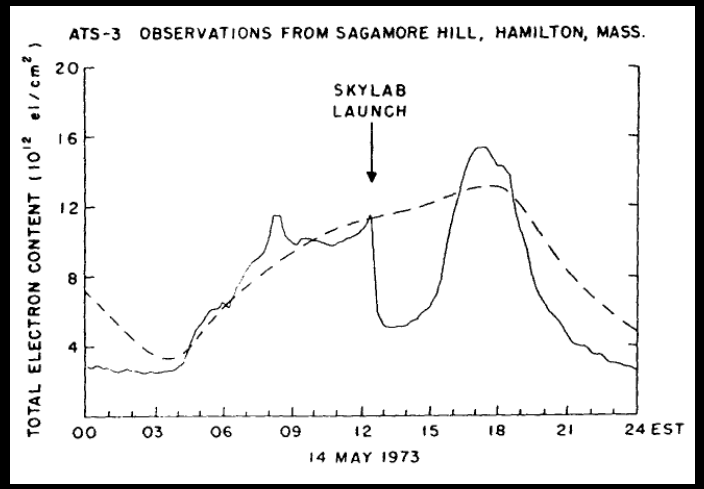
Was it caused by induced magnetic field from the comet?

Was it caused by water damping?
e.g. $H_2O^+ + e^- \rightarrow OH + H, \quad OH^+ + e^- \rightarrow H + O$



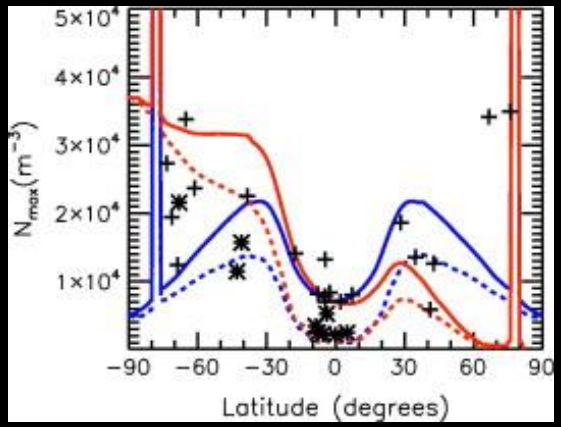
Espley et al., 2015

EARTH ROCKET LAUNCHES



Mendillo et al., 1975; 1981

SATURN RING SHOWER



Müller-Wodarg et al., 2012

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Closing thoughts (I)

ICME

- Community collaboration on planetary space weather studies
- Multiple models and data sets needed to make plausible CME-ICME associations
- Need for space weather monitoring (at least a magnetometer and a radiation monitor) on each planetary mission
- Low telemetry during cruise phase is helpful

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Closing thoughts (II)

Comet

- Comet Siding Spring was a very unique opportunity to study in-situ the interaction of two different atmospheres
  → Links to early Solar System evolution

- There are still lots of data to analyse (although it may be not an easy task)

- This is the first time that energetic cometary particles have been observed in-situ at Mars

- The Martian system was strongly affected by the comet's flyby. The comet deposited a significant fluence of energetic particles, and the system showed more variability than after the impact of a solar storm.

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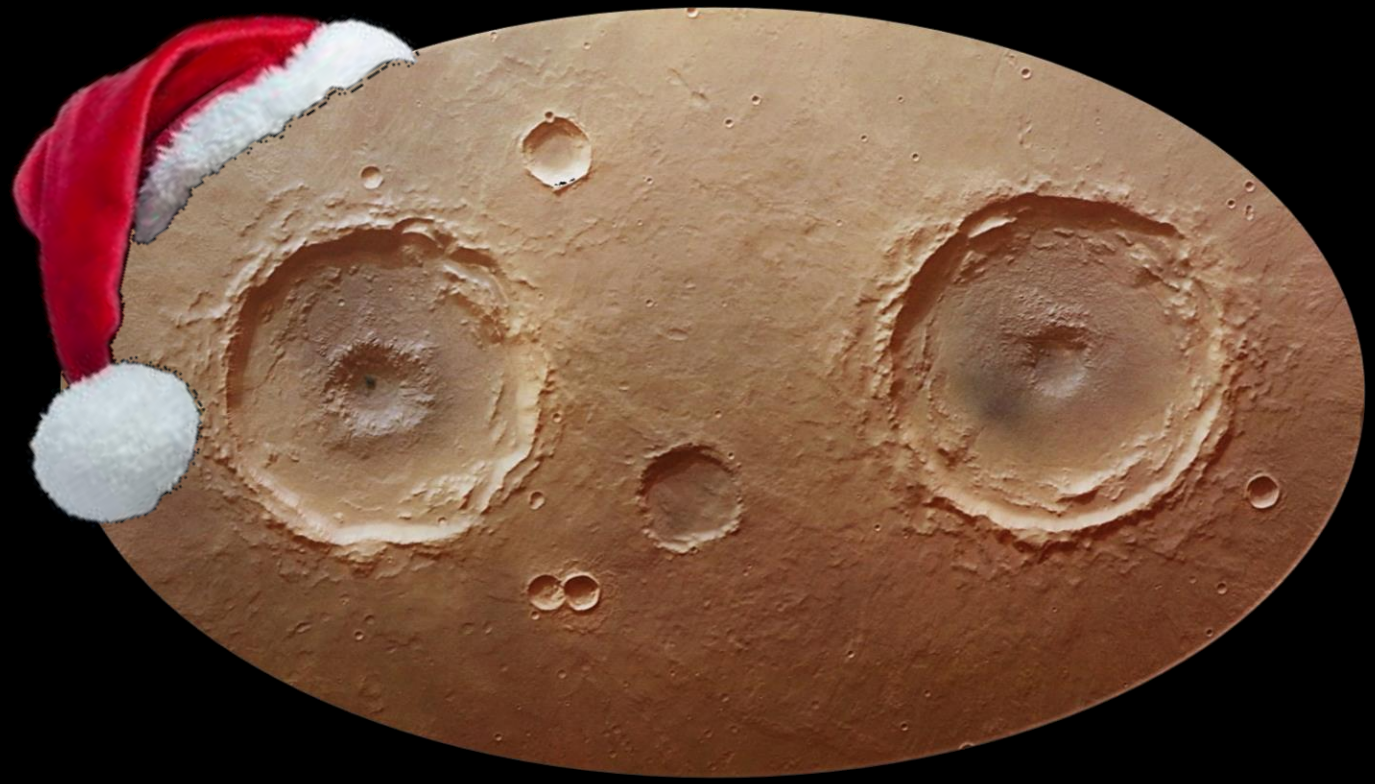
Thank you very much for your attention!!



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